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REVIEW ARTICLE

Weed pollen and its multifaceted impacts: Allergens, health risks, and effects on livestock

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ABSTRACT

Weeds are often classified as undesirable plants that disrupt cultivated areas, but they also pose significant health risks to humans and livestock. This review examines the diverse impacts of weed pollen, focusing on allergenic properties, health risks, and effects on domestic animals. Weeds, such as ragweed, mugwort, feverfew, and plantain, are known to produce potent allergens that contribute to various allergic conditions in humans, including allergic rhinitis, asthma, and contact dermatitis. The review discusses major allergenic proteins found in weed pollen, including pectate lyases, defensin-like proteins, Ole e 1-like proteins, and non-specific lipid transfer proteins, as well as panallergens such as profilins and calcium-binding proteins that cause cross-reactivity among sensitized individuals. Additionally, it highlights the health risks associated with inhaling or ingesting pollen contaminated with toxic compounds. These risks include respiratory distress, food poisoning, and adverse effects on livestock, such as reduced feed intake and weight loss. The review underscores the significance of understanding the allergenic and toxic properties of weed pollen and their impact on human health and livestock.

Keywords:, Allergens, Health risk, Livestock health, Weed pollen

INTRODUCTION

Weeds are unwanted plants that grow wildly among cultivated crops, competing for essential resources such as space, light, and nutrients. Unlike specific plant groups, weeds are a diverse assemblage of species that pose significant agricultural, environmental, and health challenges. In agriculture, weeds can severely impact major crops such as rice (Sreekanth *et al.* 2024, Pawar *et al.* 2022), wheat (Sondhia *et al.* 2023), and soybean (Chander *et al.* 2023), reducing yield and quality by competing for nutrients, water, and sunlight. Additionally, some weeds can interfere with crop physiology by releasing allelopathic compounds that hinder seed germination and growth. Furthermore, weed management is becoming increasingly difficult due to climate change, which influences weed distribution, herbicide efficacy, and environmental sustainability (Sreekanth *et al.* 2023, 2022). Changing temperature and precipitation patterns alter weed-crop competition, potentially favoring invasive weed species that can better adapt to extreme conditions. Certain weed species also act as bioaccumulators, absorbing heavy metals and contributing to soil and water contamination, thereby posing risks to both agriculture and human health (Roy *et al.* 2021).

Beyond their impact on crop production, weeds also pose significant health risks to humans. One of the primary concerns is their role as sources of allergenic pollen, which can trigger severe allergic reactions and respiratory illnesses such as hay fever and asthma. Pollen grains from certain weed species are among the most potent aeroallergens and are responsible for seasonal allergic rhinitis in millions of people worldwide. Several major weed species, including *Ambrosia artemisiifolia* (common ragweed), *Artemisia vulgaris* (mugwort), *Tanacetum parthenium* (feverfew), *Parietaria* spp. (pellitory), *Chenopodium album* (lamb's quarters), *Kali tragus* (Russian thistle), *Plantago* spp. (plantain), and *Mercurialis* spp. (dog's mercury), produce highly allergenic pollen that has been characterized to varying degrees (Gadermaier *et al.* 2004). These allergens are known to contain specific proteins that trigger immune responses in sensitized individuals, leading to symptoms such as sneezing, nasal congestion, watery eyes, and in severe cases, asthma attacks. The prevalence of sensitization to weed

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pollen allergens can exceed 50% in certain regions, complicating medical diagnosis due to cross-reactivity among different pollen types, making effective treatment challenging (Stemeseder *et al.* 2014). Moreover, urbanization and climate change have led to an increase in airborne pollen concentrations, prolonging pollen seasons and exacerbating allergic conditions.

In addition to human health risks, weed pollen may also have adverse effects on livestock. Inhalation or ingestion of allergenic weed pollen can lead to respiratory distress, allergic dermatitis, and digestive disorders in farm animals. Reduced feed intake, weight loss, and overall lowered productivity are some of the consequences observed in livestock exposed to high levels of allergenic weed pollen. Furthermore, some weed species produce toxic compounds that can contaminate fodder and grazing pastures, leading to poisoning in cattle, sheep, and other livestock species. For instance, weeds such as *Parthenium hysterophorus* can cause skin irritation and toxicity in both humans and animals, highlighting the need for integrated weed and pasture management strategies. The increasing prevalence of weed pollen due to changing climatic conditions and land-use patterns could exacerbate these impacts, necessitating further research and mitigation strategies. This review aims to explore the multifaceted impacts of weed pollen, focusing on its allergenic properties, associated health risks, and implications for livestock. By synthesizing current knowledge on weed pollen biology, its allergenic potential, and its effects on both human and animal health, to get insights into effective mitigation strategies to address the growing challenges posed by allergenic weed pollen in agriculture, public health, and livestock management.

Major weed pollen allergens

Four major protein families appear to be primarily responsible for allergic reactions to weed pollen: the ragweed Amb a 1 family of pectate lyases; the defensin-like Art v 1 family from mugwort, feverfew, and possibly sunflower; the Ole e 1-like allergens Pla l 1 from plantain and Che a 1 from goosefoot; and the nonspecific lipid transfer proteins Par j 1 and Par j 2 from pellitory. Additionally, weed pollen contains pan allergens such as profilin and calcium-binding proteins, which contribute to widespread cross-reactivity among patients sensitized to pollen (Gadermaier *et al.* 2004). Weed pollen that triggers allergic reactions spans several botanical families, with numerous allergenic molecules identified to date. Clinically significant allergens from weed pollen are found in *Ambrosia artemisiifolia*, *Artemisia vulgaris*, *Tanacetum parthenium*, *Parietaria* spp., *Chenopodium album*, *Kali tragus*, *Plantago* spp., and *Mercurialis* spp. Notably, the primary allergens from weed pollen are categorized into four main protein families: pectate lyases, defensin-like proteins, Ole e 1-like proteins, and non-specific lipid transfer proteins. Weed pollen also contains pan allergens like profilin and polcalcin, which are highly cross-reactive molecules recognized by patients sensitized to pollen (Gadermaier *et al.* 2014). Gupta *et al.* (1996) discovered a unique hydroxyproline-rich glycoprotein as the primary allergen in *P. hysterophorus* pollen. Feverfew pollen has been characterized to contain multiple allergenic proteins, with a notable IgE reactivity observed in sensitized patients (Pablos *et al.* 2017). Agriculture experts are apprehensive about *P. hysterophorus* impacting various crops, given that pollen and dust from this weed can induce allergic contact dermatitis (Gunaseelan 1987, Morin *et al.* 2009). Moreover, climate change is exacerbating pollen-related health issues by increasing pollen production, extending pollen seasons, and enhancing allergenicity due to rising CO_2 levels (Ziska and Beggs 2012). Exposure to *P. hysterophorus* pollen is also linked to allergic bronchitis (Towers and Subba Rao 1992). Increased concentrations of weed pollen correlate with higher rates of allergic rhinitis and medication prescriptions, particularly for tree and weed pollen (Saha *et al.* 2021).

***Ambrosia* spp.**

Ragweed (*Ambrosia artemisiifolia*) is a major allergen, particularly in North America, causing respiratory issues and other allergic diseases (Zhao *et al.* 2016). The genus Ambrosia includes approximately 40 species, found in Eastern and Central North America. Among these, *Ambrosia artemisiifolia, Ambrosia elatior* and *Ambrosia trifida* triggers type I allergic reactions during late summer and fall. In the USA and Canada, over 15 million people suffer from ragweed pollen allergies, affecting about 45% of susceptible individuals (Boulet *et al.* 1997). Currently, eleven allergenic molecules from Ambrosia pollen have been identified and documented in the official IUIS allergen database. Ragweed pollen, particularly from the species *Ambrosia artemisiifolia*, is a major allergen responsible for significant allergic reactions, especially in late summer and autumn. This invasive plant has spread globally, exacerbated by climate change and urbanization, leading to increased pollen concentrations and extended pollen seasons.

The primary allergens identified in ragweed include Amb a 1 and Amb a 11, with sensitization rates varying among other allergens (Chen *et al.* 2018, Chiara *et al.* 2022). Individuals sensitized to ragweed may also react to other weed pollens, such as mugwort and dandelion, indicating significant cross-allergenicity (Kim *et al.* 2015; Preda *et al.* 2024).

***Artemisia* spp.**

The genus Artemisia encompasses approximately 350 species distributed across the Northern hemisphere and Australia. *A. vulgaris* is the utmost significant and trigger allergic reactions in 10–14% of pollinosis patients in Europe (Wopfner *et al.* 2005) and 11.3% of asthma and/or rhinitis patients in China (Li *et al.* 2009). Other species like *A. annua* are grown for their antimalarial properties (White 2008). Individuals allergic to Artemisia often experience harmful reactions (Egger *et al.* 2006). Currently, six allergenic molecules from mugwort have been formally recognized by the IUIS allergen nomenclature sub-committee.

***Parthenium hysterophorus* L.**

Pollen grains of parthenium induce numerous allergies such as contact dermatitis, hay fever, asthma, and bronchitis in humans. Common allergens found in this weed include parthenin, coronopilin, tetraneuris, and ambrosin. Parthenium pollen can trigger asthma (allergic bronchitis), particularly affecting humans. Contact with the plant can cause dermatitis, spreading discomfort throughout the body (Wiesner *et al.* 2007). Clinically, parthenium dermatitis manifests in five types: (1) classical airborne contact dermatitis (ABCD), affecting areas like the face, eyelids, neck, chest, elbows, and knees (2) chronic actinic dermatitis (CAD), presenting as lichenified papules, plaques, or papulonodules on exposed areas such as the forehead, ears, cheeks, neck, forearms, and hands (3) a mixed pattern combining classical and CAD features, with scaly papules on exposed parts and dermatitis in other areas; (4) photosensitive lichenoid eruption, appearing as pruritic, flat, violaceous papules and plaques on sun-exposed areas; and (5) prurigo nodularis-like pattern, characterized by hyperkeratotic papules and nodules on extremities, resembling prurigo nodularis (Aneja 1991, Sharma *et al.* 2012). Deleterious effect of parthenium on men and animals' health's due to its pollens' allergic nature has also been highlighted by Sushilkumar (2014).

Feverfew pollen predominantly elicits type IV hypersensitivity reactions but has also been implicated in allergic rhinitis among sensitized individuals (Lakshmi and Srinivas 2007). The major allergen, is known as Par h I and is recognized by over 90% of Parthenium-sensitized patients (Gupta *et al.* 1996). Interestingly, the identified defensin domain shares significant sequence homology with SF18 protein from sunflower (88%), Amb a 4 (80%), and Art v 1 (61%). However, due to incomplete sequence information, comprehensive molecule-based studies, including IgE cross-inhibitions with other defensin-like allergens, are still required.

***Chenopodium album* L.**

Chenopodium spp. are annual or perennial plants and pollinate from June to October. Recently, there has been an increase in *C. album* sensitization in the desert areas of Saudi Arabia, Iran, and Kuwait, attributed to the use of this plant in greening initiatives (Barderas *et al.* 2002). In Kuwait, for instance, Chenopodium pollen is a major allergen for patients with allergic rhinitis or asthma (Dowaisan *et al.* 2000).

***Salsola kali* L.**

Among the Amaranthaceae family, *Salsola* is extensively studied for its allergenic properties (Ferrer *et al.* 2010). One of the most recognized species is *S. kali*, commonly known as Russian thistle, which thrives in saline soils with limited rainfall. Sensitization to *S. kali* pollen was first documented in Arizona in 1993, and currently, over 30% of allergic patients in certain regions of Spain exhibit positive skin reactions to this pollen (Carnes *et al.* 2003). Notably, *S. kali* pollen sensitization affects approximately 75% of pollen-allergic individuals in Iran, making it the primary cause of pollinosis in the country (Assarehzadegan *et al.* 2009).

***Amaranthus retroflexus* L.**

Pollen from *A. retroflexus* is a significant allergen in Iran, with a sensitization rate of 69% among allergic patients. Significant IgE cross-reactivity with other species in the Amaranthaceae family has been observed (Tehrani *et al.* 2010).

***Plantago* spp.**

The genus *Plantago* comprises approximately 250 species widely distributed worldwide, predominantly thriving in humid meadows and roadsides. Due to its exclusion from routine allergy testing, precise sensitization rates in large populations are not readily available. However, certain studies indicate sensitization frequencies ranging from 20% to 40% among pollinosis patients (Couto *et al.* 2011, Gadermaier *et al.* 2004). Allergy to plantain pollen is often linked with grass pollen allergy, and cross-reactive components such as a 30 kDa protein with similarity to Phl p 5 have been identified, though their clinical significance remains uncertain (Asero *et al.* 2000).

Parietaria spp.

The pollen of *Parietaria judaica* and *Parietaria officinalis* are the most significant allergenic species within this genus. Sensitization rates to *P. judaica* can be notably high in Southern European countries, reaching 60–90% in certain coastal regions. A high prevalence of asthma and bronchial hyper-responsiveness has been observed in patients sensitized to Parietaria (Gadermaier *et al.* 2004). Currently, four allergens from *P. judaica* and one allergen from *P. officinalis* are officially recognized.

Mercurialis annua

M. annua, native to Europe, is recognized as a significant source of allergens in the Mediterranean regions of Spain and Italy (Garcia-Ortega *et al.* 2004). Sensitization to Mercurialis pollen has been reported at high levels, ranging from 28% to 56% in various areas of Spain during the late 1990s. Two allergenic components, sized at 15.3 and 14.1 kDa, have been identified as profilins and designated as Mer a 1. Studies involving pollen extracts from other plants containing allergenic profilins have shown modest yet significant levels of IgE cross-reactivity (Vallverdu *et al.* 1997). Recognized by more than 50% of individuals allergic to Mercurialis pollen, Mer a 1 is considered a major allergen from this pollen source (Vallverdu *et al.* 1998).

Medicago sativa L.

Comparing sensitization to pollen allergens and subsequent clinical manifestations between human patients and their domestic animals such as dogs, cats, and horses is a topic of significant interest (Schafer *et al.* 2008). Pollen hypersensitivity is associated with Canine Atopic Dermatitis (CAD), characterized by elevated specific IgE levels against environmental allergens (Halliwell 2006). Generally, pollen sensitization is thought to have minimal impact on allergic dogs, despite earlier studies suggesting similar nasal congestion symptoms in both humans and dogs exposed to ragweed pollen (Tiniakov *et al.* 2003).

In Australia, intradermal tests on over 1000 atopic dogs revealed sensitization rates of 10% to 25% to various types of pollen (grass, tree, weed) (Mueller *et al.* 2000). A more recent cross-sectional study involving 651 atopic dogs indicated statistically significant associations between sensitization to tree, weed, and grass pollen in 94% of cases, distinguishing them from sensitization to other allergen sources (Buckley *et al.* 2013). The authors emphasized the importance of distinguishing between sensitization and clinically relevant sensitization that leads to symptoms.

Various toxic compounds have been identified in the pollens of agricultural weeds, including alkaloids, glycoalkaloids, lectins, and secondary metabolites, which can induce a range of adverse effects when ingested or inhaled. For instance, solanidine alkaloids found in nightshade weed pollens have been linked to digestive disturbances in livestock (Knudsen *et al.* 2006).

Health impacts on humans and livestock:

Inhaling weed pollen particles that carry toxic compounds can induce allergic reactions and respiratory distress in humans. Moreover, consuming food products contaminated with toxic weed pollen can lead to food poisoning, presenting symptoms such as nausea, vomiting, and diarrhea (D'Amato *et al.* 2007). Livestock grazing on pastures contaminated with toxic weed pollens may experience reduced feed intake, weight loss, and even mortality. Weed pollens containing alkaloids, such as those from jimsonweed (*Datura stramonium*), are particularly notorious for their harmful effects on livestock (Panter *et al.* 1999). The significant impacts of various weed pollens are detailed in **Table 1**.

Conclusion

In conclusion, the multifaceted impacts of weed pollen on human health, livestock, and agriculture underscore the critical need for continued research and proactive management strategies. This review highlights the significant role of weed pollen in triggering allergic reactions in humans, with various species such as ragweed, mugwort, and plantain being major contributors to seasonal allergies. The identified allergens from these weeds, including pectate lyases, defensin-like proteins, and nonspecific lipid transfer proteins, underscore the complexity of allergic responses and the challenge in managing cross-reactivity among different pollen types. The review underscores the severe health implications of weed pollen exposure, including respiratory issues and dermatitis in humans, and highlights the detrimental effects on livestock, such as reduced feed intake and potential mortality from consuming contaminated pollen. Additionally, the toxic compounds found in some weed pollens, like alkaloids and mycotoxins, pose risks not only to human health but also to agricultural productivity and

Table 1. Impact of weed pollens on human beings and livestock

Weed	Effect	Reference
Parthenium hysterophorus	Contact dermatitis: Skin rashes, redness, itching, and blistering	Sharma *et al.* 2011
	Allergic rhinitis: Sneezing, a runny or stuffy nose, and itchy or watery eyes	Sharma *et al.* 1998
	Asthma exacerbation: Increased wheezing, shortness of breath, and chest tightness	Pahwa *et al.* 2008
	Allergic conjunctivitis: Redness, itching, and swelling of the eyes	Shah *et al.* 2014
	Contact urticaria: Sudden appearance of hives and itching at the site of contact	Mahendra and Meena 2016
	Oral Allergy Syndrome (OAS): OAS may occur in individuals who ingest foods cross-reacting with Parthenium pollen, leading to itching and swelling of the lips, tongue, and throat	Erwin *et al.* 2006
Xanthium strumarium	Contact Dermatitis and Skin Irritation: Skin irritation, leading to symptoms such as redness, itching, and rashes	Bharali and Talukdar 2013
	Allergic Reactions in Humans: Sneezing, runny or stuffy nose, and itchy or watery eyes	Panico *et al.* 1992
	Gastrointestinal Disturbances: Nausea, vomiting, and diarrhea. The seeds contain toxic compounds that can be harmful when ingested	Cheesbrough and Kolbezen 1997
	Liver and Kidney Damage: Liver and kidney damage. The plant contains compounds known as carboxyatractylosides that are toxic to these organs	Radostits *et al.* 2006
	Neurological Effects: Convulsions and tremors	Krishnamurthy 1990
	Death in Livestock: Severe cocklebur poisoning can lead to the death of livestock	Saha *et al.* 2016
Chenopodium album	Allergic rhinitis and allergic conjunctivitis: Pollen from *C. album* can trigger allergic rhinitis (hay fever) in sensitive individuals. Symptoms include sneezing, runny or stuffy nose, and itchy or watery eyes	Cecchi *et al.* 2010
	Respiratory Allergies: Inhalation of *C. album* pollen can lead to respiratory allergies, particularly in regions where the weed is abundant	Kumar, 2016
	Cross-Reactivity: Cross-reactivity between *C. album* pollen and other allergenic pollens can lead to complex allergic responses and increased sensitivity in individuals with multiple pollen allergies	Scala *et al.* 2017
	Skin Irritation: Contact with *C. album* pollens can sometimes cause skin irritation, resulting in redness, itching, and rashes, particularly in individuals with sensitive skin	Behera and Basak 2013
	Oral Allergy Syndrome (OAS): OAS can occur in individuals who consume foods cross-reacting with *C. album* pollen. Symptoms may include itching and swelling of the lips, tongue, and throat	Villalta *et al.* 2011
Rumex dentatus	Mild Allergic Reactions: Pollen from *R. dentatus* may cause mild allergic reactions in some individuals, including symptoms like sneezing, runny or stuffy nose, and itchy or watery eyes	D'Amato, G., *et al.* 2007
	Skin Irritation: Contact with the plant or its pollen may lead to skin irritation in sensitive individuals, resulting in redness, itching, and skin rashes	Mahendra and Meena 2016
	Oral Allergy Syndrome (OAS): In some cases, individuals may experience OAS when consuming foods cross-reacting with *R. dentatus* pollen. Symptoms can include itching and swelling of the lips, tongue, and throat	Scala *et al.* 2017
	Respiratory symptoms: While *R. dentatus* is not a major pollen allergen, it may contribute to respiratory symptoms in individuals who are sensitive to a variety of pollen types or have multiple pollen allergies	Katelaris and Beggs 2018
Sorghum bicolor	Aflatoxins and fumonisins mycotoxins are present in sorghum pollen. These mycotoxins have been associated with a range of health issues, including liver and kidney damage, and have raised concerns about the safety of handling and inhaling sorghum pollen	Wu *et al.* 2014
Avena fatua	*A. fatua* pollen can be contaminated with mycotoxins, such as ergot alkaloids, which are known to cause symptoms ranging from hallucinations to gangrene. The presence of such toxic compounds in wild oat pollen poses a potential risk to agricultural workers and nearby communities	Panaccio *et al*. 2006
Ambrosia spp.	The pollen produced by ragweed plants is a major cause of hay fever or allergic rhinitis and can trigger asthma in sensitive individuals. Exposure to ragweed pollen can lead to sneezing, itchy eyes, runny nose, and other allergy symptoms. The pollen grains are small and easily inhaled, causing respiratory discomfort and exacerbating asthma in some cases	Rogers *et al.* 2006; Mendes *et al.* 2015
Urtica dioica	Skin irritation and allergic reactions when it comes into contact with the skin. People working in gardens or fields with a high presence of nettles may experience skin rashes and itching. Nettle pollen can cause skin irritation upon contact, leading to dermatitis and allergic reactions. Allergenic compounds in nettle pollen can also induce respiratory symptoms in some individuals	Haneke *et al.* 2015, Sequeira *et al.* 2018, Ghiani *et al.* 2013
Heracleum mantegazzianum	Its flowering can release allergenic pollen, which may exacerbate respiratory allergies	Asero 2009
Plantago spp.	Hay fever, sneezing, congestion, and other respiratory symptoms. Rhinitis and asthma.	Suphioglu *et al.* 2009, Smith *et al*. 2017, Niederberger *et al.* 2002
Artemisia spp.	Allergic rhinitis and exacerbate symptoms in individuals with asthma. In some cases, it can lead to food allergies due to cross-reactivity with certain foods. It pollen is known to cause allergies, with symptoms including rhinitis and conjunctivitis. The pollen can also be a trigger for asthma in some individuals.	Tunon *et al.* 1995, Pauli *et al.* 2006, Yoon *et al.* 2018

animal welfare. Overall, addressing the challenges posed by weed pollen requires a multifaceted approach that includes better allergen identification, improved control measures, and increased awareness of the health risks associated with these ubiquitous plants. Future research should continue to explore the molecular mechanisms underlying allergenicity and toxicity, aiming to mitigate the adverse effects and enhance our understanding of how to manage and protect against the diverse impacts of weed pollen.

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REVIEW ARTICLE

Weeds as ethnomedicine: Revisiting Kerala's ten indigenous plants called Dasapushpam

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ABSTRACT

Indigenous medicine consists of medicinal information about herbs which evolved through generations among various communities prior to the advances in modern medicine. Many of these plants are now considered as weeds as they grow near waysides, agricultural and wastelands. Weeds are considered obnoxious because of their negative effects on agricultural ecosystems. However many of them like the *Dasapushpam* (from Sanskrit *dasa*, meaning 'ten', and *pushpam*, meaning 'flower'), or the ten sacred flowers, are ten herbs which are culturally special to people belonging to the state of Kerala, India. These herbs usually grow in the Western Ghats region. Many medicinal properties have been attributed to these plants which grow as weeds and are used in traditional medical practices of Ayurveda, Unani and Siddha. The plants which are called collectively as Dasapushpam are *Aerva lanata, Biophytum sensitivum, Cardiospermum halicacabum, Curculiogo orchioides, Cynodon dactylon, Eclipta alba, Emilia sonchifolia, Evolvus alsinoides, Ipomoea sepiaria* and *Vernonia cinerea*. Several studies have been carried out on the individual plants as well as some plants together. This classical review aims to document the botanical nomenclatural systematics, indigenous uses and published information with respect to the phytochemical, pharmacological, and therapeutic properties of the plants belonging to Dasapushpam group. However, actual utilisation of all these plants is limited and there is a need to explore all its health benefits. These groups of plants which were common in Kerala are now difficult to find due to shrinkage of agricultural land, consideration as weeds and modernisation of home spaces. Therefore, in this review, we intended to give an up-to-date knowledge on the different bioactive metabolites from the Dasapushpam group of plants, their health-related applications, and their scope for commercial applications in herbal pharmaceutical industries.

Keywords: Indigenous medicine, Phytochemical, Pharmacological activities, Therapeutic properties

INTRODUCTION

Ethnomedicine refers to the therapies practiced in indigenous communities who make time tested, knowledgeable use of herbo-mineral resources to treat ailments (Hemmami *et al.* 2024). They are a reservoir of bioactive compounds and have found use traditionally as antimicrobial, anti-inflammatory, antidiabetic, and other therapeutics. They still hold significance as they are cost effective and have lesser side effects. The World Health Organization (WHO) has recognized and recommended the use of indigenous medicine, particularly in developing countries to achieve health for all. Many communities worldwide use indigenously sourced herbal medicines as their sole primary health care mechanism (Sundarrajan and Bhagtaney 2023).

The Dasapushpam plants are integral to Kerala's folkloric traditions. While "Dasapushpam" refers to ten sacred flowering plants, their parts hold broader significance in healing practices. They are documented in rare texts like *Vishavaidyayotsnika*, used in traditional Vishachikitsa, a system for countering afflictions (Krishnapriya *et al.* 2019). Many of these commonly found plants have been used overlappingly as medicine and food since centuries (Sharma and Wagh 2024). Rampant depletion of natural habitat, indiscriminate harvesting for commercial purposes and seasonal occurrence have resulted in pushing these plants from homesteads to weed status (Kushalan *et al.* 2022) It is important that the wealth of this information is not lost to posterity. Hence this review focusses on an exploration about the beneficial aspects of these ten plants. Also, it studies the different bioactive compounds in extracts obtained from the different plant materials from the Dasapushpam group (Arun Raj *et al.* 2013). There is a need for bioprospecting

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for new drugs due to the problems of multiple drug resistance, side effects of existing drugs, and increasing public perception about the safety of herbal medicine. This review lists the various medicinal values of the plants by documenting their ethnomedicinal use, phytochemical properties, pharmacological activities, and their therapeutic application in indigenous systems of medicine so that it can be further utilized as a knowledge base for researchers.

Objective and methodology of this study

This review has attempted an exhaustive search of published literature through various journals, books and online databases to obtain pertinent information on *the Dasapushpam group of plants.* The search terms "Dasapushpam" were entered in PubMed (https://pubmed.ncbi.nlm.nih.gov/), Web of Science (https://www.webofscience.com/), Google Scholar(https://scholar.google.com/), respectively. Articles which were important from ethnobotanical, phytochemical and therapeutic standpoints were selected (Yan *et al.* 2023). Other key words included each of the individual Dasapushpam plants, ethnobotany, pharmacology, phytoconstituent and therapeutic properties. It documented their binomial nomenclature, local names, Ayurvedic benefits, phytochemical constituents, therapeutic effects, and traditional and commercial uses. The study aims to serve as foundational knowledge for medicinal plant research.

Habitat, and geographical distribution of the plants

The plants coming under the Dasapushpam category have found use in Ayurveda and other traditional systems since centuries. Also, different plant parts show variation in the concentration of different phytochemicals so that the original form of the plant usage as prescribed in classical medicine must be kept true to text The geographical distribution, habitat and usage of the plants are discussed in (**Table 1**). This shows the distribution of these valuable plants in India and particularly the Western Ghats.

Ethnomedicinal and pharmacological activities of the plants

***1. Eclipta alba* L Hassk (Bhalerao 2013)**

The plant belongs to the family Asteraceae and is commonly known in English as False Daisy. In Sanskrit, it is referred to as Bhringaraj, while in Malayalam, it is called Kanjunni. Its Hindi name is Bhangara, and in Bengali, it goes by Kesaraj. Additionally, in Tamil, it is known as Karissalaanakanni. *Eclipta alba (E. alba)* is widely used in Ayurveda and traditional medicine for promoting hair and liver health, acting as a diuretic, and treating skin issues, burns, and inflammation (Varghese *et al.* 2010). Noted as a hepatoprotective agent in the Ayurvedic Pharmacopoeia of India, it also exhibits diverse pharmacological activities, including antimicrobial, anti-stress, antioxidant, and

Table 1. Source of plants

Plant scientific name	Part used as per classical text	Habitat	Geographical distribution
Eclipta alba (L.) Hassk.	Shoots, leaves.	Plains, Moist Localities,	Karnataka, Kerala: all districts.
Emilia sonchifolia (L.)	Shoots, leaves.	Dry and moist deciduous forests, plains	Maharashtra, Karnataka, Kerala: All districts Tamil Nadu: All districts
Evolvulus alsinoides (L.) DC.	Whole plant	Sandy soil, dry slopes, cultivated areas, roadsides	Assam, Bihar, Maharashtra, Odisha, Gujarat, Rajasthan, Uttar Pradesh, Karnataka, Kerala: All districts, Tamil Nadu: All districts
Curculigo orchioides Gaertn.	Rhizome tuber	Scrub forests, roadsides, forest floors, rocky cliffs	Andhra Pradesh, Assam, Kerala, All India plains to 1600m.
Cynodon dactylon (Pers.)	Leaves	tropical and warm temperate regions	India: Assam, Central India, Peninsular India, Kerala: all districts.
Cardiospermum halicacabum (Linn.)	Shoot, leaves	Moist deciduous forests, also, in scrub jungles	India: Assam, Bihar, Gujarat, Jammu & Kashmir, Maharashtra, Manipur, Kerala, Odisha, Punjab, Rajasthan, Tamil Nadu
Vernonia cinerea L.	Whole plant	Deciduous Forests and also Plains, Dry Localities	Maharashtra: Common throughout Karnataka, Kerala: All districts Tamil Nadu: All districts
Ipomoea sepiaria Roxb.	Whole plant	Wastelands, scrub jungles, roadsides	Tropical moist deciduous regions, Andhra Pradesh, Kerala, Karnataka, Odisha.
Biophytum sensitivum (L.) DC.	Whole plant	Growing as weeds in moist shady parts.	Throughout India
Aerva lanata (L.) Juss.	Whole plant	Wastelands in plains, wayside moist places.	Maharashtra, Karnataka Kerala: All districts, Tamil Nadu: All districts.

(Source : https://indiabiodiversity.org/)

anthelminthic effects (Nelson *et al.* 2020). Its extracts show promise in cancer prevention, diabetes management, UV protection, and as mosquito repellents, with additional activity against bacteria and snake venom (Sajon *et al.* 2017).

2. *Emilia sonchifolia* (L.) DC.(Hussain *et al.* 2023)

The plant belongs to the family *Asteraceae* and is commonly known in English as Lilac Tassel Flower. In Sanskrit, it is referred to as Sasasruti, while in Malayalam, it is called Muyalcheviyan. Its Hindi name is Hirankhuri, and in Bengali, it is known as Sadimodi. Additionally, in Tamil, it goes by the name Muyalccevi. *Emilia sonchifolia* is traditionally used to treat ailments such as stomach upsets, tumors, night blindness, liver issues, sore throat, measles, inflammation, seizures, fever, asthma, and muscular soreness (Ogundajo *et al.* 2021). Pharmacologically, it shows broad biological activities, including antimicrobial effects against pathogens like *Staphylococcus aureus* and *Escherichia coli*. It also exhibits anticonvulsant, pain relief, anti-inflammatory, anti-diabetic, and antioxidant properties (Essien et al. 2020).

3. *Evolvulus alsinoides* (L.)

The plant belongs to the family *Convolvulaceae* and is commonly known in English as Dwarf Morning Glory. In Sanskrit, it is referred to as Vishnugandhi and Shankhapushpi, while in Malayalam, it is called Vishnukranthi. Its Hindi name is also Vishnukrantha, and in Bengali, it is known as Vishnugandhi. Additionally, in Tamil, it goes by the name Vishnukranthi. *Evolvulus alsinoides* is a significant ethnomedicinal plant in Ayurveda, valued for treating fevers, nervous debility, and memory loss using a whole plant decoction with cumin and milk. It is recognized as a *Medhya Rasayana* (nervine tonic) and also serves as an antihypertensive and anthelminthic agent (Siraj *et al.* 2019). Pharmacologically, its methanolic extracts exhibit potent antimicrobial and antioxidant activities, attributed to their flavonoid and alkaloid richness (Roy *et al.* 2022).

4. *Cardiospermum halicacabum* Linn. (Mruthunjaya *et al.* 2023)

The plant belongs to the family *Sapindaceae* and is commonly known in English as Balloon Vine. In Sanskrit, it is called Karnasphota, while in Malayalam, it is known as Uzhinja. Its Hindi name is Kaanphuti, and in Bengali, it goes by Lataphatkari. In Tamil, it is referred to as Mudakkarutana, in Marathi as Kaanphodi, in Telugu as Budda Gudichi, and in Kannada as Agniballi. *Cardiospermum halicacabum* is valued in Ayurveda for its young shoots, consumed as greens or livestock feed, and extracts used for wound healing, asthma, ear pain, tumors, and fractures. It also exhibits analgesic, antipyretic, antifilarial, anti-inflammatory, and vasodepressant activities (Beula *et al.* 2019). Pharmacologically, its aqueous and alcoholic extracts show antibacterial, anti-inflammatory, antioxidant, anticancer, anti-arthritic, anti-ulcer, pain-relieving, tranquilizing, nephroprotective, and anti-diabetic properties (Shahrul *et al.* 2020).

5. *Curculigo orchioides* Gaertn. (Chauhan *et al.* 2010)

The plant belongs to the family *Hypoxidaceae* and is commonly known in English as Golden Eye Grass. In Sanskrit, it is called Musali and Talamuli, while in Malayalam, it is referred to as Nilappana. Its Hindi name is Kaali Musali, and in Bengali, it is known as Talamuli. In Tamil, it is called NilappanaiKizhangu, in Oriya as Talamuli, in Telugu as Nelatadi, and in Marathi as Bhuyimaddi. *Curculigo orchioides* is widely used in Ayurvedic medicine for its immunostimulant, hepatoprotective, anticancer, and antidiabetic properties. As a Rasayana, it balances Kapha and reduces Pitta-related burning, providing strength and acting as a stimulant (Khiem *et al.* 2024). Pharmacological studies reveal its safety, with oral administrations in mice showing a nontoxic profile and an LD50 exceeding 3 g/kg.

6. *Cynodon dactylon* (L.) Pers. (Parihar and Sharma 2021)

The plant belongs to the family *Poaceae* and is commonly known in English as Bermuda Grass. In Sanskrit, it is called Durva, while in Malayalam, it is referred to as Karukka Pullu. Its Hindi name is Doob, in Bengali it is known as Durba, and in Tamil, it is called Arugampillu. *Cynodon dactylon* is widely used in Ayurveda for various ailments, with its juice applied to stop bleeding, relieve acidity, and treat constipation (Das *et al.* 2021). It is traditionally valued for managing calculi, cough, inflammation, skin disorders, hysteria, convulsions, and snakebites, exhibiting antioxidant, wound healing, and anti-inflammatory properties. Aqueous-ethanolic concentrates aid in calcium oxalate stone reduction and kidney stone expulsion, while leaf extracts demonstrate antibacterial activity against pathogens like *Streptococcus pyogenes* and *Escherichia coli* (Chandel and Kumar 2015).

7. *Vernonia cinerea* (L.) Less (Theja and Nirmala 2024)

The plant belongs to the family *Asteraceae* and is commonly known in English as Little Ironweed. In

Sanskrit, it is called Sahadevi, while in Malayalam, it is referred to as Poovaamkurunnilla. Its Hindi name is also Sahadevi, in Bengali it is known as Kuksim, in Tamil as Puvamkuruntal, in Marathi as Sadodi, in Telugu as Gariti Kamma, and in Gujarati as Sadori. *Vernonia cinerea* is extensively used in Ayurveda to treat intermittent fever, skin discoloration, boils, and filariasis, while its leaf extracts address rheumatoid arthritis, menstrual issues, and painful urination (Dogra and Kumar 2015). Pharmacologically, its benzene fraction demonstrates broad-spectrum antibacterial activity at tested concentrations.

8. *Ipomoea sepiaria* J.König ex Roxb

The plant belongs to the family *Convolvulaceae* and is commonly known in English as Purple Morning Glory. In Sanskrit, it is referred to as Lakshmana, while in Malayalam, it is called Thiruthaali. Its Hindi name is Lachumana, in Bengali it is known as Bankalami, in Tamil as Cen-tali, in Marathi as Amti Vel, in Gujarati as Hanuman Vel, and in Oriya as Mushakani. *Ipomoea sepiaria* is traditionally used in Ayurveda for its cooling and rejuvenating effects, treating conditions like vitiated pitta, burning sensations, excessive thirst, and general debility. It is employed in hair growth formulations, sterility remedies, ulcer treatment, and as an antidote to arsenic poisoning (Cheruvathur *et al*. 2015). Pharmacologically, it exhibits antimicrobial, antioxidant, anti-inflammatory, antiasthmatic, diuretic, antiarthritic, and antidiabetic properties.

9. *Biophytum sensitivum* (L.) DC. (Sivan *et al.* 2022)

The plant belongs to the family *Oxalidaceae* and is commonly known in English as Little Tree Plant. In Sanskrit, it is referred to as Vipareetalajjaalu and Jhulapushpa, while in Malayalam, it is called Mukkutty. Its Hindi name is Lajjaalu, in Bengali it is known as Jhalaai, in Tamil as Nilaccurunki, in Marathi as Lajvanti, in Telugu as Pulicenta, and in Kannada as Horamani. *Biophytum sensitivum* is traditionally used for chest complaints, asthma, insomnia, convulsions, inflammation, tumors, chronic skin diseases, and lithiasis. Root decoctions treat gonorrhoea, while leaves, with diuretic properties, relieve strangury. Dried leaves and seeds are applied to wounds and in snake envenomation (Beldar *et al.* 2022; Jasim *et al.* 2024; Sood *et al*. 2023). Pharmacologically, its leaf extracts show antitumor, antibacterial, antioxidant, anti-diabetic, and anti-inflammatory activities.

10. *Aerva lanata* (L.) Juss. ex Schult. (Preeja *et al.* 2023)

The plant belongs to the family *Amaranthaceae* and is commonly known in English as Knot Grass. In Sanskrit, it is referred to as Pashanabhedha, while in Malayalam, it is called Cherula. Its Hindi name is Kapurijhadi, in Bengali it is known as Durba and Chaya, in Tamil as Arugampillu, in Telugu as Pindikura, in Oriya as Lopong Arak, and in Kannada as Bili Suli Gidda. *Aerva lanata* is traditionally used in Ayurveda for treating gonorrhoea, amenorrhea, dysmenorrhoea, glandular swellings, and as a diuretic and lithiasis remedy. Its root extracts address cough, liver congestion, jaundice, and indigestion, while whole plant decoctions are effective for pneumonia, typhoid, and prolonged fevers. Pharmacologically, its extracts show antibacterial and anthelminthic properties (Shanmuganathan et al. 2024), diuretic effects aiding in kidney stone expulsion, and nephroprotective activity.

Conclusion

The Dasapushpam plants hold vast therapeutic potential due to their diverse phytochemicals with activities such as antimicrobial, anti-inflammatory, antioxidant, and anticancer properties. They are underutilized despite their relevance in disease treatment and traditional use, including as edibles like *Emilia sonchifolia*. Developing drugs from these plants requires rigorous evaluation of pharmacological activity, toxicity, and clinical trials. This review emphasizes their importance for further research and innovation in phytomedicine. To produce novel drugs for a range of illnesses, researchers need to carefully examine their criteria, pharmacological activity, toxicity, and clinical trials. The potential for developing drugs from these plants is enormous, given the significant increase in global phytomedicine research**.** Further investigations are necessary to study the toxicity of these plants in detail before their usage in ethnomedicine and to rationalize their use as health food. Comprehensive research and development efforts should be directed towards unlocking the full potential of Dasapushpam in the realm of ethnomedicine. This review gives a clear picture of its traditional usage and the potential synergistic effects of plant combinations should be explored. Sustainable cultivation practices, public awareness, and collaboration with traditional healers are essential to fully realize the potential of these medicinal plants. In conclusion, additional exploratory research for the development of new drug molecules and their clinical investigations is highly essential. These medicinal plants are repositories of life-saving drugs, and their potential should be fully realized to contribute to the development of novel therapeutic compounds and improved healthcare solutions.

Table 2. Active principles and medicinal uses of the Dasapushpam group of plants

	Some of the active metabolites	Medicinal uses	References
Evolvulus alsinoides	Resveratrol, Flavonoids, Tannins Tetradecanoic acid, squalene, piperine and Hexadecanoic acid Octadecadienoic acid squalene (triterpine) Piperine	Antioxidant, antifibrinolytic, antiinflammatory, hypocholesterolemic antiarthritic activity anticancer, gastropreventive and hepatoprotective, antidepressant, anticonvulsant, antimutagenic	Varghese *et al.* 2010 Gomathi *et al*. 2015
Cynodon dactylon	Apigenin, Luteolin, Quercetin, Hydroquinone luteolin and apigenin hexadecanoic acid,	potent viral inhibitory activity anti-inflammatory	Yachna Sood *et al.* 2023 Das *et al*. 2021
Emilia sonchifolia	Caffeic acid, Chlorogenic acid Quercitrin Quercitin Rutin Flavones glycoside Senkirkine, Doronine	Antioxidant properties antiviral activity against Japanese Encephalitis Virus in vitro (Vero cells). Anti-inflammatory	Yachna Sood *et al.*2023 Hussain *et al.* 2023
Ipomoea sepiaria	Resin glycosides, Flavonoids Alkaloids Phenolic Compounds Glycolipids	Antimicrobial, anticancer, Anti-inflammatory Antioxidant, Antidiabetic, Hepatoprotective Hypoglycemic,	Yachna Sood *et al.* 2023 Srivastava D. M 2017
Aerva lanata	Beta-sitosterol, Aervin Flavonoids Phenolic Acids Steroids Terpenoids	Antioxidant, Antidiabetic, Hepatoprotective Antimicrobial, Anti-inflammatory, Anticancer Immunomodulatory, Antiurolithiatic,	Yachna Sood *et al.* 2023 Pieczykolan A *et al.* 2022
Curculigo orchioides	Curculigenin A and curculigol Curculigoside A Curculigoside,	antihepatotoxic properties reduced paw swelling Anti-osteoporosis	Bhukta *et al.*2023 Khiem *et al.* 2024
Eclipta alba	Wedelolactones Demethylwedelolactone Coumarins	Antihepatotoxic Antimyotoxic, Antihaemorrhagic Antinociceptive, Anti-inflammatory, bronchodialator	Yadav *et al.*2017
Vernonia cinerea	Flavonoids, Triterpenoids sesquiterpene lactones apigenin, sterols, alkaloids,	Antioxidant activity Anti-inflammatory activity Anti-cancer activity	K. Jiny Varghese *et al.* 2010 Trang *et al.* 2024
Biophytum sensitivum	Flavonoids, Caffeic acid Phenolic Compounds Terpenoids Amentoflavone Isoorientin	Antioxidant, anti-inflammatory, Anticancer Antimicrobial, Antidiabetic, Hepatoprotective Antibacterial, Antitumor, Radioprotective, Chemoprotective	K. Jiny Varghese *et al.* 2010 Richard JJ *et al.*2024
Cardiospermum halicacabum	Flavonoids, Steroids Cardiospermin Rutin and luteolin	Antioxidant, Anti-inflammatory, Anticancer	Elangovan *et al.* 2022 Mruthunjaya *et al.* 2023

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REVIEW ARTICLE

Harnessing johnsongrass (*Sorghum halepense*): Turning a weed into a resource

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ABSTRACT

Johnsongrass [*Sorghum halepense* (L.) Pers.] is a menace in several crops including grain sorghum, maize, cotton, soybean, etc. due to its ability to compete for space, nutrients, and light. It is classified as one of the world's worst weeds and is a target for eradication efforts worldwide. While prevention remains the most effective strategy for managing its spread to new areas, an alternative approach involves leveraging its economic potential through applications such as animal feed, manure, bioremediation, soil binder, etc. For example, johnsongrass serves as fodder grass in many regions, boasting high protein content (10-12% dry matter) and total digestible nutrients (50-60%). Similarly, it exhibits phytoremediation properties, extracting pollutants from soil and water. Despite its potential, research into the utilization of johnsongrass remains limited. Therefore, this article seeks to consolidate the available knowledge on its economic applications, including its genetic potential in sorghum breeding, role as livestock feed, human health benefits, soil conservation properties, industrial uses, etc. By shedding light on the diverse uses of johnsongrass, this article aims to promote awareness and encourage the transformation of noxious weeds into sources of wealth.

Keywords: Allelopathy, Crop Improvement, Fodder, Phytoremediation, Rhizome, Wild relative

INTRODUCTION

Johnsongrass [*Sorghum halepense* (L.) Pers.], also known as Aleppo grass, native to the Mediterranean region, is an invasive perennial species that invades agricultural pastures and natural plains (Howard 2004). Johnsongrass (2n = 4x = 40) is a naturally occurring hybrid between *S. bicolor* (2n=20) and *S. propinquum* (2n=20), widely found in the Mediterranean to the Middle East, India, Australia, central South America, and the Gulf Coast of the United States. It is the world's sixth most persistent weed, as its infestation is reported in over 53 countries and more than 30 different crops (Peerzada *et al.* 2017). Johnsongrass is found in abundance in several states of India, including Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Maharashtra, Madhya Pradesh, Nagaland, Odisha, Rajasthan, Uttar Pradesh and West Bengal (Majumdar *et al.* 2017, Sankara *et al.* 2019). Johnsongrass grows on a wide range of soil types, survives in diverse ecological habitats, and is usually found along irrigation canals, cultivated fields, field edges, orchards, and pastures (Chambers *et al.* 2002). It displaces the native flora under natural landscapes and affects the biogeochemistry of the invaded soil through its aggressive characteristics (Rout and Callaway 2009, Bais *et al.* 2006). The secondary metabolites produced in the rhizomes have shown a negative effect on popular medicinal plants grown in Iran such as *Ocimum basilicum*, *Nigella sativa*, *Cuminum cyminum*, *Foeniculum vulgare*, *Plantago ovata* and *Plantago psyllium* (Asgharipour and Armin 2010).

Johnsongrass is extremely competitive and has shown a negative impact on a wide range of field crops such as maize, wheat, grain sorghum, soybean, sunflower, sugarcane, cotton, pastures, alfalfa, vegetables, and fruits (Travlos *et al.* 2018). In India, johnsongrass is reported to be one of the important grassy weeds of minor millets such as barnyard and foxtail millet (Dubey *et al.* 2023). Johnsongrass reduces the yield of cotton by 70%, maize by 88-100%, sugarcane by 69%, and soybean by 59-88% (Williams and Hayes 1984, Bridges and Chandler

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1987, Mitskas *et al.* 2003, Dalley and Richard 2008, Barroso *et al.* 2016). Johnsongrass poses an exclusive threat to cultivated sorghum due to its close ancestry and lack of selective herbicide that can control the johnsongrass in sorghum (Bagavathiannan *et al.* 2018).

Below-ground johnsongrass forms large colonies from stout, finger-sized, multi-branched rhizome networks that usually account for up to 70% of the entire plant's dry weight (Paterson *et al.* 2020). Johnsongrass dispersal across fields is typically facilitated by human activities, such as tillage (which spreads both seeds and rhizomes), planting, and harvesting (which spreads seeds). A single plant of johnsongrass can produce up to 80,000 seeds in a single growing season, which remains viable for up to 10 years (Ryder *et al.* 2018). It survives temperatures ranging from -10°C to 40°C (CDFA 2002), however, frost and drought stress induce johnsongrass to produce hydrocyanic acid (HCN) at a level that can be harmful to cattle, sheep, and horses (Henderson 2001). The foliage rich in HCN causes 'bloat' in herbivores due to the accumulation of excessive nitrates. Furthermore, johnsongrass is an alternate host to corn leaf gall, maize dwarf mosaic, wheat streak mosaic, beet yellow viruses, and sorghum midge.

Johnsongrass in crop fields negatively impacts crop production, particularly in maize and sorghum. The potential for gene flow between grain sorghum and johnsongrass complicates its management. In Texas and Nebraska, up to 32% of unique sorghum alleles were identified in johnsongrass populations. The existing scientific evidence strongly suggests that engineered genes and herbicide resistance in sorghum have the potential to transfer to johnsongrass and spread extensively (Morrell *et al.* 2005). The conventional way of management (tillage and herbicide application) is ineffective due to its rapid vegetative proliferation and herbicide resistance (Peerzada *et al.* 2017). Johnsongrass has developed resistance to multiple herbicides utilized across North and South America. Furthermore, there is a growing concern that johnsongrass may emerge as a super weed as there is a heightened probability of herbicide-resistant genes flowing from sorghum to johnsongrass. Johnsongrass has been reported resistant to recommended doses of nicosulfuron, foramsulfuron, primisulfuron-methyl, clethodim, fluazifop, glyphosate, and imazethapyr in the USA, Chile, Mexico, and Venezuela (Heap 2014, Johnson *et al.* 2014). As a result, only very few herbicides available in the market are providing effective control against johnsongrass. The research on its management using chemical herbicides is limited. Dubey and Mishra (2023) reported that the application of tembotrione at 100 g/ha as a post-emergence treatment (15–20 DAS) effectively controlled *Sorghum halepense* compared to other treatments at 30 DAS in sorghum crops.

Johnsongrass, despite being a prime example of a weed, has frequently been overlooked for its potential benefits, prompting extensive eradication campaigns. However, these efforts have largely proven ineffective, placing a considerable financial burden on farmers as well as the government. Scientific literature predominantly emphasizes the detrimental effects of johnsongrass on crops, soil health, and the environment, with limited attention given to its positive attributes. This scarcity underscores the urgent need to delve into the beneficial aspects of johnsongrass and raise awareness within both farming and scientific communities. Presently, there exists a crucial opportunity to conduct a thorough examination of the johnsongrass positive impacts, thereby fostering understanding among agricultural stakeholders. Such endeavors hold the promise of mutually beneficial outcomes, empowering farmers to leverage the weed's potential for wealth creation akin to other plant species. Therefore, the objective of this article was to provide a comprehensive exploration of diverse uses of johnsongrass, facilitating informed decision-making processes regarding its management and utilization.

Genetic material for crop improvement

Sorghum and johnsongrass are two closely related species, with the former belonging to the primary gene pool, while the latter belonging to the secondary gene pool. This means that natural gene flow between sorghum and johnsongrass is possible with little to no difficulty. Johnsongrass has many desirable traits that can be used to increase agricultural productivity, such as resistance to various diseases and insects, and the ability to grow in a wider range of environments than either of its parent plants. It has a better ability to thrive in heat, cold, and salinity conditions to sorghum. Thus, johnsongrass can be used to develop drought-tolerant varieties of sorghum, especially for regions prone to water scarcity (Upadhyaya *et al.* 2019). It can also be used to breed sorghum for multiple harvests (perennialism) from single plantings, thus holding great potential for enhancing fodder production (Cox *et al.* 2002, Glover *et al.* 2010). The genetic novelty from johnsongrass can be used in efforts to breed ratooning/perennial sorghums that better protect 'ecological capital' such as topsoil and organic matter (Glover *et al.* 2010). Johnsongrass has been used to develop perennial sorghum as a bioenergy crop (Price *et al.* 2006).

Biotic stress induced by insect pests and diseases significantly impacts sorghum yield. Over a dozen insect pests and diseases have been documented in sorghum cultivation that directly affects its yield potential. However, the management practices designed to mitigate these infestations often prove ineffective or financially burdensome. Consequently, breeding biotic stress-resistant cultivars through conventional breeding emerges as a sustainable solution. Johnsongrass is reported to be a potential donor species for bringing resistance against green bugs, chinch bugs, and shoot fly in sorghum (Nwanze *et al.* 1995, Dweikat 2005). It can also be used for improving several other traits, including the antioxidant properties of the sorghum grain (Cox *et al.* 2018). Besides that, the johnsongrass was found to harbor N_2-fixing bacterial endophytes in the rhizomes. Therefore, the gene responsible for endophytic nitrogen fixation in johnsongrass can be transferred to sorghum (Rout and Chrzanowski 2009). This could reduce the nitrogen requirement, ultimately helping to narrow a 'yield gap' reflected by 1961–2012 yield gains in the U.S. of only 61% for sorghum versus 323% for maize (Rout *et al.* 2013). Therefore, it is evident that johnsongrass holds considerable potential for sorghum improvement programs due to its interfertility between the two. Although no sorghum hybrids have been developed to date, johnsongrass is actively utilized in sorghum breeding programs. To fully harness the above benefits, careful attention to hybridization techniques and potential ecological impacts are essential.

Feed and fodder potential

In India, the primary reason for the low productivity of the livestock sector is the shortage of feed and green fodder. Dry fodder is predominantly used to feed milk-producing animals, which results in low milk productivity per animal. **Figure 1** provides estimates of demand, supply, and deficit for green and dry fodder in India. As per the figure, India is currently facing a green fodder shortage of ~260 million tonnes (MT) and dry fodder shortage of 83 MT, and this deficit supply is projected to be 186.6 MT of green fodder and 83.3 MT of dry fodder by 2050 (IGFRI Vision 2050). Therefore, there is an urgent need to enhance the availability of green fodder in the country to increase the productivity and sustainability of the livestock sector. Identifying new green fodder and increasing the productivity of existing green fodder are the two vital options to address this gap.

Weeds have remained an important non-conventional source of fodder for some livestock. However, there is a continuous quest for new alternative forage crops to augment the availability of green fodder for livestock and reduce fodder costs, thereby enhancing profitability. Johnsongrass fodder is palatable to cattle, possesses adequate nutritive value, and can be grazed with proper management (Rankins and Bransby 1995). Deer, rodents, quails, geese, and wild turkeys consume johnsongrass (Howard 2004). Johnsongrass was introduced as a perennial warm-season forage crop in North America

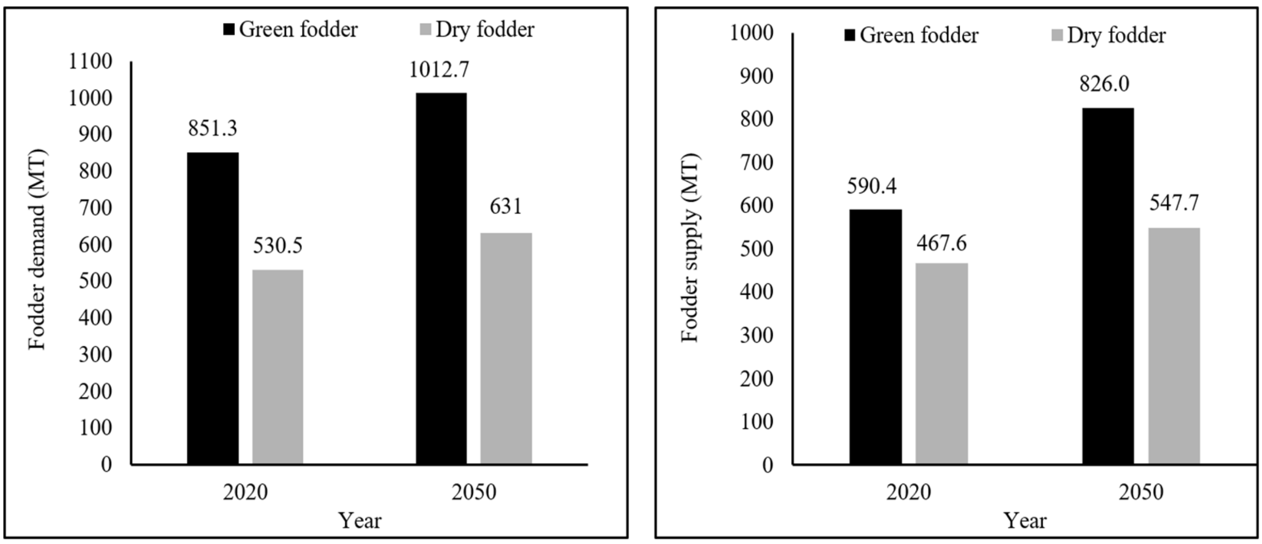

Figure 1. Estimated demand-supply gap of green and dry fodder in India (Source: IGFRI Vision 2050)

in the 1800's (Warwick and Black 1983). Today, it is widely cultivated as a fodder crop on large farms to feed livestock in the United States. Despite its desirable feed characteristics, only a limited number of studies have examined the forage potential of johnsongrass put full stop. The leaves of johnsongrass contain a large amount of protein (10-12% on a dry matter basis) and total digestible nutrients (50-60%) (Natureserve 2009). The nutritional value of johnsongrass justifies the attempts to incorporate it into forage systems and animal production **(Table 1)**.

Johnsongrass has significant forage potential in the sub-tropics for good quality hay and pasture in an emergency (Duke 1983, Kansas Forage Task Force 1998). Johnsongrass can be ensiled for beef cattle (Bass *et al.* 2016). On the contrary, Singh *et al.* (1975) reported johnsongrass hay should be fed only for a limited period, whenever required, as the johnsongrass hay did not increase the body weight of sheep although they showed a positive N balance of 3.4 g/day. Similarly, Kumar and Garg (1997) concluded that johnsongrass can meet the nutrient requirements of Murrah heifers. According to Garg *et al.* (1992), johnsongrass holds comparable nutritional contents to any other cereal fodder and can be solely used as a maintenance ration for sheep based on the chemical composition, nutritive value, and apparent digestibility coefficients. Sinha *et al.* (1986) reported johnsongrass's tolerance to salinity and drought suggests its potential for forage production on salt-affected soils. However, it is recommended to be cautious to put cattle to graze after the occurrence of prolonged drought or frost. These environmental conditions lead to the accumulation of prussic acid in the leaves, which is lethal to grazing animals. These conditions also stimulate the accumulation of nitrates in leaves at toxic levels. Therefore, it is recommended to wait up to two weeks after the drought or frost event. This allows for the dilution of built-in compounds (HCN, nitrates) after plant growth and metabolic functions are restored (Anonymous 2022). The accumulation of toxic compounds in the plant in harsh weather can be prevented by supplementing irrigation. Another condition that favors HCN accumulation in plants is high nitrogen and low phosphorus and potash in soil. Therefore, the excess application of nitrogen should be avoided in johnsongrass. Instead, the money saved in nitrogen fertilizer should be diverted to phosphorus and potassium fertilizer to ensure balanced fertilizer application. Additionally, split applications of nitrogen decrease the risk of prussic acid toxicity.

Table 1. Palatability and fodder quality of johnsongrass

Parameter	Chemical composition (% DM basis)	Reference
Crude protein	10-12	Sherasia *et al.* 2015, Gutiérrez *et al.* 2008
Crude fibre	32 - 37	Sherasia *et al.* 2015
Dry matter	22 - 32	Kumar and Garg 1997
Organic matter	89 - 94	Sherasia *et al.* 2015
Ether extract	1.2-2.5	Kumar and Garg 1997, Sherasia *et al.* 2015
Ash	8.3	Singh *et al.* 1975
Neutral detergent fibre	69- 73	Sherasia *et al.* 2015
Acid detergent fibre	32- 47	Sherasia *et al.* 2015
Total digestible nutrients	52- 63	Alex and Misha 2017
Major minerals (g/kg DM)		
Calcium	0.5-0-6	Sherasia *et al.* 2015
Magnesium	1.81	Gutiérrez *et al.* 2008
Potassium	9.0	Gutiérrez *et al.* 2008
Sodium	2.91	Gutiérrez *et al.* 2008
Phosphorus	0.3	Sherasia *et al.* 2015

Human health benefits

Out of 8000 weeds, only 250 weeds are found to be important for agriculture (Holm *et al.* 1979). Johnsongrass, renowned for its drought resistance, exhibits the remarkable ability to thrive and produce seeds even during severe drought years. This inherent resilience has endowed it with a crucial role as a food reserve during times of famine, offering a vital lifeline in periods of scarcity (Duke 1983). The seed can be eaten as a whole grain like rice or millet, or it can be ground into flour to to make bread, cakes, *etc*. (Uphof 1959, Rapoport *et al.* 1995, Paterson *et al.* 2020). Johnsongrass harbors significant potential for medicinal use, as every part of this plant is used to cure a variety of human ailments **(Table 2)**. In folk medicine, johnsongrass is reported to be cyanogenetic, demulcent, depurative, diuretic and recommended for the treatment of blood and urinary tract disorders (Duke and Wain 1981). The seed contains the bioactive compound p-cymene, a compound used to treat prostatitis (Banoon 2020). Bioactive compounds are generally added to food products for the enhancement of health-promoting properties. The phytochemical analysis of johnsongrass rhizomes showed the presence of cardiac glycosides, flavonoids, terpenes, steroids, saponins, carbohydrates, proteins, gums, and alkaloids. The phytochemical components in plant extracts are biologically active compounds that exhibit a range of beneficial effects, including anti-diabetic, anti-cancer, antifungal, anti-inflammatory, and antibacterial properties. The extracts obtained from johnsongrass rhizome showed the ability to scavenge free radicals, indicating the presence of antioxidant constituents (Shah *et al.* 2021).

Table 2. Phytochemical properties and uses of johnsongrass parts

Property	Plant parts used	Reference
Diuretic	Seed, stem	Tuzlaci and Erol 1998, Mustafa *et al*. 2021, Ahmed *et al.* 2020
Antimicrobial	Whole plant	Khayal *et al.* 2019, Salazar-Lopez *et al.* 2018
Antibacterial	-	Rooh-ul-Anin 2013
Antioxidant	Whole plant; Rhizomes	Shah *et al.* 2021
Demulcent	Seed	Chopra *et al.* 1986
Anti-diabetic	Rhizomes	Shah *et al.* 2021
Antifungal	Shoots	Naeem *et al*. 2021, Javaid *et al.* 2012
Anti-inflammatory	-	Rambabu *et al.* 2016
Anti-cancerous	Rhizomes	Tuzlaci and Erol 1998
Analgesic	Roots	Rajasab and Isaq 2004
Toothache	-	Belda *et al.* 2012

Allelopathic potential

Allopathy refers to the phenomenon where one plant species releases biochemical compounds that inhibit the growth of neighboring plants. It is a natural and environment-friendly technique for weed management. Johnsongrass has a strong allelopathic effect on a wide range of weed species. The impact of allelopathy varies with weed species and the concentration of allelochemical compounds (Sakran *et al.* 2021). Johnsongrass inhibited the germination of barnyardgrass [(*Echinochloa crus-galli* (L.) P. Beauv.)] by 46% and bristly foxtail [(*Setaria verticillata* (L.) P. Beauv.)]by 63%, respectively. (Vasilakoglou *et al.* 2005). Thahir *et al.* (2011) reported the allelopathic potential of johnsongrass on wild oat (*Avena fatua* L.), ryegrass (*Lolium temulentum* Gaud.), grass pea (*Lathyrus sativa* L.), and syrian cephalaria (*Cephalaria syriaca* (L.) Schard). Lalchand *et al.* (2021) reported the allelopathic impact of johnsongrass on the germination of purple nutsedge (*Cyperus rotundus* L.) and jungle rice (*Echinochloa colona* L.).

The allelopathic effect of johnsongrass is due to cyanogenic, glycogenic, and phenolic compounds. These allelochemicals interfere with various physiological processes in target plants, such as seed germination, root development, and nutrient uptake (Stef *et al.* 2013). Ramona *et al.* (2015) reported the presence of inhibitory substances in all the organs of johnsongrass. Studies have identified allelochemicals such as sorgoleone, a potent inhibitor of weed germination and growth, in the root exudates of Johnsongrass. Sorgoleone exhibits herbicidal activity by disrupting essential metabolic processes in target plants, making it a promising candidate for weed management. Therefore, there is immense potential for identifying allelopathic compounds responsible for weed suppression and synthesizing these identified compounds for use as natural herbicides.

Phytoremediation potential

Phytoremediation refers to the use of plants to remove, degrade, or immobilize contaminants from the environment (Gerjardt *et al.* 2017). It is a cost-effective, eco-friendly alternative to traditional remediation methods (Nascimento *et al.* 2014, Sarwar *et al.* 2017). Weeds uptake, metabolize, or accumulate contaminants through various mechanisms, thereby reducing pollution levels. Johnsongrass reduces the risk of heavy metal contaminants through hyperaccumulation (Pinho and Ladeiro 2012). Its extensive root system and vigorous growth make it highly suitable for extracting contaminants from soil and water. Lead (Pb) is one the most toxic environmental pollutant and has nonbiodegradable properties (Lou *et al.* 2013, Pinho and Ladeiro 2012). Johnsongrass is a useful species for Pb immobilization in soil (Salazar *et al.* 2014) and is also effective for phytostabilization of Pb-Zn mine waste (Madejon *et al.* 2002). Johnsongrass has also shown the ability to accumulate lead and nickel (Ni) at a high concentration (Kayal *et al.* 2019). According to Ziarati *et al.* (2015), sixty-day-old johnsongrass accumulated around 0.5 mg of cadmium, 2.2 mg of copper, 1.8 mg of chromium, 1.1 mg of Ni, 3.5 mg of lead, and 0.2 mg of cobalt per kg of dry weight.

Johnsongrass facilitates rhizo-filtration, a process wherein contaminants are filtered and immobilized by root systems, thus preventing their migration into groundwater. Phytoaccumulation involves the concentration of contaminants in above-ground biomass, which can subsequently be harvested for disposal. Johnsongrass has shown potential in extracting Sr (Strontium) from the Sr-affect soil through phytoextraction, a process where plants absorb pollutants from the soil and store them in their tissues. Entry *et al.* (1999) demonstrated that johnsongrass was highly effective at removing Sr in three harvests over 24 weeks, it accumulated 52.6% to 88.7% of the applied Sr. However, phyto-remediation employing johnsongrass is not devoid of challenges. Concerns such as plant invasiveness, potential bioaccumulation of contaminants in edible tissues, and the long duration required for effective remediation necessitate careful consideration and mitigation strategies. Nonetheless, johnsongrass can serve as an asset for phytoremediation in regions contaminated with heavy metals, as many other plant species struggle to germinate and thrive in such environments due to the presence of heavy metal pollutants and adverse weather conditions.

Acridid biomass production

Insects have been consumed by humans as a food source, dating back centuries to early civilizations. The insects provide essential nutrients such as nitrogen, potassium, sodium, iron, and magnesium, which are crucial for the growth and reproduction of various animals including birds (Studier and Sevick 1992). Grasshoppers, a type of insect, are consumed by humans in many parts of the world, including India, sub-Saharan Africa, and Madagascar (Haldar and Malakar 2017, Van Huis 2003, Van Itterbeeck *et al.* 2019). Grasshoppers and locusts belonging to the Orthoptera and the family *Acrididae*, are recognized for their high nutritional value and are increasingly considered as an alternative protein source for livestock industries, particularly in poultry farming. Johnsongrass can serve as a feed for acridid grasshoppers. Research by Mousumi *et al.* (2012) revealed that johnsongrass is the most suitable plant for enhancing the biomass production of acridid grasshoppers compared to other plants such as *Oryza sativa* L., *Triticum aestivum* L., and *Cynodon dactylon*. Therefore, utilizing johnsongrass as feed for acridid grasshoppers will indirectly promote the production of more grasshoppers. These grasshoppers can then be consumed directly by humans as a protein source or utilized as a feed supplement for poultry farming.

Ethnoveterinary uses

Johnsongrass plays a significant role in ethnoveterinary medicine due to its diverse medicinal applications. According to Martinez and Jimenez (2017), johnsongrass serves as an inducer of placental expulsion, particularly in animals. In this traditional practice, the aerial parts of the plant are utilized to facilitate the process. Furthermore, Ghasemi *et al.* (2013) highlight another aspect of its medicinal potential, noting that the leaves and stems of johnsongrass are employed externally for inducing abortion in animals. The plant's ability to aid in placental expulsion and induce abortion highlights its potential as a natural remedy in ethnoveterinary medicine. Similarly, johnsongrass seeds are reported to be the most effective treatment for diarrhea in livestock (Meena *et al.* 2023). These properties underscore the plant's potential as a natural remedy in ethnoveterinary practices. However, its medicinal use should be approached with caution, balancing traditional knowledge with scientific research to ensure safety and efficacy.

Industrial value

The use of agro-industrial waste as a raw material for pulp and paper production has been increasing over the years (Sanchez *et al.* 2016). Among these alternative materials, johnsongrass stands out as a promising candidate due to its compatibility with other raw materials used in pulp and paper manufacturing (Albert *et al.* 2011). Moreover, johnsongrass fibers exhibit exceptional qualities compared to other non-wood fibers, boasting longer lengths and superior derived values, particularly in terms of the slenderness ratio (90.37) and Runkel ratio (1.89). These characteristics hold profound implications for the quality and utility of paper produced from johnsongrass fibers.

The slenderness ratio and Runkel ratio serve as crucial indicators for assessing the suitability of fibrous material for pulp and paper production, further emphasizing the potential of johnsongrass in the paper industry. With an increased slenderness ratio and Runkel ratio, paper made from johnsongrass fibers is expected to possess increased mechanical strength. Consequently, it becomes an ideal material for a wide array of applications such as writing, printing, wrapping, and packaging. Therefore, the utilization of johnsongrass in combination with other raw materials for pulp and paper production presents a promising avenue for sustainable resource management. Its superior fiber characteristics contribute to the production of high-quality paper with increased mechanical strength, catering to various industrial and commercial needs. As efforts to explore alternative raw materials for paper production continue, johnsongrass emerges as a valuable resource with significant potential for the pulp and paper industry.

Anti-corrosive properties

Johnsongrass possesses a myriad of biochemical components that endow it with remarkable anti-corrosive properties. The biochemical analysis of johnsongrass has revealed the presence of vitamins, steroids, saponins, alkaloids, reducing sugars, tannins, glycosides, flavonoids, phenols, terpenes, carbohydrates, and proteins. These chemical structures exhibit characteristics that make them suited to binding to metal surfaces, thereby creating a protective layer. The presence of these compounds in johnsongrass has been extensively studied by researchers such as Hassannejad and Nouri (2018) and Nair (2017). Their findings underscore the potential of johnsongrass as a natural solution for combating corrosion in various industries. When applied to metal surfaces, the biochemical constituents of johnsongrass can effectively adhere to the surface, forming a protective barrier against corrosive agents. The anti-corrosive properties of johnsongrass hold significant implications for a wide range of applications, particularly in industries where corrosion poses a significant challenge. By harnessing the natural protective capabilities of johnsongrass, industries can reduce the need for synthetic anti-corrosive agents, thereby promoting environmentally sustainable practices. Additionally, the use of johnsongrass for corrosion prevention aligns with the growing interest in bio-based materials and green technologies.

Shade and shelter

Throughout history, humans have relied on natural materials for shelter construction, with thatched roofs being one of the earliest forms of roofing. In recent years, there has been a renewed interest in sustainable building practices, leading to the exploration of alternative roofing materials. With its tall, sturdy stems and abundant foliage, johnsongrass possesses qualities that make it well-suited for thatching purposes (Vegda 2012). Additionally, its widespread availability and minimal environmental impact make it an attractive choice for sustainable construction. Thatching with johnsongrass involves harvesting the mature stems and leaves of the plant, followed by cleaning, drying, and bundling them into thatch panels or rolls. These panels are installed in overlapping layers onto a framework of roof beams, providing insulation and protection from the elements. The johnsongrass stem is used to make roof thatch (Vegda 2012). Its cultivation requires minimal inputs such as water and fertilizer, making it a sustainable alternative to conventional roofing materials. Thatch roofs provide excellent insulation properties, keeping interiors cool in summer and warm in winter. Johnsongrass effectively regulates indoor temperatures, reducing the need for artificial heating and cooling. While johnsongrass offers numerous benefits, there are challenges to its widespread adoption. Concerns such as fire resistance, durability, and maintenance requirements need to be addressed through proper treatment and construction techniques.

Manure and compost making

Johnsongrass can be used for the preparation of compost as it is a fast-growing species. According to Schwinning *et al.* (2017) the johnsongrass attained 30 times more biomass at first harvest (50 days after seeding) compared to the big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparius*) and switchgrass (*Panicum virgatum*). On an average, johnsongrass produces biomass of up to 19 tonnes/hectare. To prepare compost from johnsongrass, begin by gathering fresh clippings or biomass. Chop the biomass into smaller pieces to aid decomposition. Layer the chopped johnsongrass with other organic materials, such as kitchen scraps, leaves, or manure, in a compost bin or pile, ensuring a balance of green (nitrogen-rich) and brown (carbon-rich) materials. Regularly turn the compost pile to aerate it and accelerate decomposition. Maintain moisture levels by watering periodically and avoid waterlogging. Monitor compost temperature to reach and sustain 54°C to 65°C to eliminate weed seeds and pathogens. After several weeks to months, the compost, dark, crumbly, and with an earthy aroma, will be ready. The compost prepared from johnsongrass biomass had a pH of 5.18 to 6.92, and calcium and magnesium contents were from 5.82 to 53 mEq/L and 4.94 to 38 mEq/L, respectively (Altai *et al.* 2024). Utilize this nutrient-rich compost to enhance soil structure and fertility in gardens, farms, or landscaping projects.

Role in soil conservation, revegetation and restoration

Soil conservation is crucial for sustainable farming. Revegetation using grass is a widely used method for controlling soil erosion. Johnsongrass emerges as a versatile and resilient species with significant potential in soil conservation, revegetation, and restoration initiatives. Johnsongrass plays a vital role in soil conservation through its extensive root system and erosion control capabilities. Furthermore, the dense canopy formed by johnsongrass foliage intercepts rainfall, minimizing soil surface runoff and erosion. The johnsongrass was found efficient in preventing soil erosion, particularly on steep slopes due to its fibrous roots and extensive thick creeping rhizome network (Holm *et al.* 1979, Bennett 1973). Its rapid growth and ability to establish quickly can help stabilize soils and prevent further degradation of the ecosystem. One johnsongrass plant can produce up to 5,000 rhizomes and up to 13.6 metric tons of rhizomes per acre (Horowitz 1972, McWhorter 1971). By colonizing bare soils and providing habitat for other plant species, johnsongrass initiates the succession process, paving the way for the establishment of diverse plant communities. Additionally, johnsongrass acts as a nurse plant, facilitating the germination and establishment of native vegetation by providing shelter, moisture, and nutrients. Its aggressive growth habit and ability to outcompete native vegetation can pose challenges for biodiversity conservation and ecosystem restoration efforts. Therefore, careful management and monitoring are necessary to prevent the spread of johnsongrass in sensitive habitats and to mitigate potential negative impacts on native ecosystems.

Conclusion

The potential of johnsongrass to serve as a source of income is evident through its various applications. However, harnessing its economic benefits comes with challenges, particularly in managing its intrusion into cultivated areas. While johnsongrass poses significant economic losses when it infiltrates cropping areas, its potential for generating income through activities such as thatching, manure preparation, industrial value addition, and therapeutic purposes cannot be overlooked. In India, this weed has the potential to present several economic benefits such as breeding material, thatching, animal feed, and medicine. Its economic benefits will outweigh its drawbacks compared to countries like the USA and Australia. Overall, this article underscores the importance of exploring and utilizing the beneficial potential of johnsongrass and converting them into sources of wealth.

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RESEARCH ARTICLE

Encapsulated herbicide in preceding rice on weed growth and blackgram productivity in rice-okra-blackgram cropping system under tropical conditions

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ABSTRACT

Weeds in the double cropping of rice are different from the rice-vegetable-pulse cropping system as there will be a shift in weed flora due to changes in the cropping system. Field experiments were conducted during the summer season of 2017 and 2018 to study the residual effect of encapsulated/loaded herbicide applied in preceding rice on weed control and productivity of black gram under the rice-okra-blackgram cropping system. The experiment consists of eight weed control treatments, *viz.* encapsulation of herbicide with zeolite, biochar, starch, water-soluble polymer, commercial formulation of herbicides, weed-free and weedy check of preceding rice and okra. However, the residual crop of black gram was sown without disturbing the layout of the preceding experiment. The residual effect of encapsulated herbicides expressed significant exerted difference in weed density and dry weight at 40 DAS, in both the years. Irrespective of weed control treatments, the residual effects of oxadiargyl-loaded biochar resulted in a 55.0% and 61.3% reduction in grass weed density and a 50.4% and 65.0% reduction in grass weed dry weight in 2017 and 2018, respectively when compared to the weedy control, which was comparable to all other herbicidal residual effects in blackgram. However, the residual impact of encapsulated/loaded herbicides did not significantly influence blackgram seed germination. Whereas, significantly higher clusters/plant (4.8, 7.2%) with high seeds/plant (20.0, 26.2%) and seed yield (108,101 kg) was recorded under oxadiargyl-loaded biochar compared to oxadiargyl loaded zeolite during 2017 and 2018, respectively. It can be concluded that the oxadiargyl-loaded biochar and zeolite releases active ingredients for a longer time which reduces the growth of later emerging weeds and the build-up of soil weed seed banks in succeeding crops.

Keywords: Biochar, Encapsulated/loaded herbicide, Oxadiargyl, Herbicide residue, Weed control efficiency, Zeolite

INTRODUCTION

Blackgram (*Vigna mungo* L.) is one of the important pulse crops grown throughout tropical regions and is able to resist adverse climatic conditions. It is one of the most essential constituents of the Indian diet and supplies a major part of the protein requirement to the vegetarian population. Pulse crops are an integral part of the cropping system because they fit well within the crop rotation and maintain soil fertility through biological nitrogen fixation. India is the leading producer and consumer of pulses crops, with 25 and 27% of the world's acreage and production, respectively (Pankaj *et al.* 2020). The productivity of blackgram is declining yearly due to biotic and abiotic factors. Among the biotic factors, weeds reduce crop yields substantially compared to pests and diseases, with its inhibitory effect on crop growth and productivity. Weeds compete with crops during the early period of 20-40 days is very critical, and season-long weed competition has been found to reduce blackgram yield to the extent of 87% depending upon the type and intensity of weed flora (Yadav *et al.* 2015, Upasani *et al.* 2017). Weeds survive and produce more seeds contributing to the weed seed bank from which weed seedlings are recruited in succeeding crops. Adopting crop rotation and alternating herbicide selection could alter weed seed bank in soil. In the present agricultural scenario, farmers mostly prefer chemical methods of weed control because of its excellent efficacy, quick results, low cost, and ease of application in larger areas. Meanwhile, continuous and indiscriminate use of the same herbicide in the same field causes soil degradation and pollutes water bodies, aquatic flora, and fauna. Suzer

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and Byuk (2010) reported that soil persistence of imazethapyr+ imazamox causes residual toxicity in succeeding crops of sugar beet and rape seed. In contrast, maize, winter wheat and barley were non-susceptible to the residue of imazamox. Janaki *et al.* (2014) reported that the influence of clay and organic matter on herbicide sorption and observed that persistence of pyrazosulfuron-ethyl depends on the clay and organic matter content of soils. Janaki *et al.* (2015) reported that few sulfonylurea herbicide residues in soil can affect rational crops even at lower concentrations. Herbicide residue persists relatively long, placing succeeding sensitive crops at risk. Janaki *et al.* (2017) reported that oxyfluorfen persists in soil and contaminates aquatic surroundings through leaching and runoff, a highly persistent and toxic herbicide. Zahana *et al.* (2018); Shamim *et al.* (2020), Bommayasamy and Chinnamuthu (2021) found that herbicides used for weed control in soil or foliar application may be expected to control weeds within the season. At the same time, herbicides are expected to persist in soil and have a residual effect on succeeding crop growth (Paul *et al.* 2022). Because of the above facts, the present investigation was carried out to study the residual effect of encapsulated/loaded herbicide applied in preceding rice crop on weed control and productivity of blackgram, under rice-okra-blackgram cropping system in tropical conditions.

MATERIALS AND METHODS

Experimental details and design

Field experiments were conducted during the summer season of 2017 and 2018 at Agricultural College and Research Institute, Madurai and Central Island Agricultural Research Institute, Port Blair, to study the residual effect of encapsulated/loaded herbicide applied in preceding rice crop on weed control efficacy and productivity of blackgram, under rice-okra-blackgram cropping system. The field experiment was laid out in a randomized block design and replicated thrice. The field experiment consisted of eight weed control treatments of preceding rice, *viz.* oxadiargyl loaded biochar, oxadiargyl loaded zeolite, oxadiargyl encapsulated starch, oxadiargyl encapsulated water-soluble polymer, oxadiargyl at 100 g/ha, butachlor at 1.25 kg/ha *fb* hand weeding (HW) at 40 DAT, weed free check and weedy check. Succeeding crops were sown without disturbing the layout of the experimental field of preceding rice, and recommended packages of practices were followed to raise the crops. T_1 to T_5: No weed control treatment is applied, and observing the residual effects of herbicides from the rice crop on the succeeding crops (okra and blackgram) helps assess how long the herbicide persists in the soil and whether it impacts weed growth or crop performance (two hand weeding at 20 and 40 DAS) involves manual weed removal at two critical crop stages and ensures that the crops are kept free from weeds. Comparing the untreated groups will help evaluate the effect of manual weed control versus the residual herbicide effect. T_7 (Weed-free check): This treatment keeps the plot free from weeds throughout the growing period, comparing how well the crops perform under ideal conditions versus with residual herbicide effects or without weed control. In T_1 to T_5 and T_8-weedy check, no treatment was imposed whereas, in succeeding okra and blackgram weed control treatment was imposed in two hand weeding at 20 and 40 DAS and weed free check. After the harvesting of okra, the experimental field was sprayed with glyphosate at 1.0 kg/ha for keeping the field clean before the next crop is sown. After seven days, blackgram variety VBN (Bg)-8 seeds were sown with 30 x 10 cm spacing during the first week of May 2017 and the fourth week of March 2018 and harvested in the third week of July 2017 and June 2018. The recommended dose of 100% NPK (25:50:25 kg of NPK per ha) was applied as basal in the form of urea, diammonium phosphate and muriate of potash. Pest and disease incidence was not observed during the growing season. All the other recommended agronomic and plant protection measures adopted to raise the crop were taken as need based. Germination of black gram was recorded by counting the number of hills germinated in each plot, ten days after sowing and expressed as a percentage over total hills sown. The height of the plant was measured from the bottom of the plant to the tip of the growing point at the harvest stage of the crop and expressed in centimeters. Blackgram seed yield from each net plot was cleaned and sun-dried to reduce moisture content by up to 9% and weighted seed yields were expressed in kg/ha.

Growth analysis is helpful for crop physiologists and agronomists interested in understanding the differential behaviour of crop varieties under complex environmental conditions and concerning various treatments. Some of the essential components of growth analysis, *viz*. leaf area index, crop growth rate and relative growth rate, were carried out. The leaf area (LA) was worked out using the formula suggested by Mc Kee (1964).

Where LAI is the leaf area index, L is the length of the leaf from the top (cm), W is the maximum width of the leaf blade (cm), and the number of leaves per plant.

Crop Growth Rate (CGR) is a critical measure of how efficiently a crop produces biomass over time. It quantifies the rate of biomass accumulation in the crop on a per-unit-area basis over a specified time period. The unit of measurement is grams per meter square per day ($g/m^2/day$), which helps assess how much dry matter the crop produces each day per unit area. Crop Growth Rates were computed at 50 DAS to harvest stage and expressed in $g/m^2/day$.

Where W1 and W2 are plant weights recorded at t1 and t2 days, respectively, t2 - t1 is the time interval in days, and G is the ground area in which W1 and W2 were estimated. Relative Growth Rate (RGR) is the rate of dry weight increase per unit weight that is already present per unit time.

Where**,** W1 and W2 whole plant dry weight at t1 and t2 days, respectively, expressed as g/g/day.

Weed density and dry weight

Species-wise weed density was observed in the weedy check using 0.5m x 0.5m quadrat in randomly fixed places in the treatments of each plot at 40 DAS. Weeds falling within the quadrat frame were counted and recorded species-wise weed density, expressed in numbers/m^2. The same weeds were dried in a hot air oven for 72 hrs at 80°C, and dry weight was expressed in g/m^2.

Statistical analysis

Data on weed density and dry weight showed high variation; hence, they were subjected to transformation and analysed. Observed data of crops and weeds subjected to statistical scrutiny ANOVA (Analysis of Variance) as per methods suggested by Gomez and Gomez (1984). Whenever a significant difference existed, the least significant difference (LSD) was constructed at 5% probability level. Such treatments where the differences were not significant were denoted as NS.

RESULTS AND DISCUSSION

Weed density and dry weight of grass weeds

The residual effect of encapsulated/loaded herbicide significantly exerted the difference in grasses, sedges, broad-leaved weed density, and weed dry weight at 40 DAS in both years of crop growth (**Table 1**). Weed-free check recorded distinctly low weed density and dry weight of grasses, sedges, and BLW. This was followed by the residual effect of butachlor at 1.25 kg/ha *fb* hand weeding at 40 DAT in rice + HW twice at 20 and 40 DAS in okra and blacgram. In 2017 and 2018, oxadiargyl-loaded biochar significantly reduced grass weed density and dry weight. Specifically, grass weed density was reduced by 55.0% in 2017 and 61.3% in 2018, while grass weed dry weight decreased by 50.4% and 65.0%, respectively, compared to the untreated weedy control. These results were consistent with the residual effects observed for other herbicides tested. Sethi *et al.* (2019) reported that grasses' significantly lower weed dry matter was recorded in rice-wheat, while the highest dry matter was recorded in the rice-vegetable pea-maize cropping system.

Sedges weed density and dry weight

During 2017, the residue of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAS in okra and blackgram recorded lower density and dry weight of sedges (16.67 weeds/m^2 and 6.06g/m^2, respectively). This was followed by the residual effect of oxadiargyl-loaded biochar (28.67 weeds/m^2), comparable with oxadiargyl-encapsulated starch and oxadiargyl-loaded zeolite. Whereas, in 2018, the residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW at 20 and 40 DAS, and that of oxadiargyl loaded biochar and oxadiargyl encapsulated starch were comparable with one another with low density and dry weight for sedges. Density and dry weight of sedges in weedy check varied from 23.6 to 58.6, 28.7 to 70.0 and 49.7 to 63.4, 49.1 to 71.9 compared to herbicidal treatments' residual effect. Weedy check registered significantly higher density and dry weight of sedge than other residual weed control treatments.

Density and dry weight of broad-leaf weeds

The density of broad-leaf weeds was higher in 2018 than in 2017 due to climatic conditions, more conducive to weed growth. Irrespective of the residual effect of herbicide, oxadiargyl-loaded biochar and oxadiargyl encapsulated starch recorded 76.7, 79.3 and 75.3, 77.5% reduced density of BLW during 2017 and 2018, respectively, as compared to the weedy check. Whereas, for BLW, hand weeding twice at 20 and 40 DAS recorded significantly lower BLW dry weight (2.42 and 8.40 g/m^2 in 2017 and 2018, respectively). However, this was comparable with oxadiargyl-loaded biochar in 2017. Nevertheless, in 2018, these two treatments differed significantly from each other. Weedy checks recorded significantly higher BLW density and dry weight of 84.2, 75.8, and 88.3, 66.0% during 2017 and 2018, respectively, than hand weeding twice at 20 and 40 DAS. Mishra *et al.* (2019) reported that maximum density and dry weight of broad -leaf weeds were recorded in rice-maize rotation, followed by rice-wheat and rice-lentil systems.

Weed control efficiency

The residual effect of herbicides applied to previous crops and their weed control treatments showed a marked difference in weed control efficiency in both years (**Table 1**). Weed control efficiency of various weed control treatments on the control of weeds compared to total weed dry weight under weedy check was worked at 40 DAS. The residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAS recorded maximum weed control efficiency of 83.3 and 79.4% in 2017 and 2018, respectively. Among the residual effects of the preceding herbicide, oxadiargyl-loaded biochar recorded higher weed control efficiency of 65.9% and 70.2% in 2017 and 2018, respectively. Subsequent best treatment was oxadiargyl-encapsulated starch. This might be due to encapsulated/loaded herbicide residue causing significantly higher reduction in the total weed dry weight. Mousa and Eata (2016) reported that the residual effect of herbicides applied in the previous crop is inferior in its effect on weeds associated with succeeding vegetable crops. Bhimwal *et al.* (2019) revealed that higher weed control efficiency could be attributed to lower weed density and dry weight, which leads to higher grain yield. This is in conformity with the earlier findings of Gupta *et al.* (2012) in chickpeas, Panda *et al.* (2015), and Patel *et al.* (2016) in soybean.

Effect on crop growth

The residual effect of encapsulated/loaded herbicide did not significantly influence blackgram seed germination. Even though the two-year mean germination percentage varied from 83.2 to 97.0%, it clearly showed no significant influence of preceding crop encapsulated/loaded herbicide residue on succeeding blackgram. Chavan *et al.* (2018) reported that post-emergence application of quizalofop-ethyl 40g/ha and pre-emergence application of pendimethalin 1.0 kg/ha used in pigeon peas also did not show any residual effect on germination of succeeding blackgram. The weed-free check showed superiority in plant growth and yield attributes, as well as the yield of blackgram, during both experiments. Maximum plant height of 72.1 and 26.3% was observed in the residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAS during 2017 and 2018, respectively, as compared to the weedy check. The next-order best treatment was the residual effect of oxadiargyl-loaded biochar, comparable with $T_3 > T_2 > T_4$.

Agronomic manipulation alters crop physiology to a certain extent to derive higher economic products. Physiological attributes like LAI, CGR, and

Table 1. Residual effect of encapsulated/loaded herbicide on weed density, weed dry weight and weed control efficiency of blackgram under rice-okra-blackgram cropping system in tropical conditions

Treatment	Weed density at 40 DAS						Weed dry weight at 40 DAS						WCE at 40 DAS	
	Summer, 2017			Summer, 2018			Summer, 2017			Summer, 2018				
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW	2017	2018
Oxadiargyl loaded biochar	6.90 (46.00)	5.53 (28.67)	3.65 (11.33)	6.22 (36.67)	5.15 (24.67)	4.16 (15.33)	4.87 (21.74)	3.76 (12.11)	2.37b (3.61)	3.52 (10.36)	3.55 (10.64)	2.90 (6.42)	65.9	70.2
Oxadiargyl loaded zeolite	7.19 (49.67)	6.02 (34.33)	3.83 (12.67)	6.63 (42.00)	6.51 (40.33)	4.80 (21.00)	5.20 (25.04)	4.21 (15.72)	2.65 (5.04)	3.71 (11.75)	4.03 (14.25)	3.36 (9.29)	58.3	61.7
Oxadiargyl encapsulated starch	7.04 (47.67)	5.86 (32.33)	3.74 (12.00)	6.27 (37.33)	5.43 (27.67)	4.32 (16.67)	4.89 (22.12)	3.74 (12.06)	2.55 (4.50)	3.59 (10.88)	3.56 (10.73)	3.65 (11.43)	64.7	64.1
Oxadiargyl encapsulated water-soluble polymer	7.46 (53.67)	6.95 (46.67)	4.52 (18.67)	7.05 (47.67)	7.22 (50.33)	5.03 (23.33)	5.20 (25.14)	4.23 (15.93)	2.95 (6.76)	3.90 (13.23)	4.44 (17.80)	3.56 (10.69)	56.4	54.7
Oxadiargyl 100 g/ha	7.50 (54.33)	7.42 (53.00)	5.53 (28.67)	7.37 (52.33)	7.79 (58.67)	5.97 (33.67)	5.45 (27.73)	4.31 (16.58)	3.37 (9.38)	4.21 (15.73)	4.77 (20.79)	3.90 (13.25)	51.1	46.0
Butachlor 1.25 kg/ha *fb* HW at 40 DAT	4.72 (20.33)	4.32 (16.67)	3.11 (7.67)	4.08 (14.67)	4.89 (22.00)	3.83 (12.67)	3.43 (9.79)	2.84 (6.06)	2.10 (2.42)	2.24 (3.03)	3.09 (7.55)	3.22 (8.40)	83.3	79.4
Weed free check	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	100.0	100.0
Weedy check	10.20 (102.3)	8.44 (69.33)	7.09 (48.67)	8.67 (74.00)	9.18 (82.33)	7.35 (52.33)	7.62 (56.11)	5.90 (32.93)	4.73 (20.71)	5.57 (29.57)	6.31 (37.87)	5.15 (24.68)	-	-
LSD (p=0.05)	0.68	0.62	0.68	0.70	0.54	0.42	0.44	0.35	0.51	0.52	0.30	0.38		
CV (%)	5.94	6.16	9.44	6.67	5.20	5.24	5.33	5.26	10.55	8.41	8.54	6.44		

Figures in parentheses indicate original values subjected to square root $\sqrt{x+2}$ transformation

RGR differed in both years of experiments. At 50 DAS, the residual effect of butachlor at 1.25 kg/ ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAT significantly increased the LAI (4.87 and 4.52 during 2017 and 2018, respectively) over other weed management practices. Among the residual effects of herbicide in preceding crop, oxadiargyl-loaded biochar registered slightly higher leaf area index of 46.4 and 49.7% compared to weedy check during 2017 and 2018, respectively, comparable with other residual effect of herbicide. The favourable weed-free situation and higher nutrient uptake might have resulted in taller plants with a higher leaf area index (Bommayasamy *et al.*, 2018). Crop growth rate altered with the age of the crop due to gradual changes in photosynthetic efficiency. The CGR determined crop production as a function of light interception in the crop canopy. At 50 DAS to harvest stage, the CGR ranged between 2.21 to 4.51 and 1.74 to 3.39 g/m^2/day during 2017 and 2018, respectively. The residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice+ HW twice at 20 and 40 DAS recorded higher crop growth rates of 2.69 and 2.53 g/m^2/day during the first and second year of the experiment, respectively, which was comparable with oxadiargyl loaded biochar in 2017. In 2018, all other treatments were comparable except for the residual effect of oxadiargyl 100 g/ha and weedy check. Among the residual effects of herbicide, higher RGR was recorded under the residual effect of oxadiargyl encapsulated water-soluble polymer at 50 DAS to harvest stage during 2017, which was comparable with oxadiargyl at 100 g/ha and oxadiargyl loaded zeolite. Whereas, in 2018, the residual effect of the preceding rice herbicide did not show any significant difference among the weed control treatments. Mundra and Maliwal (2012), Bommayasamy and Chinnamuthu (2019), Ahlawat *et al.* (2024) reported that improved growth attributes are due to reduced weed competition with crops, which creates favourable environmental conditions for crop growth and development.

Effect on yield attributes and yield

Yield attributes of blackgram, *viz.* clusters/ plant, seeds/plant and grain yield were significantly influenced by the encapsulated/loaded herbicide residue of the preceding rice crop, while test weight did not show many variations on the yield attributes of blackgram (**Table 3**). The highest clusters/plant and seeds/plant were observed under weed-free check. Among the residual effects of herbicide, oxadiargyl-loaded biochar recorded significantly higher clusters/plant (4.8, 7.2%) with higher seeds/ plant (20.0, 26.2%) compared to oxadiargyl-loaded zeolite during 2017 and 2018, respectively. However, these treatments were on par with each other. The weedy check recorded the lowest number of clusters/plants of 5.50 and 5.43 and 61.2 and 81.1 seeds/plants in 2017 and 2018, respectively. The difference in seed test weight was not significant due to the residual effect of herbicide in both years. As assessed through the weed index, the extent of yield reduction due to weed competition has indicated the suppressing effect of oxadiargyl-loaded biochar on weeds. It had minimum weed competition and maximum seed yield of 108 and 101 kg of higher blackgram seed yield during 2017 and 2018, respectively, compared to the weedy check. It might be due to better growth and yield attributes that led to efficient utilization of resources, which in turn improved the yield attributes and yield. Volova *et al.* (2020) and Bommayasamy and Chinnamuthu (2021) found that encapsulated/loaded oxadiargyl herbicide

Table 2. Residual effect of encapsulated/loaded herbicide on crop growth attributes of blackgram under rice-okra-blackgram cropping system in tropical conditions

Treatment	Summer, 2017					Summer, 2018				
	Germination (%)	Plant height (cm)	LAI at 50 DAS	50 DAS - Harvest CGR (g/m^2/d)	50 DAS - Harvest RGR (g/g/d)	Germination (%)	Plant height (cm)	LAI at 50 DAS	50 DAS - Harvest CGR (g/m^2/d)	50 DAS - Harvest RGR (g/g/d)
Oxadiargyl loaded biochar	90.3	32.3	4.32	2.34	0.0115	90.0	34.6	4.31	2.09	0.0160
Oxadiargyl loaded zeolite	88.7	30.1	3.89	2.33	0.0132	90.2	33.7	3.95	1.85	0.0185
Oxadiargyl encapsulated starch	81.3	30.4	4.10	1.89	0.0115	84.4	34.3	4.07	1.93	0.0154
Oxadiargyl encapsulated water-soluble polymer	89.7	29.6	3.82	2.09	0.0142	93.0	33.1	3.53	1.81	0.0189
Oxadiargyl 100 g/ha	84.0	27.6	3.21	2.12	0.0135	87.9	32.6	3.38	1.80	0.0202
Butachlor 1.25 kg/ha *fb* HW at 40 DAT	90.3	38.2	4.87	2.69	0.0121	96.4	36.6	4.52	2.53	0.0181
Weed free check	95.7	40.7	4.94	4.51	0.0129	98.2	41.2	4.58	3.39	0.0211
Weedy check	82.7	22.2	2.95	2.11	0.0111	82.0	29.6	2.88	1.74	0.0200
LSD (p=0.05)	NS	5.5	0.56	0.59	0.0036	NS	3.8	0.61	0.77	NS

Table 3. Residual effect of encapsulated/loaded herbicide on yield attributes and yield of blackgram under rice-okra-blackgram cropping system in tropical conditions

Treatment	Summer, 2017				Summer, 2018			
	Clusters / plant	Seeds/ plant	Test weight (g)	Seed yield (kg/ha)	Clusters/ plant	Seeds / plant	Test weight (g)	Seed yield (kg/ha)
Oxadiargyl loaded biochar	6.60	110.6	6.13	444	6.57	132.9	6.07	416
Oxadiargyl loaded zeolite	6.30	92.2	5.80	370	6.13	105.3	5.97	347
Oxadiargyl encapsulated starch	6.40	105.4	5.90	426	6.63	125.4	6.03	399
Oxadiargyl encapsulated water-soluble polymer	5.90	91.2	5.80	366	5.83	104.2	5.83	343
Oxadiargyl 100g/ha	5.50	68.5	5.60	358	5.80	83.2	5.80	336
Butachlor 1.25 kg/ha *fb* HW at 40 DAT	8.40	184.1	6.20	655	8.17	154.1	6.17	614
Weed free check	10.20	251.0	6.60	842	8.80	196.7	6.30	790
Weedy check	5.10	61.2	5.26	336	5.37	81.1	5.60	315
LSD (p=0.05)	0.77	17.1	NS	50	0.61	19.5	NS	79

with biochar and zeolite released active ingredient for a longer time, which reduced the growth of later emerging weed and build-up of soil weed seed bank. Yadav *et al.* (2019), Gupta *et al.* (2019) reported that lesser infestation of weeds increases translocation of photosynthesis from source to sink. In this situation, it may enhance the seed production ratio of chickpeas. The lowest yield attributes, *viz.* clusters/ plant, seeds/plant and seed yield, were recorded under weedy check. It might be due to increased weed competition with unchecked weed growth. The productivity of crops mainly depends on efficient and effective resource management, particularly weeds. Parthipan *et al.* (2013), Rana *et al.* (2019) and Anand and Singh (2023) also have reported similar findings.

Conclusion

Conventional agrochemical formulations may be replaced by encapsulation/loaded herbicide formulations to help avoid treatment with excess amounts of active substances and offer ecological and economic advantages. The results clearly indicated the residual effect of oxadiargyl-loaded biochar and zeolite, which can release active ingredients for a longer time, with reduced growth of later emerging weeds and build-up of soil weed seed bank.

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RESEARCH ARTICLE

Weed management in wheat under different sowing windows in new alluvial zone of West Bengal, India

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ABSTRACT

A field experiment was conducted at District Seed Farm (AB Block), Kalyani under Bidhan Chandra Krishi Viswavidyalaya during the winter season of 2019-20 and 2020-21 in upland situations to study the effect of different sowing windows and weed management measures on growth and yield of wheat. The experiment was carried out in a split plot design with three replications. Three sowing times (timely, late and very late) in the main plot and eight weed management options, viz. pendimethalin 750 g/ha *fb* metsulfuron g/ha, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, hand weeding thrice (at 20, 35 and 50 DAS) and weedy check in sub -plots. At 30 DAS, more weed density was observed with the timely sowing condition and reduced with the date of progress of wheat sowing. However, broad -leaf weed density was less with very late sown conditions and significantly superior to all other main plot treatments. With different subplot treatments, the lowest density of grasses was found with hand weeding thrice and was followed by pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, and was statistically better to all other treatments except pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS. However, at 60 and 90 DAS, the lowest density of grassy, BLWs and sedges was observed with the timely sown condition and significantly better than other treatments. With various herbicidal treatments, the lowest density of grasses registered with the pendimethalin 750 g/ha *fb* one hand weeding and markedly better than all other treatments except hand weeding thrice. Total uptake of nutrients was lowest with the timely sown condition and was notably better than all other main plot treatments. Among herbicidal treatments, significantly lower uptake by weed was seen with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha. Grain yield varies significantly with sowing windows and weed management measures. More grain yield was found with timely sown conditions and was statistically better than other main plot treatments. Timely sown conditions gain 97.6 and 45.86 % more grain yield over very late sown situations. Among various integrated weed management options more grain yield gain with hand weeding thrice and was at par with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha. The study concluded that sequential/tank-mix application of pre- and or post-emergence herbicide could be adopted with appropriate sowing time for broad-spectrum control of weeds in wheat.

Keywords: Herbicide, IWM, Nutrient, Sowing Time, Weed, Wheat, Yield

INTRODUCTION

Wheat (*Triticum aestivum* L. emend. Fiori and Paol.) as an important source of calories and energy for humans and account for a prominent share in the consumption basket. This has been cultivated around 224.05 million hectare with output to the tune of 793.37 million tonnes ((ICAR-IIWBR, 2023). Wheat is the most important cereal crop because it is the staple food of the people of India. During the post-green revolution period, the productivity of wheat has increased tremendously but is still far below the potential yield (11.2 t/ha). In India this wheat is grown in 31.09 million hectares (23.78% of total crop acreage) contributing 34.34 % of the total foodgrains produced during 2022-23 as per 4th Advance Estimate, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, India. In the current production season, the wheat output is pegged at 107.74 million tones with a national average of 3543 kg/ha. In West Bengal, wheat cultivated area is quite low 221 thousand ha with production of 657 thousand tons, with productivity only 2.9 t/ha (ICAR-IIWBR 2023), this might be due to late sowing and poor weed management options etc. In weather factors, temperature is the driving force of plant development; day length and vernalization effect. Consequently, different times of sowing with different genetic make-up mature at different rates but the difference is greater when sown early or variation in nutrient or proper weed management measures etc. Climate change influences crop productivity by altering plant growth etc. (Chetna *et*

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al. 2023). Therefore , proper time of sowing becomes another factor to optimize the appropriate weather for cultivation. In spite of cultivation of high-yielding varieties, improved cultural practices and plant-protection measures, favourable weather is a must for good harvests.

Weeds are regarded as most disdainful of crop production and account for about one third of total losses caused by all the pests. Of the several constraints to low productivity of wheat, weeds have been recognized as an important one which compete with crop plants for nutrients and other growth factors, and in absence of an effective control measure weeds remove considerable quantities of applied nutrients resulting in higher loss in yield. Weed infestation during the crop period causes more than 43.63% reduction in grain yield, depending on the weed densities and type of weed flora present (Mukherjee 2023). Achieving effective weed control in the later stages and maintaining optimal field conditions requires a comprehensive approach, where a single method, such as relying solely on herbicides or manual/mechanical weeding, may not be sufficient. Herbicides offer several advantages, including time and cost savings, enabling the coverage of larger areas in a shorter period and facilitating timely weed control. These benefits are particularly crucial for managing weed infestations in a timely manner.

In wheat growing regions, the challenge of dealing with both grassy and broadleaf weeds has become increasingly common, leading to significant yield losses and complicating weed control efforts (Mukherjee 2020). This complex situation necessitates a well-rounded weed management approach that combines various strategies to address the diverse weed species effectively. Recent research highlights that adopting appropriate sowing time and proper weed management technologies can lead to substantial additional food grain production. By employing integrated weed management practices that incorporate herbicides, manual, and mechanical weeding as appropriate, farmers can better control weed infestations, minimize yield losses, and significantly increase crop productivity. Such a comprehensive approach is key to meet the growing demand for food and ensure food security in the face of challenges posed by weed infestations (Debnath *et al.* 2021). By focusing on improving production through appropriate sowing time and effective technologies, suitable herbicides can play a pivotal role in timely and efficiently controlling weeds. Sowing windows significantly impact the composition of weeds present in a wheat field, with earlier sowing generally leading to less weed pressure and a different weed species composition compared to late sowing, as certain weed species thrive under specific temperature and light conditions that vary throughout the growing season; essentially, adjusting sowing time can be a tool to manage weed populations in wheat crops by favoring the growth of the wheat plant over specific weed species. As such, the use of herbicides has become a necessity to manage weeds effectively. Identifying appropriate herbicides that offer economical and safe weed control is of utmost importance in enhancing the productivity and sustainability of wheat production. Keeping in view these points, the present study was conducted with the objective of more wheat productivity via appropriate sowing time with different herbicide combinations for controlling different groups of weeds under the new alluvial zone of West Bengal.

MATERIALS AND METHODS

The field experiment was conducted at District Seed Farm (AB Block), Kalyani under Bidhan Chandra Krishi Viswavidyalaya during the winter season of 2019-20 and 2020-21 in upland conditions. The farm is situated at approximately 22° 56´ N latitude and 88° 32´ E longitude with an average altitude of 9.75 m above mean sea level (MSL). The soil was sandy loam in texture, low in organic carbon (0.43%), medium in available N (253.72 kg/ha), low in available P (8.04 kg/ha) and medium in available K (167.29 kg/ha) content with pH 7.2. The total rainfall recorded during crop growth period was 19.3 and 12.1 mm, minimum temperature ranges from 10.9 to 15.7 and 10.8 to 18.9, and maximum temperature 22.4 to 37.8 and 18.9 to 34.8^0 C during winter 2019-20 and 2020-21, respectively. The field experiment was conducted in split plot design with three replications, having twenty four treatment combinations including three sowing windows (timely, late and very late) in the main plot and eight weed management measures, viz. pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, pendimethalin 750 g/ha *fb* one hand weeding at 35 days after sowing (DAS), hand weeding thrice (at 20, 35 and 50 DAS) and weedy check in subplots. The recommended fertilizer dose is 120:60:40 kg N, P and K per hectare, respectively. Wheat cultivar "*DBW 187*" was used for this experiment. The sowing of crop was done as per main plot treatments allotment (Timely: 5th November to 11th November; Late: 10th December to 16th December; Very late: 01st January to

7th January) with recommended seed rate of 125 kg/ ha using 150 kg N, 26.2 kg P and 33.1 kg/ha. Pre-emergence application of pendimethalin was given 3 DAS and all post -emergence herbicides were applied 25 DAS, with the help of a knapsack sprayer fitted with flat fan nozzle at spray volume of 500 L/ha. Weed population and weed dry weight were recorded at 30, 60 and 90 DAS by placing a quadrate of 50 × 50 cm randomly at two spots in each plot. Data on weed count and weed dry weight were subjected to square root transformation before statistical analysis. The irrigation and other recommended packages of practice were adopted during the crop growth period in both the years. The five randomly selected plants from each plot were uprooted and later cleaned and observations like plant height and dry weight at peak growth stage *i.e.* 60 DAS were recorded and averaged. The yield attributes were recorded at harvest to assess the contribution of yield. The 1000 seed weights were counted from the lot, weighed and expressed as 1000 seed weight. The grain and biological yield were computed from the harvest of net plot and expressed in t/ha. Plant and soil samples were analyzed for uptake of nitrogen, phosphorus and potash as per standard laboratory procedures (Jackson, 1973). Available phosphorus was determined by Olsen's method as outlined by Jackson (1973), using a spectrophotometer (660 nm wavelength). Available potassium was extracted with neutral normal ammonium acetate and the content of K in the solution was estimated by flame photometer (Jackson, 1973). The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F test and conclusions were drawn at 5% probability level (Gomez and Gomez, 1984). The effect of treatments was evaluated on pooled analysis basis on growth, yield attributes and yields.

RESULTS AND DISCUSSION

Weed flora

The weed flora in the experimental field consisted of some grasses, sedges and broad-leaved weeds. Among the weeds, grasses were predominant weed species in both the seasons at all the stages of observations. Among the grasses, *Echinochloa colona, Panicum repens and Cynodon dactylon* were dominant species. The broad-leaved weeds constituted the major proportion of the weed flora accounting more in total weed density. Among the sedges, *Cyperus iria, Fimbristylis miliacea* were the dominant species and in broad leaved weeds, *Physalis minima*, *Chenopodium album*, *Anagallis arvensis*, *Circium arvense*, *Fumaria parviflora*, *Melilotus alba* and *Alternanthera philoxeroides* were the dominant weed species.

Weed dynamics at different stages

With different treatments, sowing time significantly influences the population of different classes of weeds. At 30 DAS, more weed density was observed with the timely sowing condition and reduced with the date of progress of wheat sowing. Lowest population was observed with late sown condition and was statistically better to other treatment and showed parity only with very late condition. However, less broad leaf weed density was observed with very late sown condition and significantly superior to all other main plot treatments. Among different classes of weeds, sedges failed to give any statistical difference with main plots, however the lowest value was found with the very late sown condition and was closely followed by timely sown condition. With different subplot treatments, lowest density of grasses found with hand weeding thrice and was followed by pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, and was statistically better to all other treatments except pendimethalin 750 g/ha *fb* one HW at 35 DAS, where they were at par to each other. Among various weed management option lowest BLW population was observed with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and was at par with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and significantly better to all other treatments except hand weeding thrice. Lowest sedges density was seen with hand weeding thrice and was followed by pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha, which showed parity with pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, and statistically superior to all other treatments. Dry weight of weeds at 30 DAS was found less with the very late sowing condition for all categories of weeds and this showed parity only with late sowing for BLW and statistically better to all other treatments. Among weed management strategies, dry weight of grasses at 30 DAS, lowest with hand weeding thrice and was closely followed by pendimethalin 750 g/ha) *fb* clodinafop-propargyl 60 g/ha, which showed parity with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and notably better to all other treatments. Further, **table 1** revealed that, with different herbicide treatments, dry weight of BLW less establish with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and was at par only with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and significantly better to all other treatment except hand weeding thrice. Reduce dry matter of sedges was seen with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and significantly better to all other treatments except hand weeding thrice which showed lowest dry weight of weed biomass. Apart from causing reductions in crop yield, weeds also deplete the soil of essential nutrients. The extent of nutrient removal by weeds is influenced by the level of weed infestation and the accumulation of weed biomass. Effective weed control measures have been observed to minimize nutrient losses attributed to weeds. At 30 DAS more nutrient uptake by weeds was observed with late sown condition, due to higher dry matter production. Among treatments, least NPK uptake by weed was observed with timely sowing of wheat and showed parity with very late sown condition and statistically better to all other treatments. With different herbicidal treatments, lowest nitrogen uptake resulted with pendimethalin 750 g/ha) *fb* clodinafop-propargyl 60 g/ha for nitrogen uptake and notable better to all other treatments except hand weeding thrice which gave lowest nitrogen uptake by weeds. Total uptake by weeds was observed lowest with hand weeding thrice and was significantly better to other treatments, this was followed by pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, which showed parity with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and significantly better to other integrated weed management options.

At 60 DAS, lowest density of grassy weeds was observed with timely sown condition and significantly better than other treatments **(Table 2)**. BLWs density was lowest with timely sown condition and was at par only with very late condition, and notably better to other treatments. While the least number of sedges was seen with very late sown condition and showed parity with timely sown wheat and statistically superior to all other treatments. Among different subplot of various herbicidal treatments lowest density of grasses registered with the pendimethalin 750 g/ha *fb* one hand weeding and significantly better to all other treatments except hand weeding thrice. Density of broad leaf weeds and sedges, were seen lowest with hand weeding thrice and this was significantly better to all other treatments. This was followed by pendimethalin 750 g/ha *fb* one hand weeding. Lowest total weed density was seen with hand weeding thrice and statistically

Table 1. Effect of treatments on weed density, dry weight and nutrient uptake pattern of weed in wheat at 30 DAS (pooled value of two years)

Treatment	Weed population (at 30 DAS) (no./m^2)			Total weed population (no./m^2)	Dry weight (no./m^2)			Total dry weight (no./m^2)	Nutrient uptake by weeds (kg/ha)			Total uptake by weeds (kg/ha)
	Grasses	BLW	Sedges		Grasses	BLW	Sedges		N	P	K	
Sowing time												
Timely	3.22* (9.90) **	5.35 (28.09)	2.48 (5.64)	6.77 (45.37)	1.63 (2.15)	3.3 (10.41)	2.22 (4.45)	4.18 (17.01)	4.36	2.06	7.34	13.76
Late	2.47 (5.59)	5.43 (29.00)	2.81 (7.38)	6.38 (40.23)	2.11 (3.95)	3.29 (10.32)	2.06 (3.75)	4.3 (18.02)	5.74	2.18	8.41	16.33
Very late	2.74 (6.99)	4.88 (23.32)	2.38 (5.16)	6.00 (35.47)	1.66 (2.26)	3.13 (9.30)	1.6 (2.05)	3.76 (13.61)	4.32	1.98	6.78	13.08
LSD (p=0.05)	0.37	0.41	NS	0.38	0.17	0.26	0.22	0.32	0.49	0.26	0.66	0.96
Weed management												
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	2.2 (4.35)	4.61 (20.73)	2.17 (4.20)	5.46 (29.28)	2.2 (4.36)	3.51 (11.79)	2.03 (3.64)	4.5 (19.79)	7.33	2.86	7.42	16.82
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	3.03 (8.68)	5.23 (26.86)	2.34 (4.99)	6.41 (40.53)	1.99 (3.48)	3.33 (10.62)	1.69 (2.35)	4.12 (16.45)	5.39	2.10	6.30	15.55
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	1.92 (3.20)	3.34 (10.64)	2.31 (4.84)	4.38 (18.68)	1.51 (1.78)	2.65 (6.50)	1.77 (2.62)	3.38 (10.90)	6.09	2.73	7.3	14.41
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	2.47 (5.60)	3.58 (12.34)	2.26 (4.63)	4.8 (22.57)	1.51 (1.78)	2.37 (5.12)	1.93 (3.23)	3.26 (10.13)	5.71	2.41	6.77	12.93
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	2.97 (8.30)	4.6 (20.66)	2.55 (6.00)	5.95 (34.96)	1.3 (1.2)	2.38 (5.18)	1.49 (1.71)	2.93 (8.09)	4.39	2.00	5.62	12.74
Pendimethalin 750 g/ha *fb* one hand weeding	2.22 (4.43)	5.9 (34.26)	2.59 (6.23)	6.74 (44.92)	1.75 (2.58)	3.21 (9.82)	1.55 (1.89)	3.85 (14.29)	5.64	1.19	6.21	14.82
Hand weeding at 20, 35 and 50 DAS	1.39 (1.44)	2.68 (6.67)	1.08 (0.66)	3.04 (8.77)	0.91 (0.32)	1.26 (1.10)	0.9 (0.31)	1.49 (1.73)	2.44	0.73	3.8	6.97
Weedy check	4.96 (24.06)	9.09 (82.09)	4.23 (17.41)	11.1 (123.56)	2.74 (7.00)	5.12 (25.69)	3.48 (11.63)	6.69 (44.32)	7.64	3.32	8.44	19.4
LSD p=0.05)	0.39	0.44	0.37	0.50	0.22	0.30	0.27	0.39	0.55	0.32	0.74	2.56

*Data analyzed after square root transformation $\sqrt{x+0.5}$; **Figures in parentheses are original values

better to other subplot treatments. This was closely followed by pendimethalin 750 g/ha *fb* one hand weeding and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha. Dry matter of weeds showed significant differences with different classes of weeds. Lowest grass and sedges dry matter were seen with timely sown condition and statistically superior to all other treatments. Reduced dry matter of broad leaf weeds was observed with very late sown condition and it showed parity with timely sown only. Dry matter of grasses and sedges were found lowest with hand weeding thrice and notably better to all other treatments, this was followed by pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha **(Table 2).** Among different chemical treatments lowest dry matter of BLWs was found with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and was at par with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically better to all other treatments except pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and hand weeding thrice. Further, table 2 revealed that, total dry matter of weeds was observed lowest with timely sown condition and statistically superior to all main plot treatments. With different subplot treatments, total dry matter of weed was found lowest with hand weeding thrice and significantly better than other treatments. This was followed by pendimethalin 750 g/ha *fb* one hand weeding and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha. Highest total weed dry matter registered with weedy check and was followed by pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha. Nutrient uptake by weeds was seen lowest with timely sown condition and was statistically better to all other main plot treatments. Understanding and managing the impact of weeds on nutrient dynamics is crucial to ensure sustainable and productive agricultural systems. By implementing effective weed management strategies, farmers can mitigate the negative effects of weeds on crop productivity and nutrient availability in the soil. Total uptake of nutrient was lowest with timely sown condition and was notably better to all other main plot treatments **(Table 2).** This was followed by very late conditions. With different sub plot treatments highest uptake of nutrient by weeds seen with weedy check and was followed by pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha. Significant lower uptake by weed seen with hand weeding thrice and statistically superior to all other treatments. This was followed by pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha.

Table 2. Effect of treatments on weed density, dry weight and nutrient uptake pattern of weed in wheat at 60 DAS (pooled value of two years)

Treatment	Weed population (no./m^2)			Total weed population (no./m^2)	Dry weight (no./m^2)			Total dry weight (g/m^2)	Nutrient uptake by weeds (kg/ha)			Total uptake by weeds (kg/ha)
	Grasses	BLW	Sedges		Grasses	BLW	Sedges		N	P	K	
Sowing time												
Timely	4.51 (19.80)	8.04 (64.16)	4.07 (16.07)	10 .00 (100.03)	4.93 (23.82)	9.06 (81.65)	4.64 (21.02)	11.24 (124.22)	9.14	2.87	10.42	22.43
Late	5.09 (25.37)	8.39 (69.93)	4.86 (23.15)	10.9 (118.45)	5.67 (31.65)	10.3 (106.02)	5.47 (29.37)	12.91 (167.04)	14.13	3.06	15.14	32.33
Very late	4.96 (24.13)	8.34 (69.10)	3.99 (15.46)	10.4 (108.69)	5.3 (27.59)	8.94 (79.38)	5.44 (29.13)	11.8 2 (138.37)	12.09	3.17	13.38	28.64
LSD (p=0.05)	0.24	0.30	0.31	0.44	0.29	0.41	0.39	0.50	0.36	0.10	0.26	2.45
Weed management												
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	3.87 (14.47)	8.42 (70.38)	5.84 (33.57)	10.9 (118.42)	4.98 (24.29)	9.95 (98.42)	6.52 (41.99)	12.93 (164.70)	13.44	2.86	14.63	30.93
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	4.65 (21.11)	9.3 (85.97)	2.34 (4.99)	10.6 (112.07)	5.57 (30.55)	11.5 (131.06)	4.59 (20.58)	13.51 (182.19)	15.44	3.98	16.81	36.23
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	5.11 (25.61)	7.97 (63.06)	4.76 (22.14)	10.1 (110.81)	5.31 (27.71)	10.7 (113.5)	5.52 (29.92)	13.18 (171.13)	13.89	2.97	14.97	31.83
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	4.36 (18.53)	7.73 (59.28)	3.77 (13.73)	9.59 (91.54)	5.53 30.13)	9.24 (84.89)	5.7 (32.03)	12.11 (147.05)	13.01	3.31	13.98	30.3
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	4.42 (19.02)	7.96 (62.84)	5.23 (26.86)	10.5 (108.72)	5.25 27.02)	9.52 (90.15)	5.00 (24.5)	11.98 (141.67)	12.69	3.28	13.23	29.2
Pendimethalin 750 g/ha *fb* one hand weeding	3.97 (15.30)	5.72 (32.26)	2.59 (6.23)	7.37 (53.79)	2.7 (6.78)	4.24 (17.49)	2.19 (4.28)	5.39 (28.55)	5.71	0.92	6.06	12.69
Hand weeding at 20, 35 and 50 DAS	1.68 (2.33)	3.44 (11.32)	1.08 (0.66)	3.85 (14.31)	1.47 (1.65)	2.08 (3.81)	0.78 (0.11)	2.46 (5.57)	1.61	0.57	2.18	4.36
Weedy check	8.29 (68.25)	12.5 (156.68)	6.17 (37.53)	16.2 (262.46)	8.63 74.01)	13.5 (183.1)	7.36 (53.72)	17.6 (310.83)	16.31	6.01	19.36	41.68
LSD (p=0.05)	0.31	0.41	0.35	0.69	0.36	0.47	0.41	0.43	0.31	0.08	0.20	2.67

*Data analyzed after square root transformation $\sqrt{x+0.5}$; **Figures in parentheses are original values

At 90 DAS, density of grasses failed to produce any significant response with various main plot treatments, however, lowest density of grasses seen with timely sown condition and was followed by very late sown condition **(Table 3).** Lowest density of BLWs was found with timely sown condition and showed parity only with very late sown situation and statistically superior to other treatments. Moreover, the least sedges population was seen with very late sown condition and was significantly better to other main plot treatments. With different subplot treatments, lowest value of grassy weeds population observed with hand weeding thrice and showed parity only with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically superior to all other treatments. Among weed management strategies, density of broad leaf weeds was seen least with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and significantly better to all other treatment except hand weeding thrice, which showed lowest density of BLWs. However, lowest sedges density was observed with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and was at par with hand weeding thrice, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and significantly better to all other weed management options. Further observation revealed that total weed density was found lowest with timely sown condition and was closely followed by very late sown condition, they were at par to each other and notably better to other main plot treatments. Total density of weeds was found less with hand weeding thrice and was at par only with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically superior to all other treatments. Biomass production significantly varies with different main and subplot treatments **(Table 3).** More value of dry matter of grassy weeds observed with late sown condition and statistically poor to rest of the main plot treatments. Less BLWs biomass production was observed with very late condition and was at par with timely sown condition. They were at par to each other and statistically superior to other treatments. Lowest sedges dry-matter production was seen with timely sown condition and was at par only with late sown condition and significantly better to other treatments. Dry matter of different classes of weeds significantly found lower with hand weeding thrice and statistically superior to all other treatments. Among weed management strategies, lowest dry matter production of different class of weeds resulted with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and showed parity only with grassy weeds with pendimethalin 750 g/ha *fb* one hand weeding and

Table 3. Effect of treatments on weed density, dry weight and nutrient uptake pattern of weed in wheat at 90 DAS (pooled value of two years)

Treatment	Weed population (no./m^2)			Total weed population (no./m^2)	Dry weight of weeds (g/m^2)			Total dry weight of weeds (g/m^2)	Nutrient uptake by total weeds (kg/ha)			Total uptake by weeds (kg/ha)
	Grasses	BLW	Sedges		Grasses	BLW	Sedges		N	P	K	
Sowing time												
Timely	3.35* (10.75)**	6.21 (38.13)	4.08 (16.21)	8.09 (65.0)	3.86 (14.42)	8.29 (68.33)	4.06 (16.02)	9.96 (98.7)	8.07	2.33	8.26	18.66
Late	3.74 (13.49)	6.99 (48.43)	4.83 (22.9)	9.23 (84.8)	4.81 (22.67)	8.71 (75.52)	4.26 (17.71)	10.7 (115.9)	11.51	2.87	13.14	28.16
Very late	3.37 (10.89)	6.48 (41.62)	3.67 (12.98)	8.12 (65.4)	4.26 (17.72)	8.24 (67.42)	4.80 (22.61)	10.4 (107.7)	10.56	2.36	11.67	24.09
LSD (p=0.05)	NS	0.42	0.38	0.77	0.29	0.31	0.24	0.39	1.64	NS	1.66	2.79
Weed management												
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	2.57 (6.14)	7.60 (57.38)	4.70 (21.6)	9.25 (85.1)	4.08 (16.22)	7.94 (62.67)	4.92 (23.71)	10.15 (102.6)	10.32	2.84	10.01	23.17
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	3.36 (10.84)	8.25 (67.68)	3.47 (11.59)	9.51 (90.1)	4.36 (18.56)	9.15 (83.37)	4.49 (19.72)	11.05 (121.6)	13.21	3.98	14.56	31.75
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	3.85 (14.39)	5.60 (30.92)	3.23 (9.98)	7.47 (55.3)	4.63 (21.02)	8.86 (78.05)	3.63 (12.69)	10.59 (111.6)	13.09	1.39	13.17	27.65
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	3.38 (10.98)	5.38 (28.48)	4.31 (18.61)	7.65 (58.0)	4.63 (21.01)	8.61 (73.8)	4.60 (20.68)	10.76 (115.4)	12.14	2.66	13.47	28.27
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	3.17 (9.59)	4.93 (23.85)	3.36 (10.81)	6.68 (44.2)	3.40 (11.09)	5.99 (35.43)	3.08 (9.01)	7.4 (55.3)	4.34	1.24	5.98	11.56
Pendimethalin 750 g/ha *fb* one hand weeding	3.68 (13.07)	5.61 (31.04)	4.99 (24.46)	8.31 (68.5)	3.95 (15.13)	8.54 (72.47)	4.63 (21.01)	10.44 (108.61)	10.69	2.63	11.18	24.52
Hand weeding at 20, 35 and 50 DAS	2.86 (7.72)	3.96 (15.21)	3.24 (10.02)	5.78 (32.9)	2.00 (3.51)	3.31 (10.43)	1.36 (1.35)	3.9 (15.2)	2.35	0.78	3.01	6.14
Weedy check	4.61 (20.76)	9.34 (86.9)	5.75 (32.59)	11.86 (140.2)	6.42 (40.72)	12.53 (156.51)	6.72 (44.72)	15.5 (241.9)	14.19	4.63	15.96	34.78
LSD (p=0.05)	0.37	0.58	0.44	0.97	0.49	0.42	0.39	0.98	1.81	1.23	1.50	2.37

*Data analyzed after square root transformation $\sqrt{x+0.5}$; **Figures in parentheses are original values

significantly better to all other treatments except hand weeding thrice. Lowest dry matter of total weeds observed with timely sown condition and was statistically better to all other main plot treatments. Total weed dry matter significantly influenced by various subplot treatments and lowest value seen with hand weeding thrice, this was followed by pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha. Nutrient uptake by weeds showed significant response with various main plot treatments, lowest nutrient uptake by weeds observed with timely sown condition and statistically better to other date of sowing. Among weed management strategies, least uptake of nutrients by weeds resulted with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, which was notably better to all other treatments except hand weeding thrice.

Crop growth parameters

Growth attributes such as plant height, dry matter production and CGR serve as indicators of effective resource utilization and play a significant role in achieving better crop production outcomes. Plant height, which can vary based on different varieties and field management practices, is influenced by the number and length of elongated internodes **(Table 4)**. Highest plant height observed with timely sown condition and was at par with late sown condition and significantly better to other main plot treatments. With different weed management options more plant height at maximum growth stage seen with pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and was at par with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and hand weeding thrice. This might have resulted in reduced crop-weed competition for the growth factors such as light, space and nutrients which in turn might have helped in efficient photosynthetic activity resulting in taller plants. The findings of this study are consistent with the results reported by Mukherjee *et al.* (2022). Sowing dates and weed management practices had a considerable impact on the dry matter accumulation, and this parameter was found more with timely sown condition and was significantly better to all other treatments except late sown where they were at par to each other. Among different herbicidal treatments, more dry matter accumulation observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with three hand weeding and pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha. The weed control treatments had a significant impact on the physiological parameters such as crop growth rate. In the current study, CGR values were observed to be relatively higher at the flowering stage, gradually declining as the crop approached maturity. The variation in CGR is a critical physiological factor that directly influences crop yield potential. CGR of wheat increased with advancement of crop growth and the highest increase was recorded between 60 to 90 DAS **(Table 4)**. CGR of wheat was not significantly influenced by time of sowing techniques except at 60 and 90 DAS. At 60 and 90 DAS, significantly higher CGR was recorded under timely sowing and statistically better than all other treatments, due to more leaf growth, more dry matter accumulated by crop. At 60 and 90 DAS, very late observed lowest CGR over other dates, due to poor growth of crops. CGR was not significantly influenced by weed control treatments at all crop growth stages except at 60, 90 and 120 DAS. With different herbicidal treatments more CGR at 60 DAS was found with hand weeding and was at par only with pendimethalin

Table 4. Effect of treatments on various growth parameters of wheat (pooled data of two years)

Treatment	Plant height at 60 DAS (cm)	Dry matter accumulation at 60 DAS (g/m^2)	Crop growth rate (g/m^2/day) 60 DAS	90 DAS	120 DAS	At harvest	Days to 50% heading	Days to physiological maturity
Sowing time								
Timely	73.39	108.02	5.77	17.08	18.07	7.86	74.66	117.35
Late	70.25	90.24	5.51	16.98	17.53	7.38	68.33	112.4
Very late	68.44	79.21	4.59	16.28	17.78	7.34	62.31	105.44
LSD (P =0.05)	3.62	3.1	0.05	0.16	NS	NS	4.81	3.56
Weed management								
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	72.25	78.25	5.64	15.48	18.33	7.65	72.66	110.43
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	79.25	102.26	5.33	16.96	18.33	8.35	68.25	112.66
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	63.25	87.25	4.03	16.64	17.15	6.92	70.43	112.36
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	58.32	89.36	4.85	16.35	16.94	7.74	63.25	113.39
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	76.10	105.36	6.01	17.56	17.03	6.36	65.65	110.31
Pendimethalin 750 g/ha *fb* one hand weeding	74.21	100.65	5.35	17.54	18.69	7.98	70.52	111.42
Hand weeding at 20, 35 and 50 DAS	75.25	104.36	6.03	17.48	18.74	7.35	68.83	113.32
Weedy check	67.36	74.23	4.63	15.68	16.5	7.18	67.66	110.25
LSD (p=0.05)	4.22	3.36	0.10	0.19	0.35	0.61	3.14	4.21

NS : Non-significant* Days after sowing

750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically better to all other treatments **(Table 4)**. At 90 DAS more CGR observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and showed parity with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and hand weeding thrice. At 120 DAS, more CGR was observed with hand weeding thrice and was at par only with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and statistically better to other treatments. Days to fifty percent heading was earlier with very late condition and was statistically less to other treatments. Days to 50% heading observed least with pendimethalin 750 g/ha *fb* one hand weeding and was at par with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and hand weeding thrice at 20, 35 and 50 DAS. Further, highest duration of physiological maturity took place by timely sown condition and statistically more to other main plot treatments. However, the least value found with very late sown condition. Various herbicidal treatments produced statistical difference and more time needed with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and was followed by pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, hand weeding thrice and significantly better to other treatments.

Yield attributes

Yield attributing characters and yield varies significantly with different treatments and showed quite distinct marks on crop yield **(Table 5)**. Ear head /m^2 observed more with timely sown condition and was statistically at par with late condition, and significantly superior to other main plot treatments. With different weed management options, more ear head per meter square were seen with hand weeding thrice and showed parity with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, and significantly better to other treatments. Lowest number of ineffective tillers per meter square determined with timely sown condition and statistically better to all other treatments. With different subplot treatments, least ineffective tiller/m^2 observed with hand weeding thrice and was at par with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically better to other treatments. Grain per spike and test weight of grain were observed highest with timely sown condition and was statistically better to other sowing time. This was followed by late and very late sowing of wheat. Grain/spike observed more with pendimethalin 750 g/ha *fb* one hand weeding and was notably better to all other treatments. Thousand grain weight more observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with hand weeding at 20, 35 and 50 DAS, pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha. The final yield of a crop is the net result of growth and developmental activities in individual plants, which in turn would depend upon the genetic potential of the cultivars and the environmental condition to which it is exposed during the course of its life cycle. Biomass production showed significant variation with different sowing time under various weed control measures.

Grain and straw yield

Grain yield varies significantly with sowing windows and weed management measures. More grain yield was observed with timely sown condition and was statistically better to other main plot treatments during first (4.94 t/ha) and second year (4.6 t/ha) of data recording. Timely sown conditions gain 97.6 and 45.86 % more grain yield over very late sown situations **(Table 5)**. Delayed sowing of wheat, exposed to both the extremes of temperature (low temperature during early growth period) which restrict the vegetative phase and high temperature during post anthesis period which reduce the duration of grain development and consequently the grain yield drastically reduced under very late sown situation (Mukherjee and Mandal 2021). With various subplot treatments, during first year more grain yield was observed with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha (4.63 t/ha) and was closely followed by hand weeding thrice, pendimethalin 750 g/ha *fb* one hand weeding, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and they were statistically at par with each other. However, during second year, more grain yield observed with hand weeding thrice (4.36 t/ha) and showed parity with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* one hand weeding, and significantly better than other treatments. These treatments registered 76.71 and 20.93% more gain yield over the control plot respectively, during the first and second year of observation. More grain yield was recorded owing to effective control of weeds and higher growth and yield attribute of wheat. This corroborates with the finding of Kumar *et al.* (2014). The study concluded that sequential/tank-mix application of pre- and or post-emergence grass, sedges and broadleaf killers could be adopted for broad-spectrum control of weeds in wheat. The adoption of effective weed management practices resulted in reduced competition between wheat and weeds for essential resources like nutrients, moisture, light, and space. This facilitated better utilization of sunlight, increased carbohydrate synthesis, and improved allocation of

Table 5. Effect of various treatments on yield attributes (pooled data of two years) and yield of wheat

Treatment	Ear head /m² (no.)	No. of ineffective tiller/m²	Grain/spike (no.)	1000 grain weight (g)	Grain yield (t/ha)		Straw yield (t/ha)		Harvest index (%)	
					2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Sowing time										
Timely	313.16	41.98	52.67	45.01	4.94	4.61	6.73	7.81	42.33	37.11
Late	287.43	50.44	44.36	41.95	3.86	3.30	6.83	4.41	36.10	42.80
Very late	256.86	58.54	37.61	37.48	2.50	3.16	4.70	3.83	34.72	45.20
LSD (p=0.05)	27.09	1.24	4.23	2.21	0.32	0.43	0.58	0.61	2.17	1.98
Weed management										
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	241.01	68.98	44.51	38.11	3.50	3.27	4.12	5.25	45.93	38.38
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	279.15	47.41	39.54	39.68	3.02	3.96	5.10	5.71	37.19	40.95
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	301.74	60.65	45.59	37.75	4.63	3.74	6.83	6.21	40.40	37.58
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	307.43	39.44	47.73	43.53	4.32	3.81	6.71	5.49	39.16	40.96
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	337.84	35.36	45.26	45.93	4.40	4.01	7.22	6.84	37.86	36.95
Pendimethalin 750 g/ha *fb* one hand weeding	336.78	46.84	51.65	44.29	4.60	3.92	6.67	6.02	40.81	39.43
Hand weeding at 20, 35 and 50 DAS	341.66	33	42.49	45.76	4.62	4.36	6.93	6.28	40.01	40.97
Weedy check	137.42	74	39.73	37.32	2.62	1.41	3.93	2.51	40.13	35.86
LSD (p=0.05)	20.97	3.00	3.03	2.44	0.41	0.47	0.67	0.73	3.14	NS

NS : Non-significant

photosynthates towards grain formation, ultimately leading to higher straw yield. This parameter, significantly influenced by main plot treatment measures and found more with the timely sown and was significantly better to other sowing windows. This gave 75.4 and 31.08% more over the very late and late sown condition. The more grain yield and straw production were resulted with timely sowing accrued mainly because of more dry matter accumulation and increase in yield attributing traits. Among various weed management measures, more biological yield observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with all the treatments except pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and weedy check. Harvest index failed to produce any statistical difference with various main plot treatments **(Table 5)**. More harvest index observed with timely sown condition during first year and in second year seen with very late sown condition and statistically better to other main plot treatments. With various subplot treatments, more harvest index was seen with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha during first year only and failed to give any statistical difference in second year of experiment. Overall, the effective management of weeds using suitable herbicidal combinations under different sowing periods proved beneficial for wheat crops, leading to increased growth, yield, and productivity.

The study concluded that sequential/tank-mix application of pre- and or post-emergence grass, sedges and broadleaf killers could be adopted with appropriate sowing time for broad-spectrum control of weeds in wheat.

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RESEARCH ARTICLE

Floristic and phytosociological studies of weeds in wheat crop fields of Mungeli district of Chhattisgarh, India

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ABSTRACT

The field study was carried out to examine the floristic diversity of weeds in wheat crop fields during the Rabi season of 2018-2020 in four villages, Barela, Semarchua, Chamari, and Karhi, of Mungeli district in Chhattisgarh (India). This study recognized the floristic composition of weed species and evaluated the most dominant and common weeds at the study area. 48 weed species belonging to 19 families were recorded in all the study sites of wheat crop fields. The maximum numbers of weeds were observed in village Barela (46) followed by villages Semarchua (45), Chamari (41), and Karhi (36). The floristic composition of weed species was recorded as dicot (16%), monocot (79%), and pteridophytic (05%) groups. According to the highest importance value index (IVI value), *Alternanthera sessilis* (L.) DC was found to be the most dominant weed species in the wheat crop fields of village Barela, followed by *Anagallis arvensis* L., *Medicago polymorpha* L., and *Chenopodium album* L. in Karhi, Semarchua, and Chamari villages, respectively. This survey will provide basic information about weed flora.

Keywords: Dominant weeds, Importance value index, Weed flora, Wheat crop

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important food crops in India and is grown extensively throughout the world. It is also cultivated by the farmers of the Mungeli district in Chhattisgarh during the rabi season. In agriculture fields, only 250 weed species were important out of the 8000 weed species in the world (Holm *et al.* 1979, Ahmad *et al.* 2016). Many factors are responsible for low wheat production, but maximum wheat yield reduction is caused by weed infestation (Rabia *et al.* 2003). There are different opinions regarding the yield loss in wheat due to weeds. According to Gill *et al.* (1979), heavy weed infestations were responsible for up to 15-50% yield loss in wheat. Qureshi (1982), reported 30% yield loss in wheat due to weeds. Due to weed infestation 34.3% loss in wheat yield was reported by Tiwari and Parihar (1993). According to Dangwal *et al.* (2010), weeds were responsible for causing up to 25-35% yield loss in wheat. Gharade *et al.* (2018) estimated 7.5 to 41% yield reduction in the wheat crop. This is quite worrying and needs attention.

The structure and composition of weeds were changed by environmental conditions such as soil type, weed management cropping system, and climate. A better design of a weed management program requires information and knowledge about the most dominant and important weed species in particular crop fields. A phytosociological survey gives overall information about weed diversity and composition in crop fields (Das 2008). So phytosociological studies of weeds are compulsory for recognizing the interconnection of wheat crops and its weed flora. This may be helpful as a device for designing a weed management strategy. The objective of the present study was to identify and determine the most common and dominant weeds in the wheat crop fields of the Mungeli district of Chhattisgarh. There are no records of ecological aspects of weeds in the study area.

MATERIALS AND METHODS

The present study was conducted to find out the common and most dominant weeds in wheat crop fields in the Mungeli district of Chhattisgarh. An extensive field- based survey was done during different months of wheat growing season of 2018-2020 in the study area. Randomly four villages in the Mungeli district were selected for the study. The observation was taken at four selected villages, which are Barela as site 1, Semarchua as site 2, Karhi as site 3, and Chamari as site 4. Five fields were surveyed in each site in 2018 to 2020. The soil in this area is black and sandy loam.

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The random quadrat method was applied for the assessment of the structure and composition of weeds. Fifty quadrates of 1 m x 1 m were laid down in the wheat crop fields of each sites. The entire weed species in quadrats were collected and identified with available authentic flora and electronic resources. An herbarium of the voucher specimens was also prepared.

Phytosociological characters such as frequency, density, abundance, relative frequency, relative density, relative dominance, and importance value index (IVI) were calculated with the help of the following methods: Curtis and McIntosh (1950) and Misra (1968). The formula for the calculation is as follows:

$$\text{Frequency (\%)} = \frac{\text{Total number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100 \quad (1)$$

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrats studied}} \quad (2)$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrats in which the species occurred}} \quad (3)$$

$$\text{Relative Frequency} = \frac{\text{Frequency of individuals of a species}}{\text{Total frequency of all species}} \times 100 \quad (4)$$

$$\text{Relative Density} = \frac{\text{Density of individuals of a species}}{\text{Total Density of all species}} \times 100 \quad (5)$$

$$\text{Relative Dominance} = \frac{\text{Basal area of a species}}{\text{Total Basal area of all species}} \times 100 \quad (6)$$

$$\text{Importance Value Index} = \text{Relative Frequency} + \text{Relative Density} + \text{Relative Dominance} \quad (7)$$

An importance value index is used to measure the importance and dominance of a species in a plant community. It is obtained by summing up relative frequency, relative density, and relative dominance.

RESULTS AND DISCUSSION

Floristic diversity of weed species

48 weed species belonging to 19 families were recorded in all the study sites of wheat crop fields (**Table 1-6**). Different types of weed species were present in the study site. The maximum number of weeds were observed in village Barela and Semarchua (44) followed by Chamari (42) and Karhi (36) in 2018.In the year 2019, the highest number of weeds were found in Barela(45) followed by Karhi (41), Semarchua(40), and Chamari (38). In the year 2020, the greatest number of weeds were observed in Barela (46) followed by Semarchua (45), Chamari (41), and Karhi (36). The floristic composition of weed species was recorded as dicot (79%), monocot (16%), and pteridophytic (5%) groups belonging to different weed species (**Figure 1**) Many other researchers, Moghe (2017), Singh *et al.* (2018) and Yousaf *et al.* (2022), have reported similar results in their findings.

At Barela (site1), the highest frequency (66%) of weed population was recorded for *Anagallis arvensis* L. in 2018 and 68% from 2019 to 2020 (**Table 2, 4,** and **6)**. At Semarchua (Site-2), *Alternanthera sessilis* (L.) DC, occurred with 64% in 2018, 60% with *Chenopodium album* L. and *Medicago polymorpha* L.in 2019. In the year 2020 again, *Alternanthera sessilis* (L.) DC, recorded with the highest frequency (66%). At Karhi the highest frequency of 72% was observed for *Anagallis arvensis* L.in 2018 and 2020. In the year 2019 *Rumex dentatus* L. was recorded with highest frequency (64%) at Karhi. At Chamari village (Site 4), a maximum % frequency value of 60% was associated with *Anagallis arvensis* L. and *Rumex dentatus* L. in 2018. In the year 2019, *Medicago polymorpha* L. was recorded with 64% and *Alternanthera sessilis* (L.) DC, was observed with a maximum frequency (62%).

The highest density of 1.3 was recorded for *Alternanthera sessilis* (L.) DC, at Barela. The weed species *Medicago polymorpha* L. showed the highest density (1.3) at Semarchua and Chamari, while at Karhi *Anagallis arvensis* L. exerted a maximum density of 1.36 in 2018. In the year 2019, the highest density was observed for *Medicago polymorpha* L. (1.3) in Barela and Semarchua. The weed species *Alternanthera sessilis* (L.) DC with a maximum density of 1.3 at Karhi and *Alternanthera sessilis* (L.) DC, *Medicago polymorpha* L. and *Rumex dentatus* L. were represented the highest density (1.1) at Chamari. The maximum density of 1.3 was recorded for *Alternanthera sessilis* (L.) DC, at Barela and 1.24 at Karhi. Weed species *Medicago polymorpha* L.

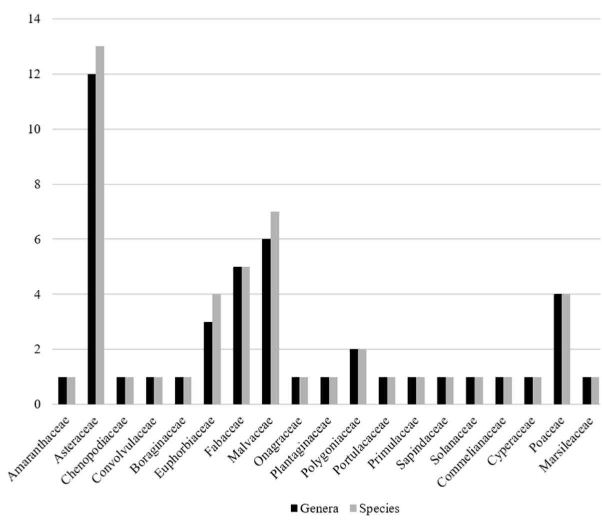

Figure 1. Graph represents no. of genera and Species distribution in different familiesFrequency, density, abundance, and important value index

showed the highest density (1.32) at Semarchua, while at Chamari *Alternanthera sessilis* (L.) DC exerted a maximum density of 1.36 in 2020. All the sites in the study area presented weed species abundance values ranging from 1 to 3. **Tables 3, 5** and **7** show the variation among the various weed species. The relative frequency value represents the less frequent and more frequent occurrences of weeds species. At the Barela village (site 1), the highest relative frequency (6.6), relative density (11.3), and relative dominance (14.6) were recorded with *Alternanthera sessilis* (L.) DC, and the IVI value was 32.5 in 2018. The maximum relative frequency (7.2), relative density (8.7), and relative dominance (15.8) were recorded with *Alternanthera sessilis* (L.) DC, and the IVI value was 32.5 in 2019. The highest

Table 1. Weed flora in wheat crop fields at the study site

S.N.	Botanical name of weed	Family	Genera	Species
Dicot				
1.	*Alternanthera sessilis* (L.) DC	Amaranthaceae	01	01
2.	*Acmella ulginosa* (Sw.) Cass. *Acmella radicans* (Jacq.) R.K. Jansen *Ageratum conyzoides* L. *Cirsium arvense* L. Scop. *Eclipta alba* (L.) Hassk *Gnaphalium lute album* L. *Grangea maderaspatana* (L.) *Parthenium hysterophorus* L. *Sonchus arvensis* L. *Sphaeranthus indicus* Kurz *Tridax procumbens* L. *Xanthium strumarium* L. *Lagascea mollis* Cav.	Asteraceae	12	13
3.	*Chenopodium album* L.	Chenopodiaceae	01	01
4.	*Ipomoea obscura* (L.)Ker Gawl.	Convolvulaceae	01	01
5.	*Heliotropium ovalifolium* L.	Boraginaceae	01	01
6.	*Chrozophora rottleri* (Geiseler) Spreng. *Euphorbia hirta* L. *Euphorbia terracina* L. *Phyllanthus niruri* L.	Euphorbiaceae	03	04
7.	*Desmodium triflorum*(L.)DC. *Cassia tora* L. *Medicago polymorpha* L. *Melilotus albus* Medik. *Rhynchosia minima* (L.)DC	Fabaceae	05	05
8.	*Abelmoschus ficulneus* (L.)Wight&Arn. *Malachra capitata* (L.)L. *Corchorus olitorius* L. *Hibiscus panduriformis* Burm.f. *Sida acuta* Burm.f. *Sida cordifolia* L. *Urena lobata* (L.)	Malvaceae	06	07
9.	*Ludwigia perennis* Burm.f.	Onagraceae	01	01
10.	*Mecardonia procumbense* (Mill) Small	Plantaginaceae	01	01
11.	*Polygonum plebeium* R.Br. *Rumex dentatus* L.	Polygoniaceae	02	02
12.	*Portulaca oleracea* L.	Portulacaceae	01	01
13.	*Anagallis arvensis* L.	Primulaceae	01	01
14.	*Cardiospermum halicacabum* L.	Sapindaceae	01	01
15.	*Physalis minima* L.	Solanaceae	01	01
Monocot				
16.	*Commelina benghalensis* L.	Commelianaceae	01	01
17.	*Cyperus difformis* L.	Cyperaceae	01	01
18.	*Cynodon dactylon* (L.) Pers. *Digitaria sanguinalis* (L.) Scop. *Echinochloa colonum* (L.) Link *Elusine indica* (L.) Gaertn.	Poaceae	04	04
Pteridophyte				
19.	*Marsilia quadrifolia* L.	Marsileaceae	01	01

relative frequency (7.56), relative density (11.33), and relative dominance (15.59) were recorded with *Alternanthera sessilis* (L.) DC, and the IVI value was 34.5 in 2020. According to IVI value, *Alternanthera sessilis* (L.) DC was found to be the most dominant weed species in 2018-2020 for site 1. At the Semarchua village (site 2), the highest relative frequency (6.8), relative density (7.1), relative dominance (18.8), and IVI value (32.7) was recorded with *Medicago polymorpha* L. in 2018.The maximum relative frequency (8.0), relative density (9.1), relative dominance (15.8), and IVI value (32.9) were observed with *Chenopodium album* L. in 2019. In the year 2020, *Medicago polymorpha* L. with relative frequency (6.78), relative density (8.39), and relative dominance (18.97) was recorded and the IVI value (34.2) was calculated. Thus, *Medicago polymorpha* L. and *Chenopodium album* L. were the most dominant weed species at the site 2. at Karhi village (site 3), the highest relative frequency (9.0), relative density (9.4), and relative dominance (13.9) were recorded with *Anagallis arvensis* L. and the IVI value was 32.3 in 2018. The maximum relative frequency (8.9), relative density (9.7), and relative dominance (19.6) were recorded with *Rumex dentatus* L. and the IVI value was 38.2 in 2019.The maximum relative frequency (9.04), relative density (9.36), relative dominance (13.91), and IVI value (32.3) were

Table 2. The frequency, density, and abundance of different weed species in the wheat crop at the study site in the year 2018 (Abbreviations: F = Frequency, D =Density, A = Abundance)

Weed species	Barela			Semarchua			Karhi			Chamari		
	%F	D	A	%F	D	A	%F	D	A	%F	D	A
Abelmoschus ficulneus (L.) Wight&Arn.	02	0.02	1.0	02	0.02	1.0	-	-	-	02	0.02	1.0
Acmella radicans (Jacq.) R.K. Jansen	04	0.04	1.0	04	0.04	1.0	02	0.02	1.0	08	0.14	1.75
Acmella ulginosa (Sw.) Cass.	10	0.16	1.6	14	0.22	1.57	04	0.04	1.0	06	0.06	1.0
Ageratum conyzoides L.	16	0.28	1.75	12	0.24	2.0	16	0.16	1.0	06	0.06	1.0
Alternanthera sessilis (L.) DC	62	1.31	2.0	64	1.2	1.81	66	1.2	1.81	58	1.12	2.0
Ammannia baccifera L.	08	0.08	1.0	02	0.04	2.0	06	0.06	1.0	04	0.06	1.5
Anagallis arvensis L.	66	0.98	1.45	58	1.21	2.18	72	1.24	1.72	60	1.16	1.93
Cardiospermum halicacabum L.	04	0.04	1.0	02	0.02	1.0	-	-	-	-	-	-
Cassia tora L.	10	0.1	1.0	12	0.12	1.0	12	0.12	1.0	02	0.02	1.0
Chenopodium album L.	58	1.27	2.21	56	1.24	2.11	54	1.04	1.92	52	0.72	1.38
Chrozophora rottleri (Geiseler) Spreng.	14	0.22	1.57	16	0.16	1.0	12	0.28	2.2	-	-	-
Cirsium arvense L.Scop.	06	0.06	1.0	-	-	-	-	-	-	02	0.02	1.0
Commelina benghalensis L.	14	0.14	1.0	02	0.02	1.0	-	-	-	06	0.1	1.66
Corchorus olitorius L.	06	0.06	1.0	04	0.04	1.0	06	0.06	1.0	04	0.04	1.0
Cynodon dactylon (L.)Pers.	26	0.28	1.0	28	0.32	1.43	20	0.24	1.83	24	0.12	1.56
Cyperus difformis L.	02	0.02	1.0	06	0.06	1.0	-	-	-	-	-	-
Desmodium triflorum(L.)DC.	18	0.18	1.0	26	0.32	1.23	22	0.26	1.18	16	0.22	1.37
Digitaria sanguinalis (L.)Scop.	10	0.21	1.35	14	0.13	1.0	08	0.11	2.1	06	0.08	1.33
Echinochloa colonum (L.)Link	45	0.78	1.72	42	0.43	1.32	46	0.76	1.63	38	0.68	2.21
Eclipta alba (L.)Hassk	22	0.22	1.0	24	0.28	1.0	20	0.23	1.08	16	0.18	1.16
Elusine indica (L.)Gaertn.	12	0.12	1.0	16	0.18	1.23	08	0.10	1.75	06	0.1	1.66
Euphorbia hirta L.	16	0.24	1.34	20	0.3	1.35	22	0.21	1.25	18	0.22	1.16
Euphorbia terracina L.	12	0.10	1.0	14	0.17	2.2	18	0.21	1.0	10	0.14	1.23
Gnaphalium luteoalbum L.	08	0.08	2.0	20	0.28	1.4	-	-	-	-	-	-
Grangea maderaspatana (L.)	36	0.34	1.98	32	0.52	1.63	32	0.13	2.0	26	0.55	2.12
Heliotropium ovalifolium L.	12	0.11	1.0	16	0.26	1.0	16	0.16	1.0	14	0.14	1.0
Hibiscus panduriformis Burm.f.	06	0.06	1.0	04	0.04	1.0	08	0.08	1.0	04	0.04	1,0
Lagascea mollis Cav.	16	0.26	1.74	22	0.28	1.27	10	0.12	1.25	06	0.26	4.33
Ludwigia perrenis Burm.f.	10	0.1	1.0	02	0.02	1.0	-	-	-	02	0.02	1.0
Malacra capitata (L.)L.	18	0.18	1.0	12	0.14	1.16	08	1.12	1.28	06	0.06	1.0
Marsilia quadrifolia L.	-	-	-	04	0.04	1.0	-	-	-	-	-	-
Mecardonia procumbense (Mill) Small	18	0.36	2.3	04	0.04	1.0	16	0.32	2.16	22	0.54	2.45
Medicago polymorpha L.	54	1.28	2.37	60	1.32	2.2	56	1.16	2.07	52	1.34	2.21
Melilotus albus Medik.	50	1.16	2.32	54	1.12	2.07	52	0.9	1.73	46	1.21	2.0
Parthenium hysterophorus L.	12	0.12	1.0	10	0.1	1.0	06	0.06	1.0	04	0.1	2.5
Phyllanthus niruri L	14	0.14	1.0	06	0.06	1.0	10	0.1	1.0	04	0.04	1.0
Physalis minima L.	24	0.24	1.0	28	0.32	1.14	20	0.3	1.5	18	0.13	1.0
Polygonum plebeium R.Br.	28	0.52	1.85	34	0.68	2.0	24	0.56	2.33	40	0.54	1.35
Rinchosia minima (L)DC	-	-	-	-	-	-	-	-	-	04	0.04	1.0
Rumex dentatus L.	60	1.04	1.73	52	1.04	2.0	54	0.94	2.23	60	0.78	1.3
Portulaca oleracea L.	02	0.02	1.0	-	-	-	02	0.02	1.0	-	-	-
Sida acuta Burm.f.	12	0.12	1.0	08	0.08	1.0	-	-	-	04	0.04	1.0
Sida cordifolia L.	08	0.08	1.0	06	0.06	1.0	06	0.06	1.0	02	0.02	1.0
Sonchus arvensis L.	08	0.08	1.0	04	0.04	1.0	04	0.04	1.0	08	0.08	1.0
Sphaeranthus indicus Kurz	08	0.08	1.0	24	0.42	1.75	26	0.46	1.79	20	0.31	1.42
Tridax procumbens L.	04	0.04	1.0	14	0.26	1.85	10	0.1	1.0	10	0.18	150
Urena lobata (L.)	-	-	-	02	0.02	1.0	-	-	-	04	0.04	1.0
Xanthium strumarium L.	02	0.02	1.0	04	0.04	1.0	02	0.02	1.0	02	0.02	1.0

noticed with the weed species *Anagallis arvensis* L. in 2020.Thus, *Anagallis arvensis* L. and *Rumex dentatus* L. were the most dominant weeds at the site 3. At the Chamari village (site 4), the highest relative frequency (7.1), relative density (8.9), relative dominance (20.5), and IVI value (36.5) was recorded for *Chenopodium album* L. in 2018. The maximum relative frequency (9.0), relative density (8.6), relative dominance (19.7), and IVI value (37.3) was observed with *Rumex dentatus* L. in 2019. *Chenopodium album* L., with a relative frequency of 7.10, a relative density of 8.89, a relative dominance of 20.54, and an IVI value of 36.5, was recorded in Chamari (site 4) in the year 2020. Thus, *Chenopodium album* L. and *Rumex dentatus* L. were the most dominant weed species in wheat crop fields of site 4. The highest IVI values of a few weeds at all the four sites have also been depicted in **Figure 2**.

Gupta *et al.* (2008), Malik *et al.* (2013) and Khobragade and Sathawane (2014) listed *Avena*

Table 3. The relative frequency, relative density, relative dominance, and IVI of different weeds in the wheat crop at the study site in the year 2018

Weed species	Barela				Semarchua				Karhi				Chamari			
	RF	RD	RDom	IVI	RF	RD	RDom	IVI	RF	RD	RDom	IVI	RF	RD	RDom	IVI
Abelmoschus ficulneus (L.)Wight&Arn.	0.5	0.3	0.0	0.8	0.2	0.1	0.0	0.3	-	-	-	-	0.7	0.4	0.0	1.1
Acmella radicans (Jacq.) R.K.Jansen	0.2	0.2	0.0	0.4	0.9	0.5	0.2	1.6	0.8	0.5	0.0	1.3	1.9	1.6	0.6	4.1
Acmella ulginosa (Sw.) Cass.	1.2	1.3	0.3	2.8	1.8	1.9	0.4	4.1	0.8	0.8	0.1	1.7	1.7	1.4	0.4	3.5
Ageratum conyzoides L.	1.9	2.5	0.8	5.2	1.6	1.5	0.4	3.5	2.5	3.4	2.4	8.3	1.9	1.9	1.0	4.8
Alternanthera sessilis (L.) DC	6.6	11.3	14.6	32.5	7.5	7.6	5.3	20.4	8.0	9.1	11.6	28.7	7.3	9.3	13.8	30.4
Ammannia baccifera L.	0.7	0.5	0.0	1.2	0.2	0.3	0.0	0.5	0.8	0.5	0.0	1.2	-	-	-	-
Anagallis arvensis L.	8.0	8.8	9.4	26.2	6.3	7.5	3.8	17.6	9.0	9.4	13.9	32.3	7.1	7.9	10.0	25.0
Cardiospermum halicacabum L.	0.5	0.3	0.0	0.8	0.5	0.2	0.0	0.7	-	-	-	-	-	-	-	-
Cassia tora L.	0.9	0.7	0.0	1.6	1.4	0.8	0.3	2.5	1.5	0.9	0.2	2.6	1.2	0.7	0.1	2.0
Chenopodium album L.	6.6	8.0	12.6	27.2	6.3	7.9	6.2	20.4	6.8	7.9	14.6	29.3	7.1	8.9	20.5	36.5
Chrozophora rottleri (Geiseler) Spreng.	1.9	1.7	0.4	4.0	2.9	2.3	0.9	6.1	1.5	1.8	0.6	3.9	1.7	1.5	0.4	3.6
Cirsium arvense L.Scop.	0.7	0.5	0.0	1.2	-	-	-	-	0.5	0.3	0.0	0.8	0.2	1.4	0.0	1.6
Commelina benghalensis L.	1.9	1.3	0.4	3.6	0.2	0.1	0.0	0.3	-	-	-	-	-	-	-	-
Corchorus olitorius L.	0.9	0.7	0.0	1.6	1.1	0.6	0.0	1.7	0.5	0.3	0.0	0.8	0.7	0.4	0.0	1.1
Cynodon dactylon (L.)Pers.	2.4	3.8	0.9	7.1	3.4	3.0	0.6	7.0	2.8	3.5	1.2	7.5	3.8	3.8	1.2	8.8
Cyperus difformis L.	0.5	0.3	0.0	0.8	0.7	0.4	0.1	1.1	-	-	-	-	-	-	-	-
Desmodium triflorum(L.)DC.	2.1	2.2	0.1	4.4	3.0	2.0	1.2	6.2	2.8	3.5	1.2	7.5	2.8	2.7	0.3	5.8
Digitaria sanguinalis (L.)Scop.	0.9	0.8	0.1	1.8	1.8	1.0	0.2	3.0	0.8	1.0	0.1	1.9	1.4	1.1	0.1	2.6
Echinochloa colonum (L.)Link	5.2	6.0	5.9	17.1	4.5	3.1	2.7	10.3	5.3	4.2	4.6	14.1	5.5	4.4	4.6	14.5
Eclipta alba (L.)Hassk	2.8	2.0	0.4	5.2	2.9	1.7	0.7	5.3	3.0	2.0	0.4	5.4	3.6	2.2	0.6	6.4
Elusine indica (L.)Gaertn.	1.4	1.0	0.3	2.7	1.6	1.0	0.5	3.1	1.3	1.4	0.5	3.2	-	-	-	-
Euphorbia hirta L.	2.1	1.5	0.4	4.0	1.8	1.3	0.7	3.8	3.3	2.6	1.4	7.3	3.6	2.2	1.0	6.8
Euphorbia terracina L.	1.9	1.3	0.3	3.6	1.4	1.7	1.2	4.3	3.0	1.8	0.9	5.7	2.6	1.5	0.5	4.6
Gnaphalium luteoalbum L.	0.9	0.7	0.4	2.0	2.3	1.8	1.6	5.7	-	-	-	-	-	-	-	-
Grangea maderaspatana (L.)	3.8	2.7	6.2	12.6	4.1	4.2	7.2	15.5	3.8	5.3	7.2	16.3	3.1	5.2	5.9	14.2
Heliotropium ovalifolium	1.7	1.2	0.2	3.1	1.6	0.9	0.3	2.8	2.0	1.2	0.3	3.5	1.4	0.8	0.1	2.3
Hibiscus panduriformis Burm.f.	0.7	0.5	0.0	1.2	0.5	0.3	0.0	0.8	1.0	0.6	0.1	1.7	0.5	0.3	0.0	0.8
Ipomoea obscura (L.)Ker Gawl.	0.2	0.2	0.0	0.4	-	-	-	-	-	-	-	-	-	-	-	-
Lagascea mollis Cav.	1.7	2.0	0.7	4.4	2.5	1.8	1.4	5.7	2.0	1.5	0.5	4.0	1.4	1.5	0.5	3.4
Ludwigia perrenis Burm.f.	1.2	0.8	0.1	2.1	0.2	0.1	0.0	0.3	-	-	-	-	0.5	0.3	0.0	0.8
Malacra capitata (L.)L.	1.4	1.0	0.2	2.6	1.4	0.9	0.4	2.7	1.0	0.8	0.1	1.9	1.7	1.1	0.3	3.1
Marsilia quadrifolia L.	-	-	-	-	0.5	0.3	0.0	0.8	-	-	-	-	0.7	0.4	0.0	1.1
Mecardonia procumbense (Mill) Small	1.7	2.7	0.2	4.6	0.5	0.3	0.0	0.8	2.0	2.6	0.2	4.8	0.7	1.5	0.0	2.28
Medicago polymorpha L.	6.4	10.7	13.7	30.8	6.8	7.1	18.8	32.7	7.0	8.8	9.6	25.4	6.2	8.5	10.2	24.9
Melilotus albus Medik.	5.9	9.7	12.6	28.2	6.1	7.1	15.3	28.5	6.5	6.8	6.5	19.8	5.2	7.3	9.3	21.8
Parthenium hysterophorus L.	1.4	1.0	0.1	2.5	1.1	0.6	0.1	1.8	0.8	0.5	0.0	1.2	1.4	0.8	0.0	2.2
Phyllanthus niruri L	1.7	1.2	0.2	3.1	0.7	0.4	0.0	1.1	0.5	0.3	0.0	0.8	0.5	0.3	0.0	0.8
Physalis minima L.	2.8	2.0	0.5	5.3	3.2	2.0	1.4	6.6	2.5	2.3	0.9	5.7	3.6	2.1	0.7	6.4
Polygonum plebeium R.Br.	3.3	4.3	0.4	8.0	3.8	4.3	4.5	12.6	3.0	4.2	2.0	9.2	3.8	4.1	2.1	10.0
Rinchosia minima (L)DC	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.3	0.0	0.9
Rumex dentatus L.	7.1	8.6	16.1	31.8	5.9	6.6	21.6	34.1	6.8	7.1	16.6	30.5	6.4	7.4	13.0	26.8
Portulaca oleracea L.	0.2	0.2	0.0	0.4	-	-	-	-	0.3	0.2	0.0	0.5	-	-	-	-
Sida acuta Burm.f.	1.4	1.0	0.0	2.4	0.9	0.5	0.0	1.4	-	-	-	-	0.7	0.4	0.0	1.1
Sida cordifolia L.	0.9	0.7	0.0	1.6	0.7	0.4	0.0	1.1	0.8	0.5	0.0	1.2	0.5	0.3	0.0	0.8
Sonchus arvensis L.	0.9	0.7	0.1	1.7	0.5	0.3	0.0	0.8	0.5	0.3	0.0	0.8	0.9	0.5	0.1	1.5
Sphaeranthus indicus Kurz	0.9	0.7	0.0	1.6	2.7	2.7	2.5	7.9	3.3	3.5	2.9	9.7	3.1	3.6	2.0	8.7
Tridax procumbens L.	0.5	0.3	0.0	0.8	1.6	1.7	0.6	3.9	1.3	0.8	0.0	2.1	1.9	1.1	0.1	3.1
Urena lobata (L.)	-	-	-	-	0.2	0.1	0.0	0.3	-	-	-	-	0.2	0.1	0.0	0.3
Xanthium strumarium L.	0.2	0.2	0.0	0.4	0.5	0.3	0.0	0.8	-	-	-	-	0.Abr e8	0.3	1.2	2.3

(Abbreviations: RF= Relative frequency, RD= Relative density, RDom = Relative dominance and IVI = Importance value index) *sativa, Anagallis arvensis, Coronopus didymus, Chenopodium album, Cynodon dactylon, Fumaria indica, Melilotus indica, Medicago polymorpha, Phalaris minor, Polypogon monspeliensis, Polygonum plebeium, Parthenium hysterophorus, Poa annua, Rumex dentatus, Stellaria media, and Veronica persica* as dominant weed species in wheat crop fields based on the highest important values index. Moghe (2017), found the highest importance value index for *Melilotus indica* L. (71.58%), *Echinochloa colonum* L. (45.58%), and *Avena fatua* L. (16.66%) in wheat crop fields in Sakri Bilaspur district of Chhattisgarh. According to Khanal *et al.* (2018), a higher IVI value was seen on *Anagallis arvensis, Vicia sativa,* and *Chenopodium album* in the wheat-mustard ecosystem at Paklihawa, Rupandehi, Nepal. Kumar *et al*. (2020), and Kumar and Shivani, (2020), observed the highest importance value for *Phalaris minor, Chenopodium album, Cynodon dactylon* L., and *Parthenium hysterophorus* L. in wheat crop fields. *Cyperus rotundas* and *Echinochloa colona* registered the highest IVI (Kumar *et al.*2023).

Conclusion

The environmental factors such as soil type, agricultural practices, weed control methods, cropping system and other cultivation practices affect the diversity, distribution and composition of

Table 4. The frequency, density, and abundance of different weed species in the wheat crop at the study site in the year 2019

Weed species	Barela			Semarchua			Karhi			Chamari		
	%F	D	A	%F	D	A	%F	D	A	%F	D	A
Abelmoschus ficulneus (L.)Wight&Arn.	04	0.0	1.0	02	0.0	1.0	-	-	-	02	0.0	1.0
Acmella radicans (Jacq.) R.K.Jansen	16	0.2	1.5	06	0.1	1.0	08	0.2	3.0	08	0.1	1.0
Acmella ulginosa (Sw.) Cass.	16	0.3	1.9	06	0.1	1.0	10	0.7	1.6	08	0.1	1.0
Ageratum conyzoides L.	14	0.2	1.1	20	0.2	1.2	14	0.3	1.9	06	0.1	1.7
Alternanthera sessilis (L.) DC	50	1.0	2.1	56	1.1	2.0	50	1.3	2.5	44	1.1	2.5
Ammannia baccifera L.	04	0.0	1.0	-	-	-	02	0.0	1.0	04	0.0	1.0
Anagallis arvensis L.	68	1.0	1.6	40	0.9	2.3	60	1.2	1.9	46	1.0	2.3
Cardiospermum halicacabum L.	-	-	-	-	-	-	02	0.0	1.0	-	-	-
Cassia tora L.	10	0.1	1.0	02	0.0	1.0	08	0.1	1.3	02	0.0	1.0
Chenopodium album L.	42	0.7	1.7	60	1.1	1.9	58	1.2	1.9	60	1.0	1.6
Chrozophora rottleri (Geiseler) Spreng.	08	0.2	3.0	12	0.2	2.0	16	0.3	0.8	-	-	-
Cirsium arvense L.Scop.	-	-	-	02	0.0	1.0	-	-	-	02	0.0	1.0
Commelina benghalensis L.	14	0.2	1.4	-	-	-	06	0.1	1.7	12	0.2	1.3
Corchorus olitorius L.	12	0.2	1.3	04	0.0	1.0	04	0.0	1.0	04	0.0	1.0
Cynodon dactylon (L.)Pers.	36	0.8	2.2	34	0.8	2.2	32	0.4	1.3	32	0.6	2.0
Cyperus difformis L.	02	0.0	1.0	-	-	-	-	-	-	-	-	-
Desmodium triflorum(L.)DC.	24	0.5	2.2	22	0.3	1.9	24	0.4	1.7	26	0.6	2.3
Digitaria sanguinalis (L.)Scop.	20	0.2	1.2	04	0.0	1.0	04	0.0	1.0	04	0.0	1.0
Echinochloa colonum (L.)Link	48	0.8	1.8	54	0.9	1.7	38	0.6	1.6	62	0.9	1.5
Eclipta alba (L.)Hassk	12	0.1	1.0	16	0.2	1.1	12	0.2	1.6	12	0.1	1.0
Elusine indica (L.)Gaertn.	04	0.0	1.0	12	0.1	1.0	08	0.1	1.3	-	-	-
Euphorbia hirta L.	08	0.1	1.8	14	0.2	1.3	16	0.3	1.3	20	0.2	1.2
Euphorbia terracina L.	14	0.3	2.3	12	0.3	2.2	16	0.2	1.0	-	-	-
Gnaphalium luteoalbum L.	08	0.1	2.0	12	0.1	1.0	-	-	-	-	-	-
Grangea maderaspatana (L.)	14	0.3	2.3	40	0.9	2.1	30	0.3	1.1	24	0.4	1.7
Heliotropium ovalifolium L.	12	0.1	1.0	14	0.1	1.0	16	0.2	1.0	10	0.2	2.2
Hibiscus panduriformis Burm.f.	02	0.0	1.0	04	0.0	1.0	02	0.0	1.0	04	0.0	1.0
Lagascea mollis Cav.	14	0.2	1.7	16	0.2	1.3	12	0.2	1.8	06	0.1	1.7
Ludwigia perrenis Burm.f.	10	0.1	1.0	-	-	-	02	0.0	1.0	04	0.0	1.0
Malacra capitata (L.)L.	04	0.0	1.0	08	0.1	1.0	12	0.2	1.3	10	0.1	1.2
Marsilia quadrifolia L.	-	-	-	04	0.0	1.0	-	-	-	-	-	-
Mecardonia procumbense (Mill) Small	24	0.6	2.3	14	0.1	1.0	08	0.1	1.5	16	0.3	2.0
Medicago polymorpha L.	62	1.3	2.2	60	1.3	2.1	40	0.9	2.4	64	1.1	1.8
Melilotus albus Medik.	46	0.6	1.4	58	0.9	1.4	46	0.8	1.7	60	1.0	1.7
Parthenium hysterophorus L.	20	0.2	1.0	12	0.1	1.0	10	0.1	1.2	08	0.1	1.0
Phyllanthus niruri L	16	0.2	1.5	06	0.1	1.0	06	0.1	1.0	08	0.1	1.3
Physalis minima L.	24	0.3	1.3	20	0.2	1.1	10	0.2	1.2	12	0.1	1.0
Polygonum plebeium R.Br.	12	0.2	1.8	32	0.6	1.9	30	0.7	2.0	32	0.7	2.1
Rinchosia minima (L)DC	08	0.1	1.0	-	-	-	04	0.0	1.0	02	0.0	1.0
Rumex dentatus L.	56	1.2	2.1	52	1.1	2.2	64	1.2	1.9	66	1.1	1.6
Portulaca oleracea L.	02	0.0	1.0	-	-	-	-	-	-	-	-	-
Sida acuta Burm.f.	12	0.1	1.0	06	0.1	1.0	04	0.0	1.0	04	0.0	1.0
Sida cordifolia L.	04	0.0	1.0	02	0.0	1.0	02	0.0	1.0	04	0.0	1.0
Sonchus arvensis L.	14	0.1	1.0	04	0.1	1.5	06	0.1	1.3	06	0.1	1.0
Sphaeranthus indicus Kurz	12	0.2	1.8	24	0.3	1.3	10	0.2	1.2	30	0.4	1.4
Tridax procumbens L.	04	0.0	1.0	06	0.1	1.3	10	0.1	1.0	10	0.1	1.0
Urena lobata (L.)	02	0.0	1.0	-	-	-	02	0.0	1.0	-	-	-
Xanthium strumarium L.	02	0.0	1.0	04	0.0	1.0	-	-	-	-	-	-

weed flora. The presence of dominant weeds shows their strong adaptability with environment. Some weeds clearly indicate that they have grown in special condition. *Alternanthera sessilis* (L.) DC, *Anagallis arvensis* L., *Medicago polymorpha* L.and *Rumex dentatus* L. were found as the most dominant weeds in all the study site of the study area. This survey provides basic and important information to design for the better weed management management strategies at the four study sites in Mungeli district of Chhatisgarh.

Table 5. The relative frequency, relative density, relative dominance, and IVI of different weeds in the wheat crop at the study site in the year 2019

Weed species	Barela				Semarchua				Karhi				Chamari			
	RF	RD	RDom	IVI	RF	RD	RDom	IVI	RF	RD	RDom	IVI	RF	RD	RDom	IVI
Abelmoschus ficulneus (L.)Wight&Arn.	0.5	0.3	0.0	0.8	0.3	0.2	0.0	0.5	-	-	-	-	0.3	0.7	0.0	1.0
Acmella radicans (Jacq.) R.K.Jansen	2.0	1.8	0.0	3.8	0.8	0.5	0.1	1.4	1.1	1.9	0.1	3.1	1.1	0.7	0.0	1.8
Acmella ulginosa (Sw.) Cass.	2.0	2.2	0.7	4.9	0.8	0.5	0.1	1.4	1.4	1.3	0.1	2.8	1.1	0.7	0.0	1.8
Ageratum conyzoides L.	1.7	1.1	0.9	3.7	2.6	1.8	0.3	4.7	1.9	2.0	0.3	4.2	0.8	0.8	0.2	1.8
Alternanthera sessilis (L.) DC	7.2	8.7	15.8	31.7	7.2	8.6	11.9	27.7	6.9	9.9	9.6	26.4	6.0	8.8	11.6	26.4
Ammannia baccifera L.	0.5	0.3	0.0	0.8	-	-	-	-	0.3	0.2	0.1	0.6	0.5	0.3	0.0	0.8
Anagallis arvensis L.	8.4	7.8	8.9	25.1	5.2	6.9	9.8	21.9	8.3	9.1	12.6	30.0	6.3	8.5	10.7	25.5
Cardiospermum halicacabum L.	-	-	-	-	-	-	-	-	0.3	0.2	0.0	0.5	-	-	-	-
Cassia tora L.	1.2	0.7	0.0	1.9	0.3	0.2	0.0	0.5	1.1	0.8	0.0	1.9	0.3	0.2	0.0	0.5
Chenopodium album L.	5.2	5.3	10.3	20.8	7.7	8.8	15.7	32.2	8.0	9.1	15.8	32.9	8.2	8.1	15.5	31.8
Chrozophora rottleri (Geiseler) Spreng.	1.0	1.8	0.5	3.3	1.5	1.8	0.6	3.9	2.2	2.1	1.0	5.3	-	-	-	-
Cirsium arvense L.Scop.	-	--	-	-	0.3	0.2	0.0	0.5	-	-	-	-	0.3	0.2	0.0	0.5
Commelina benghalensis L.	1.7	1.5	0.4	3.6	-	-	-	-	0.8	0.8	5.3	6.9	1.6	1.3	5.3	8.2
Corchorus olitorius L.	1.5	1.2	0.0	2.7	0.5	0.3	0.0	0.5	0.6	0.3	0.0	0.9	0.5	0.3	0.0	0.8
Cynodon dactylon (L.)Pers.	4.4	5.9	1.6	11.9	4.4	5.9	2.2	12.5	4.4	3.3	2.0	9.7	4.4	5.2	2.1	11.7
Cyperus difformis L.	0.2	0.1	0.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-
Desmodium triflorum(L.)DC.	3.0	3.8	0.3	7.1	2.8	2.0	0.3	5.1	3.3	3.1	0.9	7.3	3.5	4.9	0.7	9.1
Digitaria sanguinalis (L.)Scop.	2.5	1.8	0.2	4.5	0.5	0.3	0.0	0.8	0.6	0.3	0.0	0.9	0.5	0.3	0.0	0.8
Echinochloa colonum (L.)Link	6.0	6.2	5.8	18.0	7.0	7.1	21.6	35.7	5.3	4.4	21.7	31.4	8.4	7.5	21.9	37.8
Eclipta alba (L.)Hassk	1.5	0.9	0.5	2.9	2.1	1.4	0.1	3.6	1.7	1.3	0.1	3.1	1.6	1.0	0.1	2.7
Elusine indica (L.)Gaertn.	0.5	0.3	0.0	0.8	1.5	0.9	0.0	2.4	1.1	0.8	0.2	2.1	-	-	-	-
Euphorbia hirta L.	1.0	1.0	0.4	2.4	1.8	1.4	0.6	3.8	3.3	2.4	0.1	5.8	2.7	2.0	0.8	5.5
Euphorbia terracina L.	1.7	2.3	0.3	4.3	1.5	2.0	0.2	3.7	2.2	1.7	0.3	4.2	-	-	-	-
Gnaphalium luteoalbum L.	1.0	0.6	0.0	1.6	1.5	0.9	0.0	2.4	-	-	-	-	-	-	-	-
Grangea maderaspatana (L.)	1.7	2.3	0.3	4.3	5.2	6.5	6.2	17.9	4.2	2.7	3.1	10.0	3.3	3.3	3.1	9.7
Heliotropium ovalifolium	1.5	0.9	0.2	2.6	1.8	1.1	0.5	3.4	2.2	1.3	0.9	4.4	1.4	1.8	0.8	4.0
Hibiscus panduriformis Burm.f.	0.2	0.1	0.0	0.3	0.5	0.3	0.0	0.8	0.3	0.2	0.0	0.5	0.5	0.3	0.0	0.8
Ipomoea obscura (L.)Ker Gawl.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lagascea mollis Cav.	1.7	1.8	0.8	4.3	2.1	1.5	0.3	3.9	1.7	1.7	0.1	3.5	0.8	0.8	0.1	1.7
Ludwigia perrenis Burm.f.	1.2	0.7	0.1	2.0	-	-	-	-	0.3	0.2	0.0	0.5	0.5	0.3	0.0	0.8
Malacra capitata (L.)L.	0.5	0.3	0.7	1.5	1.0	0.6	0.2	1.8	1.7	1.3	0.2	3.2	1.4	1.0	0.2	2.6
Marsilia quadrifolia L.	-	-	-	-	0.6	0.3	0.0	0.9	-	-	-	-	-	-	-	-
Mecardonia procumbense (Mill) Small	3.0	4.1	0.7	7.8	1.8	1.1	0.1	3.0	1.1	0.9	0.1	2.1	2.2	2.6	0.2	5.0
Medicago polymorpha L.	7.7	10.0	12.2	29.9	7.7	9.7	12.8	30.2	5.6	7.5	8.3	21.4	8.7	9.1	12.5	30.3
Melilotus albus Medik.	5.7	4.7	11.6	22.0	7.5	6.5	10.3	24.3	6.4	6.3	9.3	22.0	8.2	8.3	12.6	29.1
Parthenium hysterophorus L.	2.5	1.5	0.3	4.3	1.5	0.9	0.1	2.5	1.4	0.9	0.1	2.4	1.1	0.7	0.1	1.9
Phyllanthus niruri L	2.0	1.8	0.1	3.9	0.8	0.5	0.0	1.3	0.8	0.5	0.0	1.3	1.1	0.8	0.0	1.9
Physalis minima L.	3.0	2.2	0.6	5.8	2.6	1.7	0.3	4.6	1.4	1.9	0.1	3.4	1.6	1.0	0.1	2.7
Polygonum plebeium R.Br.	1.5	1.6	0.1	3.2	4.1	4.6	3.7	12.4	4.2	5.7	2.6	12.5	4.4	5.4	3.9	13.7
Rinchosia minima (L)DC	1.0	0.6	0.0	1.6	-	-	-	-	0.6	0.3	0.0	0.9	0.3	0.2	0.0	0.5
Rumex dentatus L.	7.0	8.5	15.2	30.7	5.7	7.6	17.3	30.6	8.9	9.7	19.6	38.2	9.0	8.6	19.7	37.3
Portulaca oleracea L.	0.2	0.1	0.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-
Sida acuta Burm.f.	1.5	0.9	0.2	2.6	0.8	0.5	0.0	1.3	0.6	0.3	0.0	0.9	0.5	0.3	0.0	0.8
Sida cordifolia L.	0.5	0.3	0.1	0.9	0.3	0.2	0.0	0.5	0.3	0.2	0.0	0.5	0.5	0.3	0.0	0.8
Sonchus arvensis L.	1.7	1.0	0.2	2.9	0.5	0.5	0.1	1.1	0.8	0.6	0.1	1.5	0.8	0.5	0.1	1.4
Sphaeranthus indicus Kurz	1.5	1.6	0.3	3.4	3.1	2.5	1.7	7.3	1.4	1.9	1.5	4.8	4.1	3.4	1.9	9.4
Tridax procumbens L.	0.5	0.3	0.4	1.2	0.8	0.6	0.0	1.4	1.4	0.8	0.1	2.3	1.4	0.8	0.1	2.3
Urena lobata (L.)	0.2	0.1	0.0	0.3	-	-	-	-	0.3	0.2	0.0	0.5	-	-	-	-
Xanthium strumarium L.	0.2	0.1	0.0	0.3	0.5	0.3	0.0	0.8	-	-	-	-	-	-	-	-

Table 6. The frequency, density, and abundance of different weed species in the wheat crop at the study site in the year 2020

Weed species	Barela			Semarchua			Karhi			Chamari		
	%F	D	A	%F	D	A	%F	D	A	%F	D	A
Abelmoschus ficulneus (L.) Wight&Arn.	04	0.04	1.0	02	0.02	1.0	-	-	-	06	0.06	1.0
Acmella radicans (Jacq.) R.K.Jansen	02	0.02	1.0	08	0.08	1.0	06	0.06	1.0	16	0.24	1.5
Acmella ulginosa (Sw.) Cass.	10	0.16	1.6	16	0.3	1.87	06	0.1	1.66	14	0.2	1.42
Ageratum conyzoides L.	16	0.3	1.5	14	0.24	1.71	20	0.42	2.1	16	0.28	1.75
Alternanthera sessilis (L.) DC	64	1.36	2.12	66	1.2	1.81	64	1.2	1.87	62	1.36	2.19
Ammannia baccifera L.	06	0.06	1.0	02	0.04	2.0	06	0.06	1.0	-	-	-
Anagallis arvensis L.	68	1.06	1.55	56	1.18	2.10	72	1.24	1.72	60	1.16	1.93
Cardiospermum halicacabum L.	04	0.04	1.0	04	0.04	1.0	-	-	-	-	-	-
Cassia tora L.	08	0.08	1.0	12	0.12	1.0	12	0.12	1.0	10	0.1	1.0
Chenopodium album L.	56	0.96	1.71	56	1.24	2.21	54	1.04	1.92	60	1.3	2.16
Chrozophora rottleri (Geiseler) Spreng.	16	0.2	1.25	26	0.36	1.38	12	0.24	2.0	14	0.22	1.57
Cirsium arvense L.Scop.	06	0.06	1.0	-	-	-	-	-	-	02	0.02	1.0
Commelina benghalensis L.	16	0.16	1.0	02	0.02	1.0	-	-	-	-	-	-
Corchorus olitorius L.	08	0.08	1.0	10	0.1	1.0	04	0.04	1.0	06	0.06	1.0
Cynodon dactylon (L.)Pers.	20	0.46	2.3	30	0.46	1.53	22	0.46	2.09	32	0.56	1.75
Cyperus difformis L.	04	0.04	1.0	06	0.06	1.0	-	-	-	-	-	-
Desmodium triflorum(L.)DC.	18	0.26	1.44	26	0.32	1.23	22	0.26	1.18	24	0.4	1.66
Digitaria sanguinalis (L.)Scop.	08	0.1	1.25	16	0.16	1.0	06	0.14	2.33	12	0.16	1.33
Echinochloa colonum (L.)Link	44	0.72	1.63	40	0.48	1.2	42	0.56	1.33	46	0.64	1.39
Eclipta alba (L.)Hassk	24	0.24	1.0	26	0.26	1.0	24	0.26	1.08	30	0.32	1.06
Elusine indica (L.)Gaertn.	12	0.12	1.0	14	0.16	1.14	10	0.18	1.8	-	-	-
Euphorbia hirta L.	18	0.18	1.0	16	0.2	1.25	26	0.34	1.30	30	0.32	1.06
Euphorbia terracina L.	16	0.16	1.0	12	0.26	2.16	24	0.24	1.0	22	0.22	1.0
Gnaphalium luteoalbum L.	08	0.08	2.0	20	0.28	1.4	-	-	-	-	-	-
Grangea maderaspatana (L.)	32	0.32	1.93	36	0.66	1.83	30	0.7	2.33	26	0.76	2.92
Heliotropium ovalifolium L.	14	0.14	1.0	14	0.14	1.0	16	0.16	1.0	12	0.12	1.0
Hibiscus panduriformis Burm.f.	06	0.06	1.0	04	0.04	1.0	08	0.08	1.0	04	0.04	1,0
Ipomoea obscura (L.)Ker Gawl.	02	0.02	1.0	-	-	-	-	-	-	-	-	-
Lagascea mollis Cav.	14	0.24	1.71	22	0.28	1.27	16	0.2	1.25	12	0.22	1.83
Ludwigia perrenis Burm.f.	10	0.1	1.0	02	0.02	1.0	-	-	-	04	0.04	1.0
Malacra capitata (L.)L.	12	0.12	1.0	12	0.14	1.16	08	0.1	1.25	14	0.16	1.14
Marsilia quadrifolia L.	-	-	-	04	0.04	1.0	-	-	-	06	0.06	1.0
Mecardonia procumbense (Mill) Small	14	0.32	2.28	04	0.04	1.0	16	0.34	2.12	06	0.22	3.6
Medicago polymorpha L.	54	1.28	2.37	60	1.32	2.2	56	1.16	2.07	52	1.24	2.38
Melilotus albus Medik.	50	1.16	2.32	54	1.12	2.07	52	0.9	1.73	44	1.06	2.40
Parthenium hysterophorus L.	12	0.12	1.0	10	0.1	1.0	06	0.06	1.0	12	0.12	1.0
Phyllanthus niruri L	14	0.14	1.0	06	0.06	1.0	10	0.1	1.0	04	0.04	1.0
Physalis minima L.	24	0.24	1.0	28	0.32	1.14	20	0.3	1.5	30	0.3	1.0
Polygonum plebeium R.Br.	28	0.52	1.85	34	0.68	2.0	24	0.56	2.33	32	0.6	1.87
Rinchosia minima (L)DC	-	-	-	-	-	-	-	-	-	04	0.04	1.0
Rumex dentatus L.	60	1.04	1.73	52	1.04	2.0	54	0.94	2.23	54	1.08	2.0
Portulaca oleracea L.	02	0.02	1.0	-	-	-	02	0.02	1.0	-	-	-
Sida acuta Burm.f.	12	0.12	1.0	08	0.08	1.0	-	-	-	06	0.06	1.0
Sida cordifolia L.	08	0.08	1.0	06	0.06	1.0	06	0.06	1.0	04	0.04	1.0
Sonchus arvensis L.	08	0.08	1.0	04	0.04	1.0	04	0.04	1.0	08	0.08	1.0
Sphaeranthus indicus Kurz	08	0.08	1.0	24	0.42	1.75	26	0.46	1.79	26	0.52	2.0
Tridax procumbens L.	04	0.04	1.0	14	0.26	1.85	10	0.1	1.0	16	0.16	1.0
Urena lobata (L.)	-	-	-	02	0.02	1.0	-	-	-	02	0.02	1.0
Xanthium strumarium L.	02	0.02	1.0	04	0.04	1.0	-	-	-	04	0.04	1.0

Table 7. The relative frequency, relative density, relative dominance, and IVI of different weeds in the wheat crop at the study site in the year 2020

Weed species	Barela				Semarchua				Karhi				Chamari			
	RF	RD	RDom	IVI	RF	RD	RDom	IVI	RF	RD	RDom	IVI	RF	RD	RDom	IVI
Abelmoschus ficulneus (L.)Wight&Arn.	0.5	0.3	0.0	0.8	0.2	0.1	0.0	0.3	-	-	-	-	0.7	0.4	0.0	1.1
Acmella radicans (Jacq.) R.K.Jansen	0.2	0.2	0.0	0.4	0.9	0.5	0.2	1.6	0.8	0.5	0.0	1.3	1.9	1.6	0.6	4.1
Acmella ulginosa (Sw.) Cass.	1.2	1.3	0.3	2.8	1.8	1.9	0.4	4.1	0.8	0.8	0.1	1.7	1.7	1.4	0.4	3.5
Ageratum conyzoides L.	1.9	2.5	0.8	5.2	1.6	1.5	0.4	3.5	2.5	3.4	2.4	8.3	1.9	1.9	1.0	4.8
Alternanthera sessilis (L.) DC	7.6	11.3	15.6	34.5	7.5	7.6	5.3	20.4	8.0	9.1	11.6	28.7	7.3	9.3	13.8	30.4
Ammannia baccifera L.	0.7	0.5	0.0	1.2	0.2	0.3	0.0	0.5	0.8	0.5	0.0	1.2	-	-	-	-
Anagallis arvensis L.	8.0	8.8	9.4	26.2	6.3	7.5	3.8	17.6	9.0	9.4	13.9	32.3	7.1	7.9	10.0	25.0
Cardiospermum halicacabum L.	0.5	0.3	0.0	0.8	0.5	0.2	0.0	0.7	-	-	-	-	-	-	-	-
Cassia tora L.	0.9	0.7	0.0	1.6	1.4	0.8	0.3	2.5	1.5	0.9	0.2	2.6	1.2	0.7	0.1	2.0
Chenopodium album L.	6.6	8.0	12.6	27.2	6.3	7.9	6.2	20.4	6.8	7.9	14.6	29.3	7.1	8.9	20.5	36.5
Chrozophora rottleri (Geiseler) Spreng.	1.9	1.7	0.4	4.0	2.9	2.3	0.9	6.1	1.5	1.8	0.6	3.9	1.7	1.5	0.4	3.6
Cirsium arvense L.Scop.	0.7	0.5	0.0	1.2	-	-	-	-	0.5	0.3	0.0	0.8	0.2	1.4	0.0	1.6
Commelina benghalensis L.	1.9	1.3	0.4	3.6	0.2	0.1	0.0	0.3	-	-	-	-	-	-	-	-
Corchorus olitorius L.	0.9	0.7	0.0	1.6	1.1	0.6	0.0	1.7	0.5	0.3	0.0	0.8	0.7	0.4	0.0	1.1
Cynodon dactylon (L.)Pers.	2.4	3.8	0.9	7.1	3.4	3.0	0.6	7.0	2.8	3.5	1.2	7.5	3.8	3.8	1.2	8.8
Cyperus difformis L.	0.5	0.3	0.0	0.8	0.7	0.4	0.1	1.1	-	-	-	-	-	-	-	-
Desmodium triflorum(L.)DC.	2.1	2.2	0.1	4.4	3.0	2.0	1.2	6.2	2.8	3.5	1.2	7.5	2.8	2.7	0.3	5.8
Digitaria sanguinalis (L.)Scop.	0.9	0.8	0.1	1.8	1.8	1.0	0.2	3.0	0.8	1.0	0.1	1.9	1.4	1.1	0.1	2.6
Echinochloa colonum (L.)Link	5.2	6.0	5.9	17.1	4.5	3.1	2.7	10.3	5.3	4.2	4.6	14.1	5.5	4.4	4.6	14.5
Eclipta alba (L.)Hassk	2.8	2.0	0.4	5.2	2.9	1.7	0.7	5.3	3.0	2.0	0.4	5.4	3.6	2.2	0.6	6.4
Elusine indica (L.)Gaertn.	1.4	1.0	0.3	2.7	1.6	1.0	0.5	3.1	1.3	1.4	0.5	3.2	-	-	-	-
Euphorbia hirta L.	2.1	1.5	0.4	4.0	1.8	1.3	0.7	3.8	3.3	2.6	1.4	7.3	3.6	2.2	1.0	6.8
Euphorbia terracina L.	1.9	1.3	0.3	3.6	1.4	1.7	1.2	4.3	3.0	1.8	0.9	5.7	2.6	1.5	0.5	4.6
Gnaphalium luteoalbum L.	0.9	0.7	0.4	2.0	2.3	1.8	1.6	5.7	-	-	-	-	-	-	-	-
Grangea maderaspatana (L.)	3.8	2.7	6.2	12.6	4.1	4.2	7.2	15.5	3.8	5.3	7.2	16.3	3.1	5.2	5.9	14.2
Heliotropium ovalifolium	1.7	1.2	0.2	3.1	1.6	0.9	0.3	2.8	2.0	1.2	0.3	3.5	1.4	0.8	0.1	2.3
Hibiscus panduriformis Burm.f.	0.7	0.5	0.0	1.2	0.5	0.3	0.0	0.8	1.0	0.6	0.1	1.7	0.5	0.3	0.0	0.8
Ipomoea obscura (L.)Ker Gawl.	0.2	0.2	0.0	0.4	-	-	-	-	-	-	-	-	-	-	-	-
Lagascea mollis Cav.	1.7	2.0	0.7	4.4	2.5	1.8	1.4	5.7	2.0	1.5	0.5	4.0	1.4	1.5	0.5	3.4
Ludwigia perrenis Burm.f.	1.2	0.8	0.1	2.1	0.2	0.1	0.0	0.3	-	-	-	-	0.5	0.3	0.0	0.8
Malacra capitata (L.)	1.4	1.0	0.2	2.6	1.4	0.9	0.4	2.7	1.0	0.8	0.1	1.9	1.7	1.1	0.3	3.1
Marsilia quadrifolia L.	-	-	-	-	0.5	0.3	0.0	0.8	-	-	-	-	0.7	0.4	0.0	1.1
Mecardonia procumbense (Mill) Small	1.7	2.7	0.2	4.6	0.5	0.3	0.0	0.8	2.0	2.6	0.2	4.8	0.7	1.5	0.0	2.28
Medicago polymorpha L.	6.4	10.7	13.7	30.8	6.8	8.4	19.0	34.2	7.0	8.8	9.6	25.4	6.2	8.5	10.2	24.9
Melilotus albus Medik.	5.9	9.7	12.6	28.2	6.1	7.1	15.3	28.5	6.5	6.8	6.5	19.8	5.2	7.3	9.3	21.8
Parthenium hysterophorus L.	1.4	1.0	0.1	2.5	1.1	0.6	0.1	1.8	0.8	0.5	0.0	1.2	1.4	0.8	0.0	2.2
Phyllanthus niruri L	1.7	1.2	0.2	3.1	0.7	0.4	0.0	1.1	0.5	0.3	0.0	0.8	0.5	0.3	0.0	0.8
Physalis minima L.	2.8	2.0	0.5	5.3	3.2	2.0	1.4	6.6	2.5	2.3	0.9	5.7	3.6	2.1	0.7	6.4
Polygonum plebeium R.Br.	3.3	4.3	0.4	8.0	3.8	4.3	4.5	12.6	3.0	4.2	2.0	9.2	3.8	4.1	2.1	10.0
Rinchosia minima (L)DC	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.3	0.0	0.9
Rumex dentatus L.	7.1	8.6	16.1	31.8	5.9	6.6	21.6	34.1	6.8	7.1	16.6	30.5	6.4	7.4	13.0	26.8
Portulaca oleracea L.	0.2	0.2	0.0	0.4	-	-	-	-	0.3	0.2	0.0	0.5	-	-	-	-
Sida acuta Burm.f.	1.4	1.0	0.0	2.4	0.9	0.5	0.0	1.4	-	-	-	-	0.7	0.4	0.0	1.1
Sida cordifolia L.	0.9	0.7	0.0	1.6	0.7	0.4	0.0	1.1	0.8	0.5	0.0	1.2	0.5	0.3	0.0	0.8
Sonchus arvensis L.	0.9	0.7	0.1	1.7	0.5	0.3	0.0	0.8	0.5	0.3	0.0	0.8	0.9	0.5	0.1	1.5
Sphaeranthus indicus Kurz	0.9	0.7	0.0	1.6	2.7	2.7	2.5	7.9	3.3	3.5	2.9	9.7	3.1	3.6	2.0	8.7
Tridax procumbens L.	0.5	0.3	0.0	0.8	1.6	1.7	0.6	3.9	1.3	0.8	0.0	2.1	1.9	1.1	0.1	3.1
Urena lobata (L.)	-	-	-	-	0.2	0.1	0.0	0.3	-	-	-	-	0.2	0.1	0.0	0.3
Xanthium strumarium L.	0.2	0.2	0.0	0.4	0.5	0.3	0.0	0.8	-	-	-	-	0.8	0.3	1.2	2.3

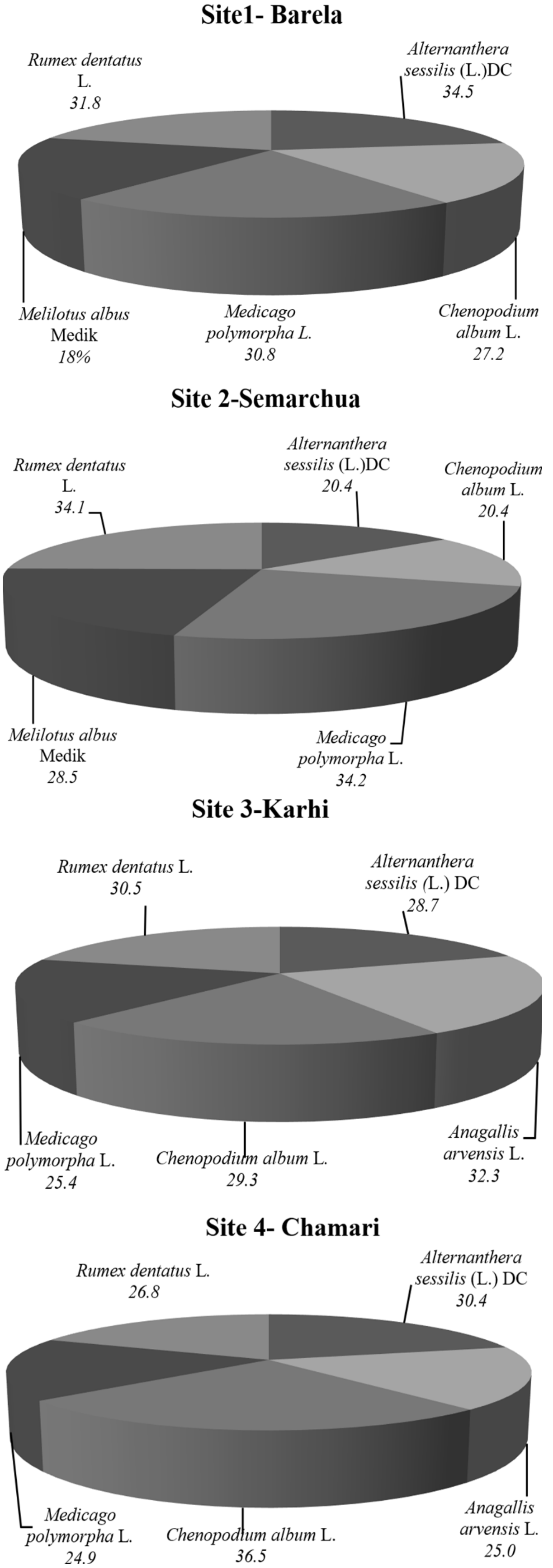

Figure 2. The graph represents the five highest IVI value of weeds at the selected study site in 2020

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RESEARCH ARTICLE

The moisture regimes and herbicides efficacy in improving productivity and profitability of spring-planted maize

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ABSTRACT

A field experiment was conducted at G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India during spring 2022 and 2023 to evaluate the impact of moisture regime and herbicide efficacy in maize (*Zea mays* L.). The experiment followed a split-plot design, with the main plots divided into two irrigation levels, *viz.* IW/CPE 0.8 and IW/CPE 1.2. Within each main plot, eight weed management treatments were tested, including atrazine 1000 g/ha, tembotrione 120 g/ha, topramezone 25.2 g/ha, atrazine 1000 g/ha *fb* hand-weeding at 35 DAS, atrazine 1000 g/ha *fb* tembotrione 120 g/ha, atrazine 1000 g/ha *fb* topramezone 25.2 g/ha, weed-free, and weedy check. Each treatment was replicated thrice in subplots. Interaction between irrigation levels and weed control practices revealed that spring maize irrigated at 1.2 IW: CPE in combinations with atrazine 1000 g/ha *fb* topramezone 25.2 g/ha produced significantly higher grain yield than other treatments. The economic analysis revealed that irrigation at 1.2 IW:CPE ratio recorded significantly higher net returns of ₹ 66207/ha and B:C (2.47). Among weed management treatments, atrazine 1000 g/ha *fb* topramezone 25.2 g/ha attained a maximum net income of ₹ 71661/ha with B:C (2.61) and next best was atrazine 1000 g/ha *fb* tembotrione 120 g/ha which fetched next highest net income (₹ 65767/ha) and B:C (2.49).

Keywords: Economics, Herbicides, Maize, Moisture regimes, Weed control efficiency

INTRODUCTION

Maize is a versatile multi-purpose crop, widely recognized as a staple food and crucial feed source globally. It occupies approximately 201.98 million hectares (mha) of land worldwide, total production of 1162.35 million tonnes (mt) and achieving an average productivity of 5.75 t/ha (ICAR-IIMR, 2021). In India, maize holds the position of the third most significant crop, following rice and wheat, covering an area of 9.89 m ha. The total production in India amounts to 35.65 mt, with an average productivity of 3.2 t/ha. As a C_4 plant, maize has high photosynthetic efficiency and can thrive in a variety of climates, including temperate, tropical, and subtropical regions (Erenstein 2022). However, there is a big gap between maize grain yield in India and the major maize-producing countries which is attributed to many challenges in maize cultivation in India; the yield gap with the USA is higher by 400% and with China, it is 225% (Mbagatuzinde 2022). The initially slow growth and wide spacing of maize plants make them susceptible to heavy weed infestations, which can significantly reduce yields. Mukhtar *et al.* (2007) highlight that unrestricted weed growth in maize fields can lead to yield reductions ranging from 67% to 79% during the summer season. Additionally, under weedy conditions, maize plants may experience an average reduction of 65% in plant height, further exacerbating yield losses. Furthermore, a concerning report on maize yield losses in India, as documented by Zaidi *et al.* (2010), indicates that approximately 25-30% of the maize crop is lost annually due to drought and waterlogging incidents. In drought conditions, herbicide application rates may need to be increased by 25-50% to achieve effective weed control compared to moist conditions (Ibrahim *et al.* 2021). These losses emphasize the urgent need for implementing climate-resilient agricultural strategies to mitigate the impact of adverse climatic conditions on maize production. Precipitation and soil moisture can directly influence herbicide uptake by washing the spray droplets off leaf surfaces or by diluting the herbicide to a less effective form (Varanasi *et al.* 2016). On the other hand, moisture stress throughout the growing season may affect both plant growth and herbicide efficacy. Maintaining optimal soil moisture levels through proper irrigation and timing herbicide applications in anticipation of precipitation events are crucial strategies for maximizing herbicide efficacy and achieving effective weed control. The IW/CPE ratio is a recognized irrigation scheduling factor that plays a crucial role in optimizing herbicide efficacy.

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By aligning irrigation practices with cumulative pan evaporation, this technique ensures that soil moisture levels are maintained at an optimal level for effective weed control, while also minimizing water loss. Thus, the objective of this research was to lower weed density while increasing spring maize output by optimizing the irrigation water regime and determining the best herbicide treatments.

MATERIALS AND METHODS

The experiment was conducted at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, during the spring seasons of 2022 and 2023. It employed a split-plot design with 16 treatment combinations, consisting of two irrigation levels and eight weed management treatments. The main plot factor involved two irrigation levels: IW/CPE:0.8 and IW/CPE 1.2 cumulative pan evaporation (CPE) intervals. In the sub-plots, the weed management treatments included: Atrazine 1000 g/ha, tembotrione 120 g/ha, topramezone 25.2g/ha, atrazine 1000 g/ha *fb* hand-weeding at 35 DAS, atrazine 1000 g/ha *fb* tembotrione 120g/ha, atrazine 1000 g/ha *fb* topramezone 25.2 g/ha, weed-free and weedy check. Each treatment combination was replicated three times. The soil characteristics were sandy loam with a pH of 7, electrical conductivity of 0.25 dS/m, organic matter content of 0.72%, available nitrogen of 281 kg/ha, available phosphorus of 25 kg/ha, and extractable potassium of 184 kg/ha. Maize hybrid Pioneer-1899 was sown on 16th February, 2022, and 28th February, 2023 with a seed rate of 20 kg/ha and spacing of 60×20 cm. The crop received fertilization with a dose of 120:26.2:33.33 N, P and K kg/ha. Daily pan evaporation and rainfall data were collected from the meteorological observatory located at the research farm of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, to calculate the Cumulative Pan Evaporation (CPE) values. During the maize growing seasons of 2022 and 2023, cumulative rainfall amounts of 74.5 mm and 225.6 mm, respectively, were observed, alongside corresponding pan evaporation values of 486.4 mm and 668.4 mm. The total number of irrigation events recorded under an IW/CPE ratio of 0.8 was 3 in 2022 and 4 in 2023, whereas under an IW/CPE ratio of 1.2, the respective irrigation frequencies were 7 and 5. Weed density was assessed at 60 DAS using a quadrat of 50 x 50 cm (0.25m^2) size positioned at the center of each plot. Weeds within the quadrat were uprooted, cut close to the root-shoot transition, and subsequently shade-dried for 2-3 days before being further dried in a hot air oven at 65±5°C until a constant weight was achieved, to determine dry matter accumulation (biomass). The dried samples were weighed and expressed as biomass (g/m^2). Data on weeds, including weed density and dry weight, were normalized using square root transformation with an additional factor of 0.5. Weed control efficiency (WCE) was calculated using formulae as suggested by Mani *et al.* (1973). Growth, yield, and economic data were statistically analysed using standard procedures.

RESULTS AND DISCUSSION

Weed flora

Among the weeds, grasses and sedges weeds were dominant in the experimental site as compared to the broad-leaved weeds (**Table 1**). *Cyperus rotundus* L. was the dominant weed followed by *Digitaria sanguinalis L.*, *Alternanthera sessilis* L., *Sorghum halepense* and *Eleusine indica* L., during both years of study.

Effect on weeds

At 60 DAS, the total weed density and weed biomass were found lower at IW/CPE 1.2 CPE in comparison to IW/CPE 0.8 (**Table 1** and **2**). Adequate soil moisture in the IW/CPE 1.2 facilitates the movement of pre-emergence herbicides into the zone of weed seed germination, thereby contributing to effective weed control. Additionally, the improved herbicide absorption, translocation, and metabolism of post-emergence herbicides in the IW/CPE 1.2 compared to the lower moisture conditions of IW/CPE 0.8. This reduction in adsorption of herbicides at IW/CPE 1.2 to soil particles enhances the availability of herbicides for uptake by plant roots, ultimately leading to improved weed control efficacy (Varanasi *et al.* 2016). Moreover, the dense canopy of maize plants under IW/CPE 1.2 inhibits weed seed germination and reduced growth rate of established weeds by limiting the amount of light reaching the soil surface germination and reduced growth rate of established weeds by limiting the amount of light reaching the soil surface.

Among weed management treatments, atrazine 1000 g/ha *fb* topramezone 25.2 g/ha followed by atrazine 1000 g/ha *fb* tembotrione 120g/ha recorded the lowest weed density at 60 DAS (**Table 1**). The density of *Digitaria sanguinalis* was reduced by 89.6%, *Sorghum halepense* by 76.4%, *Eleusine indica* by 78.3%, *Cyperus rotundus* by 63.3% and *Alternanthera sessilis* by 87% compare to the weedy check plot. Similarly at 60 DAS, total weed biomass significantly recorded lowest at atrazine 1000 g/ha *fb* topramezone 25.2g/ha followed by atrazine 1000g/ha *fb* tembotrione 120 g/ha (**Table 2**). The total weed biomass was lower by 53.5% and 76.1% as compared to atrazine 1000 g/ha applied alone and weedy check plot (**Table 2**). Sequential mixtures of atrazine and topramezone provide complementary and synergistic weed control effects. Atrazine primarily targets grass and certain broadleaf weeds, while topramezone offers additional control of broad-leaf weeds, including those tolerant to atrazine. Under herbicidal treatments, the weed control efficiency at 60 DAS was significantly higher in atrazine 1000 g/ha *fb* topramezone 25.2 g/ha (77.2%) which was statistically at par to atrazine 1000 g/ha *fb* tembotrione 120 g/ha (76.9%) owing to reduce weed biomass (**Table 4**). This sequential application of herbicides ensures comprehensive weed suppression throughout the crop growth period, ultimately leading to higher weed control efficiency at 60 DAS. These results are in accordance with Kakde *et al.* (2020), Rani *et al.* (2022) and Reddy *et al.* (2022).

Effect on crop

Data from two years indicated a significant variation in growth attributes, yield attributes, and yield across different moisture regimes. Irrigation at IW/CPE 1.2 had a notable impact, with pooled plant height reaching 246.9 cm. The number of grain rows per cob was 15.8 in 2022 and 15.9 in 2023, while the number of grains per row was recorded at 33.2 in 2022 and 33.5 in 2023. Grain yield was 6.0 t/ha in 2022 and 6.1 t/ha in 2023 (**Table 4**). The frequent irrigations under IW/CPE 1.2 ensured sufficient soil moisture availability throughout the growing season. This promotes the expansion of leaf surface area, maximizes photosynthetic efficiency, and increases the production of carbohydrates, ultimately leading to larger, more developed ears with well-filled kernels. Furthermore, the vigorous growth of maize extensive root system and release of allelochemicals; benzoxazines, phenolics, flavonoids, and terpenoids outcompeted the weeds for essential resources

Table 1. Effect of moisture regime and weed management on weed density at 60 days after sowing in spring planted maize (pooled mean)

Treatment	*Digitaria sanguinalis*	*Sorghum halepense*	*Eleusine indica*	*Cyperus rotundus*	*Alternanthera sessilis*	Total weed Density
Moisture regime						
IW/CPE 0.8	5.4(37.2)	4(17.9)	3.6(13.9)	8.9(91.1)	3.8(16.8)	12.6(189.6)
IW/CPE 1.2	5.2(35)	3.9(17)	3.5(13.2)	9(91.6)	3.8(16.1)	12.4(185.4)
LSD(p=0.05)	NS	NS	NS	NS	NS	NS
Weed management						
Atrazine 1000 g/ha	8.1(65.5)	5.5(29.7)	4.5(19.4)	10.2(102.9)	5.1(25.1)	16.2(261.1)
Tembotrione 120 g/ha	4.9(23.4)	4.2(17)	3.5(11.3)	9.6(90.3)	4(15)	13(167.7)
Topramezone 25.2 g/ha	4.8(22.1)	4.2(17)	3.4(10.5)	9.5(89.4)	3.8(13.9)	12.8(162.5)
Atrazine 1000 g/ha *fb* hand-weeding (35 DAS)	5(23.8)	3.4(10.8)	3.2(9.6)	9.8(94.3)	3.3(9.9)	12.5(156.5)
Atrazine 1000 g/ha *fb* tembotrione 120 g/ha	3.8(13.8)	3.5(11.1)	3.1(8.8)	8.7(74.8)	3(8.1)	11.2(124.8)
Atrazine 1000 g/ha *fb* topramezone 25.2 g/ha	3.7(13.2)	3.3(10.3)	3.1(8.7)	8.7(74.4)	2.8(6.9)	11.1(121.4)
Weed free	1(0)	1(0)	1(0)	1(0)	1(0)	1(0)
Weedy check	11.3(127.1)	6.7(43.6)	6.4(40.1)	14.3(204.6)	7.3(53)	22.5(506)
LSD(p=0.05)	0.22	0.20	0.18	0.22	0.20	0.25

Data were square root transformed and values in parentheses are actual mean values

Table 2. Effect of moisture regime and weed management on weed biomass at 60 days after sowing in spring planted maize (pooled mean)

Treatment	*Digitaria sanguinalis*	*Sorghum halepense*	*Eleusine indica*	*Cyperus rotundus*	*Alternanthera sessilis*	Total weed biomass
Moisture regime						
IW/CPE 0.8	6.5(50.9)	4.4(21.7)	3.2(10.6)	6(41.3)	6.4(46.4)	12.4(185.9)
IW/CPE 1.2	6.4(48.5)	4.3(20.9)	3(9.7)	6(41)	6.4(46.6)	12.2(178.9)
LSD(p=0.05)	NS	NS	NS	NS	NS	NS
Weed management						
Atrazine 1000 g/ha	9.2(84.1)	6.2(37.1)	3.9(14.3)	8.3(68.9)	8.6(73)	17.2(296.3)
Tembotrione 120 g/ha	6.5(40.7)	4.6(20.2)	3.1(8.4)	5.8(33)	6.7(43.5)	12.7(160.9)
Topramezone 25.2 g/ha	6.3(39.5)	4.6(19.9)	3(8.2)	5.8(32.9)	6.6(42.3)	12.6(158.2)
Atrazine 1000 g/ha *fb* hand-weeding (35 DAS)	6.4(40.6)	4.5(19.1)	2.6(5.7)	5.7(32)	6.1(36.6)	11.9(140.9)
Atrazine 1000 g/ha *fb* tembotrione 120 g/ha	5(23.7)	3.7(12.7)	2.7(6.3)	5.2(26.3)	6(35.3)	10.6(111.3)
Atrazine 1000 g/ha *fb* topramezone 25.2 g/ha	4.8(22)	3.6(12.1)	2.7(6.2)	5.2(25.6)	5.9(34.3)	10.4(107.2)
Weed free	1(0)	1(0)	1(0)	1(0)	1(0)	1(0)
Weedy check	12.1(146.8)	7.1(49.6)	5.7(31.2)	10.5(110.3)	10.4(106.8)	22(484.8)
LSD(p=0.05)	0.21	0.22	0.19	0.18	0.31	0.32

Data were square root transformed and values in parentheses are actual mean values

(Jabran 2017). According to Bednarz *et al.* (2023), soil microflora can convert allelochemicals such as phenolic compounds and benzoxazines into more potent bioherbicides. Because of their phytotoxicity, specific activity, and short soil persistence, these allelochemicals may be effective weed control agents.

Weed management treatments had a significant influence on growth, yield-attributing traits, and grain yield. The weed-free plot recorded the highest values, with pooled plant height reaching 250.7 cm. The number of grain rows per cob was 17.0 in 2022 and 17.1 in 2023, while the number of grains per row was 34.7 in 2022 and 35.3 in 2023. Grain yield was 6.9 t/ha in 2022 and 7.0 t/ha in 2023 (**Table 4**). These values were statistically comparable to treatments with atrazine at 1000 g/ha followed by topramezone at 25.2 g/ha and atrazine at 1000 g/ha followed by tembotrione at 120 g/ha. The growth attributes, yield attributes and grain yield in the weedy check were significantly low in both years. In the initial stage of crop growth, atrazine prevents weed seeds from germinating or disrupts early seedling growth, effectively reducing weed populations in the field, while post-emergence herbicides; topramezone and tembotrione controlled all weed species including those that may have survived atrazine, as it depletes carotenoids and stops chloroplast development causing bleaching and necrosis of foliar tissue (Fluttert *et al.* 2022). This reduces the crop's competition with weeds, enhancing the crop's vegetative and reproductive potential, and physically preventing weeds from emerging and growing by depriving them of access to nutrients, moisture, light, and space. The present findings were in accordance with the earlier findings of Rani *et al.* (2022) and Sivamurugan *et al.* (2024).

Interaction

Critical assessment of data revealed that the interaction effect (I × W) between irrigation intervals and weed management on grain yield was found to be significant (**Table 3**).The grain yield recorded significantly higher in combination of atrazine 1000 g/ha *fb* topramezone 25.2g/ha (6.91 t/ha) with irrigation scheduling at IW/CPE 1.2 over all other treatment combinations, which was statistically at par with atrazine 1000 g/ha *fb* tembotrione 120 g/ha (6.33 t/ha) under similar moisture regime. However, treatment combination at IW/CPE 0.8 intervals; atrazine 1000 g/ha *fb* tembotrione 120 g/ha (5.75 t/ha) coupled with IW/CPE 0.8 and atrazine 1000 g/ha *fb* topramezone 25.2 g/ha (5.74 t/ha) with IW/CPE 0.8 being at par with each other and found to be significantly higher over rest of treatment combinations.

Economics

The net monetary returns (₹ 66207/ha) and B:C ratio (2.47) in maize were significantly higher with irrigation at IW/CPE 1.2 (**Table 4**). Optimal soil moisture conditions at IW/CPE 1.2 promote vigorous growth and development of maize plants, resulting in better crop performance and higher grain yields outweigh the additional cost of frequent irrigation.

Among weed management treatments, the highest net return (₹ 71661/ha) and B:C ratio (2.61) was obtained with atrazine 1000 g/ha *fb* topramezone 25.2 g/ha closely followed by weed-free and atrazine 1000 g/ha *fb* tembotrione 120 g/ha (**Table 4**). The lowest net return (₹ 33271/ha) and B:C ratio (1.91) was in weedy check due to heavy weed infestation and yield decline. These results were in conformity with the results obtained by Rani *et al.* (2022), Reddy *et al.* (2022) and Kaul *et al.* (2023).

The two-year study demonstrated that for effective weed control, to achieve higher maize productivity and maximize net monetary returns, a pre-emergence (PE) application of atrazine at 1000 g/ha followed by (*fb*) post-emergence (PoE) application of topramezone at 25.2 g/ha, coupled with

Table 3. Interaction effect of moisture regime and weed management treatments (I × W) on maize grain yield (pooled data of two year)

Treatment (I × W)	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	Moisture regime means
I_1	4.51	5.11	5.52	5.64	5.75	5.74	6.67	3.23	5.27
I_2	5.38	6.08	6.11	6.29	6.33	6.91	7.17	4.04	6.04
Weed management mean	4.94	5.60	5.81	5.97	6.04	6.32	6.91	3.63	
								SEm±	LSD(p=0.05)
Two weed management at the same irrigation interval								0.13	0.40
Two moisture regimes at the same or different weed management								0.17	0.41
Irrigation interval (I)								0.05	0.17
Weed management (W)								0.12	0.35

I_1: IW/CPE 0.8, I_2: IW/CPE 1.2, W_1: atrazine 1000 g/ha, W_2: tembotrione 120 g/ha, W_3: topramezone 25.2g/ha, W_4: atrazine 1000 g/ha *fb* hand-weeding (35 DAS), W_5: atrazine 1000g/ha *fb* tembotrione 120 g/ha, W_6: atrazine 1000g/ha *fb* topramezone 25.2 g/ha, W_7: weed free, W_8: weedy check

Table 4. Effect of moisture regime and weed management on growth, yield and economics in spring planted maize (pooled mean)

Treatment	Plant height (cm)	2022			2023			Weed control efficiency (%)	Net returns (₹/ha)	B:C ratio
		No. of grain rows / cob	No. of grains /row	Grain yield (t/ha)	No. of grain rows /cob	No. of grains /row	Grain yield (t/ha)			
Moisture regime										
IW/CPE 0.8	222.1	13.9	29.1	5.2	14.0	29.4	5.4	61.6	497780	2.15
IW/CPE 1.2	246.9	15.8	33.2	6.0	15.9	33.5	6.1	64.3	66207	2.47
LSD(p=0.05)	9.3	1.9	3.5	0.5	1.6	3.3	0.6	NS	-	-
Weed management										
Atrazine 1000 g/ha	220.6	14.0	29.6	4.8	14.1	29.7	5.1	39.4	48414	2.24
Tembotrione 120 g/ha	231.1	14.2	30.9	5.7	14.3	31.5	5.6	67.7	56032	2.32
Topramezone 25.2 g/ha	232.1	14.4	31.3	5.9	14.4	31.6	5.9	69.2	58393	2.38
Atrazine 1000 g/ha *fb* hand-weeding (35 DAS)	242.2	14.6	31.8	6.0	14.6	32.0	6.1	71.5	64177	2.44
Atrazine 1000 g/ha *fb* tembotrione 120 g/ha	244.7	15.0	32.0	6.0	15.1	32.1	6.1	77.5	65767	2.49
Atrazine 1000 g/ha *fb* topramezone 25.2 g/ha	245.9	15.8	32.2	6.1	15.9	32.5	6.6	78.2	71661	2.61
Weed free	250.7	17.0	34.7	6.9	17.1	35.3	7.0	100	66234	2.08
Weedy check	208.7	14.0	26.7	3.5	14.2	26.9	3.9	0.00	33271	1.91
LSD(p=0.05)	11.7	1.6	2.9	0.5	1.6	3.3	0.6	3.6	-	-

irrigation scheduling at IW/CPE 1.2, proved to be the most effective strategy. By integrating optimized weed management and irrigation practices under evolving climate patterns, farmers can mitigate weed pressures, optimize crop productivity and enhance maize resilience to changing environmental conditions, while ensuring sustainable yields and economic viability in the *Tarai* region of Uttarakhand.

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RESEARCH ARTICLE

Weed management in chickpea through broad spectrum herbicides

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ABSTRACT

A field experiment was laid out in a randomized block design with three replications, during *Rabi* 2022-23 and 2023-24 at J Farm, Agricultural Research Institute, Rajendranagar, Hyderabad, India to evaluate the efficacy of different broad spectrum post emergence herbicides on weed control, yield and economics of chickpea. Results indicated that all the post emergence herbicides applied at 25 days after sowing (DAS) significantly reduced the weed growth and increased crop growth, yield over weedy check. Among the post emergence herbicides, the highest weed control efficiency (WCE) of 61.5% and 60% was obtained at 60 DAS and harvest with the application of sodium salt of acifluorfen 16.5% + clodinafop-propargyl 8% at 200 g/ha, respectively. However, all the post emergence herbicides applied at 25 DAS caused crop injury ranging from 10 to 16% at 14 days after herbicide application, though crop gradually recovered later. Among the post emergence herbicides tested, though higher yield of 1012 kg/ha was obtained with the application of sodium salt of acifluorfen 16.5% + clodinafop propargyl 8% at 200 g/ha but was on par with all other post emergence herbicides. There is an increased yield of 89% obtained with this treatment compared to weedy check. Higher net monetary returns (Rs. 33,485/-) and benefit cost ratio (BCR) of 1.22 were also obtained with this treatment. Thus, it was concluded that post emergence application of sodium salt of acifluorfen 16.5% + clodinafop propargyl 8% at 200 g/ha was found to be effective and economical compared to other post emergence herbicides under study.

Key words: Chickpea, Weed management, Broad-spectrum, Post-emergence herbicides, Phytotoxicity, Weed control efficiency

INTRODUCTION

Chickpea (*Cicer arietinum* L.), the world's third most important food legume is also an important major pulse crop of India. One of the reasons for its low productivity is weed infestation. Being a short statured crop with initial slow growth, severely infested with weeds and causes yield reduction varying from 40-75% (Ratnam *et al.* 2011, Shrikant *et al.* 2024). Farmers usually apply pre-emergence herbicides and/ or manual weeding (Kashyap *et al.* 2022) but due to scarcity of labour and increased cost of labour wages manual weeding is difficult and not economical. Further, the pre-emergence herbicide does not control the late emerged and many weeds. For control of grasses several post-emergence herbicides like quizalofop-ethyl, propaquizafop *etc*. recommended but for the control of broad -leaf weeds which are very problematic, suitable selective post emergence herbicide without any phytotoxicity to chickpea is not available. Farmers are repeatedly asking for a suitable post-emergence broad-spectrum herbicide for the effective and economical weed management in chickpea. Keeping all this in view, the present experiment was conducted to evaluate the efficacy of different broad spectrum post emergence herbicides on weed control, crop growth, yield and economics of chickpea.

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MATERIALS AND METHODS

A field experiment was conducted consecutively for two years during *Rabi* seasons of 2022-23 and 2023-24 at J Farm, Agricultural Research Institute, Rajendranagar, Hyderabad, Telangana, India. The soil of the experimental plot was sandy clay loam in texture with medium in available nitrogen, phosphorus and high in available potassium and with pH of 7.7. The experiment consists of seven treatments, *viz.* weedy check, hand weeding at 15 and 30DAS, imazethapyr 50 g/ha, sodium salt of acifluorfen + clodinafop propargyl 200 g/ha, topramezone 15 g/ha, fomesafen + fluazifop-butyl 250 g/ha and imazethapyr + propaquizafop 125 g/ha was laid out in a randomized block design with three replications. The seeds of chickpea (cv. *Gold 75*) during the third week of December 2022 during first year and first week of December 2023 in second year. All the recommended packages of practices except weed control were followed in raising the crop. The crop was fertilized with 20-50-20 kg/ha of N-P-K as basal. The post-emergence herbicides were applied at 25 DAS using a spray volume of 500 L/ha of water through a knapsack sprayer fitted with a flat fan nozzle. There were no major pests and diseases during the both years of experimentation but during the initial stage of crop, Spodoptera was noticed and it was controlled by spraying chlorpyriphos and novaluron. The weed density and dry matter were recorded at various stages with the help of 0.5 x 0.5 m quadrate and then converted to per square meter. The weed species were identified and separated as grasses, sedges and broad leaves. The data on the weed density and dry weight were subjected to square root transformation $\sqrt{x+0.5}$ before statistical analysis to normalize their distribution (Panse and Sukhatame 1978). The herbicide phytotoxicity on crop (like yellowing, stunting, scorching etc.) was done on a scale of 0 to 10 (0 meant no phytotoxicity and 10 meant complete death of plant) equal to 0-100 % (Rao 2000) at 7 and 14 DAA (Days After Application). The economics of various treatments was calculated taking the prevailing market prices of inputs and outputs into consideration.

RESULTS AND DISCUSSION

Weed flora

The major weed flora of the weedy check plots were *Echinochloa colona, E. crus-galli, Dinebra retroflexa, Dactyloctenium aegyptium, Panicum repens, Leptochloa chinensis, Leersia hexandra* (grasses), *Cyperus rotundus, Fimbristylis miliacea* (sedges), *Trianthema portulacastrum, Chrozophora rottleri, Celosia argentea, Cleome viscosa, Cyanotis axillaris, Parthenium hysterophorus, Alternanthera sessilis, Nicotiana plumbagin folia, Ageratum conyzoides, Abutilon indicum* (broad-leaf weeds), Similar weeds in chickpea were also reported earlier (Ratnam *et al.* 2011, Sanketh *et al.* 2021).

Weed growth

All the herbicidal treatments significantly influenced grasses, sedges and broad leaf weed population and also the total weed dry weight at 60 DAS and at harvest (**Table 1** and **2**). Among the herbicide treatments, post-emergence application of sodium salt of acifluorfen 16.5% + clodinafop-propargyl 8% at 200 g/ha applied at 25 DAS was found effective in minimizing the total weed density and dry weight at both stages of observation but was on par with imazethapyr at 50 g/ha at 60 DAS and was on par with all post emergence herbicides at harvest.

The highest WCE of 61.5% and 60% was also obtained with this treatment. This may be attributed to broad spectrum weed control properties exhibited by this ready-mix herbicide treatment. The highest weed growth was observed in weedy check and the lowest weed index of 23.7% was obtained with post-emergence application of sodium salt of acifluorfen 16.5%+ clodinafop-propargyl 8% at 200 g/ha followed by topramezone at 15 g/ha. The highest weed index of 59.6% was observed in weedy check. The results are corroborating with those reported by Nath *et al.* 2021.

Table 1. Effect of different treatments on weed density of different weed groups at 60 DAS and at harvest in chickpea (pooled data of two years)

Treatment	At 60 DAS				At harvest			
	Grasses (no./m^2)	Sedges (no./m^2)	Broad-leaf weeds (no./m^2)	Total weed density (no./m^2)	Grasses (no./m^2)	Sedges (no./m^2)	Broad-leaf weeds (no./m^2)	Total weed density (no./m^2)
Imazethapyr 50 g/ha	8.35 (71.0)	6.35 (40.9)	7.75 (61.7)	13.05 (173.7)	7.05 (49.3)	6.15 (39.2)	6.10 (39.7)	11.20 (128.2)
Sodium salt of acifluorfen + clodinafop-propargyl 200 g/ha	7.15 (53.0)	7.10 (50.0)	6.90 (45.8)	12.1 (152.3)	5.75 (34.0)	6.50 (41.7)	5.85 (34.2)	10.50 (111.5)
Topramezone 15 g/ha	8.55 (76.2)	7.05 (50.1)	7.10 (50.8)	13.2 (177.2)	7.25 (52.8)	7.05 (50.0)	6.80 (45.5)	12.15 (148.3)
Fomesafen + fluazifop-p-butyl 250 g/ha	7.55 (57.2)	7.95 (63.8)	7.05 (50.0)	13.05 (171.3)	6.60 (40.0)	6.95 (50.5)	5.80 (35.0)	11.20 (132.5)
Imazethapyr + propaquizafop 125 g/ha	7.70 (59.2)	7.75 (61.5)	7.35 (58.0)	13.20 (178.1)	7.35 (54.2)	8.00 (64.0)	6.80 (46.0)	12.75 (164.5)
Hand weeding at 15 and 30 DAS	6.10 (37.7)	4.90 (28.3)	5.15 (27.0)	9.45 (86.3)	6.00 (29.3)	5.15 (26.3)	4.95 (24.7)	9.35 (87.0)
Weedy check	10.40 (112.0)	7.68 (60.3)	8.90 (82.0)	15.80 (254.3)	8.55 (73.3)	7.00 (49.0)	9.00 (88.3)	14.30 (207.7)
LSD (p=0.05)	2.80	1.75	2.75	3.45	2.55	1.8	2.7	3.0

*Figures in parentheses are original values, data transformed to $\sqrt{x+0.5}$ transformations

Effect on crop

Herbicide phytotoxicity: Herbicide phytotoxicity observations were recorded at 7 and 14 DAA All the post emergence herbicides applied 25 DAS caused crop injury symptoms like yellowing scorching ranging from 10 to 16% at 14 DAA (**Table 3**). However, the crop gradually recovered later. Similar line of observations on herbicide injury in chickpea were also reported earlier (Gajanand *et al.* 2023, Shrikant *et al.* 2024)

Growth attributes: All the weed control treatments had significantly higher plant height, no. of branches/ plant over weedy check **(Table 4**). All the herbicidal treatments were on par among themselves but significantly lower than hand weeding which had higher crop dry weight. Among the herbicide treatments, sodium salt of acifluorfen 16.5% + clodinafop-propargyl 8% at 200g/ha had higher crop dry weight and more number of branches per plant at harvest, This treatment was closely followed by topramezone 15g/ha. This might be due to the effective weed control under these treatments created more space to crop and reduced the competition for space, light and moisture and nutrients eventually resulted in more number of branches and crop dry weight. The results are in concurrence with those of Shrikant *et al.* (2024)

Yield and yield attributes: Number of pods/plant, hundred seed weight and seed yield were significantly influenced by the weed control treatments **(Table 4**). Among the post-emergence herbicides, though the highest seed yield of 1012 kg/ha was obtained with the application of sodium salt of acifluorfen 16.5% + clodinafop-propargyl 8% at 200 g/ha but it was on par with all other post- emergence herbicides. There was an increased yield of 89% in this treatment compared to weedy check. The next best treatment was post- emergence application of topramezone at 15 g/ha with seed yield of 1000 kg/ha. The increased yield in these treatments might be due to proper utilization of moisture, nutrients, light and space by chickpea crop in the absence of weed competition resulting in more photosynthates translocated from source to sink. None of the herbicidal treatments could reach the level of hand weeding at 15 and 30 DAS, which had the highest seed yield of 1326 kg/ha, this indicates the influence of crop injury and failure of herbicides to provide crop weed free situation. Weed competition during the crop growth period due to uncontrolled weed growth caused 60% yield loss in chickpea compared to hand weeding at 15 and 30 DAS. The results are akin to those reported by Sethi *et al.* (2021) and Kashyap *et al.* (2022),

Table 3. Effect of herbicide application on phytotoxicity in chickpea (pooled data of two years)

Treatment	Phytotoxicity rating (%) at	
	7 DAA*	14 DAA*
Imazethapyr 50 g/ha	10	10
Sodium salt of acifluorfen + clodinafop-propargyl 200 g/ha	17	10
Topramezone 15 g/ha	13	10
Fomesafen + fluazifop-p-butyl 250 g/ha	20	16
Imazethapyr + propaquizafop 125 g/ha	27	15
Hand weeding at 15 and 30 DAS	-	-
Weedy check	-	-

Economics

The highest net monetary return of Rs. 33,485/- and BCR of 1.22 was obtained with the post-emergence application of sodium salt of acifluorfen 16.5% + clodinafop-propargyl 8% at 200 g/ha which may be due to higher WCE and increased crop yield **(Table 4)**. This was closely followed by the post-emergence application of topramezone at 15 g/ha with net monetary return of Rs. 32,785/- and BCR of 1.20. Though hand weeding at 15 and 30 DAS had the highest seed yield, it resulted in lower BCR of 0.87 mainly because of higher cost of labour involved in this treatment.

Table 2. Effect of different treatments on weed dry weight of different weed groups at 60 DAS and harvest in chickpea (pooled data of two years)

Treatment	Dosage (g/ha)	Weed dry weight at 60 DAS (g/m^2)	WCE (%)	Weed dry weight at Harvest (g/m^2)	WCE (%)	WI (%)
Imazethapyr 50 g/ha	50	6.35(45.4)	53.0	5.30(34.2)	52.5	26.6
Sodium salt of acifluorfen + clodinafop-propargyl 200 g/ha	200	5.20(35.5)	61.5	4.45(23.2)	60.0	23.7
Topramezone 15 g/ha	15	7.00(57.7)	48.0	5.80(40.1)	48.0	24.5
Fomesafen + fluazifop-p-butyl 250 g/ha	250	7.35(63.1)	43.7	5.80(36.8)	48.0	39.3
Imazethapyr + propaquizafop 125 g/ha	125	7.60(68.5)	45.6	5.9(44.3)	47.0	40.0
Hand weeding at 15 and 30 DAS	-	3.90(15.4)	74.1	3.05(9.2)	72.6	-
Weedy check	-	13.15(177.3)	-	11.15(125.3)	-	59.6
LSD (p=0.05)		1.60		1.78		

*Figures in parentheses are original values, data transformed to $\sqrt{x+0.5}$ transformations

Table 4. Effect of weed control treatments on crop growth, yield parameters, yield and economics in chickpea (pooled data of two years)

Treatment	Plant height (cm) at harvest	No. of branches / plant at harvest	Crop dry weight (g/plant) at harvest	No. of pods/ plant	100 seed weight (g)	Seed yield(kg/ha) 2022-23	Seed yield(kg/ha) 2023-24	Pooled yield (kg/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Benefit: cost ratio
Imazethapyr 50 g/ha	24.4	3.4	9.4	18.2	16.3	1025	900	963	57,780	31,480	1.19
Sodium salt of acifluorfen + clodinafop-propargyl 200 g/ha	27.8	4.2	10.8	22.2	17.3	1075	949	1012	60,720	33,485	1.22
Topramezone 15 g/ha	25.8	4.1	10.4	19.1	16.7	1100	900	1000	60,000	32,750	1.20
Fomesafen + fluazifop-p-butyl 250 g/ha	27.3	3.9	9.7	15.0	16.6	890	720	805	48,300	20,393	0.73
Imazethapyr + propaquizafop 125 g/ha	26.8	3.7	10.1	15.8	16.3	900	687	794	47,640	17,640	0.53
Hand weeding at 15 and 30 DAS	31.7	4.8	16.8	30.5	17.2	1451	1200	1326	79,560	36,960	0.87
Weedy check	17.3	2.8	6.3	10.8	15.3	518	554	536	32,160	7,160	0.29
LSD (p=0.05)	4.5	1.3	4.4	7.8	1.4	260.2	252.4	256.3			

From the results, it was concluded that post-emergence application of sodium salt of acifluorfen 16.5% + clodinafop-propargyl 8% at 200 g/ha was found to be effective and economical compared to other treatments under the study. In view of the initial crop injury, in all the post- emergence herbicides understudy, the future research emphasis on identification of safe and selective broad spectrum post-emergence herbicide in chickpea should be continued.

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RESEARCH ARTICLE

Efficacy of different post-emergence herbicides against complex weed flora in greengram

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ABSTRACT

A field experiment was conducted for three consecutive years (2021-23) at Agricultural Research Sub-Station, Nagaur, Agriculture University, Jodhpur during rainy season to evaluate the efficacy of different post-emergence herbicides for complex weed flora, growth and yield of greengram with twelve treatments laid out in randomized block design with three replications. The results revealed that post-emergence application of imazethapyr 50 g/ha significantly controlled grassy and broad-leaves weeds, but its efficacy was low against *Rhinchosia minima* and *Cyprus rotundus*. The significant lowest weed density (No./m^2) of different weeds like *Rhinchosia minima* (15.3), *Digera arvensis* (6.0), *Celosia argentea* (16.0), *Cyperus rotundus* (8.0), *Dactyloctenium aegyptium* (6.0), other broad-leaves and grassy weeds (5.3), total weed dry weight (27.0 g/m^2) and weed control efficiency (82.9 %) were recorded under fomesafen 11.1% w/w + fluazip-p-butyl 11.1% followed by sodium acifluorfen + clodinafop-propargyl 220 g/ha. Similar treatments resulted in significant improvement in number of seeds per pod (13.4), grain yield (1.22 t/ha), net returns (₹ 70,310/ha) and B-C ratio (2.1) and weed index (9.0%). The findings of this experiment endorse the application of either fomesafen 11.1%w/w + fluazip-p-butyl 11.1% (ready-mix) *or* sodium acifluorfen + clodinafop-propargyl 220 g/ha at 20-25 days after sowing to realized excellent control of complex weed flora in greengram consequently resulting in higher grain yields, net returns and B-C ratio.

Keywords: Economics, Fomesafen + fluazip-p-butyl, Sodium acifluorfen + clodinafop-propargyl, Weed density

INTRODUCTION

Greengram (*Vigna radiata* L.) alternatively known as green gram, green bean, moong bean, golden gram belongs to the Leguminaceae family. It is an important pulse crop and believed to be originated from India. It plays an important role as a food security crop because of its nutritional quality as well as ability to survive in harsh environmental conditions such as arid and semiarid lands. They are mainly grown for human food, flour while sprouts and immature pods as a vegetable. The grains contain approximately 25-28% protein, 3.5-4.5% fiber, 4.5-5.5% ash and 60- 65% carbohydrates on dry weight. The grains also contain vitamin-A (94 mg), Vitamin-C (8 mg), iron (7.3 mg), calcium (124 mg), magnesium (189 mg), phosphorus (367 mg) and foliate (549 mg) (Muchomba *et al*. 2023). Besides being a rich source of protein, green gram roots are important sources of soil nitrogen. The roots have the ability to develop nodules that help in fixing atmospheric nitrogen in the soil through rhizobium, the crop has the ability to add about 30-40 kg N/ha in a single season. The vegetative parts, stocks and husks are also useful sources of leguminous fodder for livestock. The crop also serves as an important cover and a rotation crop. India is the highest producer as well as consumer of pulses in the world. Greengram is the third most important pulse crop in India, with a contribution of 11.38% after chickpea (49.66%) and pigeonpea (15.67%) in total pulse production. Rajasthan is the state having highest area 23.25 lakh hectare, production 11.16 lakh tonnes and yield 480 kg/ha of greengram (Annon. 2021-22). The dominant contributors to greengram cultivation in terms of area and production are Rajasthan (70 % and 75%, respectively). The maximum area under greengram cultivation was covered in Nagaur (27%), followed by Jodhpur (13.57%) and Pali (12.18%) districts of Rajasthan. Nagaur, Jodhpur and Pali, together contribute more than 50% of the total area under greengram cultivation in Rajasthan (Sharma *et al*. 2017).

Greengram is recommended for cultivation mainly in *Kharif* season under arid conditions of Nagaur, Rajasthan. But weed infestation is one of the major constraints in greengram cultivation and causes 50 to 90% yield loss (Mishra *et al*. 2017). Weeds

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compete with crops for resources such as nutrients, water, light and space, thus reducing their yield. The presence of weeds not only reduces grain yield, but it also influences the quality of seed. The major weed flora of mung-bean is *Rhinchosia minima*, *Digera arvensis*, *Celosia argentea*, *Cyperus rotundus*, *Dactyloctenium aegyptium,* other broad leaved and grassy weeds. Weeds are present throughout the crop growth, yet there is a need to find out the exact time during which weeds cause the highest yield reductions. The critical period of weed competition is defined as the shortest period during crop growth in which weed management results in almost similar yield as that in weed free conditions throughout crop growth. The first period of 20-40 days after sowing is crucial for crop-weed competition in greengram (Pankaj *et al.* 2017). Mechanical practices such as hand weeding and inter–culturing is effective but unavailability of labour and incessant rains during the early crop season normally limit the weeding operations. Therefore, chemical weeding under such circumstances becomes indispensable and can be a cost-effective alternative.

Application of pendimethalin and imazethapyr during pre-emergence (PE) and post-emergence (PoE), respectively, have shown promising results in greengram Singh *et al.* (2015). However, narrow time window of application often makes the PE herbicides less preferred choice among the farmers. Also, application of a single herbicide is often ineffective in controlling diverse weed flora. On the contrary, either ready or tank mixes of compatible herbicides with varying modes of action may ensure effective control of diverse weed flora and check shifting of weed flora complex and herbicide resistance Banerjee *et al.* (2018). In general, there is paucity of information on the impact of new herbicide ready mixes available in Indian market on the performance of monsoon greengram. Under the above perspectives, the present study was formulated to evaluate the efficacy of different post-emergence herbicides for complex weed flora, growth, yield potential and economics of mung-bean.

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* (rainy) seasons of 2021, 2022 and 2023 at the Research farm of Agricultural Research Sub-Station, Nagaur, Agriculture University, Jodhpur, Rajasthan situated at 27° 12' 7.24'' N latitude, 73° 44' 2.18 E longitude, at an altitude of 302 m above the mean sea level. This location falls within agro-climatic zone II A, characterized as arid and semi-arid transitional plain of inland drainage zone in Rajasthan. The climate of this region is distinctly arid and semi- arid marked by significant temperature fluctuations throughout the year. Average annual rainfall of 385 mm, about 80% of which falls during July–September from the southwest monsoon while the rest is more or less equally distributed during the rest of the year. The soil samples were drawn from top 15 cm soil depth. The soil in the experimental field is classified as loamy sand and slightly alkaline in reaction (pH 8.2) and with EC of 0.35 dS/m. The soil was low in organic carbon (0.15%), available N (219 kg/ha), available P (15 kg/ha) and available K (217 kg/ha). Twelve treatments (imazethapyr 50 g/ha, imazethapyr 70 g/ha, Fomesafen 11.1% w/w + fluazip-p-butyl 11.1% 220 g/ha, fomesafen 11.1% w/w + fluazip-p-Butyl 11.1% 250 g/ha, sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC ready-mix 220 g/ha, sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC ready-mix 250 g/ha, imazethapyr 35% + imazamox 35% WG 40 g/ha, imazethapyr 35% + imazamox 35% WG 60 g/ha PoE, quizalofop-ethyl 7.5 % + imazethapyr 15 % EC 80 g/ha quizalofop-ethyl 7.5 % + imazethapyr 15 % EC 100 g/ha, along with weed free and weedy check laid out in randomized block design with three replications. Seeds of mung-bean variety "*MH-421*" were sown manually with 30 x 10 cm planting geometry in a plot size of 4m x 3m with seed rate of 15 kg/ha on 11 July, 08 July and 18 July 2021, 2022 and 2023, respectively. The crop was grown under totally rainfed conditions. Thinning and gap filling were done manually to maintain optimum plant population. A recommended dose of fertilizer (40:20 kg NP/ha) was applied as basal application through urea and diammonium phosphate (DAP) as per package of practices of crop for the area. Herbicides were applied as spray in an aqueous medium at the rate of 500 litre water/ha for post-emergence herbicides, using a knapsack sprayer with flat-fan nozzle. Data on weed count and weed biomass from an area enclosed in a quadrate of one m^2 at one places under different treatments were recorded at 45 days after sowing (DAS). The sampled weeds were then categorized into grasses, broad-leaved and sedges. Category-wise weed density was first determined by counting and then weed dry weight was measured after sun-drying for two days followed by oven-drying at 80 °C for 48 hours (h). Data on individual weed and total weed density and weed dry weight were subjected to square root transformation $(\sqrt{x+1})$. Weed control efficiency (WCE) was estimated at 45 DAS by using the formula:

$$\text{Weed control Efficiency (\%)} = \frac{\text{Dry weight of weeds in control plot} - \text{Dry weight of weeds in treated plot}}{\text{Dry weight of weeds in control plot}} \times 100$$

Weed control efficiency was calculated on dry matter basis and yield recorded in kg per plot was standardized to 12-14 % moisture and then weight was converted into kg/ha. Weed index was calculated by using grain yield in treatment plots and control plots. The important growth parameters, yield attributes and yield were recorded as per standard procedures. In order to calculate the net returns for each treatment, total cost of cultivation was subtracted from the gross returns. Total cost of cultivation and gross returns were estimated as per the prices prevailing at the time of conduct of experiment and benefit-cost ratio was calculated from gross return to cost of cultivation. The experimental data were subjected to statistical analysis employing standard techniques of analysis of variance (ANOVA). Mean analysis of the data was conducted, adhering to the methodology outlined by Gomez and Gomez (1984). Furthermore, mean comparison was carried out based on critical differences at the 5% probability level.

RESULTS AND DISCUSSION

Weed flora and weed density

The different weed flora and density (No./m^2) observed at 45 DAS in control plots in greengram were *Rhynchosia minima* (36.3), *Digera arvensis* (66.8), *Celosia argentea* (29.7), *Cyperus rotundus* (26.7), *Dactyloctenium aegyptium* (14.3), other broad-leaves and grassy weeds (11.7). All the weed control treatments significantly reduced the weed density as compared to weedy check (**Table 1**). The efficacy of application of imazethapyr 50 g/ha and 70 g/ha controlled grassy and broad-leaved weeds but its efficacy was low against *Rhynchosia minima* and *Cyprus rotundus.* The significant lowest weed density (No./m^2) of different weeds like *Rhinchosia minima* (15.3), *Digera arvensis* (6.0), *Celosia argentea* (16.0), *Cyperus rotundus* (8.0), *Dactyloctenium aegyptium* (6.0), other broad-leaves & grassy weeds (5.3) were observed under fomesafen 11.1% w/w + fluazip-p-butyl 11.1% (Ready-mix) which was closely followed by sodium acifluorfen + clodinafop-propargyl 220 g/ha. However, it was statistically on par with fomesafen + fluazip-p-butyl and sodium acifluorfen + clodinafop-propargyl 250 g/ha. Efficacy of imazethapyr + imazamox 40 g/ha and quizalofop ethyl + imazethapyr 80 g/ha and higher dose were poor against broad-leaves weeds and *Cyprus rotundus.* These findings are confirmed with the findings of Singh and Singh (2020) and Singh *et al.* (2022).

Weed dry weight and weed control efficiency

Application of various herbicides had significant effect on dry weight and weed control efficiency at 45 DAS (**Table 1**). All the weed control treatments observed lower weed dry weight compared with untreated check. The efficacy of imazethapyr 50 g/ha had significant effect to reduce the dry weight of weeds (41 g/m^2) and weed control efficiency (70.7 %) but its efficacy was low against *Rhinchosia minima* and *sedges*. Application of fomesafen +

Table 1. Effect of different post emergence herbicides on the density, weed dry matter and weed control efficiency (WCE) at 45 DAS in greengram (mean data of three years)

Treatment	Density* of the different weeds (no./m^2)						Total Weed dry matter at 45 DAS (g/m^2)	WCE (%)
	Rhynchosia minima	*Digera arvensis*	*Celosia argentea*	*Cyperus rotundus*	*Dactyloctenium aegyptium*	Other BLW& grassy weeds		
Imazethapyr 50 g/ha	(5.3) 27.7	(3.1) 9.3	(4.4) 19.0	(3.1) 9.3	(2.7) 7.0	(2.5) 6.0	41	70.7
Imazethapyr 70 g/ha	(4.9) 23.7	(2.8) 7.3	(4.3) 17.7	(2.7) 6.7	(2.5) 5.7	(2.5) 5.7	32	77.1
Fomesafen + fluazifop-p-butyl 220 g/ha	(4.0) 15.3	(2.5) 6.0	(4.1) 16.0	(2.9) 8.0	(2.5) 6.0	(2.4) 5.3	27	82.9
Fomesafen + fluazifop-p-butyl 250 g/ha	(3.0) 8.3	(2.4) 5.3	(4.1) 16.0	(2.5) 6.0	(2.5) 5.7	(2.5) 6.0	24	82.8
Sodium acifluorfen + clodinafop-propargyl 220 g/ha	(3.4) 11.0	(2.5) 5.7	(4.2) 17.3	(2.7) 6.7	(2.6) 6.3	(2.5) 5.7	26	81.0
Sodium acifluorfen + clodinafop-propargyl 250 g/ha	(3.0) 8.3	(2.3) 5.0	(4.0) 15.7	(2.9) 7.7	(2.7) 7.0	(2.6) 6.3	25	82.0
Imazethapyr + imazamox 40 g/ha	(5.0) 24.7	(2.5) 6.0	(5.1) 25.3	(2.9) 7.7	(2.6) 6.3	(2.5) 6.0	98	30.0
Imazethapyr + imazamox 60 g/ha	(5.1) 25.7	(2.5) 6.0	(4.9) 24.0	(3.2) 9.7	(2.7) 6.7	(2.5) 6.0	92	34.3
Quizalofop-ethyl + imazethapyr 80 g/ha	(4.2) 17.0	(2.7) 6.7	(4.9) 24.0	(2.9) 7.7	(2.5) 5.7	(2.5) 5.7	98	30.0
Quizalofop-ethyl + imazethapyr 100 g/ha	(3.8) 14.3	(2.4) 5.3	(4.8) 23.0	(2.9) 8.0	(2.5) 6.0	(2.3) 5.0	95	32.1
Weed free	(2.5) 6.0	(2.1) 4.0	(3.1) 9.0	(0.7) 0.0	(2.1) 4.0	(2.1) 4.0	0.0	100.0
Weedy check	(6.1) 36.3	(8.2)66.8	(5.5)29.7	(5.2)26.7	(3.8) 14.3	(3.5) 11.7	140	0.0
LSD (p=0.05)	11.1	8.8	12.2	6.3	4.5	3.9	7.0	-

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$)

Table 2. Effect of different post emergence herbicides on yield attributes, yield, harvest index, economics and weed index in greengram (mean data of three years)

Treatment	No. of seeds/ pods	1000 grain weight (gm)	Grain yield (t/ha) 2021	2022	2023	Mean	Straw yield (t/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B: C Ratio	Harvest index (%)	Weed index (%)
Imazethapyr 50 g/ha	13.2	43.2	1.04	0.82	1.20	1.02	1.89	86868	52868	1.6	34.9	24.2
Imazethapyr 70 g/ha	13.1	43.6	1.15	0.89	1.24	1.09	1.99	92853	58853	1.7	35.3	19.0
Fomesafen + fluazifop-p-butyl 220 g/ha	13.9	44.8	1.26	1.02	1.43	1.24	2.20	106362	72362	2.1	36.1	7.2
Fomesafen + fluazifop-p-butyl 250 g/ha	13.4	44.4	1.25	1.01	1.41	1.22	2.17	104310	70310	2.1	36.0	9.0
Sodium acifluorfen + clodinafop-propargyl 220 g/ha	13.3	44.1	1.24	1.02	1.38	1.21	2.10	102173	68173	2.0	36.3	10.8
Sodium acifluorfen + clodinafop-propargyl 250 g/ha	13.4	44.6	1.20	1.04	1.40	1.21	2.18	103370	69370	2.0	35.6	9.8
Imazethapyr + imazamox 40 g/ha	12.8	42.1	1.08	0.82	1.07	0.99	1.71	76523	42523	1.3	34.4	33.2
Imazethapyr + imazamox 60 g/ha	12.6	42	1.02	0.78	1.04	0.95	1.77	81567	47567	1.4	35.0	28.8
Quizalofop-ethyl + imazethapyr 80 g/ha	12.8	43.1	1.04	0.88	1.06	0.99	1.86	84816	50816	1.5	34.8	26.0
Quizalofop-ethyl + imazethapyr100 g/ha	12.4	43.6	1.08	0.93	1.11	1.04	1.98	88835	54835	1.6	34.4	22.5
Weed free	14.3	45.1	1.31	1.20	1.51	1.34	2.38	114570	74570	1.9	36.0	0.0
Weedy check	11.6	41.4	0.54	0.44	0.64	0.54	1.32	45828	17828	0.6	28.9	60.0
LSD (p=0.05)	0.6	1.0	0.108	0.074	0.099	0.094	0.16	5124	3466	-	-	-

fluazip-p-butyl 220 g/ha observed the lowest total dry weight of weeds (27 g/m^2) and weed control efficiency (82.9 %) which was closely followed by sodium acifluorfen + clodinafop-propargyl 220 g/ha over the weedy check (140 g/m^2). The better performance of combination of herbicides was due to its synergistic effect in controlling population as well as dry matter accumulation of different weed flora complex. These results are in tune with the findings of Katoch *et al.* (2023) Poornima *et al.* (2018) and Singh *et al.* (2015).

Yield attributes, yield and weed index

Yield and yield attributing characters in treated plots were found significantly superior to weedy check (**Table 2**). Among the different weed control treatments, application of imazethapyr 50 g/ha resulted in higher number of seeds/pods (13.2), test weight (43.2 g), grain yield (1.02 t/ha), straw yield (1.89 t/ha), harvest index (34.9%), and weed index (24.2) over the weedy check conditions. The efficacy of fomesafen + fluazip-p-butyl 220 g/ha registered the highest number of seeds/pods (13.4), test weight (44.4 g), grain yield (1.22 t/ha), straw yield (2.17 t/ha), harvest index (36.0%), and weed index (9.0) which was at par with weed free conditions and sodium acifluorfen + clodinafop-propargyl 220 g/ha. Notably, application of fomesafen + fluazip-p-Butyl and sodium acifluorfen + clodinafop-propargyl exhibited a considerable increase of 20% and 17.6% in greengram seed yield compared to application of imazethapyr 50 g/ha. The higher yield attributes and seed yield under these treatments might be due to least competition from weeds for nutrients, light, space and other above-and below-ground resources, which in turn led to effective weed control, reduced crop weed competition and provided almost weed-free environment. The results were in agreement with findings of Katoch *et al.* (2023), Poornima *et al.* (2018) and Singh *et al.* (2022).

Economics

Weed free treatments were found significantly superior in gross returns (₹ 1,14,570/ha) net returns (₹ 74,570/ha) and BC ratio (1.9) as compared to weedy control treatments (**Table 2**), and the lowest value of gross returns (₹ 45,828/ha) net returns (₹ 17,828/ha) and BC ratio (0.6) in weedy check. Among different weed control techniques, the highest gross returns (₹ 1,04,310/ha) net returns (₹ 70,310/ ha) and BC ratio (2.1) was recorded in post–emergence application of fomesafen + fluazip-P-butyl closely followed by sodium acifluorfen + clodinafop-propargyl 220 g/ha. However, it was statistically at par with 250 g/ha of fomesafen + fluazip-p-butyl and sodium acifluorfen + clodinafop-propargyl. Notably, application of fomesafen + fluazip-p-butyl and sodium acifluorfen + clodinafop-propargyl exhibited a statistically at par with weed free treatment. The findings are similar with Poornima *et al.* (2018).

Conclusion

It was concluded that weeds can be effectively controlled by suitable herbicidal combinations as either application of fomesafen 11.1% w/w + fluazip-p-butyl 11.1% (ready-mix) or Sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (ready-mix) 220 g/ha at 20-25 DAS were the best herbicidal combination at 45 DAS for effective control of complex weed flora in greengram with improved yields, net returns and B-C ratio.

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RESEARCH ARTICLE

Weed growth, productivity and profitability of blackgram as influenced by pre- and post-emergence herbicidal application

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ABSTRACT

The field experiment was conducted at the Research Farm of the Punjab Agricultural University, Ludhiana during rainy season 2022 and 2023 to study the effect of pre- and post-emergence herbicides on the weeds, growth, productivity and profitability of blackgram. The experiment consisted of ten treatments replicated four times in a randomized complete block design. Two hand weeding significantly reduced the weed biomass and density followed by application of imazethapyr 75 g/ha as well as 50 g/ha at 15 days after sowing (DAS). In 2022, more frequent rains were received than in 2023, which resulted in several flushes of weeds. As compared to weedy check, pre-emergence (PE) application of imazethapyr 50 g/ha at 15 DAS in 2022 and pre-mix pendimethalin + imazethapyr 450 g/ha as well as 750 g/ha in 2023 showed significant superiority in managing weeds and increasing crop growth. On the basis of pooled mean, application of imazethapyr 50 and 75 g/ha at 15 DAS and pendimethalin + imazethapyr 750 g/ha (PE) resulted in 97.8, 88.1 and 84.4% higher grain yield over weedy check. On pooled mean basis, the highest net returns were provided by imazethapyr 50 g/ha at 15 DAS (Rs 61804/ha) followed by hand weeding (Rs 59812/ha), imazethapyr 75 g/ha at 15 DAS (Rs 56618/ha) and pendimethalin + imazethapyr 750 (Rs 54650/ha). It can be concluded that imazethapyr 50 g/ha at 15 DAS or pendimethalin + imazethapyr 750 g/ha can be applied in *Kharif* blackgram for managing weeds effectively and obtaining high productivity and profitability.

Keywords: Blackgram, Economics, Grain yield, Imazethapyr, Weeds

INTRODUCTION

Blackgram [*Vigna mungo* (L.) Wilczek], commonly known as urdbean, mash and urd, is grown mainly in the South Asian region. The main grower and the consumer of blackgram is India. Apart from India, blackgram is also widely produced in Afghanistan, Bangladesh, Nepal and Pakistan (Gupta *et al* 2022). It forms an important component of diet due to high protein content and part of cropping systems due to the short duration of the crop. Blackgram, being a leguminous crop, improves health of the soil due to fixation of atmospheric nitrogen. Productivity of blackgram is limited due to different factors - poor cultural practices, cultivation of the crop on low-fertility soils, insufficient fertilization, weed infestation and a high vulnerability to pests and diseases; among these factors, infestation of weeds being a major one.

Weeds cause 9.1-37.0% decline in grain yield in blackgram (Mahajan *et al* 2021, Tripathy *et al* 2022). By competing with the crop for moisture, nutrients, space and light at every stage of its development, weeds suppress the growth of the crop. Traditionally, weed management has been done using mechanical and physical methods. Weeds can be managed effectively by manual weeding (Patel *et al* 2015) however, it is a very costly and time consuming task. Further, generally there is lack of labour availability during the critical period of weed removal. Thus, using herbicides to manage weeds is a more cost-effective way than manual weeding. The use of pre-emergence (PE) and post-emergence (PoE) herbicides becomes an important aspect of weed management in the present labour-scarce situation. Therefore, a field experiment was conducted to study the effect of PE application of pendimethalin + imazethapyr (pre-mix) and imazethapyr, and PoE application of imazethapyr at different doses and time of application in *kharif* blackgram.

MATERIALS AND METHODS

The field experiment was conducted at the Research Farm of Pulses Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab during the *Kharif* (rainy season) of 2022 and 2023. Ludhiana is positioned at North latitude of 30°542 , East longitude of 75°482 in the central plain region of Punjab which falls under Transgangetic Agro-climatic Zone of India. It has an

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average elevation of 247 metres above sea level. The meteorological data were recorded during the crop growing season (from July to October) at the Meteorological Observatory located at Punjab Agricultural University, Ludhiana. Gross rainfall received during the crop growing season was 577.9 (25 rainy days) and 203.2 mm (11 rainy days) during 2022 and 2023, respectively (**Figure 1**). The soil was loamy sand with pH 7.4 and 7.6, organic carbon 0.36 and 0.35%, available nitrogen 164 and 156.3 kg/ha, available phosphorus 23.89 and 29.9 kg/ha, available potassium 195 and 135.3 kg/ha and electrical conductivity 0.18 and 0.19 dS/m in 2022 and 2023, respectively.

Experiment was laid out in RCBD design replicated four times with 10 treatments (pendimethalin 30 EC + imazethapyr 2 SL 450 g/ha (PE), pendimethalin 30 EC + imazethapyr 2 SL 750 g/ ha (PE), imazethapyr 10 SL 50 g/ha as PE, imazethapyr 10 SL 75 g/ha as PE, imazethapyr 10 SL 50 g/ha at 15 DAS, imazethapyr 10 SL 50 g/ha at 25 DAS, imazethapyr 10 SL 75 g/ha at 15 DAS, imazethapyr 10 SL 75 g/ha at 25 DAS, hand weeding at 4 and 6 weeks after sowing and weedy check). PE herbicides were applied on the same day as of sowing and PoE was applied according to the treatments at 15 or 25 DAS. The herbicides were applied by using a knapsack sprayer. For PE application of herbicides 500 L of water per ha and for POE application 375 L of water per ha was used. In the case of two hand weedings treatment, weeds were removed manually with a *khurpa* 4 and 6 weeks after sowing. In the case of weedy check plots, weeds were not removed during the whole crop growing season. The blackgram variety Mash 883 was sown on 7 July 2022 and 11 July 2023 at a row spacing of 30 cm apart using a seed rate of 20 kg/ha. Recommended dose of 12.5 kg nitrogen and 40 kg P/ha was applied through urea and single superphosphate at sowing.

The data on weed count (species-wise) were taken at 45 DAS from random spots using the quadrat of 0.5 m × 0.5 m. Weed density was calculated by counting all the weeds inside the quadrat and computed as number per square metre (no./m^2).

The data on dry matter of weeds were taken at 45 DAS and at harvest from the quadrat of 0.5 m × 0.5 m and whole plot basis, respectively. For this, the weeds present in the quadrat were counted and removed from the area under the quadrat without roots and after that these were sun dried for a few days and then dried in an oven at temperature of 60°C to obtain a constant weight and expressed in kg/ha. Weed control efficiency (WCE) was calculated from the dry matter of the weeds and it was computed in percentage (%) using the formula (Walia 2018).

Accumulation of dry matter of shoot (crop) was taken at 45 DAS. Plants were removed slightly above the surface of soil from an area of 0.5 m × 0.3 m per plot (50 cm area of one row). Samples were first dried in the sun before being dried in an oven at 60°C to achieve a constant weight and computed in kg/ha. At harvest, data on plant height and number of branches of five randomly chosen plants were recorded and averaged. At harvest, pods were taken from 10 randomly chosen plants, pods counted, data averaged and results computed as the number of pods/plant. Ten randomly chosen pods from various plants were manually picked, grains were removed, counted, data were averaged and expressed as the number of grains/pod. After the threshing and winnowing of each plot's bulk product, 100 randomly chosen grains were weighed and the data were recorded as 100-grain weight. For biological yield, from each treatment 7.2 m^2 of net plot was harvested, then plants dried in the sun and weighed, and results expressed in kg/ha. The 7.2 m^2 of net plot area was used to record each plot's grain production after the threshing and winnowing of the grains and the figures were then expressed in kg/ha. The stover yield of every plot was obtained by subtracting the grain yield from the biological yield. Harvest index (Donald 1968) indicates the capacity of the crop to generate optimum economic output. Harvest index was calculated.

Correlation and regression analysis of weed dry matter at harvest and grain yield was calculated. Economic analysis was also done. Gross returns were calculated by multiplying the minimum support price (MSP) with the grain yield and in case of the byproduct i.e. stover yield, it was multiplied with the price that was prevalent in the market. It was expressed in Rs/ha.

Net returns were determined by subtracting the variable cost/ha from the gross returns. It was calculated in Rs/ha.

To obtain a benefit cost ratio (B:C) the net returns were divided by the variable cost i.e. cost of cultivation.

The data were analyzed statistically in randomized complete block design (RCBD) using CPCS1 software which was developed at the Department of Statistics, Punjab Agricultural University, Ludhiana, India by Cheema and Singh (1991). This software is based on the procedure given by Cochran and Cox (1967). Data on weed count were square root transformed before statistical analysis. The significance level for each comparison was set at 5 percent.

RESULTS AND DISCUSSION

Effect on weeds

The major weeds observed at the experimental location at 45 DAS were *Cyperus rotundus* and *Digitaria sanguinalis* in 2022 and *Cyperus rotundus*, *Digitaria sanguinalis*, *Mollugo* sp. and *Trianthema portulacastrum* in 2023. The lowest weed density was recorded in hand weeding treatment followed by imazethapyr 50 and 75 g/ha at 15 DAS (**Table 1)**. Imazethapyr effectively controlled the sedges, grasses and broad-leaf weeds when applied at the critical stage of competition between weeds and crop, as also reported by Priyadarshini *et al* (2023). Pendimethalin + imazethapyr (PE) controlled *Cyperus rotundus* effectively in 2023 but not in 2022 due to frequent rains (**Figure 1**) which resulted in several flushes of the weed. Application of pre-mix pendimethalin + imazethapyr effectively controls the grassy weeds due to the broad-spectrum effect of the combination of herbicides having the different modes of action but this did not control the sedges effectively (Kumar *et al* 2016).

At 45 DAS, the lowest weed dry matter (DM) was observed in hand weeding treatment during both the years. Lower weed DM was observed in imazethapyr 75 and 50 g/ha at 15 DAS (**Table 2**) than treatments of pre-emergence application and weedy check in 2022. Lower weed DM was also observed in pendimethalin + imazethapyr 750 g/ha as PE than weedy check and other treatments in 2023. In 2022, application of pre-mix of pendimethalin + imazethapyr 450 as well as 750 g/ha and imazethapyr 50 as well as 75 g/ha as PE controlled weeds for initial period only; after some time, these became inefficient in controlling weeds, resulting in high weed dry matter. This could be due to frequent rains, which increased the availability of moisture resulting in more proliferation and growth of weeds and heavy rainfall resulted in leaching of herbicides.

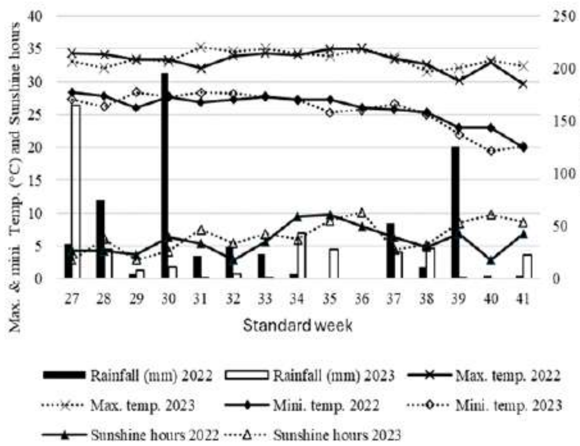

Figure 1. Meteorological data during crop season 2022 and 2023

The highest WCE was obtained in hand weeding in both years, followed by application of imazethapyr 75 and 50 g/ha at 15 DAS in year 2022 and pendimethalin + imazethapyr 750 as well as 450 g/ha and imazethapyr 50 as well as 75 g/ha as PE in year 2023 due to more effective management of weeds. Application of imazethapyr 50 as well as 75 g/ha at 25 DAS also resulted in higher WCE than weedy check due to less weed dry matter and efficient control of weeds. At harvest, the lowest weed dry matter was observed in hand weeding treatment and all treatments recorded significantly lower weed dry matter than weedy check.

At harvest, hand weeding recorded the highest WCE in both years followed by imazethapyr 75 g/ha at 15 DAS due to less weed dry matter and efficient control of weeds. Similar results were reported with application of imazethapyr 50 g/ha by Painkra *et al* (2021) and Prajapati *et al* (2018) in blackgram.

Effect on crop

At 45 DAS, shoot dry matter accumulation was the highest in hand weeding which was statistically at par with the application of imazethapyr 50 as well as 75 g/ha at 15 DAS and 25 DAS during 2022 (**Table**

Table 1. Influence of different weed control treatments on weed density at 45 DAS in blackgram

Treatment	No. of weeds /m^2									
	Cyperus rotundus		*Digitaria sanguinalis*		*Mollugo* sp.		*Trianthema portulacastrum*		Total	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Pendimethalin + imazethapyr 450 g/ha (PE)	6.3(40.2)	3.2(10)	4.0(15.7)	2.9(8)	-	2.9 (8)	-	2.6 (6)	10.4(56.0)	5.7(32)
Pendimethalin + imazethapyr 750 g/ha (PE)	6.34(39.7)	3.1(9)	4.0(15.5)	2.8(8)	-	3.(10)	-	2.1 (4)	10.3(55.2)	5.6(31)
Imazethapyr 50 g/ha (PE)	5.5(30)	3.3(12)	4.41(19.0)	3.9(17)	-	3.0(10)	-	2.4 (5)	9.9(49.0)	6.4(44)
Imazethapyr 75 g/ha (PE)	5.4(29)	3.7(13)	4.13(17.2)	2.9(8)	-	2.6 (6)	-	2.1 (5)	9.5(46.2)	5.7(32)
Imazethapyr 50 g/ha at 15 DAS	3.9(15.2)	4.1(16)	2.83(7.5)	3.2(10)	-	1.0(0)	-	2.7 (7)	6.7(22.7)	5.7(33)
Imazethapyr 50 g/ha at 25 DAS	4.9(24)	4.9(24)	3.9(15.0)	4.2(17)	-	2.4(6)	-	2.3 (5)	8.8(39.0)	7.3(52)
Imazethapyr 75 g/ha at 15 DAS	3.8(14.5)	4.3(18)	3.0(8.5)	2.9(8)	-	2.9(8)	-	2.4 (6)	6.8(23.0)	6.3(40)
Imazethapyr 75 g/ha at 25 DAS	4.92(24.2)	4.8(22)	4(16)	2.7(7)	-	2.7(7)	-	2.3 (5)	9.0(40.2)	6.4(41)
Hand weeding at 4 and 6 WAS	1.0(0)	1.0(0)	1.0(0)	1.0(0)	-	1.0(0)	-	1.0 (0)	1.0(0)	1.0(0)
Weedy check	6.98(48.5)	9.4(88)	4.4(19.2)	6.7(45)	-	5.2(27)	-	4.1 (17)	11.4(67.7)	13.3(177)
LSD (p=0.05)	0.5	1.1	0.5	1.4	-	1.3	-	2.5	0.7	1.5

Original data on weed density given in parentheses were subjected to square root transformation $\sqrt{x+0.5}$ before analysis

3). In 2023, shoot dry matter accumulation was the highest in hand weeding which was statistically at par with the pendimethalin + imazethapyr 450 as well as 750 g/ha, imazethapyr 75 g/ha as PE, imazethapyr at 50 as well as 75 g/ha at 15 DAS and imazethapyr at 75 g/ha at 25 DAS. Shoot dry matter accumulation was higher in 2022 than 2023, which could be due to frequent light rains (577.9 mm) in 2022. Among the herbicidal treatments, the high dry matter accumulation was in the case of application of imazethapyr 50 and 75 g/ha at 15 DAS due to effective control of weeds at the critical crop-weed competition period. Similar results were also reported by Aggarwal *et al* (2014).

Hand weeding resulted in the highest plant height, which was statistically at par with the application of imazethapyr 50 g/ha at 15 DAS and imazethapyr 75 g/ha at 15 DAS due to better control of weeds (**Table 3**). Similar results for imazethapyr applied at 50 and 75 g/ha at 15 DAS were also reported by other researchers (Aggarwal *et al* 2014, Priyadarshini *et al* 2023). Application of different herbicides did not affect the number of branches/ plant significantly.

The highest number of pods/plant was observed in treatment of imazethapyr 50 g/ha at 15 DAS, which was statistically at par with hand weeding and imazethapyr 75 g/ha at 15 DAS during 2022 (**Table 4**). However, the highest pods/plant were observed in pendimethalin + imazethapyr 750 g/ha, which was statistically at par with the pendimethalin + imazethapyr 450 g/ha, imazethapyr 50 as well as 75 g/ ha as PE, imazethapyr at 50 g/ha at 15 DAS and hand weeding in 2023. Different weed control treatments had no significant effect on the grains/pod. The highest 100-grain weight was observed in hand weeding treatment, which was statistically similar with imazethapyr 50 and 75 g/ha at 15 DAS. Different weed control treatments had no significant effect on the 100-grain weight in 2023. The highest biological yield was recorded in hand weeding treatment, which was, however, statistically at par with imazethapyr 50 g/ha at 15 DAS and imazethapyr 75 g/ha at 15 DAS in 2022 (**Table 4**). It was observed that different weed control treatments had no significant effect on the biological yield and harvest index in 2023. Weedy check had the lowest biological yield due to more crop-weed competition. The pre-emergence application of herbicides resulted in low biological yield. The highest grain yield was recorded by hand weeding treatment, which was, however, statistically at par with application of imazethapyr 50 as well as 75 g/ha at 15 DAS. The lowest grain yield was recorded in a weed check. Pre-emergence application of herbicides (pendimethalin + imazethapyr and

Table 2. Influence of different weed control treatments on weed dry matter and weed control efficiency at 45 DAS and harvest in blackgram

Treatment	Weed dry matter at 45 DAS (kg/ha)		Weed control efficiency at 45 DAS (%)		Weed dry matter at harvest (kg/ha)		Weed control efficiency at harvest (%)	
	2022	2023	2022	2023	2022	2023	2022	2023
Pendimethalin + imazethapyr 450 g/ha (PE)	784	140	45.5	96.4	1716	503	49.6	87.1
Pendimethalin + imazethapyr 750 g/ha (PE)	808	93	43.9	97.7	1425	475	58.3	88.3
Imazethapyr 50 g/ha (PE)	848	138	41.1	96.5	1679	637	50.6	83.9
Imazethapyr 75 g/ha (PE)	801	130	44.5	96.6	1450	627	57.3	81.8
Imazethapyr 50 g/ha at 15 DAS	567	262	60.4	93.0	955	1193	72.0	70.6
Imazethapyr 50 g/ha at 25 DAS	777	336	45.1	91.2	1392	1286	59.4	68.1
Imazethapyr 75 g/ha at 15 DAS	521	242	64.0	93.6	950	394	71.7	89.3
Imazethapyr 75 g/ha at 25 DAS	742	272	48.5	93.0	1350	1212	60.3	69.6
Hand weeding at 4 and 6 WAS	0	0	100.0	100.0	883	289	74.0	92.3
Weedy check	1452	3930	0.0	0.0	3433	3933	-	-
LSD (p=0.05)	105	90	6.5	2.1	197	637	4.1	15.5

Table 3. Influence of different weed control treatments on shoot dry matter accumulation at 45 DAS, plant height and branches at harvest of blackgram

Treatment	Shoot dry matter accumulation at 45 DAS (kg/ha)		Plant height (cm)		Branches/plant	
	2022	2023	2022	2023	2022	2023
Pendimethalin + imazethapyr 450 g/ha (PE)	801	716	40.6	36.5	5.9	6.1
Pendimethalin + imazethapyr 750 g/ha (PE)	973	750	41.5	38.5	6.4	6.1
Imazethapyr 50 g/ha (PE)	799	656	45.3	36.1	6.3	5.8
Imazethapyr 75 g/ha (PE)	778	690	41.3	37.9	6.5	6.0
Imazethapyr 50 g/ha at 15 DAS	1263	678	52.0	40.6	6.7	5.9
Imazethapyr 50 g/ha at 25 DAS	1125	658	44.3	35.8	6.2	6.0
Imazethapyr 75 g/ha at 15 DAS	1215	706	51.0	35.7	6.4	6.0
Imazethapyr 75 g/ha at 25 DAS	1129	714	45.1	33.9	5.8	6.0
Hand weeding at 4 and 6 WAS	1340	829	51.8	40.7	6.9	6.1
Weedy check	522	490	46.3	37.1	5.2	5.9
LSD (p=0.05)	233	152	4.7	3.9	NS	NS

imazethapyr) also recorded low grain yield in the year 2022. In 2023, the highest grain yield was observed in pendimethalin + imazethapyr 750 g/ha, which was, statistically similar with all other treatments except application of imazethapyr 50 g/ha at 25 DAS, imazethapyr 75 g/ha at 15 DAS and the weedy check. On the basis of pooled mean, application of imazethapyr 50 and 75 g/ha at 15 DAS and pendimethalin + imazethapyr 750 g/ha (PE) resulted in 97.8, 88.1 and 84.4% higher grain yield over weedy check. The highest harvest index was recorded in hand weeding treatment, which was statistically similar with all other treatments except the weedy check.

These treatments resulted in high yield and yield attributes due to better control of weeds (**Table 1** and **2**) at critical crop-weed competition period which resulted in less competition for space, nutrients and water among weeds and crop plants and ultimately better yield attributes. Weedy check resulted in the lowest grain yield due to low yield attributes owing to less growth attributes, symbiotic parameters and more weeds (Singh *et al* 2016, Tripathy *et al* 2022). The PE herbicides performed better in 2023 than in 2022 due to less rainfall (203.2 mm) and rainy days (11) as compared to in 2022. The lowest harvest index was recorded in weedy check due to more competition from weeds and less grain yield whereas higher harvest index was recorded in other treatments due to high grain yields (Patel *et al* 2015).

Correlation (r) between total weed dry matter at harvest and grain yield was -0.98 and -0.90 and coefficient of determination (R^2) was 0.971 and R^2 = 0.813 in 2022 and 2023, respectively. It showed that the grain production of blackgram decreased as the dry matter of weeds increased (**Figure 2**). Equation of regression analysis Y= -0.3734x + 1808 and Y= -0.1368x + 1433 was found to fit for the dry matter of weeds and grain yield of blackgram in the year 2022 and 2023, respectively, where Y= Grain yield (kg/ha) and X= Weed dry matter (kg/ha).

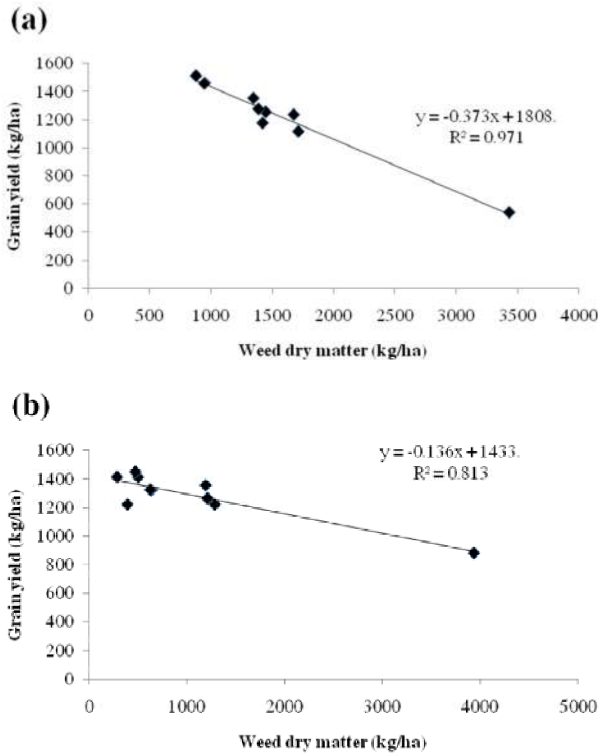

Figure 2. Effect of weed dry matter at harvest on grain yield production in blackgram during (a) 2022 and (b) 2023

Effect on economics

The hand weeding at 4 and 6 weeks after sowing had the highest overall variable costs in both the years, followed by the treatments of pre-mix herbicides pendimethalin + imazethapyr 750 g/ha as PE and imazethapyr 75 g/ha applied at 15 and 25 DAS and as PE (**Table 5**). The highest gross returns in 2022 were obtained in hand weeding treatment followed by imazethapyr 50 and 75 g/ha at 15 DAS. Weedy check recorded the lowest gross returns. The highest net returns were recorded in imazethapyr 50 g/ha at 15 DAS, followed by imazethapyr 75 g/ha at 15 DAS and hand weeding treatment due to less variable cost and more gross returns. In 2023, the

Table 4. Influence of different weed control treatments on yield attributes, yield and harvest index of blackgram

Treatment	Pods/plant		Grains/pod		100 grain-weight (g)		Biological yield (t/ha)		Grain yield (t/ha)			Harvest index (%)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	Pooled mean	2022	2023
Pendimethalin + imazethapyr 450 g/ha (PE)	22.0	26.0	5.9	5.8	2.96	3.50	5.60	6.57	1.11	1.41	1.26	20.0	21.8
Pendimethalin + imazethapyr 750 g/ha (PE)	22.1	26.7	6.1	6.0	3.00	3.60	5.87	6.67	1.17	1.45	1.31	20.0	21.9
Imazethapyr 50 g/ha (PE)	22.4	25.0	6.0	5.9	3.05	3.63	5.80	6.07	1.23	1.32	1.28	21.3	22.3
Imazethapyr 75 g/ha (PE)	23.9	25.2	5.7	5.4	3.13	3.50	5.97	5.95	1.25	1.32	1.29	21.4	22.7
Imazethapyr 50 g/ha at 15 DAS	29.4	25.1	6.0	6.0	3.77	4.25	6.72	5.92	1.46	1.35	1.41	21.7	23.5
Imazethapyr 50 g/ha at 25 DAS	24.0	23.8	6.1	5.5	3.32	3.48	6.24	5.67	1.27	1.22	1.25	20.4	21.5
Imazethapyr 75 g/ha at 15 DAS	26.2	23.7	5.7	6.0	3.63	3.48	6.72	5.30	1.45	1.22	1.34	21.8	23.2
Imazethapyr 75 g/ha at 25 DAS	24.2	24.4	5.8	5.7	3.37	3.50	6.25	5.65	1.35	1.26	1.31	21.7	23.0
Hand weeding at 4 and 6 WAS	27.5	25.5	6.0	6.0	3.92	3.55	6.90	5.87	1.51	1.41	1.46	22.0	24.3
Weedy check	19.4	19.9	6.1	5.1	2.52	3.15	3.55	4.30	0.54	0.88	0.71	15.2	20.7
LSD (p=0.05)	4.0	2.2	NS	NS	0.48	NS	0.64	NS	0.14	0.22	0.16	3.0	NS

Table 5. Influence of different weed control treatments on economics of blackgram

Treatment	Total variable cost (×10³ ₹/ha)		Returns (×10³ ₹/ha)					B:C	
			Gross		Net				
	2022	2023	2022	2023	2022	2023	Pooled mean	2022	2023
Pendimethalin + imazethapyr 450 g/ha (PE)	34.40	35.20	77.07	98.45	42.66	63.25	52.96	1.24	1.80
Pendimethalin + imazethapyr 750 g/ha (PE)	36.04	36.84	81.20	100.99	45.15	64.14	54.65	1.25	1.74
Imazethapyr 50 g/ha (PE)	35.13	35.93	84.93	91.94	49.79	56.00	52.90	1.42	1.56
Imazethapyr 75 g/ha (PE)	35.48	36.28	86.35	92.23	50.86	55.94	53.41	1.44	1.54
Imazethapyr 50 g/ha at 15 DAS	35.13	35.93	100.21	94.47	65.07	58.53	61.80	1.85	1.63
Imazethapyr 50 g/ha at 25 DAS	35.13	35.93	87.99	85.06	52.85	49.12	50.99	1.50	1.37
Imazethapyr 75 g/ha at 15 DAS	35.48	36.28	99.94	85.06	64.45	48.77	56.62	1.82	1.34
Imazethapyr 75 g/ha at 25 DAS	35.48	36.28	92.82	87.96	55.33	51.67	54.50	1.62	1.42
Hand weeding at 4 and 6 WAS	40.84	41.64	103.65	98.45	62.81	56.81	59.81	1.54	1.36
Weedy check	33.64	34.44	38.39	61.53	4.74	27.09	15.92	0.14	0.79
LSD (p=0.05)			9.17	14.68	9.17	14.68	10.58	0.30	0.39

highest gross and net returns were obtained in pendimethalin + imazethapyr 750 g/ha as PE, which was, statistically similar with all other treatments except the imazethapyr 50 at 25 DAS, imazethapyr 75 g/ha at 15 DAS and weedy check. On pooled mean basis, the highest net returns were provided by imazethapyr 50 g/ha at 15 DAS (Rs 61804/ha) followed by hand weeding (Rs 59812/ha), imazethapyr 75 g/ha at 15 DAS (Rs 56618/ha) and pendimethalin + imazethapyr 750 (Rs 54650/ha). In 2022, the highest B:C ratio was observed in the treatment of imazethapyr 50 g/ha at 15 DAS followed by imazethapyr 75 g/ha at 15 DAS and hand weeding treatment and in 2023, the highest B:C ratio was observed in pendimethalin + imazethapyr 450 g/ha as PE, which was, statistically similar with all other treatments except the imazethapyr 50 at 25 DAS, imazethapyr 75 g/ha at 15 DAS and weedy check. The high cost of hand weeding and herbicides attributed to high variable costs in these treatments. The higher gross returns in blackgram were obtained in hand weeding and imazethapyr 50 and 75 g/ha at 15 DAS due to increased yield of grain and stover. The highest net returns were recorded in imazethapyr 50 g/ha at 15 DAS, followed by imazethapyr 75 g/ha at 15 DAS and hand weeding treatment due to less variable cost and more gross returns owing to high grain and stover yield. PoE application of imazethapyr at 75 g/ha at 14 DAS resulted in higher B:C ratio than other treatments due to less variable costs and more net returns (Prajapati *et al* 2018).

It can be concluded that application of pendimethalin + imazethapyr 750 g/ha as PE and imazethapyr 50 g/ha at 15 DAS as post-emergence successfully manage weeds and achieve high production and profitability of blackgram.

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RESEARCH ARTICLE

Evaluation of living mulches for weed management in french beans

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ABSTRACT

Living mulches are cover crops grown simultaneously with and near main crops. Advantages of living mulches over dead cover crops may include increased weed suppression, reduced erosion and leaching, better soil health, and greater resource-use efficiency. An experiment was conducted at Horticultural Research Station, Kahikuchi Guwahati, Assam Agricultural University, Assam during *Rabi* 2019-20 and 2020-21 to investigate the effect of living mulches on weed control and its subsequent effects on yield of french beans. The treatments were french beans interplanted with living mulches of field pea (*Pisum sativa*) (FP), Berseem (*Trifolium alexandrinum* L) (B), Faba beans (*Vicia faba*) (FB), Conventional weed management (CWM) and weedy check (WC). The pooled mean highest weed infestation was recorded in WC which accounted for the highest weed dry weight (WDW) (75.23 g/m^2). The weed control efficiency was recorded as average pooled mean of 61.35, 60.26 % in CWM and LM with berseem respectively for both the years. The conventional method and living mulch of berseem have improved french beans yield by 1.11, 0.94 t/ha of pooled mean of two years. Among the living mulches used french beans and berseem interplant suppressed weeds. The highest net returns (₹ 26056/ha) and B:C (3.45) were in CWM fb LM with B with net returns (₹ 24625/ha) and B:C (3.10) in both the years respectively. Hence, apart from the conventional method of weed management, berseem is an ideal weed suppressant and can be interplanted as a living mulch crop in french beans cultivation.

Keywords: Living mulch, Weed control efficiency, Weed Dry Weight, Weed Index, Yield

INTRODUCTION

In modern agriculture for weed control, chemicals are used extensively, but their use is now limited due to environmental and economic costs and weed resistance to herbicides (Yousef and Rahimi 2014). Growing living mulches with or near crops, increased weed suppression, reduced soil erosion and leaching, improve soil health and uses resources more efficiently. Ecosystem biodiversity enhanced with living mulches than synthetic mulches and more suitable for a cropping system. The mulch-crop competition depends on agroecosystem management as well as climate and other factors (Bhaskar *et al.* 2021). Nakamoto and Tsukamoto (2006) observed that "living mulches are cover crops which are preserved as a living ground cover crop throughout the growing season of the main crop". Sowing living mulches between the rows of a main crop is a weed control technique that does not employ herbicide application. Living mulches minimizes field weed infestation and enhance crop yield. Giorgi *et al.* (2022) revealed that living mulches, namely herbaceous plants with a habit of covering the soil, balancing different species biodiversity, crop biomass production, yield, quality, soil fertility and ultimately increase C sequestration. Fracchiolla *et al.* (2020) reported that living mulch provide many benefits to agro-ecosystems such as erosion control, nitrogen fixation, nutrient recycling, increasing organic matter, controlling weed and pest and increasing soil organism.

French beans (*Phaseolus vulgaris* L.) is a rich in several nutrients like protein (17.5-28.7% in dry seed and 1.0-2.5% in green pods, carbohydrates (61.4%), mineral content (3.2-5.0%), crude fibre (4.2-6.3%) crude fat (1.2-2.0%) and vitamin A and C (Messina 1999). Berseem (*Trifolium alexandrinum* L) is a leguminous cool season forage crop and has the potential as cover crop or annual forage in living mulch cropping system. Field pea (*Pisum sativum*) is a winter season grain legume crop. Faba beans (*Vicia faba*) can fix atmospheric nitrogen by symbiotic relationship with bacteria and enhance the productivity of agricultural land.

The objective of the study was to investigate the potential of living mulches for weed control of french beans and its subsequent effects on yield and profitability.

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MATERIALS AND METHODS

A field experiment was conducted at Horticultural Research Station Kahikuchi Guwahati, Assam Agricultural University, Assam, India situated at latitude 26°3'N, longitude 91°7'E and 64.0 m above mean sea level during *Rabi* 2019-20 and 2020-21 consecutively for two years. All the living mulches used in the experiment were leguminous crops viz. berseem, faba beans and field pea with the main crop french beans. A randomized block design was laid out with five treatments and five replications. The treatments were Living mulch (LM) of field pea (FP), Living mulch of berseem(B), Living mulch of faba beans (FB), Conventional weed management (CWM) (20 and 40 DAS) and weedy check (WC) as control. The living mulches were sown in inter spaces of the main crop. The average annual rainfall of experimental site was 651 mm extending over the period of mid-July to October and few scattered showers during winter months from south-west monsoon. Whereas, the average minimum and maximum temperature vary from 12^0C -36^0C. The soil of the experimental field was sandy loam in texture, acidic in reaction, low in organic carbon (0.35%) and available nitrogen (235 kg/ha) and was medium in available phosphorus (13.2 kg/ha) and potassium (260.2 kg/ha). French beans variety '*Arka Komal'* was sown in rows 30 x 10 cm apart on 25 October in 2019 and 30 October in 2020 using 120 kg seed/ha. Application of farm yard manure 10 t/ha. Fertilizers of phosphorus and potassium at the rate of 60 and 50 kg/ha were applied respectively. A basal dose of half of the nitrogen (60 kg/ha) was applied as per treatment and full dose of phosphorus and potassium was applied to the experimental plots by placement method just after demarcation of layout and the remaining half of nitrogen (60 kg/ha) was top dressed at maximum flowering stage. The recommended dose of fertilizers was applied to the main crop as basal. In weed free plots, weeds were removed manually twice. Other standard agronomical package and practices were followed uniformly in both the years.

Weed and weed dry weight (WDW) productions were measured at mid-season and at final harvest. Different yield and yield attributing parameters were measured at the time of harvest and adjusted to 14% moisture contents. For mid-season sampling, weed dry weight were measured from two using 0.25 m^2 quadrats from each plot. The economics of the french beans were also calculated for gross returns, net returns and B:C.

Data recorded from the field were statistically analyzed through analysis of variance (ANOVA) method and treatment means were compared through least significant difference (LSD) at 5% level of significance.

The observations recorded were **c**rop growth parameters, yield and quality, weed density, fresh and dry weight at 40 and 60 DAS, weed population, dry weight and weed control efficiency.

The weed control efficiency (WCE) of individual treatments were calculated using following formula *i.e*.

WCE (%) = WC – WT x 100/ WC

Where,

WC=Weed in control plot

WT=Weed in treated plot

Weed index (WI) refers to the reduction in crop yield due to the presence of weed in comparison to weed free plots. It was calculated by using the formula:

WI (%)= Yield from weed free plot-Yield from treated plot x100/Yield from weed free plot

RESULTS AND DISCUSSION

Yield and yield attributes

All the records were presented as pooled mean of both the years. The plant height (26.22 cm), branches/ plant (7.12 nos), pod/ plant (37.77 nos), pod length (14.34 cm) of french beans were found significantly high in treatment CWM practice fb treatment living mulch with berseem where plant height (25.22 cm), branch/plant (6.43 nos), pod/plant (33.56 nos), pod length (13 cm) for both the years. The highest yield was recorded in conventional weed management (1.11 t /ha) fb berseem (0.94 t/ha) for both the years (**Table 1**). Among the living mulch used in french beans and berseem inter plant suppressed weed. The least weed density was observed in CWM fb berseem treatment. Bhaskar *et al*. (2021) depicted from his study that optimal living mulch planting dates vary in the system, though simultaneous planting of living mulches and main crops also gave good results. The result also has close conformity with the findings of Bhaskar *et al.* (2020), where the use of living mulches in cotton production was feasible and it was effective for both weed suppression and acceptable yield. Ellis *et al.* (2000) also found that puralane living mulch gave broccoli yields as comparable to yields with conventional methods of weed management with no

Table 1. Crop growth parameters, yield of french bean

Treatment	Plant height (cm)			Branches/plant (no.)			Pod/plant (no.)			Pod length (cm)			Yield (t/ha)		
	2019	2020	Pooled mean	2019	2020	Pooled mean	2019	2020	Pooled mean	2019	2020	Pooled mean	2019	2020	Pooled mean
LM with field pea	24.0	24.1	24.1	5.3	6.0	5.7	25.3	26.7	26.0	12.6	11.6	12.1	0.56	0.64	0.6
LM with berseem	25.1	25.3	25.2	6.3	6.5	6.4	32.4	34.7	33.6	13.1	12.9	13.0	0.89	0.99	0.94
LM with faba beans	24.7	24.9	24.8	5.8	6.1	5.9	28.4	32.0	30.2	13.4	12.5	13.0	0.65	0.78	0.72
Conventional weed management	26.1	26.3	26.2	7.0	7.3	7.1	36.2	39.3	37.8	12.9	15.7	14.3	1.06	1.15	1.11
Weedy check	20.0	20.1	20.1	4.9	5.4	5.1	22.1	23.9	23.0	12.0	12.5	12.1	0.49	0.56	0.53
LSD (p=0.05)	0.01	0.03	0.01	0.9	1.0	0.9	3.2	3.5	3.3	2.0	2.1	2.1	0.09	0.12	0.10

Table 2. Economics of the french beans

Treatment	Gross return (₹ /ha)			Net return (₹ /ha)			B:C		
	2019	2020	Pooled mean	2019	2020	Pooled mean	2019	2020	Pooled mean
LM with field pea	22400	24800	23600	12488	13750	13119	2.26	2.38	2.32
LM with berseem	35600	38750	37175	23800	25450	24625	3.00	3.19	3.10
LM with faba beans	26000	30560	28280	18474	21630	20520	2.47	2.69	2.58
Conventional weed management	37400	40235	38818	25267	26845	26056	3.15	3.29	2.15
Weedy check	19600	21846	20723	9284	10280	9782	1.9	2.09	1.20

reduction in crop quality and growth. Another findings also has similar results like cowpea living mulch plot provide maize grain and stover yield of 2, 3 t/ha compared to 0.98, 2 t/ha respectively in the control (Masud *et al.* 2021).

Economics and weed growth

The highest gross returns, net returns and B:C of ₹ 38817.5, 26056 /ha and 3.45 recorded in CWM which were fb LM with berseem with gross returns, net returns of ₹ 37175, 24625 /ha with B:C of 3.10 for both the years probably due to higher sale price and higher grain yield. This showed that french bean was more responsive towards conventional weed management and use of living mulch which gave a higher return (**Table 2**). The results depicted that the highest weed infestation was in WC (Control) which accounted for the highest average WDW (75.23 g/m^2) for both the years. In general, pooled mean data recorded at 40 and 60 days after sowing (DAS) showed that CWM, LM of B, FB and FP have reduced weed density (98.5, 233, 382.5 and 389 g/m^2) compared to weedy check (569.5 g/m^2) in 40 DAS and weed density of 84.5, 217, 231 and 278 g/m^2 in 60 DAS compared to weedy check (428.5 g/m^2) for both the years. The fresh weight (g/m^2) and dry weight(g/m^2) recorded for both the years also showed the similar trend in both 40 and 60 DAS (**Figure 2**). Weed population (no/m^2) recorded as 8.08, 8.96, 9.51 and 10.53 in CWM, LM of berseem, faba bean and field pea respectively which were significantly higher than weedy check with 20.92 no/m^2. WDW (g/m^2) were found significantly higher in weedy check with 75.23 g/m^2 compared to conventional weed management (11.72 g/m^2), LM of berseem (13.41 g/m^2), faba beans (18.69g/m^2) and field pea (15.35 g/m^2) (**Figure 1**). The results are at par with the findings of Khaliq *et al.* (2010) where the dry weights of weeds from weedy check plots were significantly greater than the mulches applied plots and hand weeding plots (396.23 and 2178.93 g/m^2). The weed control efficiency was recorded as 61.35, 60.26 % in CWM and LM with berseem respectively which were at par. The weed control efficiency (%) were significantly lower in LM with faba beans, LM with field pea and weedy check. The weed index percent lowest in LM with berseem (24.12) fb LM with faba beans (44.24), LM with field pea (53.69) and weedy check (65.79) from both the years (**Figure 1**). The results also supported by Gandomkar 2019 for weed control using live and abiotic mulches which were more effective, economical and environmentally friendly. The similar findings were reported by Talebbeigi and Ghadiri (2012) in maize with cowpea as a living mulch where increasing density of living mulch canopy closure occurred, decreasing the amount of photosynthetically active radiation (PAR) available beneath the canopy. This would decrease in weed biomass until an optimum living mulch density was achieved and after that no decrease in weed biomass occurred. Romaneckas *et al.* (2015) also reported that fabaceae living mulches reduce weed seed bank in the plough layer in maize crop by 14.1 to 57.1%. The results of the study were also supported by the findings of Kitis *et al.* (2018), they observed that living mulch of vetch in citrus orchard reduce weed density, biomass and dry weight of weeds compare to

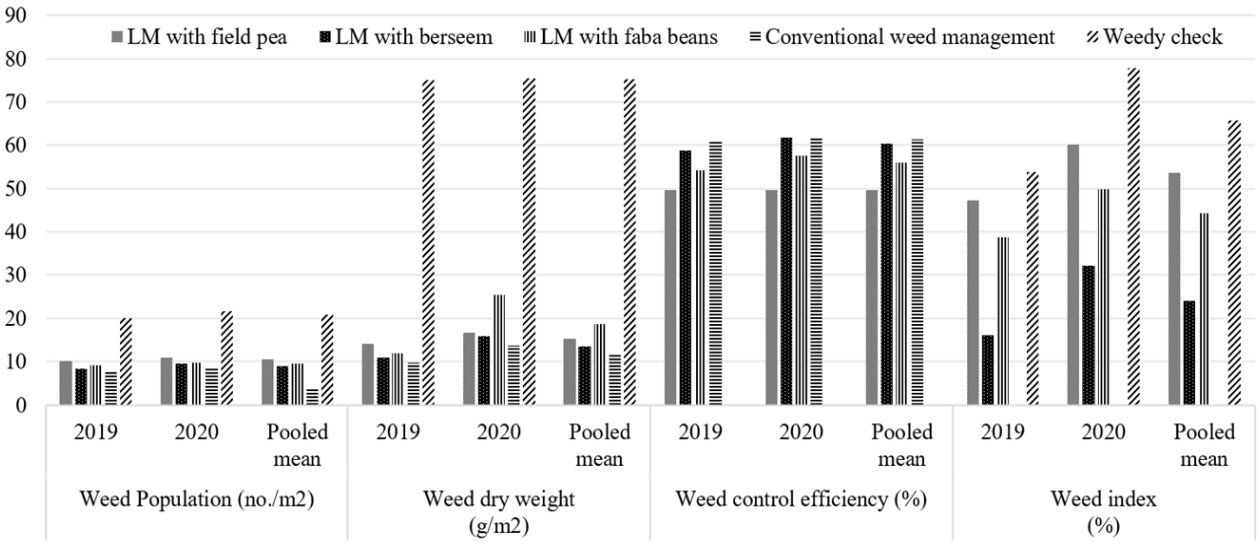

Figure 1. Weed population, dry weight, weed control efficiency and weed index

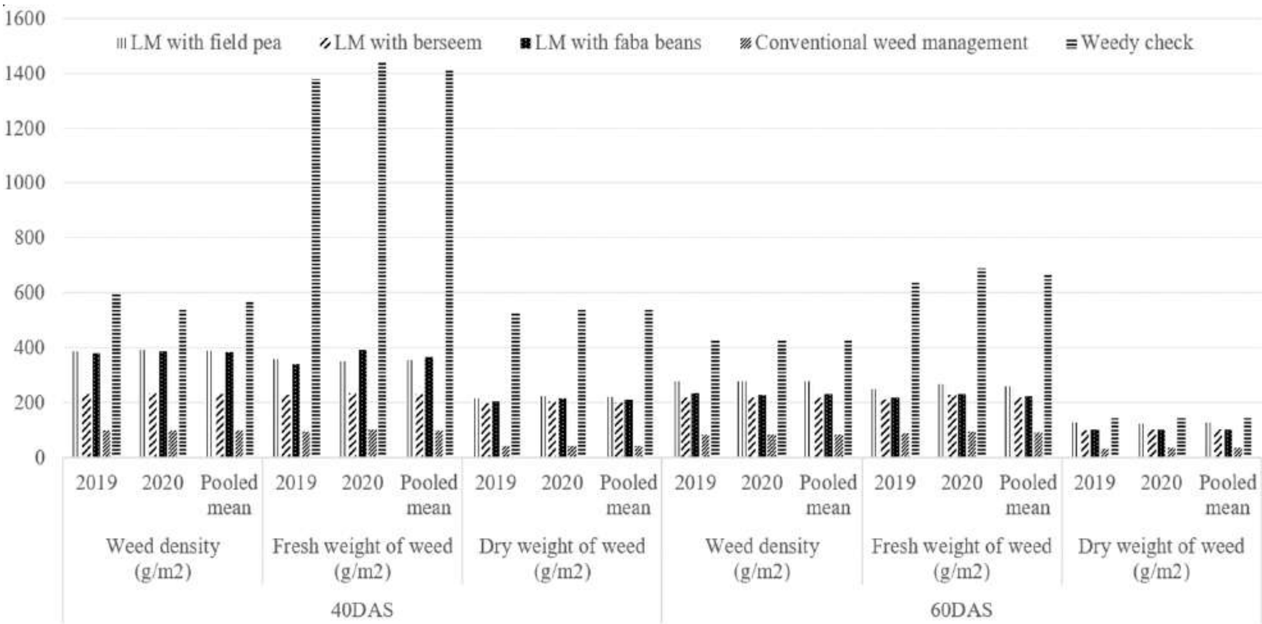

Figure 2. Weed density, fresh weight and dry weight at 40 and 60 DAS

control. Masud *et al*. (2021) also showed similar findings that cowpea living mulch plot had 0.5 t/ha weed biomass compared to 2.6 t/ha in the control. It was also reported by Borowy (2012) that living mulches decrease the soil surface temperature which lead to slow growth of weeds. The different weed flora in experimental field identified were *lternanthera sessilis, Chenopodium album, Cleome rutidosperma, Isachne globosa, Mimosa diplotricha var. inermis, Oxalis debilis, Physalis minima and Setaria pumila.*

Conclusion

On the basis of two years experimentation, it was concluded that the living mulches may be an alternative for weed management without the use of chemical herbicides without much deteriorating yield of the main crop and also good for ecosystem services. Hence, our findings confirmed that apart from the conventional method of weed management, berseem can be used as living mulch to reduce the biomass of weed and can be interplanted as a living mulch crop in french beans cultivation.

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RESEARCH ARTICLE

Weed management in yellow mustard using herbicide and weed mulch in lateritic soil of West Bengal

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ABSTRACT

A field experiment was conducted during 2018-19 and 2019-20 at Agriculture Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal with the objective to study the integrated use of herbicide and weed mulch on weed growth and yield of yellow mustard. The soil of the experimental field was sandy loam in texture. The experiment comprising of seven treatments *viz.* pre-emergence (PE) application of pendimethalin at 0.75 kg/ha, mulching with *Eichhornia crassipes* (water hyacinth) at 15 t/ha, mulching with *Antigonon leptopus* (coral vine) at 4 t/ha, pendimethalin as PE at 0.75 kg/ha followed by mulching with *Eichhornia crassipes* (water hyacinth) at 15 t/ha , pendimethalin as PE at 0.75 kg/ha followed by mulching with *Antigonon leptopus* (coral vine) at 4 t/ha , weedy check and weed free was laid out in a randomized block design with three replications. Result revealed that pendimethalin as PE at 0.75 kg/ha followed by mulching with *Eichhornia crassipes* (water hyacinth) at 15 t/ha recorded the lower values of total weed density (5.76 and 7.01 no/m^2) and biomass (5.04 and 4.82 g/m^2) at 45 DAS and higher seed yield of 1250 and 1183 kg/ha in first and second year, respectively.

Keywords: Coral vine, higher yield, pendimethalin, water hyacinth, weed biomass, weed density

INTRODUCTION

Edible oil crops are highly significant in India's agriculture and industrial economy. India has the unpleasant distinction of being the world's largest producer, consumer, and importer of edible oil despite being the leading producer of vegetable oil globally. If the production potential of our annual edible oilseed crops is utilised through improved weed and nutrient management technology, India could eventually become self-sufficient in edible oil. Weed infestation is one of the main causes of low productivity of mustard (Singh *et al.* 2013). Weed management focuses on reducing weed growth and competition below the economical injury level in order to increase the yield and enhance the profit. Farmers need efficient weed management practices that offer a quick response to produce more. But not many management practices are available except the use of manual weeding or chemical herbicides. Manual weeding is labor intensive and tiresome. The dominance of chemical control in weed management also raises concerns that weeds are adapting to this control and that few proven alternatives are available where their effects diminish. For example, weeds are more likely to evolve resistance to herbicides where herbicide use is more intense (Duary 2008 and Duary *et al.* 2015a). Much work has not been done in this field to devise any method of weed management that would be cheap as well as feasible to be used by the local farmers and that would not have any harmful effect on the environment. Considering the ubiquity, diversity, plasticity and adaptability of weeds, it seems impossible that any single weed control technique, including herbicides, will prove to be a lasting panacea for weed management. Integrated weed management (IWM) explicitly calls for combining an array of chemical, cultural and mechanical control tools and techniques. This approach can prevent weeds from adapting and lead to successful long-term control. Mulching may be one of the important components of IWM in mustard. Use of locally available weeds as bio-organic mulch to suppress the growth of other weeds is a vital option. There is also scope of integrating herbicides with cultural practices to improve the sustainable use of herbicides. There are pre-emergence herbicides successfully used in mustard such as fluchloralin, pendimethalin, *etc*. Alternative weed management practices like use of straw and weed mulch as a component in IWM have been found effective in direct seeded rice, wheat and oilseed crops like sesame in eastern India (Fatima and Duary 2020,

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Fatima *et al*. 2020, Fatima *et al*. 2021, Malik *et al*. 2021, Kumar *et al*. 2023, Jaiswal *et al*. 2023, Jaiswal *et al*. 2024). Keeping this in view, a field experiment was carried out to study the effect of herbicide and weed mulch on weed growth and yield of yellow mustard.

MATERIALS AND METHODS

A field experiment was conducted during 2018-19 and 2019-20 at Agriculture Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal (India). The soil of the experimental field was sandy loam in texture with acidic in reaction (pH 5.8), low in organic C (0.41%) and available N (145.4 kg/ha), high in available P (33.53 kg/ha) and medium in available K (133.94 kg/ha). The experiment comprising of seven treatments, *viz*. pre-emergence (PE) application of pendimethalin at 0.75 kg/ha, mulching with *Eichhornia crassipes* (water hyacinth) at 15 t/ha, mulching with *Antigonon leptopus* (coral vine) at 4 t/ha, pendimethalin as PE at 0.75 kg/ha followed by mulching with *Eichhornia crassipes* (water hyacinth) at 15 t/ha, pendimethalin as PE at 0.75 kg/ha followed by mulching with *Antigonon leptopus* (coral vine) at 4 t/ha, weedy check and weed free, was laid out in a randomized block design with three replications. The mulching was done by spreading water hyacinth and coral vine in between rows at 12 DAS. The seeds of yellow mustard variety "*B-9*" were sown on November 16, in both the years (2018-19 and 2019-20) using a seed rate of 6 kg/ha at a distance of 30 cm in rows. Plant to plant distance of 10 cm was maintained by thinning after 15 days of sowing. Recommended N, P and K at 80:40:40 kg/ha in yellow mustard were applied as per recommended practice. Source of N, P and K was urea, single super phosphate and muriate of potash, respectively. Herbicide was applied with the help of hand operated knapsack sprayer fitted with a flat fan type nozzle at 1 DAS. All other recommended agronomic practices were followed and plant protection measures were adopted as per need. Weed density was recorded by placing 50 x 50 cm quadrats from the marked sampling area in each plot and after drying them in hot air oven at 70^{o} C, weed biomass was recorded. The data were subjected to a square root transformation to normalize their distribution. Yield attributes and seed yield of yellow mustard was recorded at harvest and statistically analyzed at a 5% level of significance. Weed control efficiency (%) was computed using the dry weight (biomass) of different category of species.

RESULTS AND DISCUSSION

Effect on weeds

Yellow mustard was infested with six weed species out of which 3 were monocots and 3 dicots. *Digitaria sanguinalis*, *Echhinochloa colona* and *Cynodon dactylon* among monocots and *Polygonum plebeium*, *Gnaphalium purpureum* and *Eclipta alba* among dicots were predominant weeds in the experimental field during both the years. *Digitaria sanguinalis* and *E. colona,* among the grasses and *Anagallis arvensis* and *Chenopodium album,* among the broadleaved weeds were the predominant weeds in yellow mustard (Teja and Duary 2018).

Pendimethalin at 0.75 kg/ha followed by mulching with water hyacinth registered significantly lower density and biomass of monocots, dicots and total weeds at 45 DAS during both the year and was at par with pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus* (**Table 1**). Sole application of pendimethalin at 0.75 kg/ha performed better to control of monocot weeds during both the years and it was at par with mulching with *Eichhornia crassipes* and *Antigonon leptopus* (**Table 1**). Pendimethalin alone reduced the density of monocots weeds by 67.05 and 69.00% in first and second year, respectively. But it was less effective against dicot weeds.

Mulching with *Eichhornia crassipes* was reasonably effective in controlling dicots during both the years and it was on par with mulching with *Antigonon leptopus* (**Table 1**). Use of weed mulch alone reduced the total weed density by 51.89-54.46% and biomass by 62.57-67.45%, in the first and second year, respectively. Choudhary and Kumar (2014) reported that mulched plot registered the least weed parameters.

Integrated use of pre-emergence herbicide pendimethalin at 0.75 kg/ha followed by mulching water hyacinth or *Antigonon* reduced the density of monocot by 75.92-80.15%, dicots by 51.08-69.47% and total weeds by 66.39-75.82% in first and second year, respectively. Sole application of herbicide pendimethalin or weed mulch did not exhibit broad spectrum management of weeds. Thus, it can be emphasised that integration of both herbicide and weed mulch can give broad spectrum management of weeds. Similar results of integrated use of herbicide and other methods were also reported by Duary *et al.* (2014), Fatima and Duary, (2020), Fatima *et al.* (2020), Fatima *et al.* (2021), Malik *et al.* (2021), Kumar *et al.* (2023), Jaiswal *et al.* (2023) in sesame and direct seeded rice.

The highest density and biomass of monocots and dicots were recorded in weedy plots, whereas lowest density and biomass obtained in weed free plot at 45 DAS in both the years (**Table 1**). Duary *et al.* (2015b and 2016) and Sar and Duary (2022) also reported similar results.

Among the weed management practices, integrated use of herbicide pendimethalin at 0.75 kg/ha and mulching with water hyacinth registered the highest weed control efficiency (WCE) at 45 days and closely followed by pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus* during both the years (**Figure 1**).

Effect on crop

Number of siliquae / plant, seeds/siliqua, siliqua length and test weight were registered significantly higher with the integrated use of pendimethalin at 0.75 kg/ha and mulching with water hyacinth and it was at par with pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus* during both the years **(Table 2)**. Pre emergence herbicide with mulching increased number of siliquae/plant and seeds/siliqua as reported by Raj *et al.* (2020).

All the weed management treatments significantly increased seed yield over unweeded control **(Table 2)**. Among the weed management treatments pendimethalin at 0.75 kg/ha followed by mulching with water hyacinth also registered significantly higher seed yield over other treatments during both the years and was at par with pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus*. Mulching conserved soil moisture and increased in yield of mustard (Regar *et*

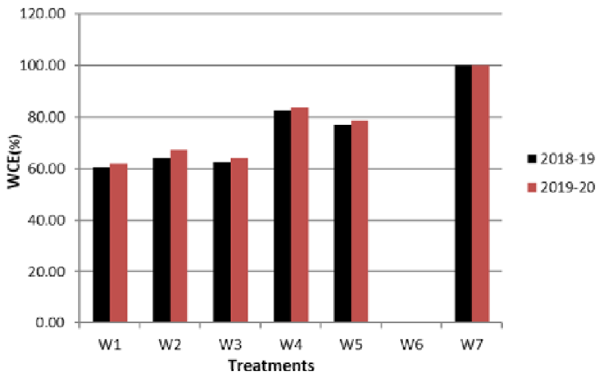
Table 1. Weed density and biomass in yellow mustard under different weed management practices at 45 DAS

Treatment	Weed density (no./m^2) at 45 DAS						Weed biomass (g/m^2) at 45 DAS					
	Monocots		Dicots		Total		Monocots		Dicots		Total	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin at 0.75 kg/ha	5.29 (27.67)	5.60 (31.00)	6.23 (38.33)	6.95 (48.00)	8.15 (66.00)	8.91 (79.00)	4.86 (23.39)	4.40 (19.06)	5.79 (33.14)	5.89 (34.14)	7.54 (56.53)	7.32 (53.20)
Mulching with *Eichhornia crassipes* (water hyacinth)	5.83 (33.67)	6.05 (36.33)	5.34 (28.00)	6.14 (37.33)	7.88 (61.67)	8.59 (73.67)	5.28 (27.49)	4.78 (22.42)	4.88 (23.50)	4.84 (23.57)	7.16 (50.99)	6.77 (45.99)
Mulching with *Antigonon leptopus* (Coral vine)	6.04 (36.00)	6.09 (36.67)	5.43 (29.00)	6.40 (40.67)	8.09 (65.0)	8.82 (77.33)	5.38 (28.59)	5.00 (24.59)	5.00 (24.65)	5.11 (25.65)	7.31 (53.24)	7.12 (50.24)
Pendimethalin at 0.75kg/ha followed by mulching with *Eichhornia crassipes* (water hyacinth) 15t/ha	4.18 (17.00)	4.81 (22.67)	4.00 (15.67)	5.13 (26.00)	5.76 (32.67)	7.01 (48.67)	3.84 (14.44)	3.50 (11.81)	3.19 (9.75)	3.36 (11.08)	5.04 (24.89)	4.82 (22.89)
Pendimethalin at 0.75kg/ha followed by mulching with *Antigonon leptopus* (Coral vine) 4t/ha	4.14 (16.67)	4.93 (24.00)	4.93 (24.00)	5.54 (30.33)	6.41 (40.67)	7.40 (54.33)	3.94 (15.14)	3.86 (14.45)	4.31 (18.25)	3.99 (15.58)	5.73 (32.69)	5.51 (30.03)
Weedy check	9.17 (84.00)	9.99 (99.67)	7.20 (51.33)	7.90 (62.00)	11.64 (135.13)	12.72 (161.67)	9.11 (82.9)	8.38 (69.91)	7.73 (59.35)	8.43 (70.68)	11.93 (142.2)	11.86 (140.59)
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71(0. 00)	0.71 (0.00)	0.71 (0.00)
LSD (p=0.05)	0.94	0.87	0.71	0.86	0.71	0.76	0.99	0.74	0.85	0.98	1.04	1.02

Figures in parentheses are the original values. The data was transformed to SQRT ($\sqrt{x+0.5}$) before analysis

Table 2. Yield attributes, seed yield and economics of yellow mustard as influenced by weed management practices

Treatment	Siliqua length (cm)		No. of siliquae/plant		No. of seeds/siliqua		Test weight (g)		Seed yield (kg/ha)		Net return (x10^3 /ha)		Returns per rupee invested	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin at 0.75 kg/ha	4.21	4.14	89.44	74.44	20.22	19.22	2.51	2.48	998	827	45.55	40.89	1.48	1.23
Mulching with *Eichhornia crassipes* (Water hyacinth)	4.37	4.30	98.89	86.89	22.56	21.22	2.53	2.40	1021	958	48.08	46.36	1.37	1.29
Mulching with *Antigonon leptopus* (Coral vine)	4.29	4.19	93.56	81.89	21.56	20.42	2.51	2.37	1005	888	47.64	44.45	1.35	1.19
Pendimethalin at 0.75 kg/ha followed by mulching with *Eichhornia crassipes* (Water hyacinth) 15 t/ha	4.48	4.68	112.44	107.78	25.33	23.67	2.53	2.67	1250	1183	55.12	53.29	1.62	1.53
Pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus* (Coral vine) 4 t/ha	4.47	4.57	104.78	98.11	23.67	22.73	2.56	2.59	1228	1093	54.52	50.84	1.59	1.41
Weedy check	3.81	3.44	76.56	68.22	17.11	16.11	2.48	2.35	740	617	37.72	34.37	1.15	0.96
Weed free	4.98	4.78	125.65	119.65	28.65	26.98	2.65	2.88	1315	1342	58.79	59.52	1.56	1.59
LSD(P=0.05)	0.76	0.68	10.68	10.80	2.43	2.29	0.30	0.25	205.4	185.24	-	-	-	-



W_1-pendimethalin at 0.75 kg/ha, W_2-mulching with *Eichhornia crassipes* (water hyacinth), W_3-mulching with *Antigonon leptopus* (coral vine), W_4-pendimethalin at 0.75 kg/ha followed by mulching with *Eichhornia crassipes* (water hyacinth), W_5-pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus* (Coral vine), W_6-weedy check and W_7-weed free

Figure 1. Weed control efficiency (%) of different treatments

al. 2007 and Saikia *et al*. 2014). Weed free check registered significantly the highest seed yield of yellow mustard. Punia *et al*. (2017) also observed that weed free treatment recorded the highest seed yield over other treatments. The crop weed competition as a result of ineffective control of weeds caused lower values of growth attributes in unweeded plot (Mahajan *et al*. 2012; Duary *et al*. 2016). Yield reduction due to weeds in yellow mustard was 43.72% in first year and 54.02% in second year. Pendimethalin alone registered 34.86 and 34.03% yield increase over unweeded control during first and second year, respectively. Similarly, weed mulch alone was able to improve yield by 35.81-37.97% in first year and 43.92-55.26% in second year over unweeded control. However, integrated use of herbicide and weed mulch resulted in 65.54-68.91% and 77.14 to 91.73% higher yield over unweeded control in first and second year, respectively. Among the different weed management practices higher values of yield attributes and yield were obtained in the treatment pendimethalin + weed mulch. The reason for this might be the conservation of soil moisture, supplement of nutrients and other growth promoting substances from weed mulch in these treatments. Also, it may be due to higher weed control efficiency of these treatments which maintained lower weed density as well as biomass thus least crop weed competition from the very early stage of the crop till maturity facilitating higher nutrient and water uptake, accelerated photosynthetic activity, availability of optimum space for better crop growth resulting into higher dry matter accumulation and yield. among the weed management practices Weed free check registered the highest net return and returns/rupee invested during both the years followed by pendimethalin at 0.75 kg/ha followed by mulching with water hyacinth and pendimethalin at 0.75 kg/ha followed by mulching with *Antigonon leptopus*.

Conclusion

Thus, integrated use of pre-emergence herbicide pendimethalin at 0.75 kg/ha followed by mulching with easily available weeds like water hyacinth or A*ntigonon* appeared to be promising for effective weed management in yellow mustard in eastern India.

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RESEARCH ARTICLE

Identification of host range, germination ecology and management of field dodder

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ABSTRACT

This study aimed to assess the distribution, host range, habitat, germination ecology, and management of *C. campestris* in the central zone of Kerala, India. A field survey across five districts identified 40 host species of *Cuscuta*, predominantly dicotyledons, with severe infestations in converted rice fields, agricultural fields, rice-fallows and wastelands. Experiments were conducted to study the germination response of *C. campestris* seeds to various dormancy breaking treatments, pH, burial depth and moisture levels. Scarification by sandpaper and concentrated H_2SO_4 improved the germination rate, while neutral pH (pH 7) gave higher germination (85%). Seeds failed to emerge beyond 5 cm burial depth and alternate-day irrigation promoted the highest germination (47%). Post-emergence management of *Cuscuta* in cassava using foliar spray of ammonium phosphate sulphate (3% and 5%) and urea (3% and 5%) exhibited effective control with complete drying of the parasite by 10-15 days after treatment. However, regrowth necessitated repeated applications.

Keywords: Ammonium phosphate sulphate, Field dodder management, Germination ecology, Host range, Urea toxicity

INTRODUCTION

Field dodder is an obligate stem parasite belonging to the family Convolvulaceae. It is native to North America and that has been spread to different parts of Asia. Its broad geographical distribution, wide host range, and the difficulties associated with management place it among one of the most damaging parasites world-wide. The genus *Cuscuta* consists of about 180 species worldwide of which 12 species are reported in India (Gaur 1999). Of these *C. campestris* and *C. reflexa* are more common. *Cuscuta* seeds usually germinate on or near the soil surface. Seedlings are rootless, leafless having thin stems about 0.8 mm in diameter. After emergence, the seedlings twine around the leaf or stem of a suitable host plant and penetrate the host through haustoria formation, absorbing water and nutrients from the host plant. Once *Cuscuta* attaches to a host plant, it remains parasitic until the host was harvested. *Cuscuta* causes severe damage in forage legumes, pulses, citrus and numerous ornamental plants and crop losses ranging from 24 to 90 % have been reported previously (Mishra *et al.* 2006).

Recently, *Cuscuta* infestations have emerged as a significant challenge for farmers in Kerala. As reported by the AICRP on Weed Management (AICRP 2022), the weed has infested crops such as cowpea, amaranthus, cassava, bitter gourd and ornamental plants in the state. The severity of these infestations has also intensified following the floods in 2018.

If *Cuscuta* infestation is not managed timely, it is too strenuous for mechanical removal; hence, post-emergence herbicide application is a viable option. Post-emergence applications of herbicides such as pendimethalin and imazaquin suppress the parasite, but *Cuscuta* generally recovers. Contact herbicides like paraquat and diquat and non-selective systemic herbicides like glyphosate kill *Cuscuta* and also damage the host plant (Mishra *et al.* 2006).

The present study was a non-herbicidal approach to manage *Cuscuta* without damaging the host using nutrient formulations such as urea and ammonium phosphate sulphate. A survey was conducted to investigate the habitat and host range, and laboratory experiments were conducted to study the influence of environmental factors on germination, which could help formulate better weed management practices.

MATERIALS AND METHODS

Identification of host range

A survey was conducted throughout Kerala to identify the distribution and host range of *C. campestris*, with focus on the districts of Thrissur,

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Ernakulam, Palakkad, Kozhikode, and Malappuram. The survey was conducted from June 2023 to May 2024, using a selective sampling method focused on crop fields, rice fallows and wastelands of roadsides and railway tracks. The infested plants were initially recorded based on visual observation of the attachment of vegetative parts of *Cuscuta* to the host plant. The species was confirmed as *C. campestris* based on the standard characteristics outlined by Costea and Tardif (2005). The girth of the *Cuscuta* stem was measured as 0.6-0.8 mm.

Germination ecology

C. campestris seeds were collected from *Cuscuta* infested rice-fallows around Kerala Agriculture University, Thrissur, India (10°32' N and 76°17' E). Cleaned seeds were stored at room temperature in air tight plastic containers. Laboratory experiments were conducted during 2023 and 2024 in the Department of Agronomy lab, College of Agriculture, Vellanikkara, Kerala Agricultural University. Germination of *C. campestris* collected from infested areas was evaluated by placing 25 scarified seeds evenly in Petri dishes containing Whatman No. 1 filter paper and 5 ml distilled water. The number of germinated seeds was counted daily after the start of the experiment, with visible protrusion of radicle being the criterion for germination and time to take 50% germination also calculated. As seeds of *C. campestris* were reported to show dormancy, various dormancy breaking treatments were tried. The methodology followed is given below.

Effect of scarification treatments on germination

Fully matured seeds, collected two weeks prior, were subjected to various scarification treatments in batches of twenty-five seeds per type, with five replicates. These included mechanical scarification by rubbing the seed with sandpaper and chemical scarification using concentrated sulfuric acid for two minutes, followed by washing in running water. The scarified seeds were then allowed to germinate in petri dishes at room temperature. The non-scarified seeds were used as a control.

Effect of pH on germination

The effect of pH on seed germination was investigated using solutions of pH 4, 7, and 9, prepared with 4, 7, and 9.2 buffer capsules. These solutions were used to moisten 10 scarified seeds in petri dishes and the number of germinated seeds was counted daily from the start of the experiment, with visible protrusion of the radicle being the criterion for germination. Scarified seeds were used for this experiment, and unbuffered distilled water (pH 6.6) was used as a control.

Effect of burial depth on germination

The experiment was conducted in pots of depth 20 cm and radius 10 cm filled with sandy clay loam soil. The soil was collected from uninfected area to avoid any interference in germination count. Mechanically scarified seeds were sown in each pot at depths of 0, 2, 5 and 10 cm. The soil was kept moist throughout the study period. Emergence of *C. campestris* was recorded daily for two weeks.

Effect of soil moisture on germination

Germination of seeds of *C. campestris* was studied at different irrigation intervals. A pot culture experiment was done in CRD with four replications. Treatments were saturated condition (maximum water holding capacity), daily irrigation, irrigation on alternate days and irrigation at two days intervals. Pots (depth 20 cm and radius 10 cm) for experimenting were filled with an equal quantity of soil (5 kg) and water was added according to treatments. Twenty-five seeds of *C. campestris* were sown in each pot on the soil surface and covered with a thin layer of soil. The number of germinated seeds was counted daily after the start of the experiment, with visible protrusion of radicle being the criterion for germination.

Management of *C. campestris* in cassava (*Manihot esculenta*)

The experiment was conducted at two locations in the farmer's field in 2023-2024, where severe infestation of *Cuscuta* was observed in cassava. Treatments were 3% and 5% solution of urea (46-0-0), ammonium phosphate sulphate (20-20-0-13) and unsprayed check (no. of treatments=5). Three infested plants were selected in each replication (3 numbers). The treatments and doses of chemicals were fixed based on the preliminary investigation conducted in *Cuscuta* infested weed singapore daisy (*Sphagneticola trilobata*) in a rice fallow. Chemicals were applied by spraying, along with adjuvant, at the rate of 2 ml/L using a knapsack sprayer calibrated to a rate of 200 litres per acre with a flood jet nozzle. Phytotoxicity symptoms of browning, drying, and necrosis were systematically recorded at intervals of 1, 3, 5, 7, 10 and 15 DAT (days after treatment). These symptoms were evaluated using a rating scale ranging from 0 to 5 (0- no control, 1- slight control, 2- moderate control, 3- good control, 4- very good control, 5- complete control for *Cuscuta*) (rating scale: 0- no injury, 1- slight injury, 2- moderate injury, 3- severe injury, 4- very severe injury, 5- complete destruction for host) by Thomas and Abraham (2007).

Statistical analysis

The data generated were processed through the statistical package "GRAPES" (General R- based Analysis Platform Empowered by Statistics) developed by Gopinath *et al.* (2021). Wherever large variation in data was observed, angular transformation was performed (Gomez and Gomez, 1984). Multiple comparisons among treatment means, where the F test was significant (at 5% level), were made with Tukey's HSD test (Honestly Significant Difference).

RESULTS AND DISCUSSION

Distribution and host range of *C. campestris*

The survey revealed that distribution of C. *campestris* was primarily found in converted rice fields, agriculture fields, rice-fallows, potting media of ornamental plants and roadside wastelands (**Figure 1**). The incidence of *C. campestris* was identified among 42 host species belonging to 22 families. Of these, 88% were dicots, and the rest (12%) were the monocots (**Table 1**). These results indicated predominance of *C. campestris* mostly on dicotyledonous annual and perennial host plants and rarely parasitised monocotyledonous plants. Mishra *et al.* (2006) reported that *Cuscuta* has a wide host range, mainly dicotyledonous, including legumes, pulses, ornamental plants and numerous weeds. *Cuscuta* also parasitise asparagus and onion, which are monocotyledonous crops, but grasses and grains

Table 1. Host range of *C. campestris* in central zone of Kerala

Hosts plant species	Family	Habit	Dicot/ Monocot/ Another group
Weed hosts			
Ageratum conyzoides L.	Asteraceae	Herb	Dicot
Alternanthera bettzickiana (Regel) G.Nicholson	Amaranthaceae	Herb	Dicot
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	Herb	Dicot
Brachiaria mutica (Forssk.) Stapf	Poaceae	Herb	Monocot
Centrosema pubescens Benth.	Fabaceae	Herb	Dicot
Calopogonium mucunoides Desv.	Fabaceae	Herb	Dicot
Calotropis gigantea (L.) W.T.Aiton	Apocynaceae	Shrub	Dicot
Christella dentata (Forssk.) Brownsey& Jermy	Thelypteridaceae	Herb	Fern
Chromolaena odorata (L.) King et H. E. Robins.	Asteraceae	Herb	Dicot
Cleome rutidosperma (Wight & Arn.)	Cleomaceae	Herb	Dicot
Cyanthillium cinereum (L.) H.Rob.	Asteraceae	Herb	Dicot
Cyclea peltata (Burm.f.) Hook.f. & Thomson	Menispermaceae	Climber	Dicot
Digitaria sanguinalis (L.) Scop.	Poaceae	Herb	Monocot
Ficus hispida L.f.	Moraceae	Tree*	Dicot
Leucas aspera (Willd.) Link	Lamiaceae	Herb	Dicot
Ludwigia perennis L.	Onagraceae	Herb	Dicot
Macaranga peltata (Roxb.) Mull.Arg.	Euphorbaceae	Tree*	Dicot
Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs	Poaceae	Herb	Monocot
Melochia corchorifolia L.	Sterculiaceae	Herb	Dicot
Merremia vitifolia (Burm.f.) Hallier f.	Convolvulaceae	Climber	Dicot
Mikania micrantha Kunth	Asteraceae	Climber	Dicot
Mimosa invisa Mart.	Fabaceae	Herb	Dicot
Mimosa pudica L.	Fabaceae	Herb	Dicot
Pennisetum pedicellatum Trin.	Poaceae	Herb	Monocot
Phyllanthus niruri L.	Phyllanthaceae	Herb	Dicot
Ricinus communis L.	Euphorbaceae	Shrub	Dicot
Sida acuta Burm. F.	Malvaceae	Shrub	Dicot
Sphagneticola trilobata (L.) Pruski	Asteraceae	Herb	Dicot
Synedrella nodiflora (L.) Gaertn	Asteraceae	Herb	Dicot
Urena lobata L.	Malvaceae	Herb	Dicot
Xanthium strumarium L.	Asteraceae	Herb	Dicot
Crop hosts			
Amaranthus L.	Amaranthaceae	Herb	Dicot
Capsicum annuum L.	Solanaceae	Herb	Dicot
Manihot esculenta Crantz	Euphorbaceae	Shrub	Dicot
Momordica charantia L.	Cucurbitaceae	Climber	Dicot
Musa spp.	Musaceae	Herb	Monocot
Solanum melongena L.	Solanaceae	Herb	Dicot
Solanum lycopersicum L.	Solanaceae	Herb	Dicot
Vigna unguiculata (L.) Walp	Fabaceae	Herb	Dicot
Ornamentals			
Duranta erecta L.	Verbenaceae	Shrub	Dicot
Polyscias fruticosa (L.) Harms	Araliaceae	Shrub	Dicot
Pseuderanthemum carruthersii var. Atropurpureum	Acanthaceae	Shrub	Dicot

***Infestation observed on seedlings

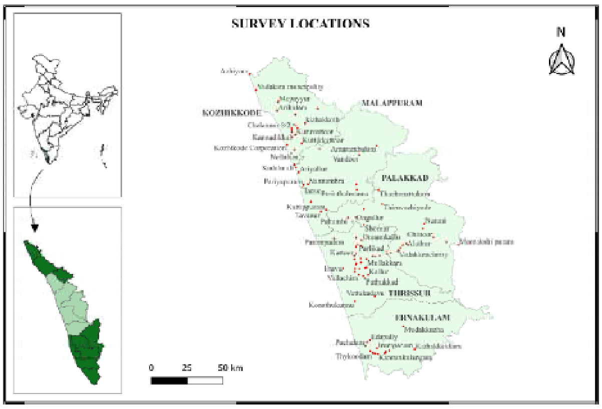

Figure 1. Distribution of *C. campestris* in central zone of Kerala

(Poaceae) are usually not parasitised. The prevention of haustoria penetration to monocot stem could be because of lignified tissues and the absence of epidermal hairs or sclerenchymatous hypodermis in monocots (Dawson *et al*., 1994). However, in our study, we observed that monocotyledons (*Brachiaria mutica, Digitaria sanguinalis, Megathyrsus maximus, Pennisetum pedicellatum* and *Musa* spp.) were also affected by the parasite, but the severity and intensity were very low, and haustorial connections were inconspicuous and needs further studies to confirm parasitisation.

Infestation of *C. campestris* was observed mostly on 31 weed hosts, 8 cultivated crops and 3 ornamental plants. The host species includes 29 herbs, 7 shrubs, 4 climbers and 2 trees. Mostly, herbs were found to be affected by the parasite, while the trees were resistant. Trees are affected only in the juvenile or seedling stages. Some of the crops infested with *Cuscuta* are cassava, banana, bitter gourd, cowpea, chilli, brinjal, tomato, amaranthus and few ornamental plants. The most preferred hosts are *Mikania micrantha* and *Sphagneticola trilobata* both of which belong to the family Asteraceae. Sarma *et al*. (2008) also reported that the prominent plant families infested with *Cuscuta* are Rosaceae, Asteraceae and Solanaceae due to their suitable morphology for haustoria attachment.

Germination ecology of *C. campestris*

Effect of scarification: Scarification treatments improved the germination of *C. campestris*, with the higher germination percentage observed in sandpaper scarification (89%) and scarification by concentrated H_2SO_4 (86%) (**Figure 2**). Similarly, Benvenuti *et al*. (2005) reported that germination rate of non-scarified seeds of *C. campestris* did not exceed 20% whereas, scarification by concentrated H_2SO_4 for 10 minutes increased germination to over 80%. According to

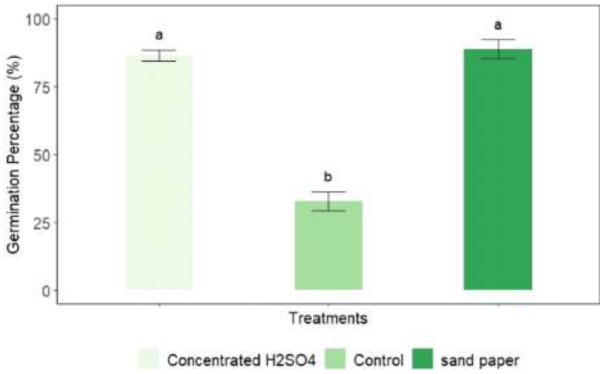

Figure 2. Effect of scarification treatments on germination

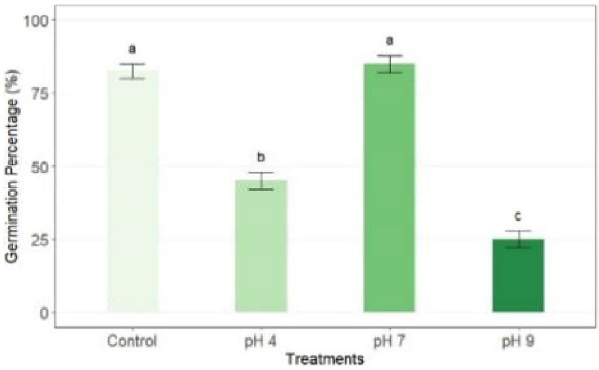

Figure 3. Effect of pH on germination

Ashton and Santana (1976) rubbing seeds between fine sandpaper gave almost 100% germination of *C. campestris*. The higher time to take 50% germination (2 days) was observed in non-scarified seeds which was significantly higher than scarification treatments (1.71 days).

Effect of pH: The seeds of *C. campestris* were germinated at pH 4, 7 and 9 (**Figure 3**). Germination of *C. campestris* was higher (85%) at neutral pH (pH 7) and was on par with the control treatment (distilled water having pH 6.6). Zaki *et al*. (1998) also recorded the highest germination of C*uscuta* at a pH of 7. There was a decrease in germination with either increase or decrease in pH. Alkaline pH was found to be unfavourable for germination compared to acidic pH. The ability of *C. campestris* to germinate under pH 4 and 9 indicated that this weed can also become problematic in all soils. However, in alkaline pH, the chances of infestation are less. The highest time to take 50% germination was observed in pH 9 (2.3 days) which is significantly different from other treatments (1.6 days).

Effect of burial depth: Emergence of *C. campestris* decreased with increase in depth of placement of seeds in the soil (**Figure 4**). *C. campestris* seeds exhibited highest emergence at surface (92%) which significantly differed from deeper layers. At 2 cm depth, emergence was reduced by about 50%. No

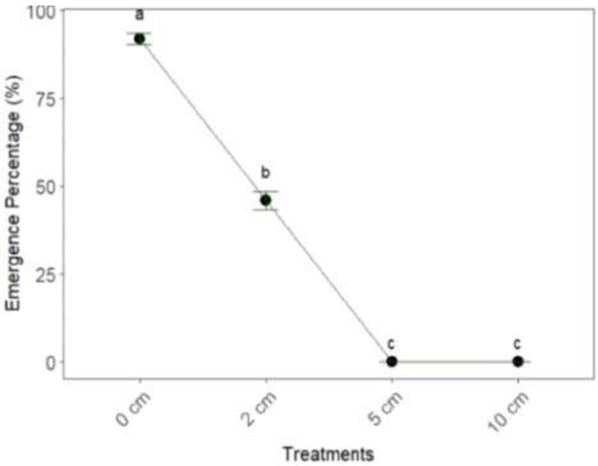

Figure 4. Effect of burial depth on emergence

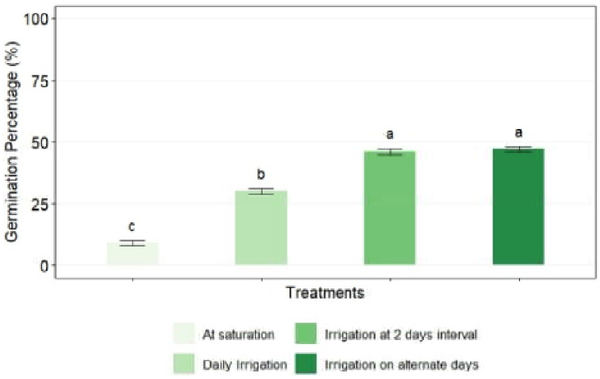

Figure 5. Effect of moisture content on germination

emergence was recorded at depth of 5 cm and beyond. According to Benvenuti *et al*. (2005) no emergence was observed at a sowing depth greater than 4 cm, and the lack of emergence was not because of fatal germination. Lack of oxygen presence and poor diffusion with increasing soil depth decrease the emergence rate (Benvenuti 2003).

Effect of moisture content: The germination percentage recorded under irrigation on alternate days and irrigation at two days intervals were on par (46%), which was significantly higher than that under daily irrigation and saturated condition (**Figure 5**). The lowest germination was observed at saturated condition (9%). Jang and Kuk (2020) observed poor germination of *C. pentagona* under saturated conditions. The higher time take to 50% germination observed at saturation (2.06 days) which was significantly higher than other treatments (1.88 days).

Effect of weed management treatments on phytotoxicity

The phytotoxic effects on *Cuscuta* and cassava due to various treatments are presented in **Table 2** and **3**. Ammonium phosphate sulphate and urea application resulted in complete drying of *Cuscuta* at 15 days after spraying (score of 5). Phytotoxicity score of 4 was observed in all treatments at 5 days after treatment (DAT). The oxidative damage caused by these chemicals led to tissue scorching in *Cuscuta*. Maleva *et al*. (2015) also observed urea-induced oxidative damage in *Elodea densa* leaves. Lim *et al*. (2009) noted that, at higher concentrations, urea functions as a chaotropic agent, causing protein denaturation in *Cuscuta* cells.

Regrowth of *Cuscuta* was observed in all treated plants at 7 DAT, indicating the need for repeated applications for sustained control. The second dose of all treatments was sprayed in 7 DAT. Although some phytotoxicity on young cassava leaves was observed, the crop regained the vigour by two weeks post spraying. No phytotoxicity was observed on cassava stem. The anatomical difference between

Table 2. Phytotoxicity on *Cuscuta* due to various treatments

Treatment	Days after treatment application					
	Day 1	Day 3	Day 5	Day 7	Day 10	Day 15
Urea (3%)	1	2	4	4	4	5
Urea (5%)	1	2	4	4	5	5
Ammonium phosphate sulphate (3%)	2	3	4	4	5	5
Ammonium phosphate sulphate (5%)	2	3	4	4	5	5
Unsprayed check	0	0	0	0	0	0

(Rating scale: 0- none, 1- slight toxicity, 2- moderate, 3- good, 4- very good, 5- complete drying)

Table 3. Phytotoxicity on cassava due to various treatments

Treatment	Days after treatment application					
	Day 1	Day 3	Day 5	Day 7	Day 10	Day 15
Urea (3%)	1	1	1	1	0	0
Urea (5%)	1	2	2	2	2	0
Ammonium phosphate sulphate (3%)	1	2	2	2	2	0
Ammonium phosphate sulphate (5%)	2	2	2	2	2	0
Unsprayed check	0	0	0	0	0	0

(Rating scale: 0- no injury, 1- slight injury, 2- moderate injury, 3- severe injury, 4- very severe injury, 5- complete destruction)

Table 4. Effect of treatments on plant height and yield of cassava

Treatment	Location 1			Location 2			Pooled yield/plant (kg)
	Plant height (cm)		Yield/ plant (kg)	Plant height (cm)		Yield/plant (kg)	
	Before treatment	Harvesting stage		Before treatment	Harvesting stage		
Urea (3%)	80.00[c]	127.50[b]	4.25[b]	95.00[b]	184.00[b]	4.60[b]	4.40[b]
Urea (5%)	80.50[c]	128.05[b]	4.15[b]	93.75[b]	186.00[b]	4.70[b]	4.40[b]
Ammonium phosphate sulphate (3%)	85.00[b]	129.00[b]	4.30[b]	96.00[b]	186.25[b]	4.65[b]	4.47[b]
Ammonium phosphate sulphate (5%)	83.00[bc]	128.00[b]	4.20[b]	96.00[b]	185.00[b]	4.82[b]	4.51[b]
Unsprayed check	82.00[bc]	93.50[c]	1.00[c]	94.50[b]	120.00[c]	1.33[c]	1.17[c]
Uninfested plant	93.00[a]	134.50[a]	5.00[a]	112.50[a]	196.00[a]	5.43[a]	5.22[a]
LSD (p=0.05)	3.50	2.44	0.31	6.42	6.11	0.60	0.18

cells of *Cuscuta* and hardy nature of cassava plant resulted in less phytotoxicity of cassava compared to *Cuscuta*.

Effect of treatments on plant height and yield of cassava

In general, infestation caused an average 40% decrease in plant height and an 80% reduction in yield (**Table 4**). Yield loss was only 15% with foliar spray of urea and ammonium phosphate. Average tuber yield differed statistically among the treatments. The highest average tuber yield was observed in uninfected plants (5.22 kg/plant). The tuber yield in urea and ammonium phosphate sprayed plots were at par. The lowest yield of 1.17 kg/plant registered from *Cuscuta* infested plants, when no management measures were adopted.

Conclusion

The survey revealed extensive distribution of *C. campestris* in converted rice fields and wastelands, infesting 40 host species, mainly dicots, and affecting crops such as cassava, banana, bitter gourd, cowpea as well as various weeds and ornamental plants. Seed dormancy enables *Cuscuta* to emerge annually from the soil. Scarification significantly enhances its germination and the species has the adaptability to germinate even in extreme pH conditions. However, saturated soil and deep seed burial inhibit its emergence. The management study indicates the possibility of using a foliar spray of urea or ammonium phosphate solution at 3 and 5% concentrations, along with an adjuvant for managing *Cuscuta* in a hardy crop like cassava. However, regrowth was observed within a week post-spray, indicating repeated treatments for sustained management.

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RESEARCH ARTICLE

Alterations in the primary metabolite profiles of field dodder (*Cuscuta campestris*) and its associated hosts cutleaf evening primrose (*Oenothera laciniata*) and swine cress (*Coronopus didymus*) in the fields of North-West India

Navjyot Kaur*, Lavanya Vij, Tarundeep Kaur and Makhan Singh Bhullar

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ABSTRACT

Cutleaf evening primrose (*Oenothera laciniata* Hill.) and swine cress (*Coronopus didymus* (L.) Sm.) are the two weeds which were found to be infested by a stem holoparasitic plant, field dodder (*Cuscuta campestris* Yunck.) in the fields of Punjab Agricultural University, Ludhiana, Punjab, during 2023-24. Although, detailed records of host-parasite associations of *Cuscuta* spp. are present in a large number of field crops predominantly belonging to families Solanaceae, Poaceae, Leguminosae and Brassicaceae; this is the first report to our knowledge of parasitic associations of *C. campestris* to two new weeds as hosts – *O. laciniata* and *C. didymus* belonging to the families Onagraceae and Brassicaceae, respectively in the fields under continuous rice-wheat rotation since more than twenty years. Parasitic plants are finding new hosts owing to increasing concerns of habitat suitability and host variability amidst rising trends of global climate change for agriculturalists. Biochemical analysis documented nutrient acquisition by field dodder from weed hosts, demonstrating the different host parasite assemblages as cause for variation in the primary metabolites' profiling in the hosts as well as the parasite. Evidently, the stem and leaves of *O. laciniata* and *C. didymus* were used by this noxious parasitic weed as a means for reaching the fruits of its host for maximum nutrient acquisition so as to complete its life cycle and expanding its seed bank in a field where its few seeds may have accidentally arrived from an unknown source.

Keywords: *Cuscuta campestris*, Haustoria, Host, Parasite, Proteins, Starch, Total soluble sugars

INTRODUCTION

Total parasitic angiosperms are non-photosynthesising plants which are totally dependent on the host plant for photosynthates as well as water and nutrients. They span over 12 families comprising of about 300 genera grouping more than 4500 species (Nickrent *et al.* 2020). Regardless of the taxonomical classification or degree of parasitism, they all share a common feature called the haustorium (pl: haustoria) (Albanova *et al.* 2023). Haustoria are the functional physiological links between hosts and parasites through which they acquire solutes, nutrients, minerals and carbohydrates from their hosts, but also bidirectionally exchange signalling molecules and pathogens (Kim and Westwood 2015). Despite the parasitic nature, very few such plant species represent relatively damaging agricultural pests' responsible for annual yield losses and ecological threats. The most damaging parasitic plants belong to the *Cuscuta* spp. from the Convolvulaceae family and *Striga* spp. and *Orobanche* spp. from the Orobanchaceae family (Kaiser *et al.* 2015).

Parasitic plants of the genus *Cuscuta* are referred to as cryptically photosynthetic due to the absence of or negligible levels of chlorophyll, making them non-photosynthetic. Thus, all *Cuscuta* spp. (commonly known as dodder) are obligate holoparasites dependent on the host plant, mostly herbs and shrubs to complete their life cycle since a germinating *Cuscuta* seedling has very limited seed reserves (Patel and Patel 2010). It neither bears root nor fully expanded leaves and the only vegetative portion appears to be the thin pale stem, thus it must attach itself to an appropriate host plant with in the initial days. *Cuscuta* spp. recognize and infests the host plant *via* releasing chemoattractant plant volatiles directing the successful parasitic growth and infection (Kaiser *et al.* 2015).

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Cuscuta spp. have become a major problem in many field crops, *viz*. berseem, lucerne, tomato, potato, mustard, soybean, chillies, chick pea, green gram, black gram, lentil, alfalfa, onion, *etc*. (Albert *et al*. 2008). Huge crop losses have been reported due to *Cuscuta* in 25 crop species in 55 countries (Lanini and Kogan 2005). The yield reductions due to infestation of *Cuscuta* spp. have been reported to be 60–65% in chillies, 31–34% in green gram/black gram, 87% in lentil, 86% in chickpea, 72% in tomato and 60–70% in alfalfa (Mishra 2009). This parasitic plant establishes physiological connection with the host plant through haustoria for penetrating the vascular bundles of the host to withdraw water, carbohydrates and other resources.

Oenothera laciniata (commonly known as cutleaf evening primrose) belongs to the family Onagraceae. It is an annual or short-lived perennial herb producing a spreading stem. Leaves are lanceolate, deeply notched, medium green with hairs on the surface and none below. Flowers occur in the axils of leaves higher on the stem. Each flower has pale to deep yellow petals which fade orange, pink, or red with age. The fruit is a cylindrical capsule up to 5 centimeters in length. *O. laciniata* is endemic to the eastern United States but has been reported from many other countries including India as a noxious weed in agriculture. It has also been reported from different countries such as Hawaii, Australia, Britain, France, Korea and Japan (Nayar *et al*. 2012).

Coronopus didymus (commonly known as swine cress) is a small herbaceous annual weed belonging to the family Brassicaceae growing in rosette on ground with a 15-30 cm long prostate stem, commonly seen growing in pasture, wastelands and along roadsides between an altitude of 700-3000 m in Western Himalaya. Its seeds are easily disseminated by wind and are harvested for food and medicine. Leaves are pinnatifid or pinnatipartite with lobes spreading, almost entire. Flowers are small pale green with sub-erect sepals and short or no petals, 1-2 mm in size situated in elongated, lateral racemes. Fruits are bilobed 1.5 to 2.5 mm in size producing falcate, finely netted and brown seeds (Anonymous 2019).

The association of *Cuscuta* spp. has been reported with many field crops (Holm *et al*. 1997). In this paper, we report the first observation on the host-parasite interactions of *C. campestris* with two weeds namely *O. laciniata* and *C. didymus* along with the alterations caused in the profile of primary metabolites of the associated parasite as well as host plants.

MATERIALS AND METHODS

The host-parasite assemblage of *C. campestris* with *O. laciniata* and *C. didymus* has been observed since many years during the months of April and May on a five-acre field in Punjab Agricultural University, Ludhiana, Punjab, India (30°56'N latitude, 75°52'E longitude and at an altitude of 247m msl). This site represents the Indo-Gangetic alluvial plains with a sub-tropical, semi-arid climate with characteristically hot summers and very cold winters. The soil was loamy sand and rice-wheat rotation was followed on the infested area from last many years and has been irrigated with canal water.

Samples from the parasite *C. campestris* and infected host plants were collected for biochemical investigations. Infected and non-infected leaves – lamina and petiole, stem and fruits were collected from the hosts alongside the respective *Cuscuta* stem, haustoria and flower. These samples were used to analyze various primary metabolites, *viz.* sucrose, total soluble sugars, starch, total soluble proteins and total free amino acids. Total soluble sugar content was estimated from the ethanolic extractions *via* phenol-sulphuric acid method as stated by Dubois *et al.* (1956). Starch was extracted in the form of soluble sugars from the residue left after the extraction of total soluble sugars using perchloric acid as described by Clegg (1956). The extracted sugars were similarly estimated *via* the phenol-sulphuric acid method (Dubois *et al.* 1956), and the starch content was calculated by multiplying the content of total soluble sugars obtained in the residue by a factor of 0.9.

Sucrose content was estimated using the ethanolic extraction as per the standard method stated by Roe *et al.* (1949). The extract was evaporated to dryness at 100°C in a water bath and the volume was raised upto 10ml with distilled water. To this, 1ml of saturated lead acetate solution was added and kept overnight for the proteins to precipitate. The extracts were filtered and a pinch of sodium oxalate was added to the clear supernatants. The extracts were filtered again following an overnight incubation to obtain a clear extract. A reaction mixture prepared by adding 0.5ml extract and 0.5ml 6% KOH was heated in a boiling water bath for 20 minutes, following which 1ml of resorcinol reagent and 3ml of 30% HCL were added and the tubes were again incubated in a boiling water bath for 20 minutes. The pink coloured complex developed was read at 490 nm on a UV-Visible Spectrophotometer (Systronics UV-VIS Spectrophotometer 117).

For extraction of total soluble proteins and total free amino acids, 0.1g tissue sample was extracted in 10ml of 0.1N sodium hydroxide (NaOH). 2ml of protein extract was further taken in new tubes, adding 2ml of 20% trichloroacetic acid to the tubes and incubating at 4°C for 24 hours. The precipitates obtained were dissolved in 0.1N NaOH. This extract was used to estimate total soluble protein content as per the estimation procedure stated by Lowry *et al.* (1951). A reaction mixture of 0.1ml extract, 0.4ml distilled water, 2.5ml solution prepared by mixing 2% sodium carbonate in 0.1N NaOH and 0.5% copper sulphate in 1% potassium sodium tartarate in ratio 50:1 and 0.25ml folin-ciocalteau reagent diluted with distilled water in 1:1 ratio. The blue coloured complex formed was read at 520nm against a reagent blank following incubation in the dark for 60 minutes. Total free amino acids were estimated as per the protocol of Lee and Takahashi (1966). A reaction mixture of 0.2 ml extract, 0.8ml distilled water and 4ml ninhydrin reagent was incubated in a water bath at 90°C for 1 hour. The violet coloured complex developed was read at 570nm on a UV-Visible Spectrophotometer after cooling the tubes against a reagent blank.

The analysis of variance for primary metabolites was computed using the Minitab (2017) software. The ANOVA was analyzed for variation in host-parasite primary metabolite profile using Tukey's test.

RESULTS AND DISCUSSION

C. campestris thrived luxuriantly on the *O. laciniata* fruits with few leaves also penetrated by this parasite. On an average 10-15 haustoria of *Cuscuta* penetrated the fruits of *O. laciniata*. Stem and leaves of *O. laciniata* were mostly used by *C. campestris* as means for reaching to another fruits. Abundant seed production was observed in host as well as parasite. Due to inability of this weed to parasitize cereals like rice and wheat, this parasitic weed must have infested these weeds for completing its life cycle for increasing its seed bank in a field where its few seeds might have landed accidentally. These new host-parasite assemblages could be attributed to the continuous rice-wheat rotation in Punjab, India combined with the ecological perturbations led by global climate change. These climatic changes have worsened the issue of invasive alien plants and weeds in the agro-ecosystems at a global scale resulting in altered parasite transmission, range changes and population densities, increasing the potential for host switching (Brooks and Hoberg 2007).

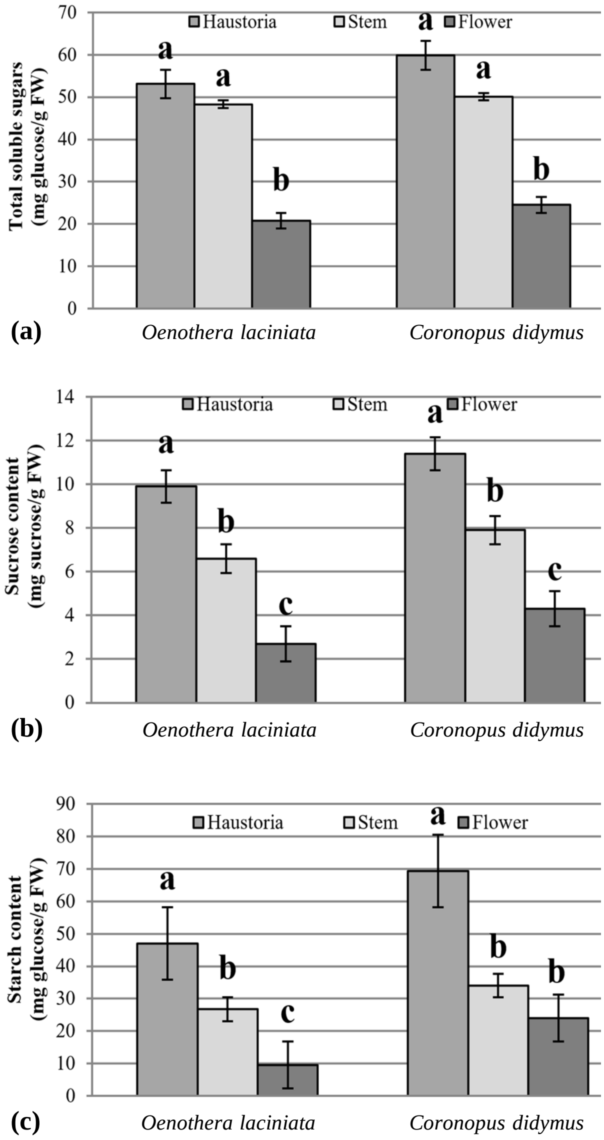

Figure 1. (a) Total soluble sugars, (b) sucrose and (c) starch content of *Cuscuta campestris* Yunck. Parasitizing on the two host plant species, *Oenothera laciniata* Hill and *Coronopus didymus* (L.) Sm. Each bar represents mean ± standard error. Least square means with different superscript letters are significantly different

Biochemical analysis of the *C. campestris* penetrating two different hosts revealed variation in the metabolite profile of three organs – haustoria, stem and flowers. Haustoria being the specialized intrusive organ for water and nutrient absorption, recorded the highest contents of primary metabolites, *viz*. total soluble proteins, total soluble sugars, sucrose and starch, followed by stem and then flowers (**Figure 1** and **2**). *C. chinensis* has also been recorded to divert huge amount of nitrogen and carbon from the host plants, completing its own life

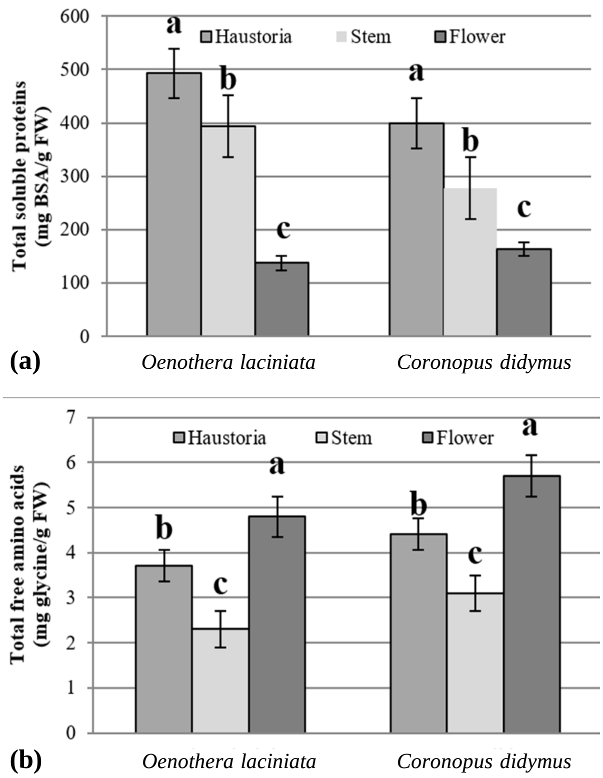

Figure 2. (a) Total soluble protein content and (b) total free amino acid content of *Cuscuta campestris* Yunck. parasitizing on the two host plant species, *Oenothera laciniata* Hill and *Coronopus didymus* (L.) Sm. Each bar represents mean ± standard error. Least square means with different superscript letters are significantly different

cycle at the cost of suppressing the host growth and development (Marambe *et al.* 2002). Comparatively, *C. campestris* extracted higher carbohydrate reserves from the host *C. didymus* than *O. laciniata* (**Figure 1**). Thus, difference in the host also contributes to alteration in the metabolite composition of the parasite. The alterations in the metabolite profile following parasitization are a complex issue. Furthermore, it is extremely challenging to distinguish the host-derived or parasite created metabolites. Amino acids recorded an atypical trend than the other metabolites, with flowers recording the highest total free amino acids followed by haustoria and stem (**Figure 2b**). Many differential results on the altered amino acid composition have been perused in the literature as the free amino acid composition fraction is exceedingly susceptible to the variations in the environmental conditions and the host plant (Borghi *et al.* 2017). Amino acids are in addition also an important constituent of floral secondary metabolism following similar partitioning routes to sugars and aiding in *de novo* amino acid synthesis in floral tissues forming a completely different amino acid profile than haustoria and stem which is further used as a nitrogen storage compound for energy for a high C:N ratio. This higher C:N ratio contributes to energy generation for ovule and pollen development, successful fertilization, maturation and embryo growth (Tsai and Chang 2022). *De novo* synthesis of free amino acids like proline, asparagine and valine is also particular to floral tissues forming protein component of pollen coat, scent, colour and nectar for pollinators (Borghi *et al.* 2017). This also allows us to assume the increasing proclivity of *C. campestris* towards seed formation in the studied host-parasite association.The investigation results documented a significant impact of the parasitic weed on the primary metabolites of the host plant. Also, a significant difference was recorded in the parasitic metabolic profile depending on the different host they developed on (**Figure 1** and **2**), suggesting the high reliability of the parasites on the host's metabolites for nutrient acquisition. Our results were in accordance with the findings of Kumar and Amir (2021). They similarly reported notable variation in the *Cuscuta campestris* metabolic profiles that developed on the different hosts, indicating that the parasites' were heavily dependent on the host plant for metabolites. However, ample

Table 1. Primary metabolite profile, *viz*. total soluble proteins, free amino acids, total soluble sugars, starch and sucrose content in *C. campestris* infected and non-infected host plant – *O. laciniata*

Oenothera laciniata Hill	Total soluble protein content (mg BSA/g fresh weight)		Total free amino acid content (mg glycine/g fresh weight)		Total soluble sugar content (mg glucose/g fresh weight)		Total starch content (mg glucose/g fresh weight)		Total sucrose content (mg sucrose/g fresh weight)	
	Infected	Non-Infected	Infected	Non-Infected	Infected	Non-Infected	Infected	Non-Infected	Infected	Non-Infected
Lamina	76.9^{b}±1.3	210.3^{a}±2.2	2.4^{a}±0.05	1.4^{b}±0.03	6.0^{b}±0.4	12.5^{a}±0.2	14.6^{b}±0.8	28.5^{a}±2.4	1.8^{b}±0.12	2.4^{a}±0.08
Petiole	63.1^{b}±0.6	80.9^{a}±1.3	3.1^{a}±0.09	2.8^{b}±0.06	4.5^{b}±0.9	9.7^{a}±0.9	15.5^{b}±1.2	23.5^{a}±0.1	1.3^{b}±0.03	2.0^{a}±0.10
Stem	60.7^{b}±1.8	73.0^{a}±0.6	3.8^{a}±0.01	2.3^{b}±0.06	10.4^{b}±0.3	11.5^{a}±0.2	25.7^{b}±0.2	33.9^{a}±0.6	2.3^{b}±0.12	3.7^{a}±0.08
Fruit	252.6^{b}±4.2	540.7^{a}±30.1	3.1^{a}±0.34	1.5^{b}±0.07	6.7^{b}±0.2	23.9^{a}±0.9	24.4^{b}±2.1	60.5^{a}±2.5	0.3^{b}±0.08	4.7^{a}±0.26

All results are expressed as mean ± standard error at p=00.5

Table 2. Primary metabolite profile, *viz*. total soluble proteins, free amino acids, total soluble sugars, starch and sucrose content in *C. campestris* infected and non-infected host plant – *C. didymus*

Coronopus didymus (L.) Sm.	Total soluble protein content (mg BSA/g fresh weight)		Total free amino acid content (mg glycine/g fresh weight)		Total soluble sugar content (mg glucose/g fresh weight)		Total starch content (mg glucose/g fresh weight)		Total sucrose content (mg sucrose/g fresh weight)	
	Infected	Non-Infected	Infected	Non-Infected	Infected	Non-Infected	Infected	Non-Infected	Infected	Non-Infected
Lamina	201.3^b±1.3	244.5^a±0.6	4.9^a±0.02	2.9^b±0.12	11.0^b±0.4	36.8^a±1.4	20.9^b±1.9	29.5^a±0.8	3.7^b±0.38	15.4^a±0.26
Petiole	124.3^b±1.6	184.9^a±0.6	5.5^a±0.06	2.8^b±0.08	12.6^b±0.1	32.8^a±0.2	20.8^b±0.1	22.2^a±0.4	4.2^b±0.38	11.6^a±0.54
Stem	83.8^b±2.9	124.5^a±0.6	3.1^a±0.06	1.6^b±0.04	6.6^b±0.4	25.4^a±0.2	10.8^b±0.7	35.9^a±1.1	2.6^b±0.03	6.8^a±0.21

All results are expressed as mean ± standard error at p=00.5

results were also obtained which infer that the parasite can self-regulate its metabolic profile between organs *via* anabolic-catabolic activities. Similar to our results, Kumar and Amir (2021) also reported higher amino acids and sugar acids in the flowers, with significantly higher levels of most sugars and polyols in the haustoria and stem.

C. campestris penetrating *O. laciniata* recorded pronounced variation in the primary metabolite profile in the host organs – lamina, petiole, stem and fruit (**Table 1**). The highest content of nutrients was extracted from the fruit with a decrease of 72% in total soluble sugars, 93.6% in total sucrose, 59.7% in starch and 53.3% in total soluble proteins with a 51.6% increase in the total free amino acids. This can be ascribed to enhanced phloem unloading at the site of attachment of *C. campestris*. **Table 2** tabulates the variation in the primary metabolite reserves of *C. didymus* following the parasitic infestation of *C. campestris* on the host weed. Host-parasitic assemblage was formed on three host organs – lamina, petiole and stem. A significant decrease of 70.1%, 76% and 26.2% was recorded in total soluble sugars, sucrose and starch content, respectively in the infected *C. didymus* plant lamina than non-infected. Significant increase of 40.8%, 49.1% and 48.4% was recorded in total free amino acid content in infected lamina, petiole and stem of the *C. didymus*, respectively. This increase in the free amino acids was parallel to the 17.7%, 32.8% and 32.7% decrease in the total soluble proteins in lamina, petiole and stem in the infected host respectively. *Cuscuta* can withdraw almost all photosynthates originally intended for the developing host fruits *via* an unusually enhanced phloem unloading rate as recorded in *Vicia faba* beans (Wolswinkel *et al*. 1984). This could be attributed to the fact that primary metabolites such as amino acids and carbohydrates are energy sources and precursors of floral secondary metabolism and seed set (Borghi *et al.* 2017).

Conclusion

The stem and leaves of *O. laciniata* and *C. didymus* were used by *C. campestris*, a noxious parasitic weed as a means for reaching the fruits of its host for nutrient acquisition so as to complete its life cycle and expanding its seed bank in a field where its few seeds may have accidentally arrived from an unknown source.

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RESEARCH ARTICLE

Socio-economic determinants of the adoption of improved weed management technologies in rice-wheat system: Evidence from central India

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ABSTRACT

The Rice-Wheat Cropping System (RWCS) is one of the most widely adopted systems by farmers in Punjab, Bihar, Haryana, Uttar Pradesh, and Madhya Pradesh. Weed menace is a major challenge in this system, limiting production capacity per unit area and causing significant losses to farmers. However, the adoption of Improved Weed Management Technologies (IWMTs) enables farmers to effectively manage weed flora in the RWCS, allowing them to maximize the production potential of their land. The present study aims to offer a social science perspective on IWMT adoption within the rice-wheat system, focusing on identifying the socio-economic determinants influencing farmers' adoption. Jabalpur and Katni districts in the Madhya Pradesh state were selected for the study, and primary data were collected from a sample of 240 farmers. The major weed flora observed in rice fields included *Anagallis arvensis*, *Cynodon dactylon*, *Cyperus iria*, *Cyperus rotundus*, *Echinochloa colona*, *Echinochloa crusgalli*, and *Eclipta alba*. In wheat fields, the prominent weeds identified by farmers were *Avena fatua*, *Chenopodium album*, *Convolvulus arvensis*, *Cyperus rotundus*, *Parthenium hysterophorus*, and *Phalaris minor*. The study further revealed that 62% of the surveyed farmers had adopted *IWMT*, while the remaining 38% had not. Key factors influencing IWMT adoption among farmers included extension contact, participation in improved weed management training, and attendance at IWMT field demonstrations. Shortage of labourers during peak seasons for hand weeding and the absence of skilled workers for herbicide application was identified as the top-ranked constraints to adoption.

Keywords: Rice-wheat system, Improved weed management technologies, Adoption, Determinants

INTRODUCTION

The rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping system (RWCS) spans approximately 18 million hectares in Asia, with 10 million hectares in the Indo-Gangetic Plains (IGP) of India, and it is the most adopted system by the farmers of IGP as rice and wheat constitute staple food for millions of Indians (Farooq *et al.* 2007, Saharawat *et al.* 2010). Regarding states, the RWCS is predominantly practiced in Punjab, Bihar, Haryana, Uttar Pradesh, and Madhya Pradesh (Debangshi and Ghosh 2022). In north-western India, Punjab and Haryana collectively supply approximately 50% of the rice and 85% of the wheat procured by the Indian government (Deep *et al.* 2018).

The diverse climatic conditions in India facilitate the prevalence of the most commonly adopted weeds, leading to significant crop yield losses (Rao *et al.* 2020). According to available estimates, weeds contribute to approximately one-third of the overall crop yield loss caused by agricultural pests, in addition to problems like diminishing quality of produce, increasing production costs, and acting as the alternate hosts for various insect pests and diseases (Directorate of Weed Research, 2015). Overall, weeds are responsible for the highest potential loss (34%), with animal pests (18%) and pathogens (16%) being comparatively less significant (Oerke 2006).

Indian farmers have long relied on their experience to combat weeds through a combination of chemical and non-chemical methods. Hand weeding, the most ancient practice, persists even today alongside modern herbicide-based strategies, which have been the primary focus of Indian researchers. Herbicides are extensively used across more than 20 million hectares in India, approximately 10% of the total cropped area (DWR 2015), and constitutes nearly 20% of total pesticide usage. Wheat (28%), rice (20%), soybean (9%), and sugarcane (7%) are the major crops utilizing herbicides (Yaduraju 2012), with Punjab leading in consumption followed by Uttar Pradesh, Andhra Pradesh, Maharashtra, and West Bengal (Rao *et al.* 2020). Non-chemical methods include various ecological approaches such as weed-free seed

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sowing, adjusting sowing times, seed rate, cultivating competitive cultivars, and employing techniques like soil solarization, stale seed-bed technique, scientific crop rotations, laser land levelling (Kumar *et al.* 2021).

Weed seeds and seedlings are spatially clustered across agricultural landscapes, even though the fields are typically managed more-or-less similarly (Johnson *et al.* 2015). The variation in weed populations over space and time is influenced by various interactions between plants and their environment. Factors such as changes in topography, soil type, and drainage patterns contribute to the variability in weed density and composition within fields. In this context, improved weed management technologies play crucial role for the effective weed management at field level. However, relying solely on one method, whether it be mechanical, chemical, biological, or cultural control tactics, presents challenges due to the aggressive, adaptive, and persistent nature of weeds. Therefore, effective weed management necessitates a holistic and integrated approach for sustainable crop production.

Weed management technologies are critical for addressing weed-related challenges in the Rice-Wheat Cropping System (RWCS). Over the years, research institutions across various regions have developed and disseminated numerous IWMTs to farmers, aiming to improve weed control and minimize crop yield losses. However, the effective implementation of these technologies' hinges on their successful dissemination from scientific institutions to end users. In this context, farmers' awareness and socio-economic characteristics play a vital role in influencing the adoption of these technologies. Research highlights those factors such as education level, farming experience, training, access to farm machinery, extension contacts, and innovativeness significantly shape farmers' knowledge and their capacity to adopt new technologies (Rajashekhar *et al.* 2017). Despite these insights, there is a notable lack of socio-economic survey-based studies that specifically analyse the adoption of IWMTs and their determinants. Moreover, weed management technologies are often tailored to regional conditions, requiring continuous efforts from research and extension agencies to effectively disseminate these innovations and promote sustainable agricultural practices. Therefore, farmers' survey-based studies that explore the determinants of adoption are critically important from a policy perspective. They serve as valuable feedback mechanisms to refine and enhance the dissemination of technologies based on insights into the factors influencing adoption. In this context, the present study seeks to identify the key socio-economic factors that determine the adoption of IWMTs by farmers.

MATERIALS AND METHODS

Katni and Jabalpur districts in Madhya Pradesh (**Figure 1**) were deliberately chosen as the study area, taking into account the extensive extension activities conducted by ICAR-DWR over the years to disseminate Integrated Weed Management Technologies (IWMTs) in these regions. Primary data for the study were collected from November to February 2022-23 through a well-structured, pre-tested interview schedule from a comprehensive sample of 240 farmers**,** comprising 120 farmers from each of the two districts, who cultivate rice and wheat crops. Details on the socio-economic characteristics, weed flora, technology adoption, yield etc. were collected from the farmer respondents.

We classified farmers as adopters of IWMT if they applied at least one pre-emergent herbicide and one post-emergent herbicide in rice, and if at least one post-emergent herbicide was used in wheat. Subsequent survey results highlighted Pendimethalin and bispyribac-sodium as the predominantly used herbicides in rice, whereas metsulfuron-methyl + clodinafop-propargyl emerged as the predominant choice for wheat cultivation.

Descriptive statistics, such as percentages and means, were employed to describe different variables under study. Further, t-tests were conducted for continuous variables such as age, annual income, farming experience etc. to ascertain significant differences between adopter and non-adopter groups. Conversely, the chi-square (χ^2) test was utilized for categorical variables such as gender, education, social group *etc*. to know any significant difference

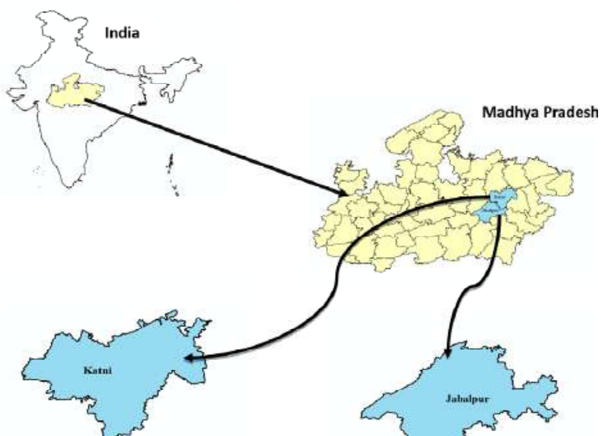

Figure 1. Study area map: Jabalpur and Katni districts in Madhya Pradesh

between the groups. Five-point continuum-based scoring technique was used to rank and prioritize the constraints.

We employed a linear probability model (LPM) to analyze the determinants of adoption, with the adoption of IWMT captured as a binary dummy variable. Our interest lies in measuring the marginal effects of independent variables on the probability of adoption. In this context, the linear model is preferable to logit and probit models, which provide estimates in index form (Angrist and Pischke 2009, Friedman 2012). The general form of the model used is as follows:

$$D_i = \propto + \beta_1 X_{1i} + \beta_2 X_{2i} \ldots\ldots\ldots\ldots + \beta_j X_{ji} + \varepsilon_i$$

Where,

D_i is the dummy for adoption (=1 if the farmer has adopted IWMT, 0 otherwise)

X_j is vector of independent variables used in the model

ε_i is the error term

RESULTS AND DISCUSSION

This particular section of the paper is discussed under different headings as given below;

Major weeds reported by the farmers

Open-ended questions were asked to farmers about major weeds observed and makes serious menace in their respective fields. The figure 2 depicted the weeds composition as percentage share of farmers' responses. *Anagallis arvensis*, *Cynodon dactylon*, *Cyperus iria*, *Cyperus rotundus*, *Echinochloa colona*, *Echinochloa crus-galli* and *Eclipta alba* were the weed flora observed in rice fields. *Avena fatua*, Chenopodium *album*, *Convolvulus arvensis*, *Cyperus rotundus*, *Parthenium hysterophorus* and *Phalaris minor* were the weed flora observed in wheat fields. It is noteworthy that *Cyperus rotundus* was reported as one of the most problematic weeds in both rice and wheat fields. Upon examining comparisons between districts, it becomes clear that *Echinochloa colona* is the most prevalent weed in rice fields across both districts though. Nevertheless, when considering percentage distributions, it was found that over 50% of farmers in Katni identified this as the major weed, whereas 31% of farmers in Jabalpur acknowledged this. Maun and Barret (1986) highlighted *Echinochloa crus-galli* as the most problematic weed in rice ecosystems, with just 9 plants per square meter causing a 50% reduction in rice yield. Furthermore, losses exceeding

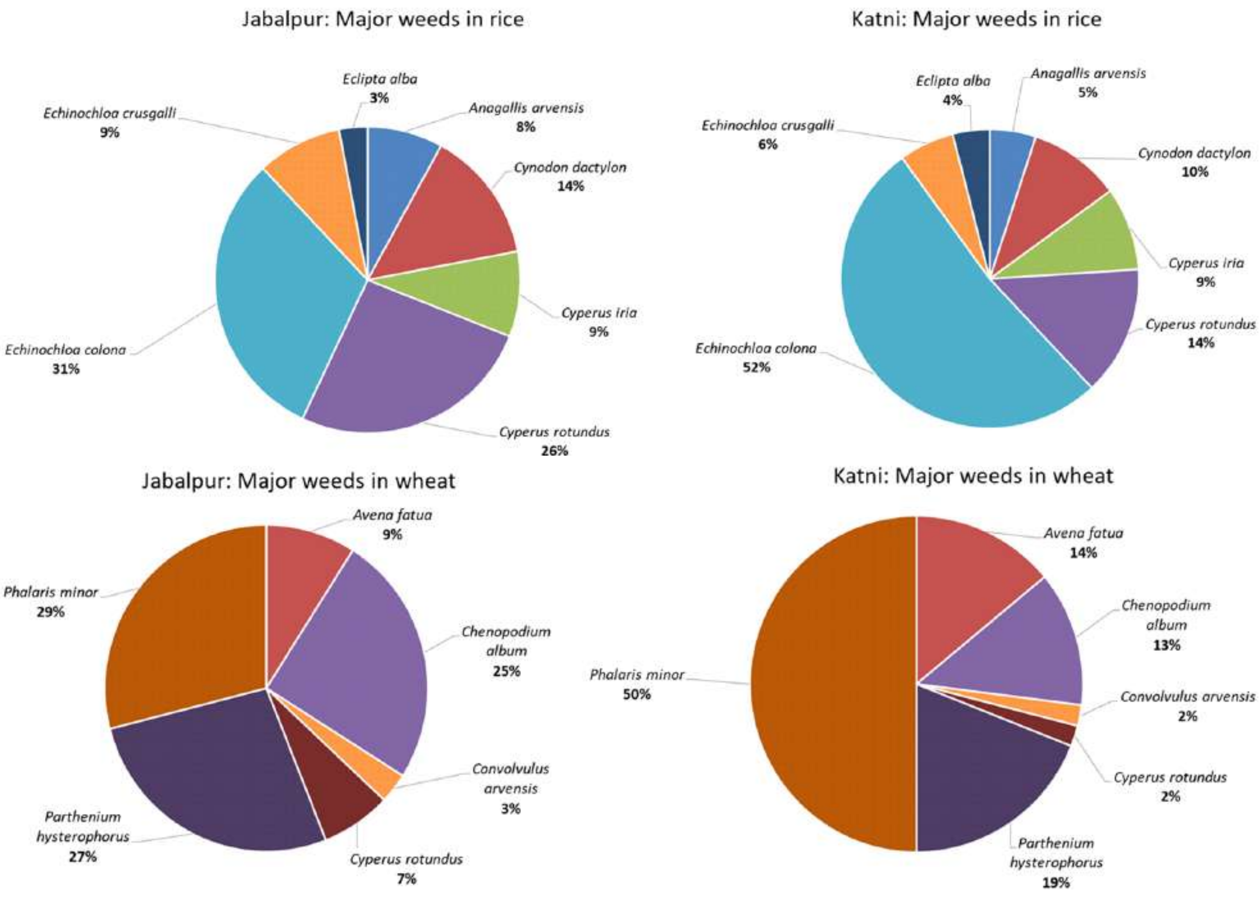

Figure 2. Percentage share of major weeds in the rice-wheat system as reported by the farmers

75% were observed with *Echinochloa colona* densities reaching 280 plants per square meter (Mercado and Talatala 1977). *Cyperus rotundus* was the second most prevalent weed in rice, with 26% and 14%, respectively, for Jabalpur and Katni. Similarly, *Cynodon dactylon* occupied the third position, registering respective percentage share of 14% in Katni and 10% in Jabalpur.

In the context of wheat crop, six weeds, namely, *Avena fatua, Chenopodium album, Convolvulus arvensis, Cyperus rotundus, Parthenium hysterophorus,* and *Phalaris minor* were identified as highly infested in the wheat fields. Notably, the composition varied between the two districts in terms of percentage distribution. In Katni, approximately 50% of farmers reported *Phalaris minor* as the most severe weed in wheat, while in Jabalpur, this figure stood at 29%. Several weed species significantly impact wheat productivity, with *Phalaris minor* being among the most prominent (Jat *et al.* 2003). The noxious weed *Parthenium hysterophorus* emerged as the second most severe weed in both districts, but the percentage distribution was significantly higher in Jabalpur (27%) compared to Katni (19%). *Avena fatua*, recognized as the third most important weed in wheat, exhibited a higher incidence in Katni (14%) compared to Jabalpur (9%).

From 2003 to 2014, India suffered a wheat production loss of US$ 3376 million across 18 states due to weeds (Gharde *et al.* 2018). Weeds like *R. dentatus* and *C. arvense* pose challenges in harvesting and threshing operations, while heavy infestations of *P. minor* during the maturity period cause severe lodging of the crop (Chhokar *et al.* 2012).

Adoption status and profile characteristics of sample farmers

Post-survey classification was done to know the adoption status of the farmer respondents. **Table 1** indicated that around 64% of farmers in Katni districts were adopters and 36% did not adopt the technology. While in Jabalpur, it was 59% adopters and 41% non-adopters. Overall, around 62% of farmer respondents adopted the IWMT while 38% of respondents fall under the non-adopter category.

The **Table 2** presents a comprehensive comparison of different demographic and socio-economic variables between adopters and non-adopters. The mean age of adopters was 44 years while it was 45 years for non-adopters. Each category exhibits similar size of house hold, that is on an average 5 members family. Farming experience also more or less similar 20.26 years and 20.54 years) in both groups. The gender distribution between the groups is not significant, similar to the caste category, and no significant difference was shown between adopters and non-adopters. Variables such as annual income, landholding, education, and credit availing exhibit significant differences between adopters and non-adopters. The average size landholding for adopters

Table 1. Post-survey classification of sample respondents (n=240)

District	Adopters	Non-adopters	% of adoption	% of non-adoption
Katni	77	43	64.17	35.83
Jabalpur	71	49	59.17	40.83
Total	148	92	61.67	38.33

Table 2. Profile characteristics of sample respondents

Variables	Adopters (N=148) Mean/%	Non- adopters (N=92) Mean/%	t-statistic/Chi-square statistic	P value
Age	44.49	45.47	-0.8544	0.3939
Household size	5.22	5.15	0.3116	0.7557
Farming experience (years)	20.26	20.54	-0.2636	0.7923
Annual income (Rs.)	89547.28	77347.83	2.0892	0.0380
Landholding (acres)	4.09	3.27	1.9983	0.0472
Gender			1.7175	0.1900
Male	63.06	36.94		
Female	44.44	55.56		
Education			6.5757	0.0103
Illiterate	47.69	52.31		
Literate	66.86	33.14		
Social group (caste)			4.35	0.1136
General	70.00	30.00		
OBC	65.13	34.87		
SC/ST	51.47	48.53		
Credit			20.658	0.000
Availed	76.47	23.53		
Not-availed	47.11	52.89		

was higher (4.09 acres) for adopters as compared to non-adopters (3.27 acres). Similarly, annual income of adopter groups was significantly higher (Rs. 89,547) compared to non-adopters (Rs. 77,347).

Determinants of adoption of improved weed management technologies

Description of the variables used in the LPM estimation is given in the table 3. Age, farming experience, and annual income were the continuous variables; rest of the variables were in the form of dummy variables, which took the value of either 0 or 1. The dependent variable was adoption which takes value 1 if the farmer adopted IWMT, 0 otherwise. Average age of the farmer respondents was 45 years, farming experience was 20 years and average annual income was Rs. 84871/-. The average area under cultivation was around 3.8 acres and as high as 49 per cent of farmers fall under below poverty line. Around 60 per cent of farmers had contact with extension institutions, while only 6 per cent of farmers became part of the IWM related field demonstrations.

Table 4 revealed the results of the linear probability model estimation. The variable extension contact was found to be highly significant (at 1% level) in order to determine the adoption of IWMT by the farmers. We specifically queried farmers about their engagement in extension contacts, focusing on whether they sought information on improved weed management technologies from ICAR-DWR or KVKs. This inquiry was motivated by the geographical proximity of these institutes to the study area and their concerted efforts in disseminating IWMTs. Participation in the improved weed management trainings and participation in the field demonstrations of IWMTs were the other significantly determining factors for the adoption of IWMTs. ICAR-DWR have been conducting field demonstrations on IWMTs in different localities of these study districts since many years and every year KVKs and ICAR-DWR do organize trainings on IWMTs in different crops and cropping systems (Prasad *et al.* 2018, Annual Report 2022. ICAR-DWR, Jabalpur). Therefore, as expected, the aforementioned two variables found to be a significant determinant of adoption of IWMTs in rice-wheat system. In a study by Singh *et al.* (2018) on IWM practices adoption among 108 farmers in Jabalpur district, Madhya Pradesh, most exhibited moderate adoption rates for rice (56%), soybean

Table 3. Summary of key variables used in the linear probability model

Variable	Mean	Unit
Age	44.87	Years
Farming experience	20.37	Years
Annual income	84871	Rupees (INR)
Area under cultivation	3.77	acres
Lower caste	0.92	Dummy (=1 if SC/ST/OBC, 0 otherwise)
Below poverty line	0.49	Dummy (=1 if BPL, 0 otherwise)
Credit	0.50	Dummy (=1 if availed credit, 0 otherwise
Membership in social organization	0.17	Dummy (=1 if has membership in any registered organization, 0 otherwise
Crop insurance	0.25	Dummy (=1 if subscribed PMFBY, 0 otherwise
Literacy	0.73	Dummy (=1 if literate, 0 otherwise)
Extension contacts	0.60	Dummy (=1 if has contact with KVK/ICAR-DWR, 0 otherwise)
Participation in the field demonstrations of IWMT	0.06	Dummy (=1 if participated, 0 otherwise)
IWM training participation	0.58	Dummy (=1 if participated, 0 otherwise)
Adoption	0.62	Dummy (=1 if adopted IWMT, 0 otherwise)

Table 4. Factors determines the adoption of improved weed management technologies

Dependent variable: Dummy for adoption			
Explanatory variable	Coefficient	Std. Error	Probability
Constant	-0.0408	0.0360	0.2591
Age	-0.0004	0.0007	0.5829
Farming experience	0.0014	0.0014	0.2988
Lower caste	0.0222	0.0158	0.1610
Annual income	0.0000	0.0000	0.1891
Below poverty line	0.0097	0.0150	0.5203
Credit	-0.0068	0.0131	0.6041
Membership in social organization	0.0151	0.0222	0.4965
Crop insurance	-0.0323	0.0233	0.1676
Area under cultivation	0.0015	0.0014	0.3046
Literacy	0.0193	0.0127	0.1314
Extension contacts	0.7029***	0.1330	0.0000
Participation in the field demonstrations of IWMT	0.2168**	0.1040	0.0382
IWMT training participation	0.2714**	0.1288	0.0363

*** Significant at 1% level; **Significant at 5% level

(49%), greengram (50%), and wheat (55%). Significant positive correlations were found between adoption levels and factors such as age, education, farm size, training, extension contacts, media exposure, input availability, and innovativeness. Rajashekar (2018) also reported similar results in Mahaboobnagar district, Telangana.

We employed Heteroskedasticity consistent robust standard errors in estimating the linear probability model. Notably, when predicted probabilities fall within the range of 0.2 to 0.8, the model yields consistent results (Hausman *et al.* 1998; Horrace and Oaxaca 2006). In our study, predicted probabilities ranged from 0.21 to 0.84 (**Figure 3**), reinforcing the model's suitability. Given the purpose of the analysis and the uncertainty about the cumulative distribution function of the error term, adhering to the linear model is advantageous (Hippel and Workman 2016, Ochalibe *et al.* 2015, Aditya *et al.* 2018).

Constraints faced by farmers in adopting weed management technologies

In the next stage of the study, we attempted to prioritize the adoption constraints faced by farmer respondents. In fact, we posed questions on various components of Integrated Weed Management Practices, considering IWMTs as part of the same, in order to obtain a holistic picture of the constraints in weed management in the rice-wheat system. For this, firstly we have identified important constraints through literature review and pilot survey. Subsequently, we included these constraints in the survey schedule. The responses were collected on a five-point continuum *viz.* strongly agree, somewhat agree, unsure, somewhat disagree and strongly agree. The scores were assigned as 5, 4, 3, 2 and 1, corresponding to strongly agree, somewhat agree, unsure, somewhat disagree and strongly disagree. Based on the total score, the average score for each constraint was calculated to ascertain the seriousness of each constraint, and finally, the ranking was done.

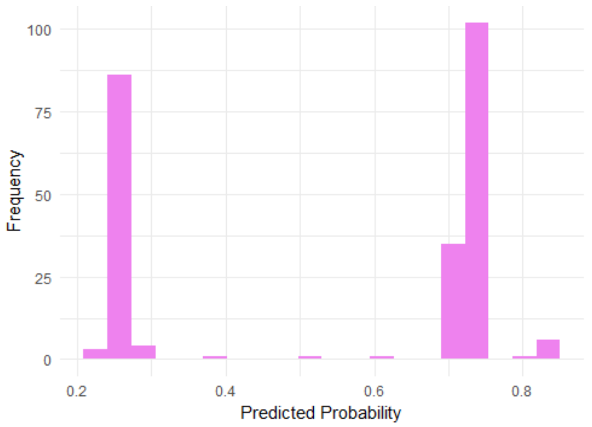

Figure 3. Histogram of predicted probabilities in the LPM estimation

The results (**Table 5**) indicated that the non-availability of laborers during the peak season for hand weeding ranked as the top constraint, with a total score of 701 and an average score of 2.92. The non-availability of skilled laborers for herbicide application appeared as the second-ranked constraint with an average score of 2.72, while the lack of knowledge about sprayers and nozzles was the third-ranked constraint, having an average score of 2.66. Interestingly, awareness-related constraints, such as the lack of awareness about chemical weed management technologies and mechanical weed management technologies, were found at the bottom of the table. This clearly indicates that farmers are aware of improved technologies through various extension activities; however, other constraints hinder their widespread adoption. Moreover, since labour availability is identified as the most significant constraint among others, it reinforces the importance of herbicide-based chemical weed management practices to achieve better productivity and profitability for farmers. Gharde and Singh (2021) identified key constraints in the adoption of weed management technologies by farmers, including a lack of technical expertise concerning herbicides, inadequate awareness regarding improved weed management technologies, and lack of knowledge about the precautions during spray of herbicides.

Table 5. Constraints faced by the respondents to adopt improved weed management technologies

Constraints	Total score	Average score	Rank
Non-availability of labourers during peak season for hand weeding	701	2.921	1
Non-availability of trained/skilled labourers for herbicide application	653	2.721	2
Lack of knowledge about sprayer and nozzle	639	2.663	3
Lack of proper technical knowledge about recommended dose of herbicides and its application	576	2.410	4
Lack of awareness about cultural methods of weed management	568	2.367	5
Non-availability of required spraying equipment and nozzles	562	2.342	6
Non-availability of herbicides at local level	558	2.325	7
Supply of spurious/adulterated herbicides	531	2.213	8
Lack of awareness about chemical weed management technologies	522	2.175	9
Lack of awareness about mechanical weed management technologies	519	2.163	10
Fear about the use of herbicides	503	2.096	11

Conclusion

The findings of the present study provide a micro-level insight into the adoption behavior of farmers concerning improved weed management technologies in the rice-wheat system. While the major weed flora found in both studied districts were the same, their composition differed. *Echinochloa colona* emerged as the most prevalent weed in rice fields, while *Phalaris minor* was reported as the most severe weed in wheat fields. Notably, *Cyperus rotundus* was identified as one of the most problematic weeds in both rice and wheat fields. Approximately 62% of farmer respondents adopted IWMT, while 38% did not. Socio-economic variables such as annual income, landholding, education, and access to credit exhibited significant differences between adopters and non-adopters. Extension contacts emerged as a highly significant variable determining the adoption of IWMT by farmers. Participation in improved weed management trainings and field demonstrations of IWMTs were other influential factors affecting adoption. Constraints related to labor availability, such as the unavailability of laborers during peak seasons for hand weeding and the absence of skilled laborers for herbicide application, were identified as the top-ranked constraints for adoption. Conversely, awareness-related constraints, such as the lack of knowledge about chemical and mechanical weed management technologies, were perceived as less significant barriers hindering the adoption of weed management technologies. This underscores the importance of improved weed management technologies, particularly chemical methods, for effective weed management in the rice-wheat system, leading to reduced yield losses and enhanced productivity.

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RESEARCH ARTICLE

Heavy metal adsorption potential of weed compost derived humic substances

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ABSTRACT

The chemical pollution due to anthropogenic origin especially through heavy metals, pesticides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls are serious threats to the environment, and their main sources are industry, transport, and agriculture. Most of these pollutants reach and accumulate air, water and/or soil and threaten the life on this planet. In this context, this paper mainly evaluates the Cadmium (Cd) and Lead (Pb) adsorption potential of weed compost derived humic substances for detoxification of these two heavy metals. Weed compost was produced during August to December from locally available weeds such as *Chromolaena odorata, Macaranga peltata, Lantana camara,* and *Mikania micarantha* in 3:2:1:1 proportion, and humic substances such as humic acid (HA) and fulvic acid (FA) were extracted using standard procedure. In particular, six different concentrations (2–10 mg) of lead nitrate and cadmium nitrate were used to study the adsorption of $Cd2^+$ and $Pb2^+$ onto HA and FA. The findings demonstrated that the adsorption of cadmium and lead on humic substances were positively correlated, increased with increase in concentrations of the metal ions. For Cd, HA showed maximum adsorption of 383.5 ppm at 10 mg, while FA showed 340.50 ppm. For Pb, HA and FA showed adsorption of 605.60 ppm and 595.60 ppm, respectively, at 10 mg. Lead adsorption by humic substances surpassed that of cadmium. In addition to heavy metal adsorption, this study also characterized the structural and functional properties of humic substances. The study revealed the heavy metal adsorption potential of weed compost derived humic substances.

Keywords - Cd, Fulvic acid, Heavy metals, Humic acid, Pb, Weed compost

INTRODUCTION

The environment is seriously threatened by chemical contamination, which mostly results from human activity. Among the most dangerous contaminants include pesticides, heavy metals, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). The main sources of these pollutants are transportation, agriculture, and industrial operations. The environmental implications of these pollutants are far-reaching. Heavy metals, such as lead, cadmium, mercury, and arsenic can accumulate in soil, water, and air, causing irreversible damage to ecosystems. Implementing best management practices (BMPs) can prevent heavy metal contamination and reduce environmental impacts. Instead of synthetic fertilizers, use organic amendments like compost, manure, or green manure one of the best methods to reduce heavy metal contamination and at the same time it improves soil physical properties, nutrient availability, soil carbon storage and microbial activity. The agricultural value of composts is increased when they are added to soil with more humified organic matter because the impacts of this organic matter in the soil persist longer. Two large groups of compounds found in compost are non humic and humic substances. Polysaccharides, sugars, proteins, amino acids, lipids, fatty acids, waxes, pigments and other substances of low molecular weight are non humic substances and heterogeneous with dark coloured substances with high molecular weight is the humic substances.

Humic substances are more stable organic matter which makes up a significant portion of the total soil organic carbon and nitrogen. They can improve soil buffering capacity, increase moisture retention, and supply plants with available nutrients. Moreover, these compounds can also bind metals, alleviating both heavy metal toxicity and metal deficiency in soils (McCarthy2001).

The importance of humic acid in improving agricultural soils is well established, especially in soils with low organic matter. It is an alternative for increasing crop production, and humic acid is a promising natural resource to be utilized.

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Due to the functional groups like OH, COOH, and COO- which aid the humic acid in enhancing the physico-chemical characteristics of the soil and biologically stimulating plant growth. It acts as a catalyst in promoting the activity of microorganisms in soil. Fulvic acid is effective in increasing drought resistance to plants, reducing leaching of fertilizer, stabilizing soil pH and improving uptake of nutrients. The ability of humic substances to form stable complexes has been well accepted. One of the most important parameter controlling heavy metal behavior in soils is the soil organic matter, together with soil pH. The insoluble humic substances bound on heavy metals are relatively immobile, but on the other hand, the metal mobility and bioavailability may increase if binding is on smaller organic molecules (Kabata-Pendias 1993). The formation of metal-humic complexes mainly involved with the carboxylic -COOH and phenolic -OH groups of humic substances. However, the organic matter complexation with both Cd and Pb is more important than their adsorption through cation exchange. The detailed information regarding the interaction of heavy metals with humic substances in soils can be applicable in the development of remediation methods for polluted soils (Halim *et al*. 2003). The migration and bioavailability of pollutants in the soil can be reduced significantly through complexation with organic matter. Fulvic acid has strong complexation with heavy metals and significantly affect the adsorption-desorption behavior of heavy metals in soil because of solubility of fulvic acid -metal complex (wang *et al*.2017). The phenolic and carboxyl groups on the molecular chain of humic acid interact with cationic metal to form spherical compounds, which claimed the soil remediation mechanism of humic acid. The humic acid is considered to have the greatest affinity with Pb^{2+}, Cu^{2+} (Yates and von Wandruszka's 1999).

Due to their structure and properties, they can interact with metal ions and, with them, form relatively stable complexes, and these substances are thus responsible for the so-called self-cleaning ability of soils and it can be used as an environmental friendly adsorbent for heavy metals (Klucakova and Pavlikova 2017).

Sustainable remediation strategies for treating soil are required due to high levels of heavy metals in soil, which otherwise leads to pollution of drinking water and contamination of food chain. The effect of several composts derived from source-separated and mixed municipal wastes in the presence and absence of lime were evaluated in a highly acidic heavily contaminated soil with As, Cu, Pb, and Zn. The results of the study indicated that PTE (potentially toxic element) amelioration was enhanced by compost, but at the same time lime had little effect and even exacerbated PTE mobilization (e.g., As) (Farrell and Jones 2010). Bioremediation experiments are generally carried out to reduce heavy metal bioavailability in contaminated soils utilizing manures and compost originated from different sources. A significant reduction in the concentrations of Cd in the shoots and roots of amaranth was observed by the application of 10–20 t/ha farmyard manure in a sandy loam soil (Alamgir *et al*. 2011). Similarly, application of manure decreased plant tissue concentration of three metals (Cu, Zn, and Pb) in Chenopodium album L. (Walker *et al.* 2004).

Toxic heavy metal such as Cd is used in electroplating industries, manufacturing vinyl plastics, metal and even in mining operations. The industrial wastes always contain significant amounts of Cd and Pb. One of the best methods to remove toxic metals like Cd and Pb is chelating with the humic substances such as humic and fulvic acids. Considering the above facts, and the superior quality of weed composts (Sujatha *et al.*2021), the present study aimed to explore the Cadmium (Cd) and Lead (Pb) adsorption potential of weed compost derived humic substances such as humic acid (HA) and fulvic acid (FA) for detoxification of these two heavy metals

MATERIALS AND METHODS

This study was conducted at Kerala Forest Research Institute, Kerala, India during the year 2023. The compost was produced from locally available weeds such as *Chromolaena odorata, Macaranga peltata, Lantana camara, and Mikania micarantha* in 3:2:1:1 proportion using farm derived inoculum namely *jeevamrutham* as described by (Sujatha *et al* 2021). The methodology employed for the extraction and characterization of humic and fulvic acids from the compost is outlined below.

Extraction of humic substances

The complex HA and FA present in the weed compost were extracted according to guide lines suggested by international humic substance society and (Satisha and Devarajan 2011).

Fifty g of sample was mixed with 500ml 0.1M NaOH (1:10) and shaken for 24hrs in a shaker. This mixture was then centrifuged at 3000 rpm for 15 mins. The alkaline supernatant was then collected, and the insoluble materials discarded. The pH of this alkaline supernatant containing both HA and FA was noted, and acidified using conc. HCl to make the pH 1. Once the pH became stable, it was allowed to precipitate. When the HA was completely precipitated, the clear supernatant containing fulvic acid was collected, and centrifuged at 3000rpm for30min.

The clear supernatant FA and the precipitate HA were collected, and dried in hot air oven.

Spectroscopic characterization of HA and FA

The E_4/E_6 ratio of HA and FA were measured in the visible (200-800nm) by Ultraviolet-Visible Spectroscopy (AgilentCary5000) (Dick and Burba 1999). One mg of HA and FA were dissolved in 10ml of 0.05N $NaHCO_3$ and the absorbance at 465 and 665 nm were measured. Fourier-transform infrared spectra (Thermo Nicolet Avtar 370) of HA and FA were recorded with a resolution of 4 cm^{-1}, at 4,000 to 400 cm^{-1} in KBr pellets method using DTGS detector.

Adsorption of heavy metals

The concentrations of Cadmium (Cd) and Lead (Pb) in the samples were determined using atomic absorption spectrophotometry (Varian 240 spectrophotometer) (Carbonell *et al.* 2009b). Element-specific cathode lamps and fuel oxidant systems were employed to ensure accurate analysis.

To investigate the adsorption of heavy metals by humic substances, 20 mg of humic acid and fulvic acid samples were prepared and mixed separately with different concentrations of lead nitrate ($PbNO_3$) and cadmium nitrate ($CdNO_3$) salts. Six different concentrations of each salt (2 mg, 4 mg, 5 mg,6mg,8mg, and 10mg) were considered. Each different concentrations(mg)of the metal salts along with 10 ml of distilled water is dissolved with 20 mg of each humic substances separately and stirred well by a magnetic stirrer.

The solutions were then centrifuged at 6500 rpm for 30 minutes to separate the solid and liquid phases. The supernatant was collected and analysed using atomic absorption spectroscopy (AAS) to determine the concentrations of $Pb2^+$ and $Cd2^+$ ions. This experimental procedure allowed for the investigation of the adsorption of cadmium and lead ions on humic acid and fulvic acid samples at different salt concentrations.

RESULTS AND DISSCUSSION

The weed compost was produced from locally available weeds as reported by (Sujatha *et al.* 2021) and humic substances such as humic acid and fulvic acid were extracted from it.

Characterization of humic substances

Fractions of humic and fulvic acids extracted from weed compost were identified using Ultraviolet-Visible Spectroscopy and Fourier-transform infrared spectroscopy (FTIR) spectroscopy

TheE4/E6 ratio of humic acid and fulvic acid samples were scanned in the 200–3000 nm region using Ultraviolet-Visible spectrophotometer. The absorbance ratio was considered as a traditional parameter in the case of humic substances to estimate its degree of humification and/or its molecular size. In order to characterize humic substances with respect of aromaticity, E4/E6 ratio is a valid and informative index. Further, the magnitude of the E4/E6 ratio of humic substances is related to the relative concentration of condensed aromatic rings in these materials frequently suggested in soils. As suggested by (Dick and Burba 1999) the ratio between absorbance (E_4/E_6ratio) at 465 and 645 nm was determined.

The higher E4/E6 ratio of fulvic acid than humic acid (**Table 1**) indicates greater proportion of aliphatic natured substances, and an equivalent finding was made by (Satisha and Devarajan 2011).

Table 1. E4/E6 ratios of fulvic and humic acids

	Absorbance at 465 nm	Absorbance at 665 nm	E4/E6 ratio
FA	0.0288	0.0031	9.29
HA	0.3793	0.0973	3.89

Therefore, the high E4/E6 ratios of humic substances supposedly indicates a relatively low concentration of condensed ring structures, which reflects a low degree of aromatic condensation and thus, infers the presence of relatively large proportions of aliphatic structures.

Fourier-transform infrared spectroscopy (FTIR) spectroscopy is a powerful tool that can be used in the identification of complex compounds and it serve as a qualitative tool for monitoring functional groups and bands of fulvic acids and humic acids. The IR spectra of the two humic fractions are shown in (**Figure 1** and **Figure 2**). They have a diversity of bands more or less typical to those distinguishing the humic materials. Major absorption bands are in the regions of 3400–3300/cm (H-bonded OH groups), 2940–2900/cm (aliphatic C–H stretching), 1750–1720/cm (CO stretching of COOH), 1620/cm (aromatic CC, COO-, H-bonded CO), 1280–1230/cm (C–O stretching and OH deformation of COOH) and 1040/cm (C–O stretching of polysaccharide). It is clear from the spectra that fulvic acid is characterized by absorption near 1767/cm, which implies the

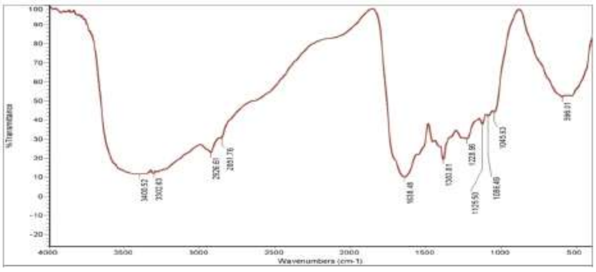

Figure 1. Fourier-transform infrared spectra of humic acid

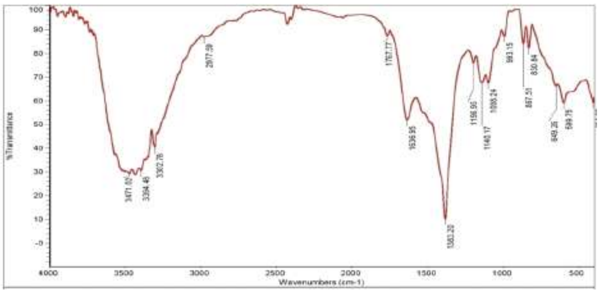

Figure 2. Fourier-transform infrared spectra of fulvic acid

dominant carboxylate groups. The spectra evidently show predominance of OH, COOH and COO-groups which are the most characteristic features of humic materials.

Adsorption of heavy metals

Adsorption of heavy metals such as Cd^{2+} and Pb^{2+}on HA and FA extracted from weed compost was tested in different concentrations of respective metallic salts, such as cadmium nitrate and lead nitrate. The data obtained are given in the (**Tables 2-5**).

Results of cadmium adsorption by HA at different concentrations are shown in (**Table 2**). The amount of cadmium adsorbed by HA increases with increasing cadmium concentration, from 84.91 ppm at 2 mg to 383.5 ppm at 10 mg. The efficiency remains relatively high across all concentrations.

Table 2. Adsorption of Cd on HA

Weight of HA (mg)	Concentration of salt (mg)	Total Cadmium (ppm)	Free Cadmium (ppm)	Cadmium adsorbed (ppm)
	2	95	10.09	84.91
	4	190	17.51	172.49
	5	237	23	214
20	6	285	30.09	254.91
	8	380	52.73	327.27
	10	475	91.5	383.5

The results of cadmium adsorption by FA at various cadmium salt concentrations are shown in (**Table 3**). The amount of cadmium adsorbed by FA increases with increasing cadmium concentration, from 62.74 ppm at 2 mg to 340.50 ppm at 10 mg.

Table 3. Adsorption of Cd on FA

Weight of FA (mg)	Concentration of salt (mg)	Total Cadmium (ppm)	Free Cadmium (ppm)	Cadmium adsorbed (ppm)
	2	95	32.26	62.74
	4	190	46.10	143.90
	5	237	55	182
20	6	285	65.87	219.13
	8	380	94.12	285.88
	10	475	134.5	340.50

The amount of cadmium adsorbed by FA is lower than that adsorbed by HA at the same concentrations. Humic acid adsorbed 383.50 ppm of cadmium while fulvic acid adsorbed 340.50 ppm of cadmium in 10 mg of salt. Compared to FA, HA has a higher adsorption efficiency. Whereas FA's adsorption efficiency was 71%, HA was 80%.

It is inferred from the data that adsorption of Cd on HA and FA increases with increase in the concentration of metal ions (**Figure 3** and **Figure 4**). The adsorption was remarkably higher on HA than FA.

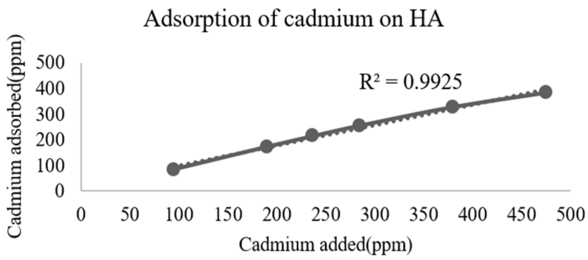

Figure 3. Humic acid-Cadmium (Cd)

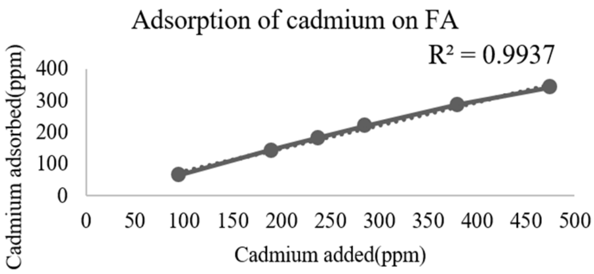

Figure 4. Fulvic acid- Cadmium (Cd)

The findings of Lead (Pb) adsorption on HA at various Lead salt concentrations are shown in the (**Table 4**). With an increase in lead concentration, the amount of lead absorbed by HA rises from 122.94 ppm at 2 mg to 605.60 ppm at 10 mg. The results suggest that HA is highly effective in adsorbing lead ions from solution, with an average adsorption efficiency of 97%. The adsorption capacity of HA increases with increasing lead concentration, indicating its potential as a natural adsorbent for lead removal.

Table 4. Adsorption of Pb on HA

Weight of HA (mg)	Concentration of salt (mg)	Total Lead (ppm)	Free Lead (ppm)	Lead adsorbed (ppm)
	2	125.12	2.18	122.94
	4	250.24	3.79	246.45
	5	312.8	5	307.80
20	6	375.36	6.60	368.76
	8	500.48	11.49	488.99
	10	625.6	20	605.60

The results of lead (Pb) adsorption by FA at various cadmium salt concentrations are shown in (**Table 5**). With an increase in lead concentration, FA adsorbed more lead from 115.22 ppm at 2 mg to 595.60 ppm at 10 mg. The amount of lead adsorbed by FA is lower than that adsorbed by HA at the same concentrations. HA adsorbed 605.60 ppm of lead and FA adsorbed 595.60 ppm of lead in 10 mg of salt. The adsorption efficiency of HA is slightly higher than that of FA. The adsorption efficiency of HA was 96.8% at 10 mg of salt, whereas FA's was about 95.2%. Overall, the results suggest that both HA and FA are effective in adsorbing lead ions from solution, but HA has a slightly higher adsorption efficiency.

Table 5. Adsorption of Pb on FA

Weight of FA (mg)	Concentration of salt (mg)	Total Lead (ppm)	Free Lead (ppm)	Lead adsorbed (ppm)
	2	125.12	9.90	115.22
	4	250.24	13.06	237.18
	5	312.8	15	297.80
20	6	375.36	17.23	358.13
	8	500.48	22.74	477.74
	10	625.6	30	595.60

The data in general indicated that, as the concentration of the Pb^{2+}increased, their adsorption on both HA and FA also increased (**Figure 5** and **Figure 6)**.

The research studies on humic substances interactions with heavy metals from natural bulk material like compost counts few. The metal ions and humic acids interactions are complex in nature due to their heterogeneous, polyelectrolyte and poly dispersive character by (Klucakova and Pavlikova 2017). Due to predominance of OH, COOH and COO-groups humic acid can interact with the heavy metals in soil (Hizal and apek 2006).

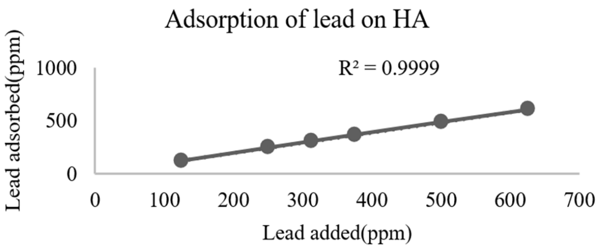

Figure 5. Humic acid-Lead (Pb)

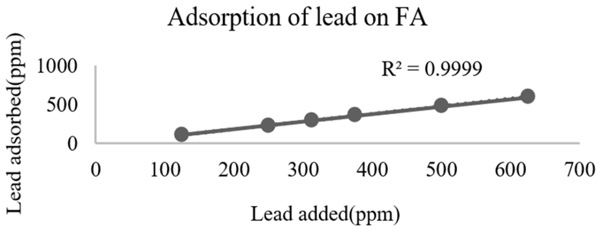

Figure 6. Fulvic acid -Lead (Pb)

Conclusion

Humic acid is a kind of organic matter, whose inner structure contains not only abundant benzene ring but also some complex functional groups such as hydroxyl group(-OH), carboxyl group (R-COOH) which can provide electrons to coordinate with heavy metals to form into complex compounds or chelates. The coordination mentioned in the results positively related to the concentration of metal ions. Meanwhile, humic acid can easily be adsorbed on the surface of soil colloid. Therefore, adsorption sites in soil particle will increase. It is the combined effects of coordination and adsorption that makes the concentration of available heavy metals decrease in a comparatively large scale. The humic substances can bond with metal ions in several different ways from the net negative charge on the surface of a humic particle with purely electrostatic, nonspecific interaction of metal cation to specific interactions in the formation of complexes and chelates with functional groups (Klucakova and Pekar 2006).

The results suggest that both HA and FA are effective in adsorbing cadmium and lead ions from solution, but HA has a slightly higher adsorption efficiency. Among two toxic heavy metals, adsorption capacity of HA is greater than FA indicating its potential as a natural adsorbent for heavy metal removal and more potential for lead removal.

The humic substances act as a natural barrier for the pollution due to anthropogenic origin. The active functional groups such as OH, COOH and COO-groups present in the humic substances adsorb the pollutants leading to the detoxification. The weed compost was additionally endowed with higher content of phytochemicals which lead to the formation of humic substances with active functional groups for detoxification of heavy metals.

Based on the study it is revealed that humic substances produced from weed compost have great potential in detoxifying the pollution due to heavy metals.

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RESEARCH ARTICLE

Efficacy and environmental safety of flame weeding in the humid tropical region

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ABSTRACT

Weed management in agriculture and landscaping is a great need, especially in the humid tropics where there is a vast species diversity and conducive environment for weed growth. High cost and residual effects of popular pre-emergent herbicides urge for low cost and eco-friendly alternatives. Even though manual weeding is eco-friendly, its small operational scale and low disturbance to the underground parts does not meet the efficacy of control. At this backdrop, thermal stress caused weed suppression by flame weeding was carried-out with the objective of detecting its efficacy as well as possible negative effects on the micro flora in the top soil. A five-burner flame weeder was used for the experiment conducted at the experimental farm of the University of Peradeniya, Sri Lanka (under humid tropical conditions) during the dry season in 2021, in a replicated trial. Moisture content of the top soil was maintained at near 40±8.5 % (w/w) of the field capacity. Rates of plant mortality and reemergence of three prominent weed species, and also the rate of suppression of the microbial population due to burning were determined before and after the application of flame. The theoretical and actual field capacity of flame weeding was 0.162 ha/hr and 0.119 ha/hr, respectively while weeding efficiency was 73.5 %. Effect of flame weeding on delaying re-immergence of broad leaves was faster than the sedges and grasses, limiting the rate of re-immergence of the weed population to initial population density by 24 days. Effect of flame weeding on micro-flora in soil is insignificant, both at the top level and at 5 cm depth. Eventhough CO2 emission rate (26.9 kg/ha) was higher than mechanical weeders, less frequent repeated weeding need makes it similar to them on seasonal or yearly basis. Based on its field capacity, weeding efficiency and environment friendly nature, flame weeding could be recommended to dry regions and seasons of the humid tropics.

Keywords*:* Eco-friendly, Recovery rate, Soil microbial biomass, Weed management, Weed types

INTRODUCTION

Agricultural lands occupy 20.7% of the total land area of 25600 km^2 in Sri Lanka while other countries in the humid tropical region of the world possess for even more percentage of extent of cultivation. This sector comprises of food crops (e.g. rice, other cereals, pulses, fruits and vegetables), plantation crops (tea, rubber and coconut) and spice crops (cinnamon, pepper, cloves and Nutmeg, *etc*.) (Central Bank Report 2016). Weeds, insect pests and pathogens are the three major biological factors affecting agriculture. Among these, weeds cause significant crop losses and yield reduction. The impact of weeds on productivity of food crops have been increasingly experienced worldwide. Marambe *et al.* (2009) estimates 50% crop losses due to weed competition in Sri Lanka. According to (Gharde *et al.* 2018) total actual economic loss due to weeds alone in 10 major field crops of India was estimated as USD 11 billion. Further it reduces the quality of crop harvest and threatens the native biodiversity. The annual global economic loss caused by weeds has been estimated at more than $100 billion U.S. dollars (Appleby *et al.* 2000). Several technologies are available for managing weeds in agricultural fields. One of the traditional methods for weed control is hand weeding. Smallholder farmers practice hand weeding by pulling or using simple tools such as hand-held hoe and inter-cultivators (Rao *et al.* 2017). However, labor shortage and tediousness in handling hard-to-pull grassy weeds (*e.g. Echinochloa crus-galli*), make hand weeding is less practicable. Mulching and intercropping are two agronomic methods used to suppress weed growth. Organic mulches such as leaf litter, rice straw, rice hull, saw

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dust, *etc*. provide stronger physical barriers to all kinds of germinating weeds. Apart from that healthy ground cover (live mulch) maintained using less competitive weed species can also provide all-round protection for the crop. Meanwhile, another chapter in weed management opens up with weed suppression through allelopathy, which utilizes the inhibitory effects of phytochemicals secrete from the crop or companion species on the germination, early growth and reproduction of weed species (Saha *et al.* 2018). On top of all these options, the most popular option for weed control in agriculture is the use of synthetic herbicides. It was part of the large-scale agriculture introduced during the green revolution nearly 70 years ago in the world (Sharma and Singhvi, 2017). High efficacy and relatively low cost of herbicide application has made it popular among farmers all over the world, despite its negative impact on human health and the environment. Some nations and areas have outlawed the use of highly toxic herbicides. As an eco-friendly alternative to herbicide use, integrated weed management (IWM) in which farmers try to maintain the weed population below the economic threshold level.

Meanwhile with the recent boom in mechanization and automation, use of mechanical and power weeders or grass cutters have becoming increasingly popular among the farmers all over the world. Mechanical weeders were reported to reduce 74% of the need for labour and 72% of the cost of weed control (Islam *et al.* 2016). Shekhar et al. (2010) tested range of mechanical weeder options, namely field hoe, grubber, Khurpai and power weeder under hot and humid field conditions in India and found their actual field capacity (AFC) was 0.002 – 0.008 ha/hr while field efficiency (FE) was within 76.4–94.7%. Starting from tractor mounted conventional power weeders introduced in 1980s, and its versatile more popular version of man-operated brush cutter in 1990s, the global agriculture has moved to much more precise inter and intra row weeders such as sensor-based brush, finger and eco weeder, for large, raw planted fields and they have been further upgraded with artificial intelligence (AI) tools during last few years (Kumar *et al.* 2022, Vasileiou *et al.* 2023). However, fast re-growth of weed species from the undisturbed root system is a disadvantage for the use of power weeders. At this backdrop, "flame weeding" can be considered as another effective weed control option. Flame weeding is a type of thermal weed control method used from the late 1930s until the mid-1960s (Raffaelli *et al.* 2010, Ulloa *et al.* 2010). This relies on liquefied petroleum gas (LPG) burners to produce a carefully controlled and directed flame that briefly passes over the weed. Flaming is more effective on tender, herbaceous plants with high water content such as seedling or juvenile annual weeds, and particularly on broadleaf weeds. However, its efficacy in controlling grasses and sedges, and the possible damage the flame can do on useful flora and fauna in the eco-system and also its detrimental effects on soil flora and fauna are still debatable (Altheiri 1980, Abou *et al.* 2018). Therefore, this experiment was conducted to investigate the efficacy of flame weeding and investigate its side effects on soil and atmosphere under humid tropical conditions in Sri Lanka.

MATERIALS AND METHODS

Burner type and specifications

The flame weeder was fabricated in the Agriculture Engineering Department of the University of Peradeniya in Sri Lanka (**Figure 1a** and **1b**). It was a five-burner weeder, having a width of 90 cm and a 20 cm distance between adjoining burners. Weeder and the gas cylinder were mounted on to a steel frame and supported on to a push-cart type two-wheel frame. The unit was maneuvered by a waist height handle (**Figure 1a**). It was an "open-flame" type atmospheric burner that utilize LPG in gaseous form. The flame length was nearly 20±2.4 cm while the mean flame temperature was 1416±107.2° C. The nozzle size was 0.7 mm. Gas pressure was maintained within 3–5 x 10^{-5} Pa during the operation.

Experimental setup and design criteria

The field experiment was conducted in the experimental farm of the University of Peradeniya in Sri Lanka during March–April in 2021. The location belongs to mid-country wet zone of Sri Lanka, having an annual rainfall of 3000 mm and an average temperature of 28° C. The soil type of the region was red-yellow podolic (RYP). A flat land, which is subjected to grass cutting (moving) three months before the experiment was used for the flame weeder testing under dry weather conditions (having soil moisture content at 40±8,5 %. High temperature shock was given to weeds by applying a uniform flame by moving the weeder at the speed of 3-5 km/hr in a single run. Weeding was done in two-meter plots keeping five (05) replicates. Each plot contained all three types of weeds at a density of 18 -23 weeds ft^{-2} before flame weeding. Main three weed types, categoried according to their morphological features, namely grasses, sedges and broad leaves (Altieri,

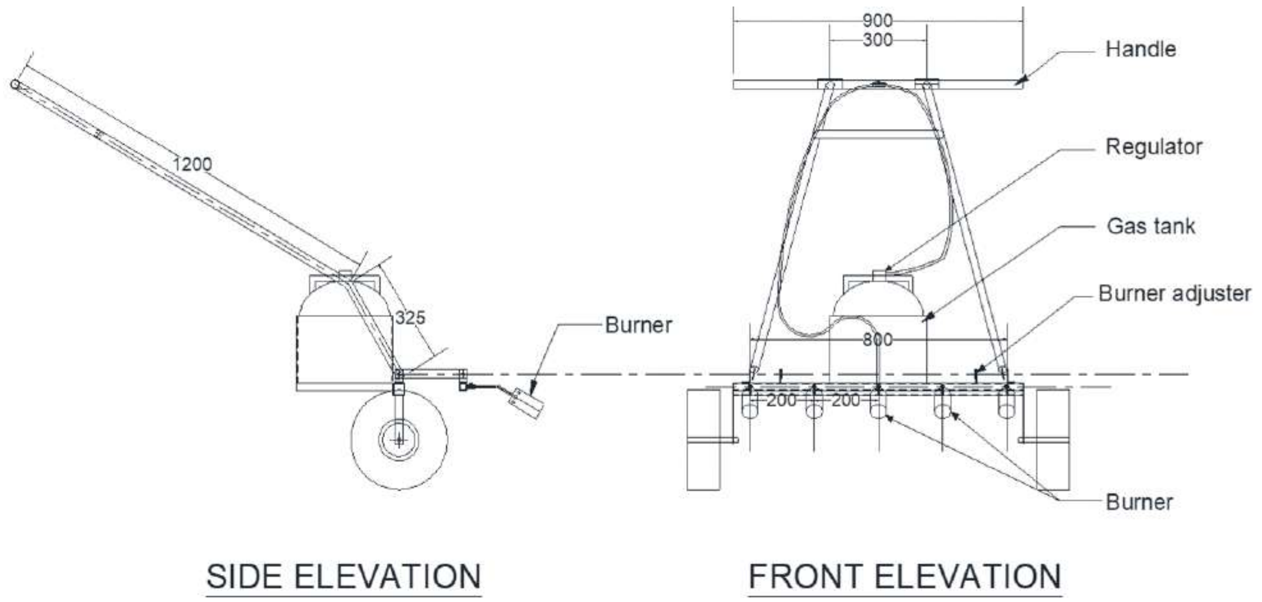

Figure 1a Main components of the five-burner flame weeder (dimensions are given in mm) [*Copy rights reserved*]

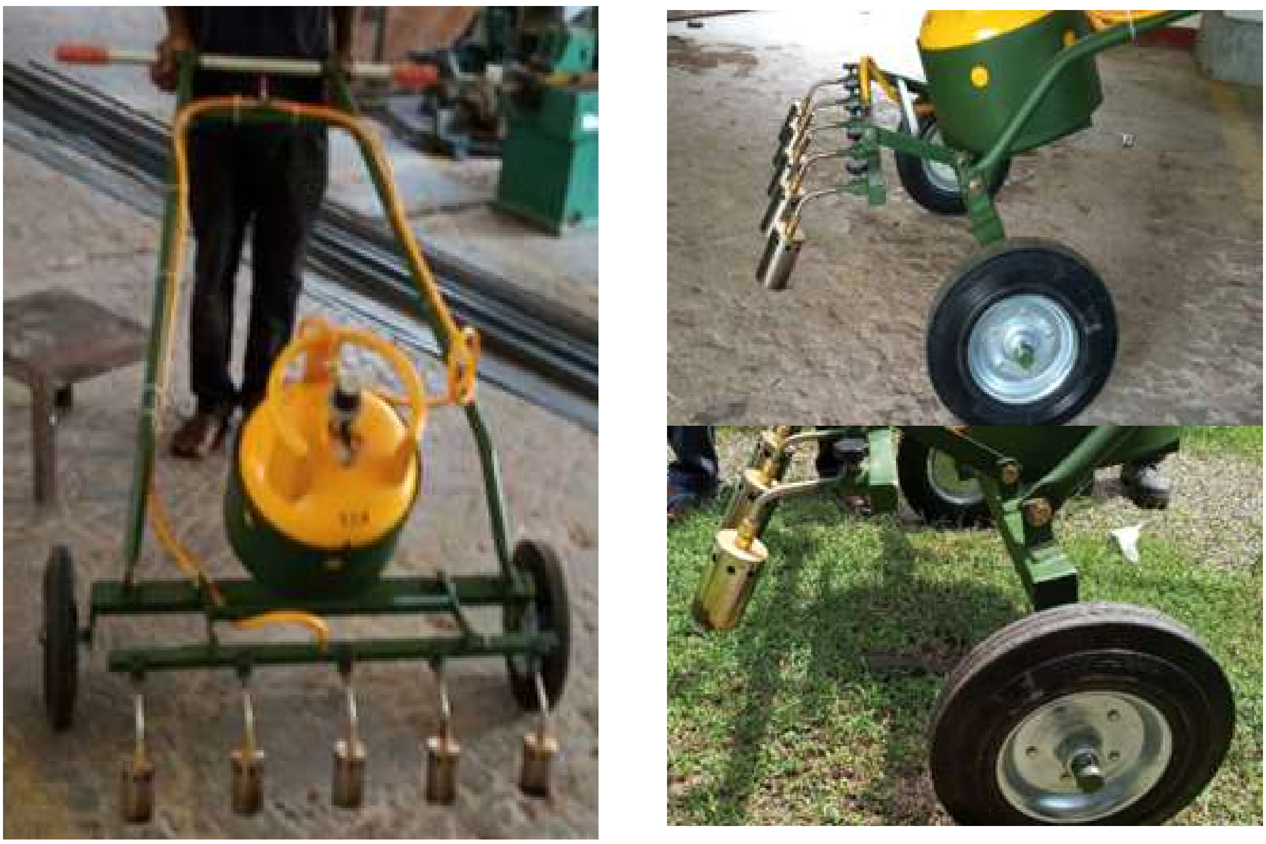

Figure 1b. Flame weeder – Front elevation (Left); Burner alignment and gas supply (top right); Burner mount and gas regulation (bottom right)

[Designed and manufactured by the Department of Agricultural Engineering, University of Peradeniya]

1988) present in each plot were considered as weed treatments (03) (independent variable) while the counts of three types of weeds (broad leaves, grasses and sedges) before and after weeding and microbial colony counts were considered as the assessment criteria (dependent variables).

Weeder performance testing

The weeder performance was tested on a flat grassy upland agricultural field during off-season (without having crops). Data collected for computing the following parameters to assess the weeder performance;

Table 1. Diversity of weed population at the research field

No.	Common name	Local (*Sinhala*) name	Botanical name	Family
01.	Coatbuttons[1]	*Kurunegala dasi*	*Tridax procumbens*	Asteraceae
02.	Coco-grass[3]	*Kaladuru*	*Cyperus rotundus*	Cyperaceae
04.	Citronella grass[2]	*Mana*	*Cymbopogon nardus*	Poaceae
05.	Blady grass[2]	*Illuk*	*Imperata cylindrica*	Poaceae
06.	Lilac tasselflower[1]	*Kadupahara*	*Emilia sonchifolia*	Asteracea
07.	Joy weed[1]	*Mukunuwenna*	*Alternanthera sp*	Amaranthaceae
08.	Copperleaf[1]	*Kuppameniya*	*Acalypha indica*	Euphorbiacea
09.	Little Ironweed[1]	*Monarakudumbiya*	*Vernonia cinerea*	Asteracea
10.	wild indigo[1]	*Kathurupila*	*Tephrosia purpurea*	Fabaceae

[1]Broad-leaves, [2]Grasses, [3]Sedges

Table 2. Weeding parameters of flame weeding

Parameter	Technical field capacity (ha/hr)	Actual field Capacity (ha/hr)	Field efficiency (%)	Weeding efficiency (%)
Value	0.162	0.119	73.5	93

Field capacity (FC): FC indicates the area (in hectares) covered by the weeder to completely exert its harmful action on weeds within a limited time (per hour), and was determined based on the following formula (Shekhar *et al.* 2010).

Theoretical field capacity $(TFC) = (WxS/10)$ in ha/hr

where W – width in m; S – speed in km/hr

Actual field capacity (AFC) = Time taken in hrs to operate the weeder within a 1 ha field.

Field efficiency = (AFC/TFC) * 100

Weeding efficiency (WE): WE indicates the percentage number of weeds or weed biomass effectively controlled by the weeder in a given land mass after exerting its harmful action. It was determined using the following formulae (Shekhar *et al.* 2010).

WE = ((W1 – W2)/ W2) x 100   W1 – Weed count or biomass before weeding
W2 – Weed count or biomass after weeding

Determination of effect of flame weeding on re-emergence of weeds

After application of the gas flame on the weedy experimental plot, re-emergence or re-growth of each weed group were determined by counting them plot wise. Measurements were taken 7 days after the application of flame. Then data were collected on three-day intervals until 24th day after application of the flame. Weed suppression and re-growth was presented as a percentage of the initial weed count.

Determination of the effect of flame weeding on soil microbial population

Effect of flame weeding on soil microbial properties was examined immediately after the application of flame and also at 01 week after the application of flame. Here, soil samples were collected on the top of the soil layer and a 5 cm depth from the top layer. Microbial populations were counted as cfu/g with using four dilution series (10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}).

Estimation of GHG emissions by the flame weeder

Estimation of the emission of greenhouse gasses (GHG), namely CO_2 (carbon dioxide), CH_4 (methane) and NO_2 (nitrous oxide), by a standard gas nozzle fixed to the flame weeder within a unit time (per hr) was used to estimate the rate of GHG emitted by the flame weeder during its operation. Estimations were done by using the following parameter estimates and computational protocols.

Time of operation (hr/ha):

$$\text{Time of peration} = \frac{\text{length of the field x Number of turns}}{\text{Speed of movement}}$$

$$\text{Number of turns} = \frac{\text{Width of the field}}{\text{Flame or Cutting span}}$$

CO_2 emission per hectare (kg/ha):

$$\text{CO2 emmision} = \text{CO2 emission rate x Time of operation x Fuel consumption}$$

<u>Assumptions/ Constants</u>:

CO_2 emission rate: Petrolium = 3.07 kg/L; LP gas = 2.98 kg/kg [2.3 L/kg]

(Ref. Watson and Gowdie, 2000)

Fuel consumption: Brush cutter = 500-750 Petrol L/hr (Manufactures spcifications); Flame weeder = 1.46 LP gas kg/hr (Test results)

Statistical analysis of data

Five repeated weeding observations in different but equally dense field plots were taken for testing the detrimental effects of the flame weeder (replicates). Mean weed numbers and standard deviations of repeated tests were computed on each weed type.

The count data of weed and microbial coloney counts which were lower than 30 in number were subjected to non-parametric data analysis through Kruskal–Wallis test using statistical software, SPSS (IBM Coop 2020).

RESULTS AND DISCUSSION

Diversity of weed population at the research field

There were ten main weed species abundantly in the field which belong to the sub-categories, broad leaves, grasses and sedges **(Table 1).** Hence their propagules, rate of growth and impact resistance *etc.* must be entirely different.

Field capacity and weeding efficiency

Theoretical field capacity (TFC) was calculated based on the average moving speed of 1.8 km per hour. The width of the burner span moving at the average speed made TFC to be 0.162 ha per hour, slightly higher than the TFC of a brush cutter (0.154 ha/hr) but incomparable with power weeders (0.67 ha/hr) (Shekhar *et al.* 2010, Elkoud *et al.* 2022). Meanwhile the actual field capacity (AFC) tested during the weeding trials (**Table 2**) gave a similar value of 0.119 ha/hr to brush cutters (0.118 ha/hr) (Elkoud *et al.* 2022) but much higher than manual weeding gear (0.001 – 0.033) such as wheel hoe, grubber and Khurpi (Kumar et al., 2022). Hence the field efficiency (FE) was relatively lower (73.5 %) than brush cutters (76.6 %) (Elkoud *et al.* 2022).

As shown in **Table 2**. a relatively higher weeding efficiency (WE), calculated based on the number of weeds (93 %), was found compared to relatively low WE of power weeders (89.9 %), reported by Shaker et al. (2010). The reason could be the burning effect resulted on all flora on the ground by the flame.

Effect of flame weeding on re-emergence of weeds

According to **Figure 2**, dotted lines indicate the initial weed population of each type of weed, and solid lines indicate the regrowth of each weed types after flame weeding. Broad leaves type of weeds didn't reach to initial weed population even after 24 days of flame weeding. Sedges and grass type of weeds took 13 - 16 days after flame weeding and 16 - 19 days after flame weeding, respectively. From 13 - 24th days after flame weeding the regrowth rates between grasses and sedges are not significantly different and higher than broad leaves. The rate of regrowth of broad leaves is significantly lower than the other two weed types from the very beginning. Due to rapid regrowth, grasses and sedges should can be successfully controlled by repeated flame weeding at 10 - 16 days after the first weeding practice. But the control is very effective for broad leaves until 24 days after weeding or bit longer.

According to the studies conducted by Abou Chehade et al. (2018), application of pre-emergent weedicides (Glyphosate), showing a slight weed cover decrease of 15% (±7%) 27 days after the application or the weed cover did not increase and remained statistically in sedges type of weeds. But after flame weeding, regrowth increased up to 90–94% (±5%) 27 days after flame weeding. This fact could be assured by the current study with respect to regrowth of sedges after flame weeding. Another study has assured application of Nonanoic acid also for suppression of weeds but regrowth of sedges up to 98–100% (±5%) after 27 days of application (Sivalingam *et al.* 2022).

GHG emissions

As a part of the environmental impact of different weeding options, Greenhouse gas (GHG) emissions are considered. Compared to CO_2, the emission of other GHGs such as methane and N_2O are considered negligible for petroleum as well as LP gas burning. However, the rate of fuel consumption for a five-burner flame is relatively higher (1.4 L/hr) while it is 500 – 750 ml/hr for a brush cutter (with the capacity of 1.1 – 1.3 kW power). In the meantime, the rate of weeding and rate of CO_2 emissions are not much different between two optional weeding methods. Therefore, CO_2 emissions from flame weeding becomes significantly higher (26.9 kg/kg) than that of mechanical weeding such as brush cutters (14.9 kg/L). However, when consider a few

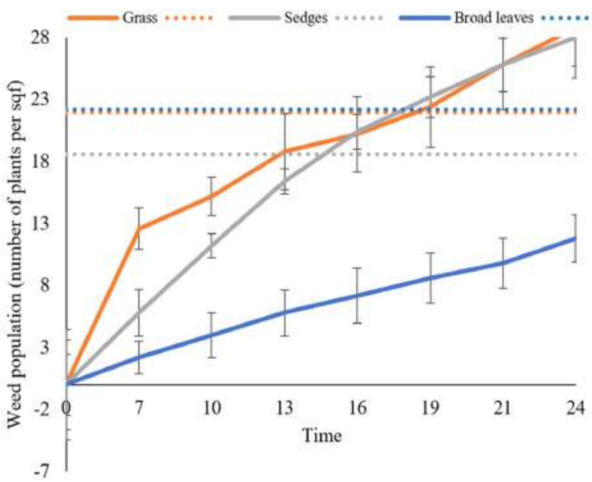

Figure 2. Rate of re-emergence of weeds after flame weeding

(Vertical bars indicate the SE of means at p=0.05) months' period or a cultivation season, low recovery rate (**Figure 2**) under flame weeding requires less frequent repeated weeding compared to mechanical weeding. This is very much obvious when flame weeding of predominantly broad leaf weed infested fields. Therefore, GHG emissions from flame weeding could be either similar or lesser than mechanical weeding options for a relatively long period.

Effect of flame weeding on soil microbial population

According to **Figure 3**, a higher microbial population was observed in one week after flaming in top soil. The microbial population is decreased just after flaming in both top soil and soil in 5 cm depth. After one week of flaming, microbial population in both top soil and soil in 5 cm depth, increased than the initial population (Hatcher and Melander (2003) stated that flame weeding could be detrimental to some airborne as well as soil-surface-inhabiting organisms. Soil is a very good insulator and can absorb a significant amount of heat with little increase in temperature flame weeding the thermal treatment is brief and during the flame weeding only the uppermost few milli meters of the soil are heated. Therefore, a significant damage to the soil microflora or fauna is not expected during a normal flame weed control operation (Rahkonen *et al.* 1999).

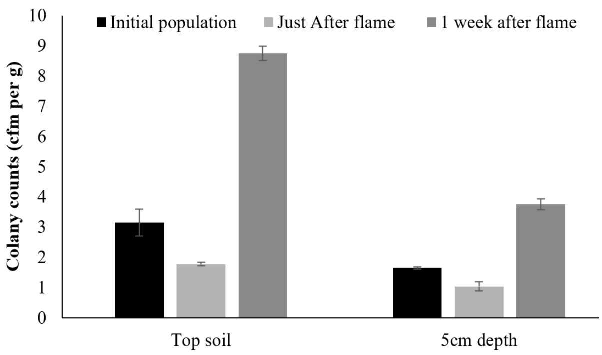

Figure 3. Suppression ad regrowth of microbial population at different soil depths

(Vertical bars indicate SE of the means at p=0.05)

Thermal weed control options are eco-friendly because they do not leave chemical residues in the crop, soil and water and can control herbicide-tolerant or resistant weeds, and provide rapid weed control. In the current study, flame weeding was found most suitable for controlling broad leaved weeds, because the population of broad leaves did not reach to initial population density even at 24 days after flaming. And also, the adverse effects of flame weeding on the microbial population was found to be insignificant. Therefore, the thermal (flame) weeding can be recommended for weed control under humid tropical conditions, particularly in the dry season.

Conclusion

The newly developed flame weeder is equally capable and efficient in weed control to common mechanical weeders in terms of weeding efficiency and actual field capacity. Eventhough its rate of GHGs emission is somewhat higher, less frequent repeated weeding need due to relatively high degree of weed suppression makes it insignificant in a long-run. Among different types of weeds, flame can control broad leaves much better than grasses and sedges. In addition to its lack of residual effect (agro-chemical) on the environment, the possible influence of flame weeding on soil microorganisms at shallow depths is considerable but their regain is much faster and greater. Hence five-burner flame weeder designed and manufactured by the Agricultural Engineering Department of the University of Peradeniya can be recommended as a high capacity, efficient and eco-friendly weeder for humid tropical countries.

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RESEARCH ARTICLE

Occupational work-related health hazards among workers involved in weeding activity

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ABSTRACT

Occupational health hazards in agriculture, particularly during weeding activities, pose significant risks to farmers' well-being. Most of the work in the agriculture field are performed manually using traditional hand tools. These hand tools lack ergonomic design, causing excessive strain on workers and leading to musculoskeletal disorders (MSDs) throughout their bodies. The study aims to identify and analyze the occupational health hazards faced by workers involved in manual weeding activities in agriculture. Data showed that 94% of respondents experienced muscle fatigue and pain, 88% reported reduced grip strength, and 79% had tingling sensations in fingers. The most frequent health issues included pain in fingers, shoulders, and wrists (mean score 2.22), muscle fatigue (2.16), and reduced grip strength (2.13). Perceived exertion during weeding was rated as moderately heavy by 44.5% of respondents. The highest joint discomfort was in the back (mean rating 4.08) and lower back (4.03). Work-Related Musculoskeletal Disorders (WMSDs) were common, with the lower back, knee, and shoulder being most affected. Acute pain was prevalent in the lower back (75%), upper back (65%), and knee (60%). These findings highlight the need for better ergonomic tools and practices in agriculture.

Keywords: Musculoskeletal disorders, Occupational health hazards, Perceived discomfort, Weeding activity

INTRODUCTION

Occupational well-being is essential for farm workers in the agricultural sector, as it significantly affects their health, safety, and productivity (Reed and Wachs 2004). Ergonomics is pivotal in this context, influencing workers' well-being through the design of tools, workstation arrangements, and ergonomic practices. By addressing factors such as posture, repetitive movements, and tool design, the risk of musculoskeletal disorders (MSDs) is reduced, leading to enhanced job satisfaction. Customizing tools to match individual physical capabilities improves comfort and efficiency, thereby promoting job retention and skill development. This holistic approach not only fosters a healthier workforce but also supports sustainable agriculture and strengthens the resilience of farming communities. Ergonomic disorders are currently the fastest-growing category of work-related illnesses, accounting for 56-63 percent of illnesses reported to OSHA, according to the latest statistics from the U.S. Bureau of Labor Statistics (Tarlengco 2024).

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Manual weeding remains a common practice in Indian agriculture, particularly in North East India and Assam, due to factors such as unreliable labor and increasing wages (Yaka, 2017). This method is predominantly employed by small-scale and subsistence farmers with limited land holdings, exposing workers to various health risks including musculoskeletal disorders (MSDs) and general discomfort. These risks are often exacerbated by the design of traditional tools, such as hoes, sickles, and weeding hooks, which do not always consider the ergonomic needs of users (Khayer *et al.* 2019). Despite these challenges, manual weeding plays a crucial role in weed control and provides significant employment opportunities, especially for rural women and marginalized communities, thus making a substantial contribution to Assam's agricultural sector.

Workers engaged in weeding face multiple challenges affecting their well-being and productivity. Studies have highlighted issues such as musculoskeletal problems, exhaustion, and pain (Singh 2007, Parvez 2017). Extreme weather conditions, including heat stress in summer and cold in winter, further complicate their work, while the use of traditional tools and poor posture during weeding exacerbate these problems, leading to increased physical strain and musculoskeletal disorders

(Burman *et al.* 2020). The lack of ergonomic tools designed specifically for weeding tasks contributes to poor work postures and repetitive strain injuries, reducing efficiency. Additionally, insufficient training and awareness about safe weeding practices lead to a higher incidence of work-related injuries and health issues.

The physical demands of weeding, involving manual handling of materials, often lead to musculoskeletal disorders (MSDs) such as lower back, shoulder, and upper limb strains and sprains (NIOSH, 2007). Addressing these occupational risks through ergonomic interventions is essential for reducing adverse health effects and enhancing worker well-being. Integrating ergonomic principles into agricultural tasks, including wedding, can significantly lower injury rates and boost job satisfaction. By applying ergonomic design to tools, workstations, and processes, agricultural organizations can create safer, more sustainable work environments, helping to prevent work-related musculoskeletal disorders (Aptel *et al.* 2002).

MATERIALS AND METHODS

Study design

This study employed a cross-sectional design to explore the occupational health hazards associated with manual weeding activities among agricultural workers. Data were collected through a combination of surveys, interviews, and direct observations to gain comprehensive insights into the musculoskeletal problems and perceived exertion faced by workers.

Time period of Study: 2022-2024

Sample selection

The study sample consisted of 200 agricultural workers engaged in manual weeding activities across various farms in Assam. Participants were selected using purposive sampling to ensure a representative mix of gender, age, and work experience. The inclusion criteria required participants to have at least one year of experience in weeding activities, ensuring familiarity with the tasks involved.

Data collection tools

Questionnaire: A structured questionnaire was developed based on the Standard Nordic Musculoskeletal Questionnaire (SNQ) to assess musculoskeletal problems. The questionnaire included sections on demographic information, work history, types of tools used, and detailed questions on the frequency, severity, and location of musculoskeletal pain.

Three-point rating scale: To assess the severity of pain, a three-point rating scale was used, categorizing the pain as acute (3), less acute (2), and negligible (1).

Perceived exertion scale: A five-point rating scale (Very Light, Light, Moderately Heavy, Heavy, Very Heavy) was used to evaluate the perceived exertion during weeding activities.

Observation checklist: An observation checklist was used to record the postures adopted by workers during weeding and the types of tools used. This helped in correlating the postural data with the reported musculoskeletal problems.

RESULTS AND DISCUSSION

Health hazard faced by workers

The findings revealed that the majority of respondents experienced significant muscle fatigue and pain in various body parts, including fingers, shoulders, and wrists, with 94% reporting these issues. Other common complaints included reduced grip strength (88%) and tingling sensations in the fingers (79%). To assess the frequency of these health hazards, a three-point rating scale was employed, with results indicating that pain in the hands and fingers was the most frequently reported issue, achieving the highest mean score of 2.22. This was closely followed by muscle fatigue with a mean score of 2.16 and reduced grip strength with a mean score of 2.13. Additional complaints, ranked by frequency, included tingling sensations, changes in skin color, joint swelling, blisters, cut injuries, and muscle numbness (**Table 1**). These results align with previous research highlighting similar occupational

Table 1. Frequencies of health hazards faced by workers while using hand tools during weeding

Health hazards	Often (3)	Sometimes (2)	Never (1)	Wt. score	Mean	Rank
Tingling of finger	64	76	60	404	2.02	IV
Swelling in the joints	29	32	139	290	1.45	VI
Reduced grip strength	73	80	47	426	2.13	III
It causes muscle fatigue	70	92	38	432	2.16	II
Cut injuries	18	26	156	262	1.31	VIII
Blisters on palm skin	30	23	147	283	1.415	VII
Numbness of muscle	0	32	168	232	1.16	IX
Change in skin colour of hands and fingers	0	110	90	310	1.55	V
Pain in fingers, shoulder, wrist and other body parts	83	79	38	445	2.225	I

health challenges, such as pain and fatigue, experienced by agricultural workers (Kalyani *et al.* 2008, and NAG *et al.* 2016). Despite advancements in mechanization and automation, manual labor remains a significant part of agriculture in Assam tasks (Brahma and Daimary 2017), where hand tools are essential for tasks like weeding. This manual labor results in notable perceived exertion among workers.

Table 2 reveals that 44.5% of workers considered weeding activity to be moderately heavy, while 32% perceived it as heavy, and 23.5% found it to be very heavy. Despite the continuous and intensive nature of weeding, which occurs from morning until evening throughout the year, most workers viewed the task as involving relatively light to moderate exertion. This perspective aligns with findings reported by Hasalkar *et al.* (2004), which also suggested that, although labor-intensive, weeding is often perceived as less strenuous compared to other activities.

Rating of joint discomfort perceived by the workers involved in weeding activity

According to Strasser (2009), joints are essential connections between bones that support movement and maintain skeletal structure, facilitating activities like sitting, walking, and running. Results, presented in Table 3, indicated that the highest mean rating of perceived joint discomfort occurred in the back (4.08), followed by the lower back (4.03) and knee (3.58). In contrast, the elbow reported the least discomfort (1.91), with the neck and fingers also experiencing relatively lower discomfort (2.34 and 2.55, respectively). These findings are consistent with prior research by Khogare and Borkar (2011) and Rosa *et al.* (2023), which similarly identified significant joint discomfort in the neck, wrist, shoulder, and knee during weeding activities.

Work related musculoskeletal disorder faced by the respondents

Work-Related Musculoskeletal Disorders (WMSDs) are common among agricultural workers, particularly those engaged in weeding activities, as noted by Shivakumar *et al.* (2023) and Varghese and Panicker (2022). These disorders affect various body parts, including muscles, bones, joints, and connective tissues, and are often linked to high-risk activities such as heavy lifting and repetitive movements. Agricultural workers frequently face health issues due to poorly designed machinery and tools, leading to symptoms like body pain, fatigue, numbness, cramps, and tingling. Initially presenting as vague pain, these symptoms can worsen over time, resulting in severe musculoskeletal illnesses that reduce productivity and performance. Workers commonly adopt unfavorable postures, such as squatting or stooping, which contribute to these disorders. To assess the prevalence and severity of musculoskeletal problems, the Standard Nordic Musculoskeletal Questionnaire (SNQ) was utilized. This tool categorizes issues into three areas: trouble in the past 12 months, interruptions to normal work over the last 12 months, and recent discomfort experienced in the last 7 days. The findings highlight the impact of prolonged, repetitive tasks and poor ergonomics on workers' musculoskeletal health.

The data analysis in **Table 4** highlights that in the past 12 months, the most frequently affected regions for work-related musculoskeletal disorders (WMSDs) among workers were the lower back (31%), knee (30%), shoulder (29%), upper back (24%), and neck (20%). These findings are consistent with the study by Gowri S et al. (2015), which also reported a high incidence of lower back problems (29%), knee issues (28%), leg pain (28%), and headaches (25%) among agricultural workers. The table further reveals that a significant number of workers were unable to work in the past 12 months due to lower back (15%), shoulder (14%), upper back (12%), and knee issues (11%). In the last 7 days, the most commonly affected regions were the lower back (38%), knee (33%), upper back (25%), shoulder (13%), and neck (5%). Workers have reported experiencing pain in the lower back and spinal region, attributing it to difficulties in gripping tools during their daily activities, as shown in Figure 1. The repetitive nature of their tasks, the exertion

Table 2. Distribution of respondents according to exertion perceived in performance of weeding activity

Activity	Rating of perceived exertion				
	Very light (1)	Light (2)	Moderately heavy (3)	Heavy (4)	Very heavy (5)
Weeding	-	-	89	64	47
	-	-	(44.5)	(32)	(23.5)

Table 3. Distribution of respondents according to joint discomfort perceived while performing weeding activity

Activity	Joint involved	Rating of perceived joint discomfort
Weeding activity	Back	4.085±1.077
	Shoulder	3.455±1.070
	Neck	2.34±1.062
	Leg	2.595±1.054
	Elbow	1.91±1.046
	Hand	3.335±1.038
	Finger	2.555±1.029
	Knee	3.58±1.020
	Lower back	4.03±1.011

Table 4. Distribution of respondents based on musculoskeletal problems by using Standard Nordic Musculoskeletal Questionnaire (SNQ)

Body parts	Frequency and extent of musculoskeletal problems		
	Trouble (pain, pain, discomfort and numbness) in the last 12 months f (%)	Prevented from doing normal work in last 12 months due to trouble (pain, pain, discomfort and numbness f (%)	Trouble in the last 7 days f (%)
Neck	100 (50)	13 (6.5)	2 (1)
Shoulders	150 (75)	22 (11)	5 (2.5)
Elbows	50 (25)	9 (4.5)	-
Wrist/hands	80 (40)	7 (3.5)	-
Upper back	120 (60)	19 (9.5)	10 (5)
Lower back	158 (79)	24 (12)	15 (7.5)
Hips/thighs	70 (35)	4 (2)	-
Knees	152 (76)	17 (8.5)	13 (6.5)
Ankles/feet	60 (30)	6 (3)	-

*Figures in parentheses show percentage and figures without parentheses shows frequency

required, and the force needed to carry out work for extended periods daily, involving movements of the spine, hands, and legs, contribute to this issue. As a result, workers frequently suffer from musculoskeletal pain in areas such as the lower back, neck, knees, and shoulders.

Severity and frequency of pain

From **Figure 2**, 75% of workers reported acute lower back pain, 65% reported upper back pain, and 60% reported knee pain. Less acute pain was noted in the shoulders and hands (45%), hips/thighs (38%), and elbows and upper back (35%). These results align with Gowri *et al.* (2015), which found significant discomfort in the lower back, knees, and legs among agricultural workers. The majority of respondents experienced acute pain in the lower back, knees, neck, shoulders, and hands, likely due to forward bending, squatting postures, and repetitive hand movements.

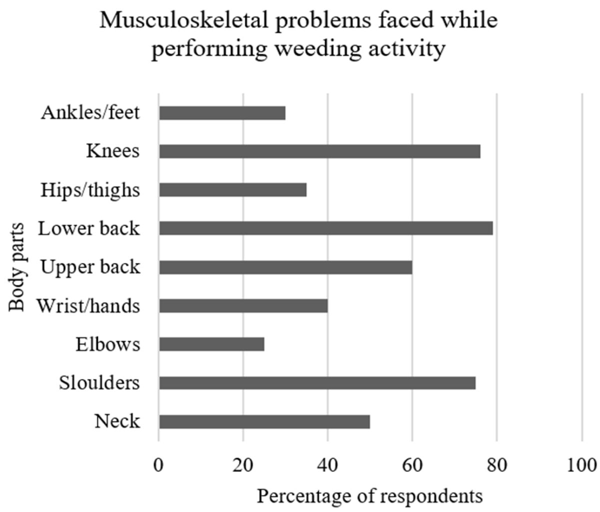

Figure 1. Percentage distribution of the respondents according to musculoskeletal problems faced in performance of weeding activity

The analysis revealed that back pain was the most commonly experienced issue, with 70% of respondents consistently experiencing lower back pain, followed by knee pain (68%), upper back pain (63%), and neck pain (55%). Additionally, 45% of workers reported sometimes experiencing MSDs in the shoulders and hands, followed by hips/thighs (38%), upper back (37%), and elbows (35%). These occurrences are likely due to the various awkward postures (such as squatting, bending, and standing) and repetitive movements required by different weeding tools (**Figure 3**).

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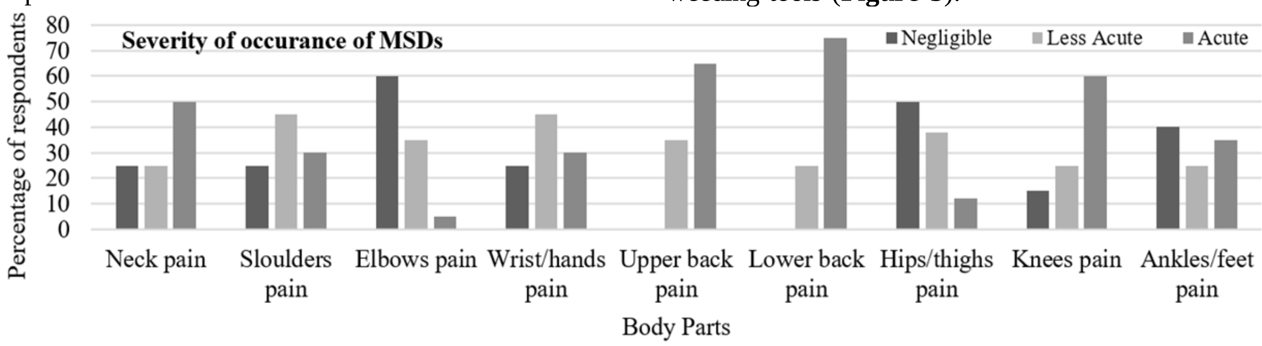

Figure 2. Severity of MSDs faced by respondents while performing weeding activity

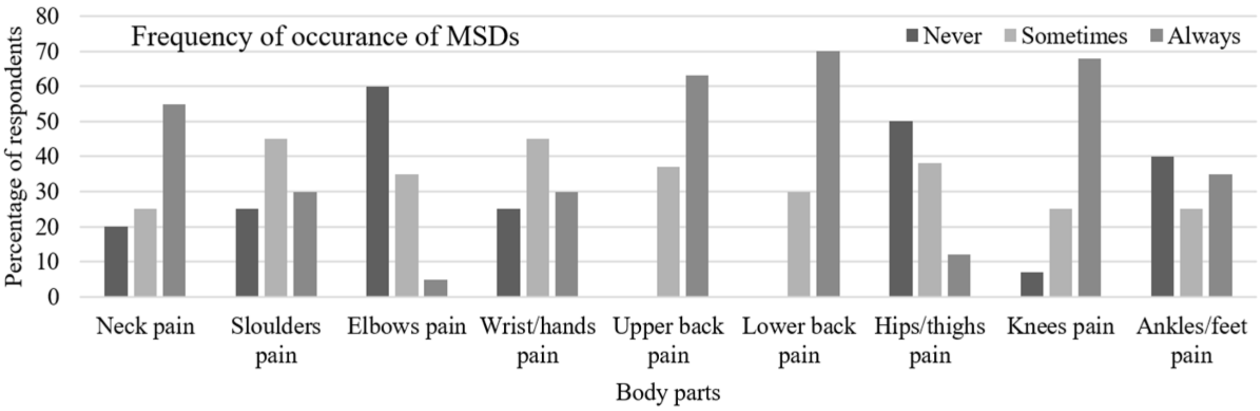

Figure 3. Frequency of MSDs faced by respondents while performing weeding activity

Conclusion

This study sheds light on the occupational health hazards faced by workers engaged in manual weeding activities in agriculture. The findings underscore the significant physical exertion, joint discomfort, and musculoskeletal problems experienced by these workers, highlighting the need for targeted interventions to improve their safety and wellbeing. From ergonomic tool design to comprehensive training on safe work practices, addressing these challenges necessitates a holistic strategy encompassing ergonomic tool design, comprehensive training on safe work practices, and ongoing health monitoring, emphasizing the collective responsibility of employers, regulators, and health professionals in safeguarding the wellbeing of agricultural workers. By prioritizing worker safety and health, we can create a safer and more sustainable agricultural workforce, ultimately contributing to the overall wellbeing of agricultural communities.

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RESEARCH ARTICLE

Ethnoveterinary utilization of ruderal and agrestal weeds in livestock treatments

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ABSTRACT

In Moradabad District of Uttar Pradesh (India), livestock is an important agricultural industry that provides financial revenue to farmers and rural communities. Weeds, or undesired plants that compete with agricultural plants, have an impact on crops both in terms of quantity and quality. From October 2021 to December 2022, the current research work investigates the ethno-veterinary practices of 58 weed species from various blocks of Moradabad, focusing on rural regions. The data came from locals such as owners of land, elderly people, agricultural workers, veterinary professionals, vaidyas (ayurved medicines doctor and hakims (Unani doctors). A wide range of agricultural locations were studied with the assistance of local intermediate and degree college students in the concern areas. The current method of classification, the Angiosperm Phylogeny Group-IV system for plant taxonomy, classified weed species into several APG-IV families and grades were followed. Poaceae, Apocynaceae, Asteraceae, Amaranthaceae, and Euphorbiaceae were categorised among the top five APG-IV weed families. Weeds were mostly connected to Lamiids, Fabids, Commelinids, Superasterids, Campanulids, Malvids, Rosids, Eudicots, Monocots, and the ANA Grade of the APG-IV. The most common livestock ailments were skin, galactogogue, dysentery, diarrhea, eye complications, placenta ectomy, constipation, maggot, and mouth infection, for which different weed species were used. The majority of weeds were herb, shrub, undershrub, creeper, and climber life forms.

Keywords: Ailments, Ethno-veterinary, Livestock, Weeds

INTRODUCTION

Livestock in Indian agriculture provide farm economy, transportation, milk, and meat, while also providing a source of income and jobs to farmers and underprivileged groups. The ethnoveterinary knowledge in the area is at risk of deterioration due to socioeconomic shifts, environmental changes, and technological advancements (Lans *et al.* 2007). Typically, generations pass down this priceless indigenous wisdom without appropriate recording or preservation (Bullitta *et al.* 2018). Ethnoveterinary medicines are highly active, versatile, and cost-effective; they are able to treat various livestock illnesses, making them accessible in remote areas as well (Ullah *et al.* 2013). The use of trial-and-error methods led to the development of ethno-veterinary medicine as it is known today (Upadhyay *et al.* 2010). Rural residents commonly treat their pets with indigenous herbal remedies, and there is no denying the importance of ethno-veterinary treatment in the advancement of livestock (Lalit and Pande 2009, Mallik *et al.* 2012, Adedeji *et al.* 2013, Galav *et al.* 2013). Atharvaveda emphasises medicine's effectiveness in treating ailments, while Yajurveda emphasises the significance of medicinal plant development. Shalihotra is the earliest known veterinarian from ancient times (Somvanshi 2002). Due to the rapid changes occurring in societies around the world, ethno-veterinary knowledge is in danger of disappearing (Kubkomawa *et al.* 2013). It has been shown that elderly people and traditional healers have a stronger understanding of traditional remedies than younger people (Yadav *et al.* 2010). Ethnoveterinary knowledge is in danger of extinction due to the present rate of change in social communities throughout the world (Kubkomawa *et al.* 2013).

About one-third of all agricultural pest losses are caused by weeds (DWR 2015). Weeds, along with other animal pests like insects, rodents, nematodes, and birds, are the most significant threat to declining agricultural output (Oerke 2006). In just 10 agricultural crops in India, weeds were responsible for more than 11 billion dollars in economic losses (Gharde *et al.* 2018). Invasive species like weeds reduce agricultural yields, raise farming costs, and

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cause major ecological damage (Sinden *et al.* 2004, Rao *et al.* 2020).

Ruderals are weed plants that thrive in waste dumps, urban wastelands, docks, footpaths, railroads, roadsides, and other areas extensively influenced by human occupation, industry, and trade (Frenkel 1977). Traditional remedies are still used by over 80% of worldwide agriculturalists, sheep farmers, and animal owners to treat livestock illnesses, demonstrating their critical role in healthcare (Lulekal *et al.* 2008, Devi *et al.* 2010).

MATERIALS AND METHODS

The study site is located in western Uttar Pradesh (IndiA) between 28°-21´ and 28°-16´ latitude north and 78°-4´ and 79° longitude east (**Figure 1**). Moradabad represents the Gangetic plain, which is divided into three portions by the rivers Ramganga and Sot.

From October 2021 to December 2022, an ethnobotanical research survey was conducted in Moradabad district blocks (8) to investigate the ethnoveterinary potential of ruderals and agrestals. The study collected data from knowledgeable locals, including landowners, elders, shepherds, veterinarians, vaidyas, and hakims, following the International Society of Ethnobiology's (2008). We collected data from intimate animal contacts, but despite thorough informing and verbal agreement, most informants did not provide written consent due to illiteracy. The study involved outdoor interviews to avoid misunderstandings about therapeutic plants' identities, and explored field locations with farmers. Using the documentation that is presently accessible and morphological analysis, collected grassy weeds have been identified (Singh and Beena 2018). Weed plant specimens were identified on-site, while unidentifiable plants were identified using available documentation, including Flora of Uttar Pradesh vol. I (Singh *et al.* 2016) and vol. II, (Sinha *et al.* 2020), 'Handbook on Weed Identification' (Naidu 2012), weeds just reported from the Global Compendium of Weeds (Randall 2017), and also, weeds were cross-verified with the help of virtual herbarium of B.S.I. Kolkata (https://ivh.bsi.gov.in/), Virtual Herbarium of the (ICAR-DWR),(https://dwr.icar.gov.in/Weeds_Herbarium.aspx) and the citation of plant name was checked with the help of www.ipni.org.in. Based on the modern Angiosperm Phylogeny Group-IV system for plant taxonomy, the weed species were put into different families and grades (A.P.G., Chase, M. *et al.* 2016). Plant collections were handled, toxoid with 5% HgCl, and mounted on herbarium sheets with specific identification for future considerations. S. K. Jain (1977). The collected weed plant specimens were preserved and submitted to the department for further use.

RESULTS AND DISCUSSION

31 families and 58 weed plants' ethnobotanical applications (**Table 1**) have been noted in the current study for their intriguing medicinal potential in treating a wide range of veterinary conditions like fever, diarrhea, coughing, and foot-and-mouth disease. Studies have also demonstrated their ability to eliminate intestinal worms, stimulate labour, control placenta retention, treat eye issues, and alleviate joint implications. In the current research work (14%), weeds are used for skin ailments, (14%) milk production ailments, (11%) eye ailments, (11%) diarrhea ailments, (11%) dysentery, (11%) fever, (9%) placenta removal, (7%) constipation, (7%) maggot infection, and (5%) mouth infection. In this study, 71% of weeds are herbs, shrubs (16%),

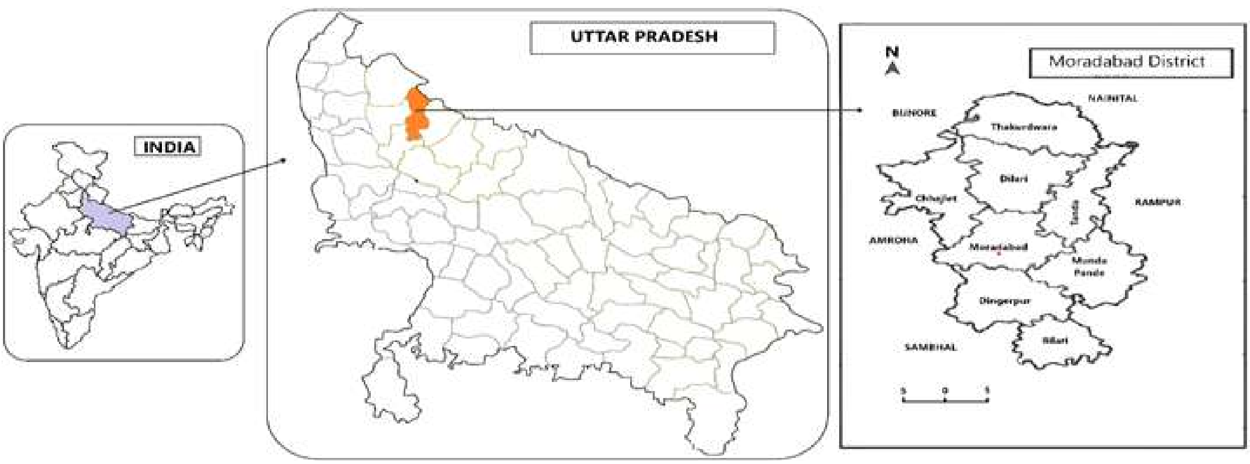

Figure 1. Map of study area

Table 1. Weeds utilization in livestock's ailments and methods of utilization

Botanical Name	APG-IV Family	Local name	Life form	Part used	APG-IV grade	Ailments	Administration
Abutilon indicum (L.) Sweet	Malvaceae	Kanghi	US	LF	Malvids	Skin problems.	(1) Animals with lice are treated twice daily by applying a paste made of fresh leaves to the afflicted areas of their bodies.
Acalypha indica L.	Euphorbiaceae	Kuppi	H	LF	Fabids	Constipation, Maggot wound, Skin diseases.	(1) An extract of fresh leaves twice a day is used to check for constipation and wounds or infections due to the maggot. (2) For skin problems, use fresh leaf paste with pepper.
Achyranthes aspera L.	Amaranthaceae	Chirchita	H	RT	Superasterids	Diarrhea, Bone fracture, Delivery and placenta expulsion.	(1) Diarrhea is treated with a root decoction twice a day. (2) To treat a bone fracture, fresh root is crushed up, and the paste is administered. (3) To make the application of contact therapeutic interventions simple and secure, roots are connected to buffalo horns. The buffaloes' genitalia are filled with fresh roots to help the placenta pass.
Acorus calamus L.	Acoraceae	………..	H	RT	Monocots	External parasites.	(1) Freshly prepared hot water extract is administered topically twice daily to ward off external parasites.
Aerva javanica (Burm.f.) Juss. Ex Schult.	Amaranthaceae	safed buti	US	RT	Superasterids	Mouth infection.	(1) For the cure of a mouth disease, boiled root extract is administered orally twice a day for 7-8 days.
Alternanthera sessilis (L.) R.Br	Amaranthaceae	Jala-jambe	H	LF	Superasterids	Galactogogue.	(1) Fresh leaves from plants are used for lactation in cattle.
Amaranthus viridis L.	Amaranthaceae	Chaulai	H	SD	Superasterids	Tympany.	(1) For the treatment of the tympany, use seeds with fresh water twice a day.
Andrographis paniculata (Burm.f.) Nees	Acanthaceae	Kal-megh	H	WP	Lamiids	Dysentery, Fever and cough.	(1) We check for dysentery twice a day using a freshly prepared entire plant extract. Freshly collected decoction is used to treat fever and cough.
Argemone mexicana L.	Papaveraceae	Pili-kateli	H	WP LX,SD	Eudicots	Constipation, Removal of retained placenta ,Chronic ulcer ,wound, Intestinal parasites.	(1) Once a day, 100 g of the entire plant is administered along with any available local grass to remove the placenta. (2) For the treatment of a persistent ulcer, latex and seed oil are employed. (3) To eradicate parasitic insects, apply vegetation juice and onion bulb juice to the surface.
Boerhavia diffusa L.	Nyctaginaceae	Punar-nava	H	WP LF	Superasterids	Removal of retained placenta ,Dysentery and dropsy.	(1) For the purpose of removing the delayed placenta in cows and buffaloes, 1500 g of fresh, complete plant is provided twice daily. (2) For the treatment of dropsy and bleeding dysentery, take fresh leaf juice three times daily.
Bothriochloa pertusa (L.) A.Camus	Poaceae	……… ……	H	WP	Commelinids	Galactogogue.	(1) To make more milk.
Calotropis gigantea (L.) W.T.Aiton	Apocynaceae	Madar	S	LF	Lamiids	Septic wound.	(1) To cure infectious infections, fresh leaves and mustard oil are administered twice daily.
Calotropis procera (Aiton) W.T.Aiton	Apocynaceae	Aak	S	LF LX	Lamiids	Removal of retained placenta, To kill the intestinal worm,	(1) After delivery, a buffalo spends 4-5 minutes dipping its tail into latex to remove the residual placenta. (2) To eliminate the gastrointestinal parasite in sheep, 250 g of green leaf extract are fed daily as feed.

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Botanical Name	APG-IV Family	Local name	Life form	Part used	APG-IV grade	Ailments	Administration
						To increase the milk quantity, To cure mouth and eye watering, Tumour.	(3) Goats, in particular, add dried leaves to their diet to increase milk production. (4) Fed fresh leaves and black salt for 1-2 days. (5) Tumors are treated by using latex and peanut seed oil twice daily.
Cannabis sativa L.	Cannabaceae	Bhang	H	LF	Fabids	Blood in excreta, Loose motion.	(1) To prevents the reproduction of cows and buffaloes using the excrement of fresh leaf paste, is applied. (2) To treat loose motion, take whey-infused leaf powder orally twice daily.
Centella asiatica (L.) Urb.	Apiaceae	Brahmi-buti	H	LF	Campanulids	Fever and dysentery.	(1) Dysentery is treated with a decoction of fresh leaves. When animals have a fever, apply green leaf paste to your forehead.
Cissus quadrangularis L.	Vitaceae	Har-jora	H	ST	Rosids	Dog bite, To retain the placenta, Fracture healing.	(1) For the treatment of dog bites and placenta retention, crushed stem is employed. (2) The fracture uses a freshly crushed stem.
Citrullus colocynthis (L.) Schrad.	Cucurbitaceae	Indra-yani	CR	FR	Fabids	Dysentery, Weak Digestion.	(1) To treat dysentery, 100 g of fruits and 50 g from the complete plant of *Solanum surratense* are combined. (2) Cattle are fed fruits to help with digestion.
Cleome viscosa L.	Cleomaceae	Hur-hur	H	LF	Malvids	Wound healing, Microbial growth.	(1) Fresh leaf paste. (2)On the lesion, fresh leaf juice is administered to check for microbiological growth.
Commelina benghalensis L.	Commelinaceae	Konkoa	H	WP	Commelinids	Galactogogue.	(1) Fresh feed is useful in lactation.
Cucumis callosus (Rotteler) Cogn.	Cucurbitaceae	Bislumbha	H	FR	Fabids	Stomach-ache.	(1) For a few days, crush 50 g of fruits with fresh whey twice daily.
Cuscuta reflexa Roxb.	Convolvulaceae	Amar-bel	CL	WP	Lamiids	Bitten by poisonous worm, Diarrhea.	(1) Cuscuta decoction is given to the affected area. (2) A fresh plant decoction is used twice daily for a successful outcome in diarrhea.
Cyanthillium cinereum (L.) H.Rob.	Asteraceae	Sahadevi	H	SD	Campanulids	Appetite.	(1) Kali Jiri, 2 kg. garlic, 20 g. To boost the appetite of cattle, 200 g of jaggery is combined with 100 g of onion and 20 g of ginger.
Cynodon dactylon (L.) Pers.	Poaceae	Brahma ghash	H	WP	Commelinids	Digestion and mastitis, Wound healing.	(1) For proper digestion and lactation, fresh plant material is treated with mustard oil. (2) Fresh plant paste was applied directly to the skin for two to three days.
Cyperus rotundus L.	Cyperaceae	Motha	H	RZ	Commelinids	Fever, Diarrhea, Galactogogue.	(1) Fever and diarrhea are treated by making a decoction from freshly crushed rhizomes. (2) Fresh feed from the plant is useful to increase lactation.
Datura metel L.	Solanaceae	Dhatura	S	LF, RT	Lamiids	Rheumatism, Maggot infection.	(1) To treat rheumatism, a solution made from newly harvested leaves is taken twice a day. (2) Fresh root powder is used twice a day to check for bleeding due to a maggot infection.
Dendrocalamus strictus (Roxb.) Nees	Poaceae	nar bans	H	WP	Commelinids	Galactogogue	(1) Fresh feed is useful in lactation.
Eclipta prostrata (L.) L.	Asteraceae	Bhrang-raj	H	LF	Campanulids	Septic wound.	(1) Fresh paste is used twice a day.

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Botanical Name	APG-IV Family	Local name	Life form	Part used	APG-IV grade	Ailments	Administration
Euphorbia heterophylla L.	Euphorbiaceae	………..	H	LF SD	Fabids	Food poisoning.	(1) Leaves and seeds are combined with water and fed to livestock.
Euphorbia hirta L.	Euphorbiaceae	Badi-duddhi	H	LX	Fabids	Wound healing,	(1) The latex of the fresh plant is used twice a day.
Gymnema sylvestre (Retz.) R.Br. ex Sm.	Apocynaceae	Gud-mar	US	LF	Lamiids	Eye problems, Ephemeral fever, Opacity of cornea.	(1) Fresh leaves extract. (2) To treat ephemeral fever, a combination of fresh leaves, pepper, garlic, and black salt is taken orally. (3) Fresh leaf juice twice a day is used to cure the opacity of the cornea.
Hemidesmus indicus (L.) R.Br.	Apocynaceae	anantamul	S	LF	Lamiids	Convulsive seizure.	(1) To treat convulsive seizures, apply a fresh leaf extract twice daily.
Justicia adhatoda L.	Acanthaceae	Bisanta	US	LF, RT, FL	Lamiids	Cough and cold, Dysentery, ecto-parasite and skin disease, Wound healing; Foetus discharge & cough, and cold.	(1) A decoction of leaves is useful for coughs and colds. (2) In dysentery, leaves are with grass and fed to animals for two to three days. (3) Fresh leaf extract is applied to the afflicted skin area. (4) Fresh leaf paste is applied in wound healing. (5) For the safe delivery of the fetus, root bark extract and black pepper paste (5:2) are administered. Burning flower fumes is used to cure cold and cough symptoms.
Lantana camara L.	Verbenaceae	Ghaneri	S	LF	Lamiids	Joint pain.	(1) The decoction of fresh leaves is given to cattle.
Launaea procumbens (Roxb.) Ramayya & Rajagopal	Asteraceae	van gobhi	H	LF	Campanulids	Skin infection.	(1) Fresh leaf paste is topically applied for 3–4 days.
Lepidium sativum L.	Brassicaceae	Halim	H	WP	Malvids	Galactogogue.	(1) Good for the lactation.
Leucas aspera (Willd.) Link	Lamiaceae	Gummi	H	WP	Lamiids	Ephemeral fever.	(1) Fresh plant decoction
Mimosa pudica L.	Fabaceae	Lajbanti	H	LF	Fabids	Maggot infection.	(1) Eating freshly made leaf chapatti twice a day treats the maggot infection.
Mirabilis jalapa L.	Nyctaginaceae	Gulabaans	H	RT	Superasterids	Neck-sore.	(1) The aching neck receives fresh root paste twice daily.
Nymphaea nouchali Burm.f.	Nymphaeaceae	Kumudini	CR	RZ	ANA	Stop mastication.	(1) Crushed parts of the rhizome
Ocimum tenuiflorum L.	Lamiaceae	Tulsi	H	LF	Lamiids	Cough and cold.	(1) A decoction of fresh leaves twice a day is used to cure coughs and colds.
Oxallis corniculata L.	Oxalidaceae	Khatti-buti	H	LF	Fabids	Eye problems.	(1) The juice from the leaves treats white rashes.
Plumbago zeylanica L.	Plumbaginaceae	Chitrak	H	LF	Superasterids	Appetite.	(1) To increase hunger, 250 g of dry leaves powdered with meetha soda are taken orally for two to three days.
Portulaca oleracea L.	Portulacaceae	Kulfa	H	WP	Superasterids	Excessive bleeding.	(1) To reduce excessive bleeding in buffaloes during and after birth, the entire plant is fed to them as feed.
Ricinus communis L.	Euphorbiaceae	Anduaa	S	SD, LF	Fabids	Stomach problem,	(1) For a few days, take seed oil twice a day for gastrointestinal issues.

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Botanical Name	APG-IV Family	Local name	Life form	Part used	APG-IV grade	Ailments	Administration
						Constipation and rheumatism, Ulcer.	(2) Ulcers are treated with a poultice made of green leaves. (3) Constipation is frequently treated with seed oil.
Rubia cordifolia subsp. cordifolia	Rubiaceae	Majith	CL	LF	Lamiids	Foot problems.	(1) Apply leaf juice externally to the foot's troublesome areas.
Saccharum spontaneum L.	Poaceae	Kaans	H	WP	Commelinids	Heat production.	(1) Buffaloes receive daily oral feedings of 2 kg of plant to help them produce heat.
Senna occidentalis (L.) Link	Fabaceae	Kasaundi	H	LF	Fabids	Wound healing, Skin disease.	(1) In skin and wound issues, fresh leaf paste is applied twice daily.
Senna tora (L.) Roxb.	Fabaceae	Chakunda	H	SD	Fabids	Skin Disease.	(1) Apply seed paste to the affected area of skin.
Solanum nigrum L.	Solanaceae	Makoi	H	LF	Lamiids	Pterygium.	(1) Decoction of fresh leaves.
Solanum virginianum L.	Solanaceae	Bhatkataiya	H	LF	Lamiids	Eye problems.	(1) Decoction of fresh leaves.
Sorghum bicolor (L.) Moench	Poaceae	Jowar	H	SD	Commelinids	Loose motion.	(1) Twice a day, use seed flour with whey.
Strychnos nux-vomica L.	Loganiaceae	Kuchla	S	RT	Lamiids	Wound healing.	(1) Crushed root paste.
Tribulus terrestris L.	Zygophyllaceae	Chhota-Gokhru	H	WP,	Fabids	Diarrhea.	(1) Oral water extract of the entire plant twice daily for 2–3 days.
Tridax procumbens L.	Asteraceae	kanphuli,	H	LF	Campanulids	Wound healing.	(1) Fresh leaf extract.
Tripidium bengalense (Retz.) H.Scholz	Poaceae	………	H	LF	Commelinids	Removal of retained placenta.	(1) Young leaves to remove retained placenta, particularly in buffaloes.
Vitex negundo L.	Lamiaceae	Malla	S	LF	Lamiids	Antibacterial and insecticide.	(1) Fresh leaf decoction is ingested orally.
Withania somnifera (L.) Dunal	Solanaceae	Ashwagandha	H	RT	Lamiids	Cold and cough.	(1) To treat colds and coughs, camels and buffaloes are given daily dosages of a root infusion.
Ziziphus nummularia (Burm.f.) Wight & Arn.	Rhamnaceae	Jharberi	S	WP, FR, RT,	Fabids	Intestinal worms, Diarrhea, Cold and cough, Mouth and foot diseases.	(1) You administer leaves twice daily for 5–6 days to get rid of intestinal worms. (2) For two days, fruits and tea are used to treat diarrhea. (3) For 3–4 days, a camel is given a daily dose of 200 g of root decoction and 350 g of jiggery to treat a cold and cough.

Life forms. (H) = Herb, (S) = Shrub, (US) = under shrub, (CR) = Creeper & (CL) = Climber. Part used (LF) = Leaf, (RT) = Root, (FR) = Fruit, (FL) = Flower, (LX) = Latex, (SD) = Seed, (WP) = Whole plant, (RZ) = Rhizome & (ST) = Stem.

under shrubs (7%), climbers (3%), and creepers (3%). The leaves were the most often used weed plant component (42%), followed by entire plants (20%), roots (13%), fruit (4%), seeds (10%), latex (4%), flowers (2%), rhizomes (3%), and stems (2%). The plants that were studied mostly belonged to the following families: Poaceae (6 species), Apocynaceae (4 species), Euphorbiaceae (4 species), Asteraceae (4 species), Amaranthaceae (4 species), Solanaceae (4 species), Lamiaceae (3 species), Fabaceae (3 species), Acanthaceae (2 species), and Nyctaginaceae (2 species). The rest of the species belonged to the Malvaceae, Acoraceae, Papaveraceae, Cannabaceae, Apiaceae, Vitaceae, Cucurbitaceae, Cleomaceae, Commelinaceae, Convolvulaceae, Cyperaceae, Verbenaceae, Brassicaceae, Nymphaeaceae, Oxalidaceae, Plumbaginaceae, Portulacaceae, Rubiaceae, Loganiaceae, Zygophyllaceae, and Rhamnaceae families. In this study (17), reported weed species belong to Lamiids, (13) Fabids, (8) Superasterids, (8) Commelinids, (5) Campanulids, (3) Malvids, (1) Rosids, (1) Eudicots, (1) Monocots, and (1) ANA grade of APG-IV. The data gained is substantially equivalent to findings from research of a similar nature carried out in a few other areas of Uttar Pradesh. *Justicia adhotoda* leaves are used to treat constipation, fever, water loss, diarrhea, dysentery, and discomfort in the stomach. The medicinal benefits of *Achyranthes aspera* are well known for treating a variety of gastrointestinal and respiratory issues as well as skin conditions. To cure constipation, *Ricinus communis* seed oil is used. Many ethno-cultural and rural people employ some ethno-veterinary weed plants that grow in the study area because they have impressive medicinal characteristics. Plants often used by them are *Justicia adhatoda, Argemone mexicana, Boerhavia diffusa, Calotropis procera* and *Ziziphus nummularia etc*. This investigation explores indigenous practices using locally occurring wild medicinal herbs for various ailments, demonstrating the potential of these plants as affordable and recyclable alternatives to synthetic medications.

Conclusion

The excessive use of wild plants endangers plant variety, necessitating sustainable utilization and study to enhance animal health, promote indigenous knowledge, and demand further scientific inquiry and intellectual property rights protection.

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RESEARCH NOTE

Effect of crop geometry, ALS and 4-HPPD inhibitor herbicides on weeds, soil enzymes and yield of maize

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ABSTRACT

A field experiment was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during rainy season of 2022 to study the effect of crop geometry and herbicide treatment on weeds, soil enzymes and yield of maize. The experiment was conducted in a Randomized Complete Block Design with two factors, crop geometry and weed management. Narrower crop geometry (60 x 15 cm) recorded lower weed density and dry weight as compared to wider crop geometry (60 x 20 cm). However, in case of herbicidal treatment, atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha at 25 DAS had lower weed density and dry weight in comparison to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS except *Cyperus esculentus*. Grain and stover yields were significantly higher (0.52 and 0.77 t/ha) in narrower crop geometry (60 x 15 cm) as compared to wider crop geometry (60 x 20 cm) 0.43 and 0.66 t/ha, respectively. Significantly higher grain yield (0.51 t/ha) was observed in atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha at 25 DAS as compared to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS (0.47 t/ha).

Keywords: Crop geometry, Halosulfuron, Soil enzymes, Tembotrione, Topramezone

Maize (*Zea mays* L.) is one of the important cereal crops of the world, known as "Queen of cereals" due to its great importance in human and animal diet, and has immense potential for higher yield. It is known for its wider adaptability and multipurpose uses as food, fodder and industrial products (Murdia *et al.* 2016). There are numerous reasons for the lower production of maize in our country. Among them, weed infestation in maize is the key detrimental factor causing huge grain yield loss, because of slow initial crop growth and wide row spacing along with frequent rains during the rainy season. Crop yield loss was recorded up to 90% depending upon weed flora and density when weed species reaches above the critical population threshold level (Lavanya *et al*. 2021). The most critical period for crop weed competition is the first six weeks after crop planting owing to initial slow growth and wider row spacing coupled with congenial weather for weed growth, yield reduction may be up to by 28–100% (Dass *et al.* 2012). Maize production is significantly more impacted by variable planting density than other grass family members, because of its monoecious floral arrangement and its low tillering cognition, in order to provide a greater yield, maize should be planted with the ideal plant population (Ali *et al*. 2017). Therefore, it is recommended that current maize hybrids be grown at optimal density to limit plant competition and to provide higher yields. The crop geometry combinations of 60 x 20 cm were discovered to help achieve a greater grain yield of maize (Getaneh *et al*. 2016). There is a good pre-emergence herbicidal option available in maize, however, results on post-emergence herbicides are scarce. Topramezone and halosulfuron methyl are the selective, post-emergence herbicides in maize introduced recently. These HPPD (4-hydroxyphenylpyruvate dioxygenase) and ALS (acetolactate synthase) inhibiting herbicides are most effective for weed control by bleaching developing tissues (Singh *et al.* 2015). Topramezone [3-(4, 5-Dihydro-3-isoxazolyl)-2-methyl-4-(methylsulfonyl) phenyl] (5-hydroxy-1-methyl-1H- yrazol-4-yl) methanone] inhibits the hydroxylphenyl pyruvate dioxygenase enzyme of carotenoid biosynthesis (pigment). It is selective to maize by rapidly metabolizing the herbicide into non-active substances and used primarily to manage broad and narrow leaved weeds. Soil enzyme activity is a crucial indicator of biological activity, with significant implications for both agriculture and ecology.

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Enzymes, being protein catalysts, drive all biological reactions in soil. Soil hosts a diverse group of enzymes, shaping metabolic processes influenced by soil's physical, chemical, microbiological, and biochemical attributes. These enzymes are pivotal in vital soil functions, including nutrient cycling and energy transformations, as they catalyze a multitude of chemical, physiological, and biological reactions (Pan *et al.* 2020). Therefore, keeping above facts in view present study was carried out to find suitable crop geometry and weed management treatments for weed control in rainy season maize.

The experimental trial was conducted during rainy season of 2022 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (Uttar Pradesh). The soil of the experimental field was sandy clay loam in texture and alkaline in nature (pH 7.2), 0.17 dS/m EC, low in organic carbon (0.341%) and available nitrogen (188.1 kg/ha), and medium in available phosphorus (20.45 kg/ha) and potassium (122.52 kg/ha). The experiment was laid out in a randomized complete block design (RCBD) with three replications and the factors were crop geometry and four weed management treatments. These treatment combinations were S_1: narrower crop geometry (60 x 15 cm), S_2: wider crop geometry (60 x 20 cm), atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS, atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha at 25 DAS, W_3-Atrazine 1.0 kg/ha *fb* one hand weeding at 25 DAS and W_4- Weedy. The herbicide doses were calculated as per the treatments and applied as aqueous spray 400 l/ha water using a knapsack sprayer fitted with a flat fan nozzle. Pre-emergence herbicide atrazine 1.0 kg/ha was applied as per the treatments in W_1, and W_2 within two days after sowing of the crop. Pre-emergence followed by post-emergence application of herbicide was done at 25 DAS in W_1 and W_2. A hand weeding was also done in W_3 treatment at 25 DAS with the help of *khurpi* (local hand spade). The recommended dose of nutrients 150-60-40; N-P-K kg/ha with 33% basal N for Varanasi region in hybrid maize (CP-858) was applied at the time of sowing and the rest of N was applied in two equal splits at knee high and tasseling stages. The soil samples collected after post-emergence herbicide application was assessed for the enzyme activities, *viz.* dehydrogenase, soil microbial biomass carbon and phosphatase. The methods involved in determination of dehydrogenase activity in the soil was spectrophotometry of Tri Phenyl Formazon (TPF) produced when soil is treated with Triphenyl Tetrazolium Chloride (TTC), given by (Cassida *et al.* 1964). Likewise the acid and alkaline phosphatase activity was assayed by quantifying the amount of p-nitrophenol released and expressed as µg of p-nitrophenol released/g soil/h as described by (Tabatabai and Bremner 1972).

The observation on the weed density and dry weight of grasses, broad-leaved weeds and sedges was recorded at 60 DAS. The weed control efficiency (Mani *et al.* 1973) and weed index (Yadav *et al.* 1997) were also calculated with observed data on weed dry weight and grain yield, respectively. For analysis of variance (ANOVA) the data on weed density and weed dry weight were transformed by square root to obtain homogeneity of variances.

Effect on weeds

The field was infested with the grassy weeds *Echinochloa colona*, *Digitaria sanguinalis* and *Dactyloctenium aegyptium*, *Trianthema portulacastrum*, *Commelina benghalensis* and *Cyperus esculentus* during experimentation (**Table 1**). At 60 days after sowing (60 x 15 cm) characterized by narrower crop geometry, exhibited significantly lower weed density and dry weight compared to S_2 (60 x 20 cm) wider crop geometry except *Cyperus esculentus.* However, weed density and dry weight of *Echinochloa colona* and *Digitaria sanguinalis* were found statistically at par in both the crop geometry, respectively. Amongst weed management treatments, the density and dry weight of *Echinochloa colona*, *Digitaria sanguinalis*, *Trianthema portulacastrum* and *Commelina benghalensis* were statistically lower compared to atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha as compared to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS except *Cyperus esculentus*. However, density and dry weight of *Commelina benghalensis* were reported to be at par to each other in both weed management treatments. Narrower crop geometry (60 x 15 cm), showed higher weed control efficacy compared to the wider crop geometry (60 x 20 cm). However, atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha recorded higher weed control efficiency as compared to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS. Weed index was found to be higher in wider crop geometry (60 cm x 20 cm) in comparison to narrower crop geometry (60 cm x 15 cm). Atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha had lesser weed index as compared to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS. This might be due to effective control of weeds by sequential application of pre as well as post emergence herbicide application.

Table 1. Effect of crop geometry and weed management treatments on weed density and weed dry weight at 60 DAS in maize

Treatment	Weed density (no./m^2)					Weed dry weight (g/m^2)				
	Echinochloa colona	*Digitaria sanguinalis*	*Cyperus esculentus*	*Trianthema portulacastrum*	*Commelina benghalensis*	*Echinochloa colona*	*Digitaria sanguinalis*	*Cyperus esculentus*	*Trianthema portulacastrum*	*Commelina benghalensis*
Plant crop geometry										
60 cm x 15 cm	4.26 (19.41)	3.99 (18.58)	2.57 (7.25)	1.93 (3.58)	2.38 (5.00)	3.67 (14.16)	3.62 (14.43)	2.24 (5.32)	2.24 (5.01)	1.79 (3.04)
60 cm x 20 cm	4.66 (23.25)	4.55 (23.41)	2.86 (9.75)	2.18 (4.83)	2.70 (7.25)	4.22 (19.33)	3.95 (17.46)	2.54 (6.80)	2.53 (6.34)	2.08 (4.20)
LSD (p=0.05)	0.28	0.45	NS	0.23	0.24	0.41	NS	0.11	0.10	0.25
Weed management										
Atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS	5.09 (25.66)	4.80 (23.33)	1.60 (4.16)	2.18 (4.33)	2.53 (6.00)	4.45 (19.59)	4.46 (19.51)	1.74 (2.63)	2.56 (6.13)	1.93 (3.29)
Atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha at 25 DAS	3.58 (12.50)	3.23 (10.00)	3.25 (11.50)	1.69 (2.50)	2.20 (4.16)	3.15 (9.75)	2.78 (7.34)	2.90 (8.13)	1.88 (3.07)	1.78 (2.76)
Atrazine 1.0 kg/ha *fb* one hand weeding at 20-25 DAS	2.87 (7.83)	2.25 (4.66)	2.11 (2.66)	1.34 (1.33)	1.70 (2.83)	2.57 (6.23)	2.21 (4.62)	1.45 (1.70)	1.74 (2.56)	1.34 (1.36)
Weedy	6.28 (39.33)	6.79 (46.00)	3.90 (15.66)	3.05 (8.66)	3.44 (11.50)	5.61 (31.42)	5.69 (32.31)	3.47 (11.79)	3.38 (10.76)	2.72 (7.05)
LSD (p=0.05)	0.40	0.64	0.43	0.33	0.34	0.58	0.56	0.16	0.15	0.36

The values of parentheses were the original values that had been changed to $\sqrt{x+0.5}$

Table 2. Effect of crop geometry and weed management treatments on soil enzymes at harvest, weed control efficiency (%), weed index (%), seed index, grain and stover yields and harvest index in maize

Treatment	Dehydrogenase activity (µg of TPF released/g soil 24/h)	Alkaline phosphatase (µg PNP released/g soil/h	Soil microbial biomass carbon (SMBC µg /g)	Weed control efficiency (%)	Weed index (%)	Seed index (g)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)
Plant crop geometry									
60 cm x 15 cm	13.48	99.98	260.70	35.87	8.98	23.79	0.52	0.77	40.14
60 cm x 20 cm	13.71	106.18	180.41	28.86	24.65	23.67	0.43	0.66	39.41
LSD (p=0.05)	0.19	0.42	0.62	-	-	NS	0.02	0.05	-
Weed management									
Atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS	13.53	94.22	104.99	26.74	20.29	23.60	0.47	0.65	41.75
Atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha at 25 DAS	13.49	105.17	178.69	43.90	11.20	23.55	0.51	0.81	38.32
Atrazine 1.0 kg/ha *fb* one hand weeding at 20-25 DAS	13.47	100.78	209.62	58.82	0.00	24.70	0.57	0.88	39.31
Weedy	13.82	112.14	388.94	0.00	38.04	23.08	0.32	0.52	38.27
LSD (p=0.05)	NS	0.59	0.88	-	-	NS	0.03	0.07	-

Effect on soil enzymes

At harvest, dehydrogenase activity and alkaline phosphatase values were observed significantly higher in wider crop geometry (60 x 20 cm) in comparison to narrower crop geometry (60 x 15 cm). However, soil microbial biomass carbon was noted lesser in wider crop geometry (60 x 20 cm) compared to narrower crop geometry (60 cm x 15 cm). Amongst weed management treatment, alkaline phosphatase value and soil microbial biomass carbon were recorded significantly higher in atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha as compared to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS (**Table 2**). This exhibited the residual activity of herbicides on soil properties. In atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha treated plots, the activity of these enzymes increased at harvest due to higher dissipation of these herbicides after application. These, results were also in conformity with the finding of Tabatabai and Bremner (1972).

Effect on maize

Grain and stover yields were significantly higher (0.52 and 0.77 t/ha) in narrower crop geometry (60 x 15 cm) as compared to (0.43 and 0.66 t/ha) compared to wider crop geometry (60 x 20 cm). This might be due to lesser weed competition in narrower crop geometry. Amongst herbicide treatment, atrazine

1.0 kg/ha *fb* topramezone 25.2 g/ha had statistically superior grain and stover yields (0.51 and 0.47 t/ha) as compared to atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS (0.81 and 0.65 t/ha). Harvest index was also noted to be higher (40.14 %) in narrower crop geometry (60 x 15 cm) then (39.41 %) compared to wider crop geometry (60 x 20 cm) while atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha had lesser harvest index (41.75%) than atrazine 1.0 kg/ha *fb* halosulfuron 67.5 g/ha at 25 DAS (38.32 %) (**Table 2**). Narrow row spacing was found to reduce weed growth and yield enhancement. Similarly, reduction in weed competition due to weed control by pre as well as post herbicides resulted in significant grain and stover yields in these treatments. Similar results were also reported by Sanodiya *et al*. (2013).

Atrazine 1.0 kg/ha *fb* topramezone 25.2 g/ha and narrower crop geometry (60 x 15 cm) effectively suppressed weed growth, improved weed control efficiency and subsequently enhanced crop growth and yields. In context to soil enzymes, dehydrogenase activity and alkaline phosphatase values were recorded superior in wider crop geometry (60 x 20 cm) and atrazine1.0 kg/ha *fb* topramezone 25.2 g/ha.

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RESEARCH NOTE

Pre- and post-emergence herbicidal impact on nodulation of soybean crop and soil biological indicators

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ABSTRACT

A field trial to investigate the effect of pre- and post-emergence herbicides on soil biological indicators in soybean was conducted at AICRP-Weed Management farm, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *Kharif* 2021. The experiment was laid out in a randomized block design with three replications and twelve treatments. Wheat straw applied as mulching 5 t/ha on the soil recorded significantly higher dehydrogenase activity, CO_2 evolution, soil microbial biomass carbon, microbial count (bacteria, fungi and actinomycetes) and maximum root nodulation. Among chemical weed control, higher soil microbial biomass carbon was recorded in diclosulam 84% WDG 0.026 kg/ha as pre-emergence whereas in post-emergence herbicides, it was higher with quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009 + 0.2% surfactant. Results revealed that mulching may have very good effect facilitating the degradation of herbicides also not only maintaining but increasing the microbial biomass carbon. Higher dehydrogenase activity was observed in mulching with wheat straw 5 t/ha and farmer's practice at flowering stage due to higher substrate availability. In herbicidal application treatments, suppression of dehydrogenase activity was observed, which might be due to the lethal action of herbicides on soil microorganisms,

Keywords: Diclosulam, Mulching, Nodulation, Quizalofop-ethyl + Chlorimuron-ethyl, Soil microflora, Soybean

Soil enzymes are a group of enzymes commonly found in soil and play vital role in maintaining soil ecology, physical and chemical properties, soil fertility and soil health. These enzymes form key biochemical functions in organic matter decomposition in the soil system (Sinsabaugh *et al.* 1991). They are important in catalysing many vital reactions required for the life processes of micro-organisms in soils, stabilization of soil structure, decomposition of organic wastes, organic matter formation and nutrient cycling hence playing an important role in agriculture (Dick *et al.* 1994 and Dick 1997). The enzyme levels in soil systems vary in quantity, mainly because each soil type has different amounts of organic matter, composition, activity of its living organisms and intensity of biological processes. In practice, biochemical reactions occur mainly through the catalytic contribution of enzymes and transformable substrates that serv as energy sources for microorganisms (Kiss *et al.* 1978).

A field investigation was carried out at AICRP - Weed management farm, Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *Kharif* 2021 to study the effect of different weed management practices on soil biological indicators. The soil texture of the experimental field was clayey, with slightly alkaline pH (7.80), moderate organic carbon status (0.46%), low nitrogen content (178 kg/ha), medium available phosphorus content (17.05 kg/ha) and high potassium status (384 kg/ha). Soybean cv *PDKV Yellow Gold* was sown on 18th June 2021 on Broad Bed Furrow (BBF) with 45 x 5 cm spacing and 30:60:30 NPK kg/ha and was harvested on 7th October 2021. Total rainfall received during the crop growth period was 850 mm. The experiment was set up in a randomized block design with three replications and 12 treatments. The treatments comprised of flumioxazin 50% SC 0.125 kg/ha, diclosulam 84% WDG 0.026 kg/ha, pendimethalin 38.7% CS 0.677 kg/ha, pendimethalin 30% + imazethapyr 2% EC 0.960 kg/ha (ready mix), sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (ready mix), pendimethalin 30% EC + diclosulam 84% WDG 0.750 + 0.0252 kg/ha (tank mix), sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC 0.245 kg/ha POE (ready mix) at 20 DAS, quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009 + 0.2% surfactant kg/ha POE (ready mix) at 20 DAS, fomesafen 12% + quizalofop-ethyl 3% SC 0.225 kg/ha PoE (ready mix) at 20 DAS,

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mulching (wheat straw) 5 t/ha, farmer's practice (2 HW at 15 and 30 DAS and one hoeing at 20 DAS) and weedy check. All pre-emergence herbicides were applied on the same day after sowing and post-emergence herbicides were applied at 2-3 leaf stage (25 DAS). Dehydrogenase activity in the soil samples was determined at flowering stage of soybean following procedure as described by Casida *et al.* (1964). CO_2 evolution in the soil sample was determined by Anderson (1982). Soil samples were stored at (28±2) ºC for a week to stabilize respiration, subsequently used for further analysis. Microbial biomass-C (MB-C) in herbicide treated as well as control soil sample was determined by fumigation extraction method (Vance *et al.* 1987) through back titration against 0.04 N (NH) Fe (SO_2). 6HO using ferroin indicator. Soil samples were collected from the rhizosphere of soybean after the next day of application of herbicide. The count of total bacteria, fungi and actinomycetes in fresh rhizosphere soil samples was carried out by following serial dilution plate count technique as described by Pahwa and Prakash (1996). Nodule count was recorded from the five randomly selected plants at 20 and 40 DAS, nodules were separated from the root and oven dried at 65ºC to determine their dry weight.

Dehydrogenase activity

Higher dehydrogenase activity was observed in cultural practices *i.e.* mulching with wheat straw 5 t/ha and farmer's practice at flowering stage due to higher substrate availability. Among herbicide treated plots, application of diclosulam 84% WDG 0.026 kg/ha as pre-emergence recorded higher dehydrogenase activity whereas among post-emergence application, quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009 + 0.2% surfactant kg/ha registered higher DHA. In herbicidal application treatments, suppression of dehydrogenase activity was observed, which might be due to the lethal action of herbicides on soil microorganisms, which in turn affect the enzymatic chemical process as well as toxicity of the metabolites produced from herbicides. This result corroborates with the findings of Jyot *et al.* (2015), Sabale *et al.* (2015), Lal *et al.* (2017), Sinchana and Sheeja (2020).

Carbon-dioxide evolution

Higher carbon-dioxide evolution at flowering stage was recorded with mulching with wheat straw 5 t/ha and farmer's practice. Among pre-emergence herbicides, it was higher in diclosulam 84% WDG 0.026 kg/ha whereas, and in post-emergence herbicides applications it was observed in quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009 + 0.2% surfactant kg/ha. Similar results were reported by Jyot *et al.* (2015), Sabale *et al.* (2015) and Lal *et al.* (2017).

Soil microbial biomass carbon

Soil microbial biomass carbon is considered to be one of the most responsible parameters for regulating nutrient cycling. Higher soil microbial biomass carbon was recorded in mulching with wheat straw 5 t/ha. Among chemical weed control, higher soil microbial biomass carbon was recorded in diclosulam 84% WDG 0.026 kg/ha as pre-emergence whereas in post-emergence herbicides, it was higher with quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009 + 0.2% surfactant. Results revealed that mulching may have very good effect facilitating the degradation of herbicides also not only maintaining but increasing the microbial biomass carbon. Similar results are in accordance with Singh *et al.* (2014) and Mahapatra *et al.* (2021).

Microbial count

Higher count of all soil microflora was recorded in mulching with wheat straw 5 t/ha which was followed by farmers practice hand weeding at 15 and 30 DAS and hoeing 20 DAS (**Table 1**). Whereas, among pre-emergence herbicides application, diclosulam 84% WDG 0.026 kg/ha recorded highest bacterial count and in post-emergence herbicides treatments, quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009. It might be due to the degradation of herbicides served as carbon source for growth of microbes. The microbial population started to regain after the weeds were killed by the herbicides and got mixed in the soil during this period and these might have served to increase the nutrients. There is temporary suppression in population of beneficial microorganisms, but with passage of time the population again recovered in this biological soil environment. It was in conformity with Ghosh *et al.* (2012), Sebiomo *et al.* (2011) and Trimurtulu *et al.* (2015)

Number of root nodules

All the weed control treatments significantly influenced the number of root nodules/plant at 20 and 40 DAS. Maximum number of root nodules was recorded in mulching with wheat straw 5 t/ha which was closely followed by farmer's practice. Among the weed control treatments mulching with wheat straw recorded higher number of nodules per plant

Table 1. Soil biological indicators as influenced by different weed management practices

Treatment	DHA (µg TPF g^{-1} $24hr^{-1}$)	CO_2 evolution (mg 100^{-g} soil)	SMBC (µg/g soil)	Microbial count		
				Bacterial (cfu g^{-1} soil×10^7)	Fungal (cfu g^{-1} soil ×10^4)	Actinomycetes (cfu g^{-1} soil ×10^6)
Flumioxazin 0.125 kg/ha	22.47	23.83	187.84	14.97	17.09	10.92
Diclosulam 0.026 kg/ha	24.10	26.70	193.85	15.80	17.42	11.67
Pendimethalin 0.677 kg/ha	21.66	22.73	184.80	12.97	15.62	10.65
Pendimethalin + imazethapyr 0.960 kg/ha (ready mix)	22.68	25.67	190.22	15.30	17.22	11.36
Sulfentrazone + clomazone 0.725 kg/ha (ready mix)	23.49	26.40	191.36	15.67	17.33	11.59
Pendimethalin + diclosulam 0.750 + 0.0252 kg/ha (tank mix)	22.06	23.47	186.60	14.97	16.76	10.84
Sodium acifluorfen + clodinafop-propargyl 0.245 kg/ha PoE (ready mix)	25.03	26.71	194.31	15.90	17.76	11.87
Quizalofop-ethyl + chlorimuron-ethyl 0.037+0.009 + 0.2% surfactant kg/ha PoE (ready mix)	26.04	27.87	199.29	16.7	18.09	12.81
Fomesafen + quizalofop-ethyl 0.225 kg/ha PoE (ready mix)	25.22	27.77	198.06	15.95	18.00	12.04
Mulching (wheat straw) 5 t/ha	29.11	30.07	207.85	20.80	21.1	15.51
Farmer's practice (2 HW at 15 & 30 DAS and one hoeing 20 DAS)	27.73	28.60	204.11	17.23	18.26	13.26
Weedy check	26.91	28	200.57	16.88	18.23	12.97
LSD (p=0.05)	4.39	4.45	13.33	1.73	1.45	1.26

Table 2. Root nodules/plant (mg) as influenced by different weed management practices

Treatment	No. of root nodules		Dry wt. of root nodules (mg)	
	20 DAS	40 DAS	20 DAS	40 DAS
Flumioxazin 0.125 kg/ha	7.23	17.57	34.85	65.75
Diclosulam 0.026 kg/ha	7.80	18.32	38.80	70.65
Pendimethalin 0.677 kg/ha	7.30	17.64	36.10	68.45
Pendimethalin + imazethapyr 0.960 kg/ha (ready mix)	7.20	17.30	34.35	69.18
Sulfentrazone + clomazone 0.725 kg/ha (ready mix)	6.96	17.23	31.92	63.98
Pendimethalin + diclosulam 0.750 + 0.0252 kg/ha (tank mix)	7.27	17.07	35.15	67.88
Sodium acifluorfen + clodinafop-propargyl 0.245 kg/ha PoE (ready mix)	7.70	18.64	36.41	67.79
Quizalofop-ethyl + chlorimuron-ethyl 0.037+0.009 + 0.2% surfactant kg/ha PoE (ready mix)	7.73	17.47	39.29	66.28
Fomesafen + quizalofop-ethyl 0.225 kg/ha PoE (ready mix)	7.66	17.31	36.52	67.42
Mulching (wheat straw) 5 t/ha	8.45	18.93	39.52	72.42
Farmer's practice (2 HW at 15 & 30 DAS and one hoeing 20 DAS)	8.07	18.29	38.22	72.36
Weedy check	6.96	16.39	29.49	60.22
LSD (p=0.05)	0.98	1.68	6.40	8.54

than farmer's practice due to soil disturbances which might had affected the root growth and consequently poor nodulation (**Table 2**). Increase in number of effective nodules per plant in these treatments mainly attributed to complete or partial removal of weed competition in terms of allelopathic effect. A marginal effect of herbicides on number of root nodules owing to the limited infection sites on soybean roots to initiate the nodulation. However, mulching with wheat straw 5 t/ha showed significant improvement in dry weight of root nodules over weedy check but was statistically at par with remaining treatment except sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (ready mix). Antagonistic effect of herbicidal treatment on number and dry weight of nodules/plant might due to either phytotoxic effect on crop plants or adverse effect on nodule forming rhizobia. The increased in the nodule dry weight significantly possibly due to stimulatory effect of these chemicals on synthesis of nodular tissue. These results are in accordance with the results reported by Billore *et al.* (2001), Jha (2014), Singh *et al.* (2015), Deepa *et al.* (2017) and Singh *et al.* (2019).

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RESEARCH NOTE

Herbicidal effects on *Cyperus rotundus* in soybean under custard apple based agri-horti system

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ABSTRACT

A Field experiment was conducted during *Kharif* season of 2021 under custard apple based agri-horti system, at agricultural farm of Rajiv Gandhi South Campus, BHU, Barkachha, Mirzapur to study the effect of herbicide on *Cyperus rotundus*. The experiment was carried out in randomized block design (RBD) having seven treatments replicated thrice. Application of different doses of pyroxasulfone as company sample (GSP sample) were compared with pyroxasulfone 85%WG (Market sample) 150 ml/ha, imazethapyr 1000 ml/ha, hand weeding at 20 and 40 DAS and weedy check. Application of pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha, significantly reduced the density and dry weight of *C. rotundus* with least weed effectiveness (WE) and highest weed control efficiency (WCE) and crop resistance index (CRI). Compared to the other treatments, application of pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha produced maximum net returns and hence proved to be more effective.

Keywords: Agroforestry, Biological yield, Crop resistance index, Herbicides, Weed control efficiency

Being an important and cheapest source of concentrated protein of good quality as well as vegetable oil, Soybean [*Glycine max* (L.) Merrill.] holds an important position among Indian agricultural crops accounting for 37% of total oilseeds area and 54 % of area under *Kharif* season oilseed crops. Among all the states, Madhya Pradesh (M.P.) dominates soybean cultivation, contributing approximately 83% of the nation's total production, earning it the title of 'soy-state' (Jadav *et al.* 2022). Soybeans contain high proportion of unsaturated fatty acids, 18% oil, and about 45% protein (Malukani 2016). Hence, many agricultural scientists and food specialists view it as a potential tool against world hunger and a source of protein for the future (Kumar *et al.* 2022).

With the rising population, the demand for food security intensifies, paving the way for sustainable agricultural practices such as Agroforestry. It is an integrated approach of cultivating forest trees, agricultural crops as well as livestock on same unit of land. It provides a diverse source of income to the farmers by providing more than one output at a time from limited land resources. However, presence of tree components on the field supplies moisture, nutrients with leaf litter and regulates temperature. With this perspective, soybean has been cultivated within diverse agroforestry systems worldwide, with the goal of improving productivity and overall profitability (Sharma *et al.* 2023). Nevertheless, among the major challenge faced by soybean-producing countries, weeds pose critical threat, potentially reducing the yield by up to 40% (Soliman *et al.* 2015). These invasive plants have a more substantial economic impact than other crop pests (Gharde *et al.* 2018). In the initial growth phases of soybean, severe weed infestations, particularly *C. rotundus* (family Cyperaceae) diminishes the productivity of the crop. This perennial sedge propagates through under-ground vegetative structures demonstrating tolerance to or evasion from herbicides. They are widely distributed across the tropical and sub-tropical regions globally and proliferates rapidly through an extensive network of under-ground tubers exhibiting strong apical dominance. Hence, effective weed management practices are essential for enhanced crop growth and improved productivity using herbicides, which are effective and economical (Khaffagy *et al.* 2022).

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The field experiment was conducted at Rajiv Gandhi South Campus, BHU, Barkachha, Mirzapur (U.P) (25º 302 N Latitudes and 82º 352 E Longitudes and at an altitude of 168 m above mean sea level) during *Kharif* season of 2021-22. The region falls under semi-arid eastern plain zone (Zone-III A) which is mostly rainfed with extreme summer and extreme winter season. The experimental field has sandy clay loam soil. The soybean cv. (*NRC 86*) *Ahilya-6* was sown manually at a spacing of 40 x 40 cm and at a depth of 2-3cm utilizing 70-75 kg seed/ha. Foot sprayer equipped with a flat fan nozzle was used for the herbicidal application as per the treatment using 500 litres of water/ha. Recommended fertilizers dose (N:P:K-25:60:40) was supplied through Urea, SSP and MOP to fulfil the nutritional requirement of soybean. The experiment employed randomised block design with 7 treatments each replicated thrice. The treatments were: pyroxasulfone 85%WG (GSP sample) 120 ml/ha, pyroxasulfone 85%WG (GSP sample) 150 ml/ha, pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha, pyroxasulfone 85%WG (market sample) 150 ml/ha, imazethapyr 1000 ml/ha, hand weeding at 20 and 40 DAS and control. The Pyroxasulfone treatments were applied as pre-emergence herbicides, while Imazethapyr was used as a post-emergence herbicide. A non- treated controlled plot was included for comparative analysis. In the Agri-horti system, trees were planted at a distance of 4x4 m, reaching heights of 3-7 m, characterized by broad, open crowns and irregularly spaced branches.

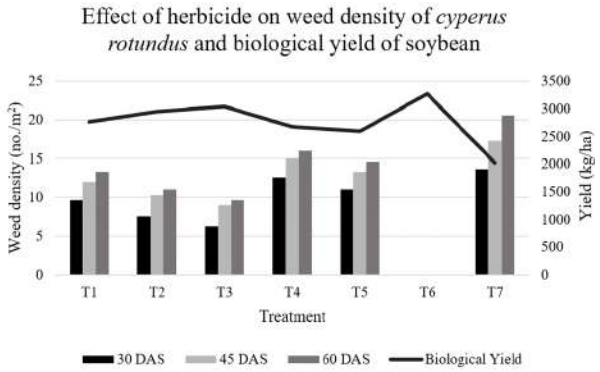
A quadrate of 0.25 m^2 was randomly placed at three places within each plot. Total weed density, weed dry biomass, Weed Control Efficiency (WCE) (Prachand *et al.* 2015) of *C. rotundus* (number/m^2) was monitored periodically at 30, 45 and 60 DAS. Additionally, absolute weed density, Crop Resistance Index (CRI) (Mishra and Misra 1997) and Weed Effectiveness (U.S.D.A./I.C.A.R. A.I.C.R.P.W.C. 1988) were also calculated. Upon reaching full maturity the crop was harvested. After thorough sun drying, the yield from each net plot was weighed for biological yield (kg/ha) as well as grain yield (kg/ha). Data were analysed by using standard statistical techniques. Least significant differences (LSD) at 5% level of probability were worked out for comparing the treatments means.

Effect on *C. rotundus*

The herbicidal treatments, during critical period of crop weed competition effectively suppressed both the density and biomass of weeds (**Table 1**), leading to a significant reduction in population and dry weight of *C. rotundus* compared to weedy check. Kumar *et al*. (2021) reported similar findings, highlighted that density and dry weight of grassy weeds were significantly lower with application of pyroxasulfone. The pre-emergence application of herbicides delayed the critical weed period, allowing crop to establish themselves more effectively at an early stage as indicated by Knezevic *et al.* (2019). Furthermore, increased doses of pyroxasulfone 85%WG, corresponded to lower population and weight of *C. rotundus*. Among herbicidal treatments, pre-emergence application of 187.5 ml/ha of pyroxasulfone 85%WG (GSP sample) significantly reduced the population and dry biomass of *C. rotundus* compared to other herbicidal treatments and it was statistically at par with the application of 150 ml/ha of pyroxasulfone 85%WG (GSP sample) across all stages of observations (**Table 1**). These results align with findings of Kumar *et al*. (2021) which indicated that different concentrations of Pyroxasulfone have significantly lowered the weed density. However, the application of 1000 ml/ha of Imezathapyr 85% SL recorded highest density and dry biomass of *C. rotundus* respectively as these provided less restricted growing environment to *C. rotundus* when compared to other herbicidal treatments. Moreover, the pyroxasulfone 85%WG (GSP sample) 150 ml/ha and pyroxasulfone 85%WG

Table 1. Effect of herbicides on density and dry weight of *C. rotundus* at 30, 45 and 60 days after sowing (DAS)

Treatment	Weed density (no./m^2)			Absolute density (no./m^2)			Dry weight (g/m^2)		
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
Pyroxasulfone 85%WG (GSP sample) 120 ml/ha	9.60	12.00	13.30	3.20	4.00	4.43	2.3	2.52	2.79
Pyroxasulfone 85%WG (GSP sample)150 ml/ha	7.60	10.30	11.00	2.53	3.43	3.67	1.82	2.47	2.64
Pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha	6.30	9.00	9.60	2.10	3.00	3.20	1.51	2.16	2.30
Pyroxasulfone 85%WG (Market sample) 150 ml/ha	12.60	15.00	16.00	4.20	5.00	5.33	3.02	3.15	3.36
Imazethapyr 1000 ml/ha	11.00	13.30	14.60	3.67	4.43	4.87	2.64	3.19	3.50
Hand weeding at 20 and 40 DAS	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.00
Control	13.60	17.30	20.60	4.53	5.77	6.87	3.26	3.63	4.33
LSD (p=0.05)	3.10	2.80	3.42	1.03	0.93	1.14	0.32	0.32	0.35



T_1-Pyroxasulfone 85%WG (GSP sample) 120 ml/ha, T_2-Pyroxasulfone 85%WG (GSP sample) 150 ml/ha, T_3-Pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha, T_4-Pyroxasulfone 85%WG (Market sample) 150 ml/ha, T_5-Imazethapyr 1000 ml/ha, T_6-hand weeding at 20 and 40 DAS and T_7-Control.

Figure 1. Effect of herbicide on weed density of *Cyperus rotundus* and biological yield of soybean

(GSP sample) 187.5 ml/ha concentration of herbicides used in the experiments were suggested as the best treatments for suppressing the weed growth in different crops *i.e.* 125-250ml/ha when compared to other pre-emergence herbicides (Yamaji *et al.* 2014).

Relative efficiency of weed control treatments is judged by calculating the WCE compared to untreated check (**Table 2**). The application of pyroxasulfone 85%WG (GSP sample) at 187.5 ml/ha observed the highest WCE of *C. rotundus*, indicating that relative killing of potential weeds under particular treatment has a significant impact on WCE. In contrast, plots that were hand weeded twice exhibited minimum density and dry biomass of *C. rotundus* due to reduced crop-weed competitions and even exhibited maximum WCE similar to findings of Meena *et al.* (2022). Nevertheless, the plots underwent two hand weeding outperformed all the herbicidal treatments suggesting this method may be a better alternative for controlling *C. rotundus*.

Weed effectiveness index is the per cent reduction in crop yield under a particular treatment due to the presence of weeds in comparison to weed free plot. The highest weed effectiveness index for *C. rotundus* was observed with the application of 150 ml/ha of Pyroxasulfone 85%WG (market sample), demonstrating that higher herbicide concentrations led to a reduction in weed populations.

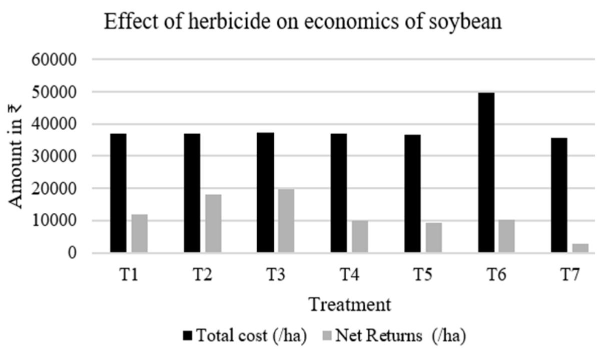
The healthiness of the crop plant is indicated by crop resistance index parameter due to effective weed management. The maximum crop resistance index was recorded with application of 187.5 ml/ha of pyroxasulfone 85% WG (GSP sample) outperforming other herbicidal treatments. This dosage of pyroxasulfone 85%WG (GSP sample) consistently enhanced the CRI at all stages of crop growth, indicating reduced harmful effect of herbicidal treatment on soyabean crop as compared to others. In contrast, the control plot exhibited a lower CRI value of 1.00, highlighting the severe effects of weed competition on the soybean crop, as noted by Gupta *et al.* (2019). The variation in growth of sedges with higher doses of pre-emergence application of Pyroxasulfone is attributed to higher absorption of herbicidal solution by infant weeds, aligning with the studies of Kumar *et al.* (2021).

Effect on yield of soybean

Significant influence of herbicidal application on soybean yield was recorded (**Table 2**). The use of 187.5 ml/ha of pyroxasulfone 85%WG (GSP sample) resulted in significant enhancement of both the grain yield (1264 kg/ha) and biological yield (3048 kg/ha) compared to other herbicidal treatments, and it was statistically at par with 150 ml/ha of pyroxasulfone 85%WG (GSP sample). This was attributed to maximum crop growth associated with higher dose of herbicide applied in T_3, which provides a relative weed free environment, thereby minimizing competition and promoting enhanced crop growth and yield. The results were corroborated with the findings of Kumar *et al.* (2021) who recorded significant difference in growth and yield attributes at different doses of Pyroxasulfone treatment in Maize crop. Conversely, the lowest yield was recorded under weedy check over herbicides application due to

Table 2. Effect of herbicides on *C. rotundus* indices and yield of soybean

Treatment	WCE (%)			CRI			WE (%)			Grain Yield (kg/ha)	Biological Yield (kg/ha)
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS		
Pyroxasulfone 85%WG (GSP sample) 120 ml/ha	29.4	30.6	35.4	2.63	2.17	2.36	70.6	69.4	64.6	1061	2768
Pyroxasulfone 85%WG (GSP sample)150 ml/ha	44.1	32.0	39.0	3.67	2.39	2.55	55.9	59.5	53.4	1223	2946
Pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha	53.7	40.5	46.7	4.83	2.92	3.07	46.3	52.0	46.6	1264	3048
Pyroxasulfone 85%WG (Market sample) 150 ml/ha	7.4	13.3	22.3	1.44	1.36	1.72	92.6	86.7	77.7	1020	2672
Imazethapyr 1000 ml/ha	19.1	12.1	19.0	1.82	1.46	1.72	80.9	76.9	70.9	1003	2601
Hand weeding at 20 and 40 DAS	100.0	100.0	100.0	0.00	0.00	0.00	0.0	0.0	0.0	1316	3278
Control	0.0	0.0	0.0	1.00	1.00	1.00	100	100	100	852	2026



T_1-Pyroxasulfone 85%WG (GSP sample) 120 ml/ha, T_2-Pyroxasulfone 85%WG (GSP sample) 150 ml/ha, T_3-Pyroxasulfone 85%WG (GSP sample) 187.5 ml/ha, T_4-Pyroxasulfone 85%WG (Market sample) 150 ml/ha, T_5-Imazethapyr 1000 ml/ha, T_6-hand weeding at 20 and 40 DAS and T_7-Control.

Figure 2. Effect of herbicide on economics of soybean

heavy weed infestation and poor performance of yield attributes. Moreover, twice hand weeded plot recorded maximum biological yield (3278 kg/ha) than all other herbicidal treatments.

Although, maximum WE, grain and biological yield was achieved with twice hand weeded plots but it showed a lower net returns (10232 ^{1} /ha) than 187.5 ml/ha of pyroxasulfone 85%WG (GSP sample) (19828 ^{1} /ha) (**Figure 2**) due to high labour charges which ultimately increased the cultivation cost.

Based on the above results it is concluded that application of 187.5 ml/ha of pyroxasulfone 85%WG (GSP sample) had significantly reduced the density of *C. rotundus* with highest WCE and CRI as well as highest net returns. Hence, use of 187.5 ml/ha of Pyroxasulfone 85% WG (GSP sample) will prove to be an excellent weed control in soybean crop. Further, pyroxasulfone is also successful in supressing weeds for various other crops like corn, sunflower, peanuts, potatoes etc (Yamaji *et al.* 2014). Its low dosage, high activity, broad control and long-lasting effect can meet all the objectives of weed management. Moreover, involvement of agri-horti system in the present experiment will also prove beneficial to the farmers by increasing crop productivity and enhancing their net income compared to sole cropping.

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RESEARCH NOTE

Non-chemical weed control impact on growth, yield quality and profitability of mustard in Eastern plateau and hill zone of India

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ABSTRACT

A field experiment was conducted at Divyayan Krishi Vigyan Kendra, Morabadi, Ranchi, Jharkhand (India), during the winter 2022-23 to find out the non-chemical weed control impact on growth, yield, quality and profitability of mustard in Eastern plateau and hill zone of India. The experiment was executed in a randomized block design using 10 treatments: control (unweeded), hand weeding (weed free), ginger + garlic (1:1) extract 40 %, parthenium leaf extract 40%, bamboo leaf extract 40%, teak leaf extract 40%, lantana leaf extract 40%, calotropis leaf extract 40%, neem leaf extract 40%, guava leaf extract 40%), replicated three times. Among all the treatments, hand weeding (weed free) resulted best in controlling the weeds in the mustard crop field. Consequently, it ensured maximum plant growth, seed yield (2.14 t/ha), stover yield (4.48 t/ha), harvest index (32.5 %) and quality attributes (Total soluble solids (TSS) 11.3°Brix, total sugar 9.39%, protein 22.1%, oil 37.7%) of mustard. On the contrary, botanical leaf extract sprays showed very less weed control efficiency (WCE) (5.27-17.06%). Spraying of lantana leaf extract 40% ensured relatively better WCE (17.06%) and consequently, improved mustard growth, seed yield (1.72 t/ha), stover yield (4.03 t/ha), harvest index (29.9) and quality attributes (TSS 11.0°Brix, total sugar 8.52%, protein 21.1%, oil 36.5%) to an extent. Hand weeding further obtained maximum net returns (₹ 96460/ha) and B:C (3.36), closely *fb* spraying of lantana leaf extract 40% (net returns ₹ 77560/ha, and B:C 3.30). The lowest mustard growth, yield and quality were obtained from the unweeded (control plot), indicating the harmful impact of weeds on crop.

Keywords: Leaf Extract, Hand Weeding, Yield, Net returns, Quality, Weed CE

Oilseeds hold a significant position in the human diet. They accelerate the activities of the brain, liver, nerves etc. through the synthesis of phospholipids (Alam *et al*. 2014). Over the years, agricultural land is occupied mostly by food grains to meet the food demand of the country and therefore, oilseeds have been neglected. As a consequence, there arise disparity between demand and supply of oilseeds, which in turn urges for foreign imports and thus, makes oilseeds or their products very costly. Under such circumstances, the cultivation of oilseeds as well as the strengthening of the demand-supply chain is highly needed to address high market price and availability issues. Indian mustard (*Brassica juncea* L. Czern. Coss) is an annual, herbaceous, winter growing, oilseed crop contributing a production of 9.26 million metric tonnes and a productivity of 1511 kg/ha in 2017-18 from 6.12 million ha area in India (Chauhan *et al*. 2020). Mustard is nutritionally rich in phytonutrients (calcium, manganese, copper, iron, zinc, selenium and magnesium), vitamins (A, B-complex, C, E and K) and antioxidants. Mustard seeds in general contain 35-45% oil, 17-25% protein, 8-10% fibres, 6-10% moisture and 10-12% extractable substances (Chauhan *et al*. 2002). In the present context of agriculture, the imbalance between demand and supply of mustard is a result of various issues. Among these, weeds play a key role in harming mustard cultivation and reducing its productivity. Weeds are the most severe and widespread biological constraints to crop production in India and weeds alone cause 33% of losses out of total losses due to pests (Verma *et al*. 2015). Weeds are the major concern everywhere, as they steal the resources that are otherwise could have been utilized by the crop. Therefore, proper weed management practice is now the fundamental requisite for the cotton growers to address such drastic yield reduction.

Hand weeding or inter-culture by far is the best and the most common conventional practice to manage weeds and consequently to increase the yield

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and quality of the mustard crop. However, in the present scenario of labour shortage and frequent rise in wages coupled with its non-suitability for all agro-climatic conditions, this uneconomical weeding option is losing focus and alternative options are getting acceptance in its place (Biswas and Dutta 2019). Chemical measures of weed control are now widely practiced by the farmers as it is quick, economical and effective way to destroy weeds and contribute to higher crop yield. However, continuous use of these chemicals leaves a toxic footprint in the environment as they persist for a long period of time. Non-chemical weed control measures can be some potential alternatives to chemical herbicides and these are in the center of organic and/or natural farming. Various botanical extracts of plants contain secondary compounds and metabolites which can exhibit toxic properties on weeds when applied. In many researches, botanical extracts or phyto-herbicides have shown their effectiveness in controlling weeds from crop field and thereby, allowed the crop to utilize the resources properly for its growth and productivity. Allelopathic effect of various botanical extracts on weed control and germination of rapeseed and mustard was earlier documented by Rys *et al*. (2022). The compounds present in these botanical extracts are biodegradable and have great structural diversity and complexity and are safer for non-target plants. Further, these phytotoxins have different levels of action and the combination of different modes and multiple levels of action makes these substances effective for weed control. So far, the use of botanical extracts for weed control is very less. Unfortunately, research in this direction is also limited. Most of the uses of botanical extracts are for controlling insects and diseases. Therefore, considering the need to develop organic, eco-safe bio-herbicides, the present research was planned and executed.

A field experiment was carried out at Divyayan Krishi Vigyan Kendra, Ramakrishna Mission Ashrama, Morabadi, Ranchi, Jharkhand (23.23°N latitude, 85.23°E longitude and 628 m above the mean sea level) during the *Rabi* 2022-23. The soil of the experimental site was well drained, highly fertile, clay loam textured, laterite and slightly acidic in nature. The organic farming was in practice for the last fifteen years in the plot where the experiment was conducted. The experiment was carried out in a randomized block design using ten treatments involving non-chemical weed control measures, viz. control (unweeded), weed free check (hand weeding), ginger + garlic (1:1) extract 40%, parthenium leaf extract 40%, bamboo leaf extract 40%, teak leaf extract 40%, lantana leaf extract 40%, calotropis leaf extract 40%, neem leaf extract 40%, and guava leaf extract 40%.

Mustard seed variety '*PM-30*' 6 kg/ha was treated with Beejamrit 10% solution and sown on November 14, 2022 at 30 cm × 10 cm spacing and harvested on March 3, 2023. To prepare Beejamrit solution, at first, 5 litres of cow urine and 5 kg of cow dung were taken in a container. Then, 20 liters of water, 50 g lime and a fist of virgin soil were added into it. The materials were thoroughly mixed and kept for 48 hours with regular stirring. The seeds were mixed with 10% solution of Beejamrit and thereby, drying of seeds was done under shade. In weed free check plots, at 10, 20, 30, 40, 50, 65 and 80 DAS with the help of khurpi and spade and also as and when emerged in between days, weeds were removed. Botanical extracts were prepared on 5th December, 2022 and 20th December, 2022 for two times sprays on 8th December, 2022 and 23rd December, 2022, respectively. The preparation process of botanical extracts has been shown in **Figure 1.** The experiment also followed standard package of practices of mustard cultivation.

Observations on weeds comprised of dominant weed flora of mustard field, weed density (/m^2) and biomass (g/m^2) and weed control efficiency (%) recorded on 7th January, 2023 (15 days after final spray of botanical extracts). The weed control efficiency (WCE) was computed as:

$$\text{WCE (\%)} = \frac{(X-Y)}{X} \times 100$$

Where, X = Weed biomass (g/m^2) in control (unweeded) plot and Y= Weed biomass (g/m^2) in treated plot

Further, plant height and dry matter accumulation were taken at harvest, while crop growth rate was computed between 30-60, 60-90 DAS and 90 DAS-harvest stage. Yield attributes such as number of siliqua / plant, numbers of seeds/siliqua, test weight, siliqua length and breadth, seed yield, stover yield and harvest index were calculated at harvest stage. Harvested seeds' quality parameters such as total soluble solids, total sugar, protein and oil contents were tested in the laboratories of Ramakrishna Mission Vivekananda Educational and Research Institute, Ranchi, based on the methods as suggested by Rangamma (1987), Dubois *et al*. (1956), Gupta *et al*. (1972) and AOAC (1960), respectively.

Finally, production economics (cost of cultivation, gross returns, net returns and benefit-

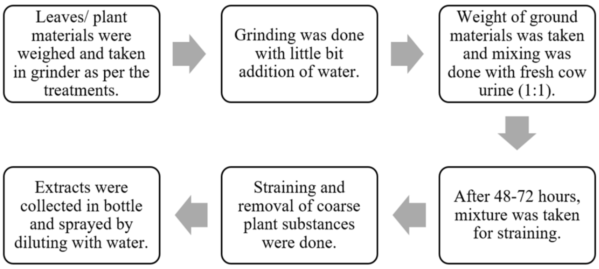

Figure 1. Botanical extract preparation process

cost ratio (B:C)) was chalked out. Data obtained from the field and laboratory were statistically analyzed using analysis of variance method given by Panse and Sukhatme (1985). The treatment means were compared using the LSD values at 5% level of significance ($p=0.05$). Due to wide variations existed in the original data set, for analysis of variance, values of weed density and weed biomass were subjected to square root transformation ($\sqrt{X+0.5}$).

Weed density (/m^2) and biomass

Major weeds found in the experimental plots were *Amaranthus viridis*, *Anagallis arvensis*, *Chenopodium album*, *Ageratum conyzoides*, *Oxalis corniculata*, *Commelina benghalensis*, *Euphorbia hirta*, *Cynodon dactylon*, *Alternanthera philoxeroides etc*. No sedge was found. Infestation of broad-leaved weeds were higher as compared to grasses.

Hand weeded plots recorded no weeds while unweeded control recorded maximum weed density/m^2 (grass: 31.3, broad-leaved weeds: 170.7 and total: 202.0) and biomass (g/m^2) (grass: 6.85, broad-leaved weeds: 45.37 and total: 52.22) (**Table 1**). Among botanical weed control measures, the lowest weed density/m^2 (grass: 19.0, broad-leaved weeds: 147.7 and total: 166.7) and weed biomass (g/m^2) (grass: 4.50, broad-leaved weeds: 38.81 and total: 43.31) were recorded by spraying of lantana (*Lantana camara*) leaf extract 40%, closely *fb* bamboo (*Bambusa vulgaris*) leaf extract 40% and guava (*Psidium guajava*) leaf extract 40%. Among the botanical extracts, spraying of lantana (*Lantana camara*) leaf extract 40% recorded the less weed density and biomass. It might be due to presence of secondary compounds which under foliar spray got absorbed and translocated inside the weed plant and triggered weed control through inhibiting or blocking one or more essential metabolic activities of the plant.

Weed control efficiency

Weed control efficiency (WCE) was estimated by taking weed biomass of grasses (narrow-leaved weeds or NLWs), broad-leaved weeds (BLWs) and total weeds' biomass (g/m^2) into account (**Table 2**). 100% WCE (both grass, broad-leaved weeds as well as total) was achieved under weed free check plot, while no weeds were controlled in unweeded control plot. Specific botanical sprays on weeds ensured WCE to a less extent (grasses: 12.41-29.05%; broad-leaved weeds: 4.80-14.46%; total: 5.27-17.06%). Botanical sprays controlled grassy weeds more than broad-leaved weeds. Among various botanical sprays, the maximum WCE was recorded by lantana (*Lantana camara*) leaf extract 40% (grass: 34.31%, broad-leaved weeds: 14.46% and total: 17.06%), closely *fb* bamboo (*Bambusa vulgaris*) leaf extract 40% and guava (*Psidium guajava*) leaf extract 40%. Less weed density and biomass indicated high weed control efficiency and vice-versa. In the present study, botanicals did not perform well. It might be due to tolerance of the weed species to spray, agro-climatic situation as well as non-effectiveness of

Table 1. Influence of non-chemical weed control measures on weed density (/m^2) and biomass (g/m^2) in mustard field at 45 DAS

Treatment	Weed density/m^2			Weed biomass (g/m^2)		
	Grasses (NLWs)	Broad-leaved weeds (BLWs)	Total	Grasses (NLWs)	Broad-leaved weeds (BLWs)	Total
Control (unweeded)	5.68 (31.3)*	13.09 (170.7)	14.24 (202.0)	2.81 (6.85)*	6.81 (45.37)	7.30 (52.22)
Hand weeding (weed free check)	-	-	-	-	-	-
Ginger + garlic (1:1) extract 40%	5.06 (24.7)	12.41 (153.0)	13.36 (177.7)	2.62 (5.85)	6.54 (41.78)	6.97 (47.63)
Parthenium leaf extract 40%	4.82 (22.3)	12.32 (151.0)	13.19 (173.3)	2.45 (5.04)	6.46 (40.74)	6.84 (45.78)
Bamboo leaf extract 40%	4.55 (19.7)	12.27 (149.7)	13.05 (169.3)	2.42 (4.86)	6.40 (39.96)	6.77 (44.82)
Teak leaf extract 40%	4.92 (23.3)	12.30 (150.3)	13.21 (173.7)	2.48 (5.18)	6.65 (43.19)	7.03 (48.37)
Lantana leaf extract 40%	4.46 (19.0)	12.19 (147.7)	12.94 (166.7)	2.35 (4.50)	6.31 (38.81)	6.65 (43.31)
Calotropis leaf extract 40%	5.16 (25.7)	12.43 (153.7)	13.42 (179.3)	2.65 (6.00)	6.61 (42.63)	7.05 (48.63)
Neem leaf extract 40%	5.29 (27.0)	12.26 (149.7)	13.32 (176.3)	2.62 (5.87)	6.68 (43.60)	7.10 (49.47)
Guava leaf extract 40%	4.79 (22.0)	12.26 (149.3)	13.12 (171.3)	2.45 (4.99)	6.49 (41.16)	6.87 (46.16)
LSD (p= 0.05)	0.40	0.36	0.43	0.09	0.18	0.17

*Data represent square root transformed value *i.e* ($\sqrt{X+0.5}$). Data in parentheses indicate original value botanical extract on the weed flora found in the area where the investigation was conducted. Earlier, Carrubba *et al*. (2020) also stated the non-effectiveness of botanical extracts on weed control.

Growth attributes

Growth attributes like plant height, dry matter accumulation and crop growth rate varied at all the observation intervals among different non-chemical weed control measures (**Table 3**). Irrespective of observation intervals, maximum plant height (50.6% higher than control) and dry matter accumulation (121.8% higher than control) were obtained from hand weeding, *fb* spraying of lantana (*Lantana camara*) leaf extract 40% (plant height: 29.5%; dry matter accumulation: 96.0% higher than control) and bamboo (*Bambusa vulgaris*) leaf extract 40% on weeds (plant height: 23.5%; dry matter accumulation: 83.0% higher than control) at harvest, respectively. Both lantana and bamboo leaf extracts remained statistically at par to each other. Control (unweeded), on the other hand, showed lowest plant height and dry matter accumulation. Crop growth rate of mustard was the direct reflection of dry matter accumulation, which also varied significantly among the different weed control measures. Weed free check recorded the highest crop growth rate (171.5, 101.8 and 112.0% higher than control at 30-60, 60-90 DAS and 90 DAS-harvest, respectively), closely *fb* spraying of lantana (*Lantana camara*) leaf extract 40%, bamboo (*Bambusa vulgaris*) leaf extract 40%, guava (*Psidium guajava*) leaf extract 40% and parthenium (*Parthenium hysterophorus*) leaf extract 40%. Teak (*Tectona grandis*), guava (*Psidium guajava*) and parthenium (*Parthenium hysterophorus*) leaf extract 40% sprays on weeds remained statistically similar to each other.

Weed is a major competitor of crop. In this study, various non-chemical weed control measures suppressed weeds to variable extents. Accordingly, crop-weed competition for different essential resources might also vary resulting in variable availability and utilization of resources by crop. Hence, the present result might be due to the fact that under variable weed control measures, crop plants responded positively to different essential resources like nutrients, water, space, sunlight etc. which in turn positively influenced the cell division, multiplication etc. resulting in development of meristematic tissues and shoot elongation (Hashim *et*

Table 2. Influence of non-chemical weed control measures on weed control efficiency in mustard field at 45 DAS

Treatment	Weed control efficiency (%)			
	Grasses (NLWs)	Sedges	Broad-leaved weeds (BLWs)	Total
Control (unweeded)	-	-	-	-
Hand weeding (weed free check)	100.00	-	100.00	100.00
Ginger + garlic (1:1) extract 40%	14.60	-	7.91	8.79
Parthenium leaf extract 40%	26.42	-	10.20	12.33
Bamboo leaf extract 40%	29.05	-	11.92	14.17
Teak leaf extract 40%	24.38	-	4.80	7.37
Lantana leaf extract 40%	34.31	-	14.46	17.06
Calotropis leaf extract 40%	12.41	-	6.04	6.87
Neem leaf extract 40%	14.31	-	3.90	5.27
Guava leaf extract 40%	27.15	-	9.28	11.60

Table 3. Influence of non-chemical weed control measures on growth attributes of mustard

Treatment	Plant height (cm)	Dry matter accumulation (g/m^2)	Crop growth rate (g/m^2/day)		
	Harvest	Harvest	30-60 DAS	60-90 DAT	90 DAS-harvest
Control (unweeded)	114.4	335.9	2.67	7.22	1.58
Hand weeding (weed free check)	172.3	744.9	7.25	14.57	3.35
Ginger + garlic (1:1) extract 40%	117.8	354.9	3.03	7.27	1.66
Parthenium leaf extract 40%	131.7	543.3	4.69	11.33	2.42
Bamboo leaf extract 40%	141.3	614.6	5.17	13.03	2.71
Teak leaf extract 40%	131.7	513.9	4.55	10.53	2.37
Lantana leaf extract 40%	148.2	658.4	5.41	14.14	2.84
Calotropis leaf extract 40%	121.8	364.4	3.14	7.38	1.81
Neem leaf extract 40%	120.0	359.9	3.07	7.36	1.69
Guava leaf extract 40%	137.0	588.9	5.18	12.30	2.50
LSD (p= 0.05)	9.6	38.4	0.74	1.44	0.76

al., 2015). Among non-chemical weed control measures, hand weeding (weed free) helped the mustard plant to attain maximum plant height. It might be due to its 100% weed control efficiency resulting in adequate availability of resources and their proper utilization by the crop which in turn ensured high shoot elongation. It helped mustard to absorb and utilize the resources properly. Consequently, it might help in emergence of more branches, leaves and synthesize chlorophyll for high photosynthetic efficiency which ultimately got reflected in maximum dry matter accumulation of mustard. Lantana leaf extract spray on weeds also ensured relatively high plant growth among other botanical spray and it was due to its weed control efficiency to an extent. Mishra and Tripathi (2021) also recognized the weed control potential of *Lantana camara* extract.

Yield attributes

Plant population was recorded at harvest and showed non-significant response towards weed control measures as it entirely depended on seed viability and its interaction with agro-climatic condition. Maximum *i.e.* 79.8, 44.4, 60.5, 36.6 and 56.9% higher numbers of siliqua/plant, siliqua length, siliqua breadth, numbers of seed/siliqua and test weight were recorded from hand weeded plot over control, *fb* spraying of lantana (*Lantana camara*) leaf extract 40% (63.9, 31.1, 50.0, 22.0 and 40.5% higher numbers of siliqua/plant, siliqua length, siliqua breadth, numbers of seed/siliqua and test weight than control), bamboo (*Bambusa vulgaris*) leaf extract 40% (58.4, 26.7, 42.1, 17.1 and 37.1% higher numbers of siliqua/plant, siliqua length, siliqua breadth, numbers of seed/siliqua and test weight than control) and guava (*Psidium guajava*) leaf extract 40% on weeds (57.0, 24.4, 42.1, 14.6 and 29.2% higher numbers of siliqua/plant, siliqua length, siliqua breadth, numbers of seed/siliqua and test weight than control) (**Table 4**). Both lantana and bamboo leaf extracts remained statistically at par to each other. Teak (*Tectona grandis*), guava (*Psidium guajava*) and parthenium (*Parthenium hysterophorus*) leaf extract 40% sprays on weeds remained statistically similar to each other. On the contrary, control (unweeded) recorded the lowest yield attributes of mustard.

Hand weeding outperformed other non-chemical weed control measures as it controlled the weeds to maximum limit (100% weed control efficiency) and thus, possibly improved absorption and translocation of nutrients and water from soil to plant, which could be otherwise snatched by the weeds. Besides, hand weeding also helped in utilization of sunlight, space, and CO_2. Greater root growth as well as uptake of nutrients specially nitrogen might improve chlorophyll content which ensured higher photosynthetic efficiency along with other resources resulting in high dry matter production and translocation of dry matter from vegetative (source) to reproductive parts (sink) (Biswas *et al.* 2020). Consequently, mustard generated high yield attributes. Among the botanical sprays, spraying of Lantana (*Lantana camara*) leaf extract 40% recorded comparatively high yield attributes and it was due to potential reduction of crop-weed competition which liberated the resources for crop's use. As control (unweeded) plots were heavily infested with weeds, most of the resources have been utilized by the weeds, resulting in poor dry matter accumulation and translocation to reproductive parts.

Yield and harvest index

Significant variations existed among the different non-chemical weed control measures and

Table 4. Influence of non-chemical weed control measures on yield attributes, yield and production economics of mustard

Treatment	Plant population (/m^2)	No. of siliqua/ plant	Siliqua length (cm)	Siliqua breadth (mm)	no. of seed/ siliqua	Test weight (g)	Seed yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Net return (₹/ha)	B:C
Control (unweeded)	26.7	71.8	4.5	3.8	8.2	4.15	0.83	2.34	26.3	27580.0	2.03
Hand weeding (weed free check)	27.3	129.1	6.5	6.1	11.2	6.51	2.14	4.48	32.5	96460.0	3.36
Ginger + garlic (1:1) extract 40%	27.6	84.9	4.6	4.1	8.8	4.37	0.87	2.37	26.9	-19960.0	0.74
Parthenium leaf extract 40%	27.7	109.9	5.5	5.3	9.2	5.23	1.47	3.62	28.8	62540.0	2.90
Bamboo leaf extract 40%	27.5	113.7	5.7	5.4	9.6	5.69	1.68	4.06	29.2	75220.0	3.23
Teak leaf extract 40%	28.1	106.8	5.3	5.3	8.9	5.18	1.37	3.43	28.5	55360.0	2.64
Lantana leaf extract 40%	28.2	117.7	5.9	5.7	10.0	5.83	1.72	4.03	29.9	77560.0	3.30
Calotropis leaf extract 40%	28.3	85.6	4.7	4.2	8.6	4.28	0.9	2.45	26.9	25200.0	1.75
Neem leaf extract 40%	27.6	87.0	4.6	4.0	8.5	4.22	0.89	2.4	27.0	24500.0	1.73
Guava leaf extract 40%	27.8	112.7	5.6	5.4	9.4	5.36	1.57	3.96	28.4	68420.0	3.03
LSD (p= 0.05)	NS	7.7	0.5	0.4	0.9	0.41	0.20	0.58	2.38	-	-

the control for seed yield of mustard. Hand weeding (weed free) registered maximum seed yield, stover yield and harvest index (HI), which were 157.8, 91.5 and 23.6% higher than control, *fb* spraying of lantana (*Lantana camara*) leaf extract 40% (107.2, 72.2 and 13.7% higher seed yield, stover yield and HI over control) (**Table 4**). Bamboo (*Bambusa vulgaris*) leaf extract 40%, guava (*Psidium guajava*) leaf extract 40% and parthenium (*Parthenium hysterophorus*) leaf extract 40% spray on weeds also influenced the seed yield and harvest index positively. Both lantana and bamboo leaf extracts remained statistically at par to each other. Teak (*Tectona grandis*), guava (*Psidium guajava*) and parthenium (*Parthenium hysterophorus*) leaf extract 40% sprays on weeds remained statistically similar to each other. Control (unweeded), on the other hand, recorded the lowest seed yield (0.83 t/ha), stover yield (2.34 t/ha) and harvest index (26.3). Yield followed the trend of yield attributes. In a previous study, Anwar *et al.* (2021) observed that methanol extracts of *L. camara* flowers depressed growth parameters, protein content, chlorophyll content of weed species.

Quality parameters

Among different non-chemical weed control measures, weed free check recorded the highest TSS, total sugar, protein content and oil content (18.9, 24.9, 15.7 and 9.0% higher than control), *fb* spraying of lantana (*Lantana camara*) leaf extract 40% (15.8, 13.3, 10.5 and 5.5% higher TSS, total sugar, protein content and oil content than control) (**Table 5**). Bamboo (*Bambusa vulgaris*) leaf extract 40%, guava (*Psidium guajava*) leaf extract 40% and parthenium (*Parthenium hysterophorus*) leaf extract 40% sprays on weeds also ensured high quality parameters of mustard seeds. Both lantana and bamboo leaf extracts remained statistically at par to each other. Control (unweeded), on the other hand, recorded the lowest seed yield (0.83 t/ha), stover yield (2.34 t/ha) and harvest index (26.3). Yield followed the trend of yield attributes. In a previous study, Anwar *et al.* (2021) observed that methanol extracts of *L. camara* flowers depressed growth parameters, protein content, chlorophyll content of weed species. On a contrary, control (unweeded) recorded the lowest quality parameters of mustard.

In the present investigation, hand weeding as and when weeds emerged ensured the higher TSS, total sugar, protein and oil contents of mustard seeds over the others. It might be due to the positive influence of weed free condition throughout the crop period for the crop to flourish and uptake and mobilize nutrients inside the plants. It is well known fact that nitrogen is the precursor of protein. Higher protein and oil contents under this treatment might be due to greater availability and uptake of nitrogen and sulphur, respectively and translocation in mustard seeds under zero crop-weed competition scenario. Oil synthesis was triggered under weed free favourable environment during crop growth. Similarly, TSS and sugar contents were high under this treatment due to positive influence of nutrient availability, various phyto-hormones and upregulation of some essential enzymatic activities for synthesis of carbohydrate. Due to some weed control potential, among different botanical sprays, spraying of lantana (*Lantana camara*) leaf extract 40% ensured relatively better-quality attributes of mustard seeds. Control did not receive any weed control measure and thereby, got negatively influenced by weed infestations, which reflected in low quality attributes of mustard.

Production economics

The hand weeding (as and when required) outperformed others in terms net returns (₹ 96460/ha), *fb* spraying of lantana (*Lantana camara*) leaf extract 40% (₹ 77560/ha) and bamboo (*Bambusa vulgaris*) leaf extract 40% (₹ 75220/ha) on weeds (**Table 4**). Weed free check showed the highest B:C (3.36), closely *fb* spraying of lantana (*Lantana camara*) leaf extract 40% (3.30) and bamboo (*Bambusa vulgaris*) leaf extract 40% (3.23) on weeds. Lowest B:C was obtained from spraying of ginger + garlic (1:1) extract 40% on weeds (0.74). Hand weeding recorded the maximum net return, and B:C due to the highest yield production as weeds were completely removed during the entire crop growth period. Among different botanical extracts, spraying of lantana (*Lantana camara*) leaf extract 40% recorded a relatively high net return and B:C as it exhibited around 17% weed control efficiency, which was reflected in mustard crop yield and thereby, to economic profitability.

Based on the findings from the investigation, it was concluded that weed free check showed 100% weed control efficiency and thereby, improved the growth and yield of mustard. Further, it ensured an elevation in quality parameters of mustard as well as generated maximum net return and B:C. Among different botanicals, spraying of lantana (*Lantana camara*) or bamboo (*Bambusa vulgaris*) leaf extract 40% ensured relatively high weed control efficiency and improved crop growth, yield, quality. Further, spraying of lantana (*Lantana camara*) leaf extract 40% recorded the highest profitability. For realizing best growth, yield, quality and economic profitability

Table 5. Influence of non-chemical weed control measures on quality parameters of mustard seeds

Treatment	TSS (°Brix)	Total sugar (%)	Protein (%)	Oil (%)
Control (unweeded)	9.5	7.52	19.1	34.6
Hand weeding (weed free check)	11.3	9.39	22.1	37.7
Ginger + garlic (1:1) extract 40%	9.7	7.63	19.4	35.0
Parthenium leaf extract 40%	10.3	8.13	20.2	36.1
Bamboo leaf extract 40%	10.8	8.35	20.7	36.4
Teak leaf extract 40%	10.1	8.02	20.1	35.7
Lantana leaf extract 40%	11.0	8.52	21.1	36.5
Calotropis leaf extract 40%	9.6	7.57	19.4	34.9
Neem leaf extract 40%	9.8	7.69	19.5	35.2
Guava leaf extract 40%	10.5	8.24	20.5	36.2
LSD (p= 0.05)	0.6	0.79	0.8	1.0

through maximum weed control, farmers in Eastern plateau and hill zone of India can adopt hand weeding as non-chemical weed control measure in mustard cultivation.

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RESEARCH NOTE

Efficacy of post-emergence application of haloxyfop-R-methyl on weed control, yield and economics of soybean

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ABSTRACT

A field experiment was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, U.P. (India), during the *Kharif* (rainy) season of 2022. The experiment was laid out in a randomized block design with three replications and eight treatments to identify the ideal rate of herbicide for optimum weed control in soybean. Among the herbicidal treatments, the application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) at the rate of 164.1 g/ha as PoE 20 days after sowing (DAS) was found effective in controlling a broad spectrum of weeds with minimum dry weight of weeds and highest mean weed control efficiency (48%) among all the treatments. The same treatment also recorded the maximum seed yield (1.50 t/ha), net monetary return (₹ 50149/ha), and the benefit-cost ratio (1.37) and thus, found to be an economically viable approach to control diverse weed flora in soybean.

Keywords: Economics, Haloxyfop-R-methyl, Herbicide, Weed flora, Yield

Weed infestation is viewed as a persistent and complicated limitation in soybean cultivation because it interferes with soybean growth and development by competing with it for nutrients, water, light, and space. Due to its slow early vegetative growth, it is very susceptible to weeds in the early stages of its growth (Meena *et al.* 2009). Therefore, the first 30-45 days after sowing (DAS) is the most critical period for weed competition. If weeds are not controlled during this crucial phase, there might be losses of 20 to 84 per cent (Gharde *et al.* 2018, Kumar *et al.* 2022). In general, manually hand weeding is the most effective method of weed control, but due to the non-availability of sufficient labour during peak periods, its time-consuming nature and being a costly affair, it is an uneconomical method of weed control (Vijayakumar *et al.* 2023). Chemical weed control seems to offer greater convenience, saves time, more cost-effective, and ensures a weed-free environment during the initial stages of crop growth (Keerthi *et al.* 2022). Post-emergence herbicides, such as haloxyfop-R-methyl, imazethapyr, fomesafen, bentazone, propaquizafop, quizalofop-p-ethyl, chlorimuron *etc.* are narrow spectrum in nature. Haloxyfop and quizalofop are effective against grassy weeds. Acetachlor is most effective against grassy as well as broad-leaved weeds (Kumar *et al.* 2008). In the recent past, haloxyfop-R-methyl is reported to control grassy weeds in soybean effectively, but the information on its efficacy and doses are very meagre in the literature. Therefore, in order to find out the optimum rate of its application this study was done.

A field experiment is conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. The experiment is conducted using a randomized block design, consisting of three replications and eight treatments, *viz.* haloxyfop-r-methyl 10.5% w/w EC (BCSPL sample) 105.0 g/ha, haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 131.3 g/ha; haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha; haloxyfop-R-methyl 10.5% w/w EC (market sample) 105.0 g/ha; haloxyfop-R-methyl 10.5% w/w EC (market sample)131.3 g/ha; propaquizafop 10% EC75.0 g/ha, weed free plot and untreated control (weedy check). All the post-emergence herbicides are applied at 20 days after sowing (DAS). The experimental field's soil is typical Indo-Gangetic alluvium (Entisol), well-drained and has moderate soil fertility with a bulk density of 1.4 Mg/m^3, near neutral pH of 7.3, low organic carbon (0.3%), low available nitrogen (210.3 kg/ha), medium available phosphorus (18.1 kg/ha) and medium available potassium (176.9 kg/ha). The soybean variety JS 20-98 is sown in the furrow on

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27th June 2022 with a row to rows pacing of 45 X 10 cm. Uniform dose of 23.5:60:20 NPK kg/ha and 20 kg/ha sulphur as the basal dose is applied before the sowing of soybean and the crop is harvested on 22nd of October 2022. A total of 1200.4 mm of rainfall is received intermittently during the crop period. The data regarding density (no./m^2) and dry weight (g/m^2) of weeds are recorded at 30, 45and 60 days after the application of herbicide (DAA). The weed samples were collected from two spots in each plot with the help of 0.5 m^2 quadrate and the data is converted for one m^2 area. In each quadrate weeds are counted and cut close to the soil surface and then collected for drying in the sun followed by drying in the oven at 70^o C for 2 days. Dried samples of weeds are weighted separately to assess dry matter accumulation. Data transformation for weed density and weed dry weight is done with the help of square root transformation. Weed control efficiency (WCE) is calculated using following formula (Amare *et al.* 2014);

$$\text{WCE (\%)} = \frac{W_C - W_T}{W_C} \times 100$$

Where, WDC = weed dry matter from the control plot (untreated), WDT = weed dry matter from treated plot. The weed control efficiency (%) is calculated at 30 and 45 DAA for different treatments based on dry matter production over the weedy check plot.

Weed flora: The experimental plot contains diverse species of weed flora, *viz.* sedges (*Cyperus rotundus* (L.), *Cyperus esculentus* (L.) and *Fimbristylis miliacea*), monocots (*Echinochloa colona* (L.) Link, *Paspalum distichum Berg.* and *Cynodon dactylon* (L.) Pers.), and dicots (*Phyllanthus niruri* (L.), *Phyllanthus virgatus, Eclipta alba* (L.) Hassk, *Lindernia procumbens, Parthenium hysterophorus* (L.), *Cyanotis axillaris* and *Euphorbia hirta*). The density of sedges was much higher than that of monocots followed by dicots. Among all the weed flora, *Cyperus esculentus* (L.) was found to be predominant weed followed by *Cyperus rotundus* (L.), *Parthenium hysterophorus* (L.) and *Lindernia procumbens.*

Weed density: The weed density was found lower at 30 DAA but increased substantially at 45 DAA and again decreased at 60 DAA irrespective of the species (**Table 1**). The density of sedges and monocot weed species successively decreased after the application of post-emergence herbicides and the density of dicot weed species was not affected by the herbicidal application. The density of monocot weed species was found to consecutively decrease by the application of herbicide at all the stages of crop growth (30, 45 and 60 DAA). Weed free treatment recorded lower weed density irrespective of the species. The application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1g/ha reported the lowest monocot weed density among all the herbicidal treatments. In the case of sedges, the herbicidal application significantly reduced the weed flora at the initial stage but at later stages, its density increased. At all the rates of application, the haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) was found to be broad-spectrum herbicide control led by all sorts of weed species. Nainwal *et al.* (2010) reported that haloxyfop-R-methyl 10% EC 100 g/ha was found to be effective in controlling monocot weed species. Singh *et al.* (2023) also reported similar results.

Weed dry matter: The weed dry weight of the dicot was increased successively after the application of

Table 1. Weed density (no./m^2) as influenced by different weed control treatments

Treatment	Sedges			Monocot			Dicot			Total		
	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 105.0 g/ha	16.4 (268.30)	20.13 (404.71)	14.39 (206.67)	2.15 (4.13)	0.71 (0.00)	0.97 (0.44)	6.72 (44.67)	7.33 (53.30)	5.19 (26.48)	9.35 (86.92)	14.70 (215.49)	7.91 (62.05)
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 131.3 g/ha	15.92 (252.89)	21.14 (446.20)	15.35 (235.11)	1.86 (2.94)	0.71 (0.00)	0.71 (0.00)	7.84 (60.94)	8.11 (65.24)	4.69 (21.52)	9.61 (91.85)	15.54 (241.07)	8.15 (65.85)
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha	15.83 (249.93)	18.55 (343.69)	14.28 (203.56)	2.65 (6.51)	1.69 (2.36)	0.71 (0.00)	6.94 (47.73)	7.51 (55.85)	5.03 (24.76)	9.24 (84.88)	13.75 (188.70)	7.80 (60.31)
Haloxyfop-R-methyl 10.5% w/w EC (market sample) 105.0 g/ha	15.98 (254.79)	19.01 (360.88)	15.76 (248.00)	2.01 (3.53)	0.71 (0.00)	0.71 (0.00)	6.94 (47.72)	7.12 (50.25)	4.20 (17.14)	9.26 (85.31)	13.93 (193.61)	8.18 (66.46)
Haloxyfop-R-methyl 10.5% w/w EC (market sample) 131.3 g/ha	16.07 (257.64)	18.88 (356.11)	13.40 (179.11)	2.76 (7.11)	1.86 (2.96)	0.71 (0.00)	7.44 (54.84)	7.71 (58.90)	5.19 (26.48)	9.55 (90.63)	14.02 (196.07)	7.49 (55.59)
Propaquizafop 10% EC 75.0 g/ha	17.09 (291.41)	19.85 (393.44)	16.51 (272.00)	2.65 (6.52)	1.30 (1.18)	0.97 (0.44)	7.01 (48.67)	7.04 (49.00)	4.85 (23.05)	9.77 (94.96)	14.44 (207.97)	8.71 (75.28)
Weed free	10.79 (116.02)	13.89 (192.57)	11.39 (129.33)	3.34 (10.66)	3.72 (13.31)	2.22 (4.44)	4.09 (16.23)	6.02 (35.79)	4.49 (19.62)	6.20 (37.97)	10.42 (108.15)	6.48 (41.44)
Untreated control (weedy check)	18.46 (340.43)	21.85 (476.90)	17.25 (296.93)	6.39 (40.30)	6.84 (46.30)	5.05 (25.00)	8.33 (68.82)	8.93 (79.23)	6.04 (35.99)	11.20 (124.93)	16.23 (262.77)	9.67 (92.95)
LSD (p=0.05)	2.32	2.56	1.95	1.52	2.21	1.58	1.32	0.88	0.77	1.47	0.62	0.40

DAA- days after the application of herbicide, *Data subjected to x + 0.5 Square root transformation and figure in parentheses are the original value herbicides and was found unaffected by treatment (**Table 2**). The dry weight of monocot weeds was decreased after the application of treatments at all the dates of observation (30, 45 and 60 DAA). Plots with higher weed dry weight resulted from higher weed infestation. Among all the treatments, the weedy check plot recorded the highest weed dry weight of all the weed species at all the dates of observations while, weed free plot recorded the lowest weed dry weight (Panda *et al.* 2015). The post-emergence application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) at different rates resulted in maximum dry weight of monocot weeds at all the dates of observations (30, 45 and 60 DAA). The post-emergence application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha recorded lower dry weight of sedges at 30 DAA and haloxyfop-r-methyl 10.5% w/w EC (market sample) 131.3 g/ha recorded lower dry weight of sedges at 45 and 60 DAA among all the herbicidal treatments and this result was confirmed with the findings of Singh *et al.* (2010).

Weed control efficiency: Although, the weed-free plot resulted in highest weed control efficiency (87.79%), the post-emergence application of propaquizafop 10% EC 75.0 g/ha recorded higher weed control efficiency (46.61%) at 30 DAA. Similar results were reported by Bhadauria *et al.* (2012), Gupta *et al.* (2016) and Kumar *et al.* (2018). At 45 DAA, haloxyfop-R-methyl 10.5% w/w EC (market sample) 105.0 g/ha (53.18%) followed by haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha (52.55%) recorded higher weed control efficiency as it offered greater reduction of sedges, dicot and monocot weed species and found superior over other treatments with conformity of the findings of Singh *et al.* (2010) and Singh *et al.* (2023).

Seed yield: The data on seed yield revealed a significant influence of various treatments (**Table 3**).

Table 2. Weed dry weight (g/m^2) as influenced by different weed control treatments

Treatment	Sedges			Dicot			Monocot			Total		
	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 105.0 g/ha	8.86 (78.07)	11.74 (137.40)	7.69 (58.59)	3.07 (8.92)	3.97 (15.24)	2.65 (6.50)	1.76 (2.59)	0.71 (0.00)	0.88 (0.27)	4.89 (23.42)	6.36 (39.92)	4.19 (17.08)
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 131.3 g/ha	8.59 (73.28)	11.52 (132.32)	8.69 (75.04)	3.31 (10.47)	3.97 (15.27)	2.95 (8.20)	1.32 (1.23)	0.71 (0.00)	0.71 (0.00)	4.83 (22.83)	6.27 (38.76)	4.72 (21.74)
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha	8.35 (69.29)	10.38 (107.31)	7.68 (58.44)	3.00 (8.49)	3.65 (12.86)	2.88 (7.80)	2.29 (4.76)	1.42 (1.51)	0.71 (0.00)	4.71 (21.66)	5.70 (32.04)	4.26 (17.68)
Haloxyfop-R-methyl 10.5% w/w EC (market sample) 105.0 g/ha	8.96 (79.86)	10.17 (102.88)	8.70 (75.11)	2.57 (6.10)	3.89 (14.61)	2.64 (6.45)	1.42 (1.52)	0.71 (0.00)	0.71 (0.00)	4.75 (22.07)	5.67 (31.61)	4.62 (20.81)
Haloxyfop-R-methyl 10.5% w/w EC (market sample) 131.3 g/ha	8.59 (73.37)	9.67 (93.10)	7.09 (49.82)	2.69 (6.72)	4.62 (20.86)	2.96 (8.29)	2.27 (4.66)	1.72 (2.47)	0.71 (0.00)	4.70 (21.62)	5.81 (33.28)	4.06 (15.96)
Propaquizafop 10% EC 75.0 g/ha	8.40 (69.99)	10.78 (115.78)	8.46 (71.07)	2.76 (7.12)	3.72 (13.33)	2.72 (6.90)	1.60 (2.07)	1.59 (2.02)	0.88 (0.27)	4.58 (20.46)	5.90 (34.36)	4.55 (20.17)
Weed free	3.73 (13.41)	5.84 (33.58)	5.38 (28.41)	1.17 (0.86)	1.88 (3.05)	1.72 (2.47)	2.32 (4.87)	2.81 (7.38)	1.69 (2.34)	2.28 (4.68)	3.41 (11.09)	2.99 (8.43)
Untreated control (weedy check)	9.24 (84.90)	12.22 (148.83)	9.36 (87.03)	3.90 (14.69)	5.31 (27.69)	3.46 (11.46)	6.89 (46.92)	8.92 (79.08)	4.73 (21.86)	6.23 (38.33)	8.25 (67.51)	5.64 (31.30)
LSD (p=0.05)	0.35	0.48	0.47	0.14	0.18	0.14	0.15	0.09	2.31	0.22	0.32	0.20

DAA- days after the application of herbicide, *Data subjected to $\sqrt{x+0.5}$ Square root transformation and figure in parentheses are the original value

Table 3. Weed control efficiency (WCE) and seed yield and economics of different weed control treatments

Treatment	Weed control efficiency (%)		Seed yield (kg/ha)	Cost of cultivation (₹/ha)	Net monetary returns (₹/ha)	B:C
	30 DAT	45 DAT				
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 105.0 g/ha	38.91	40.87	1305	35261	40368	1.14
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 131.3 g/ha	40.44	42.59	1437	35856	47247	1.32
Haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha	43.49	52.55	1499	36600	50149	1.37
Haloxyfop-R-methyl 10.5% w/w EC (market sample) 105.0 g/ha	42.43	53.18	1381	34993	45000	1.29
Haloxyfop-R-methyl 10.5% w/w EC (market sample) 131.3 g/ha	43.59	50.70	1243	35521	36584	1.03
Propaquizafop 10% EC 75.0g/ha	46.61	49.10	1278	34043	40179	1.18
Weed free	87.79	83.57	1453	45078	38725	0.86
Untreated control (weedy check)	0.00	0.00	965	32238	23667	0.73
LSD (p=0.05)	--	--	65.7	--	--	--

DAT- days after the application of treatments

Among all treatments, the weedy check plot recorded the lowest seed yield, primarily due to severe weed infestation, which suppressed crop growth and negatively impacted key yield parameters such as the number of pods per plant, seeds per pod, and 100-seed weight. These findings align with those reported by Chauhan *et al.* (2012), who emphasized the detrimental effects of unchecked weed competition on crop productivity. Among the herbicidal treatment plots, the post-emergence application of haloxyfop-r-methyl 10.5% w/w EC (BCSPL sample) at 164.1 g/ha resulted in a significantly higher seed yield, closely followed by the weed-free plot and haloxyfop-r-methyl 10.5% w/w EC (BCSPL sample) at 131.3 g/ha. These treatments were statistically at par with other post-emergence herbicides. The enhanced yield in these plots can be attributed to effective weed control during critical crop growth stages, which facilitated vigorous plant growth and improved yield attributes. Similar trends were observed by Sharma *et al.* (2016), who reported that timely weed management significantly boosts crop productivity. Furthermore, the plots that were treated with such herbicides and farmer's practices exhibited superior seed yield due to efficient weed suppression, ensuring optimal resource utilization and robust crop development. These findings are consistent with those of Singh *et al.* (2010), who highlighted the importance of post-emergence herbicides in enhancing crop performance. The overall results underscore the necessity of adopting effective weed management strategies to maximize seed yield and improve farm profitability.

Economics: Weed-free plot required the highest cost of cultivation (₹ 12,000/ha) due to the highest variable cost. The post-emergence application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha recorded higher net monetary return among all the treatments (₹ 50149/ha) followed by the application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 131.3 g/ha (₹ 47247/ha) and haloxyfop-R-methyl 10.5% w/w EC (market sample) 105.0 g/ha (₹ 45000/ha). Among all the treatments, the lowest net monetary return and benefit-cost ratio were recorded under a weedy check plot, while the highest benefit-cost ratio was recorded under post-emergence application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 164.1 g/ha followed by the application of haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) 131.3 g/ha. A similar result was confirmed with the findings of Singh *et al.* (2023) reported similar findings.

Based on the findings of this study, it is advised to apply haloxyfop-R-methyl 10.5% w/w EC (BCSPL sample) as a post-emergence herbicide, at a rate of 164.1 g/ha, around 20 days after sowing. This approach offers both effective broad-spectrum weed control and an economically viable solution for managing weeds in soybean cultivation.

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RESEARCH NOTE

Temporal variability and ecological status of weeds in the home garden agroforestry system: A case study

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ABSTRACT

This paper presents a comprehensive analysis of weed status within the home garden agroforestry system at ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi, Uttar Pradesh. The study was conducted to investigate the diversity and distribution of weeds in the agroforestry system during 2022-2023. A total of 21 weed species belonging to 14 families and 17 genera were identified, with notable representation from families such as Amaranthaceae and Poaceae. The findings highlight the seasonal fluctuations in weed species composition and abundance, shedding light on the dynamic nature of weed communities in the agroforestry context. The research findings contribute to the understanding of weed ecology in agroforestry settings, offering valuable information on sustainable agricultural practices and ecosystem management.

Keywords: Agroforestry system, Home garden, Sustainable agriculture, Weed ecology

Home garden agroforestry systems represent intricate arrangements of trees, crops, and other vegetation, interwoven within household landscapes to fulfil diverse socio-economic and ecological functions. These systems, prevalent in many parts of the world, play a pivotal role in sustaining rural livelihoods, enhancing food security, and conserving biodiversity. Located in Jhansi, Uttar Pradesh, India, the ICAR-Central Agroforestry Research Institute (CAFRI) Campus serves as a microcosm of such agroforestry systems, where traditional knowledge intertwines with modern agricultural practices (Dev *et al.* 2015). Weeds constitute a ubiquitous and often overlooked component of agroecosystems, exerting profound impacts on ecosystem dynamics, agricultural productivity, and resource allocation. Despite their ecological significance, weeds remain a persistent challenge for farmers, especially in agroforestry systems where multiple plant species coexist.

There exist approximately 2,50,000 plant species worldwide, among which around 8,000 species, accounting for roughly 3%, are classified as weeds. These weeds pose multifaceted challenges, primarily by engaging in intense competition for vital resources such as space, water, soil nutrients, and light. Furthermore, they produce chemicals through allelopathy, some of which are toxic to humans, animals, and cultivated plants (Kumari 2016, Sah *et al.* 2020). The proliferation of weeds also exacerbates other biotic stressors, fostering pest and disease problems by providing alternate hosts for harmful insects and pathogens, thereby amplifying production costs and diminishing crop yields and market value (Gharde *et al.* 2018, Kubiak *et al.* 2022). The economic repercussions of weed infestation are substantial, particularly in grain, pulse, and oilseed crops, causing an annual economic loss of more than Rs. 50,000 crores in India (Sah *et al.* 2020). Recognizing the imperative of understanding weed dynamics within cropping systems, a comprehensive study on the distribution of diverse weed species is fundamental to formulating effective weed management strategies for farmers (Derksen *et al.* 2002, Sah *et al.* 2020). It is recognized that the indigenous flora of India has been subject to invasion by several exotic (non-native) species, introduced either inadvertently through imported ornamental or commercial plants, leading to the widespread dissemination of noxious weed seeds (Mallick *et al.* 2019, Joshi *et al.* 2024a). Surprisingly, current estimates indicate that approximately 18% of India's flora comprises foreign or non-native species (Joshi *et al.* 2024b).

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This work presents a study conducted within the confines of the CAFRI Campus, focusing on the intricate interplay between weeds and the agroforestry system. By examining the temporal and spatial variations in weed species composition, abundance, and distribution, this research aims to elucidate the underlying drivers shaping weed dynamics in the context of home garden agroforestry. This study seeks to inform stakeholders, policymakers, and practitioners about the importance of integrating weed management into agroforestry strategies, thereby promoting the long-term sustainability of agricultural landscapes.

Study area: The study on agroforestry home gardening was conducted at the Research Farm within the home garden of the ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi, Uttar Pradesh, India (25.514°N latitude and 78.547°E longitude, with an elevation of 285 m above mean sea level) during the period from April 2022 to March 2023. The home garden with a total area of 29.9 x 16.3 m was segmented into three distinct categories: partially shaded, fully shaded, and open areas. Experimental plots (each of 1 x 1 m) were randomly allocated across 30 quadrants, ensuring representative sampling. The climatic conditions of the study area are characterized by an average annual rainfall of 837 mm, with evaporation rates and moisture levels reaching their maximum. The temperature ranges recorded in the previous year varied between 40.35°C and 3.75°C, reflecting the region's climatic variability and seasonal fluctuations. These environmental parameters provide the backdrop for understanding the dynamics of weed populations within the agroforestry system and their interactions with prevailing climatic conditions.

Data collection: Random quadrat method was employed to investigate the phytosociological attributes of weeds. A total 10 quadrats (each of 1 x 1 m) were randomly placed throughout the home garden, with a total of 10 quadrats per site. These investigations were carried out both during and after the rainy season to capture seasonal variations. The significance of each weed species was evaluated through parameters such as the Importance Value Index (IVI), frequency, and density, following the methodologies outlined by Mishra (1968) and Curtis and McIntosh (1950). Weed specimens from each quadrat were meticulously collected, and their vegetative and reproductive characteristics were thoroughly examined. Initial identification of the collected specimens was done, following "The Handbook on Weed Identification" (Naidu 2012: ICAR-Directorate of Weed Science Research, Jabalpur, Madhya Pradesh, India) as well as other relevant state, regional, and local floras.

Data analysis: Vegetation composition was evaluated by analyzing the frequency, density, and Importance Value Index (IVI) according to Mishra (1968). The density and IVI of species was calculated as:

$$\text{Density} = \frac{\text{Total number of individuals of a single species in all quadrats}}{\text{Total number of quadrats studied}}$$

Importance Value Index (IVI)= Relative density + Relative frequency + Relative dominance

The field data were also analysed for various species diversity as Shannon diversity (H') (Shannon and Wiener 1963)

$$H' = -\sum_{i=1}^{s} \left(\frac{N_i}{N}\right) log_2 \left(\frac{N_i}{N}\right)$$

Where, H` = Shannon's diversity index, Ni = number of individuals of species belonging to the i^{th} species and N = total number of individuals in the sample.

Temporal variation in weed species

The study revealed significant temporal variation in weed species composition across the study area. Analysis of monthly data demonstrated a dynamic pattern, with the highest diversity observed during the rainy season and reduced species richness during the cooler winter months. Specifically, the maximum number of weed species (21) was recorded during the rainy season, indicative of favourable environmental conditions for weed growth and proliferation. Conversely, the lowest number of weed species was recorded during the cool winter season, highlighting the seasonal fluctuations in weed community dynamics. Further examination of monthly data pinpointed specific periods of heightened weed diversity, with the months of August, September, and October, exhibiting the highest number of weed species (21). Data in the winter months (December-February) exhibited substantially reduced weed species richness, aligning with unfavourable climatic conditions for weed growth and development (**Figure 1, Table 1**). Distribution of weed species across the year followed a distinct polygonal curve, with peak species richness coinciding with the rainy months. This temporal distribution pattern underscores the influence of seasonal variations in precipitation, temperature, and other environmental factors on weed community dynamics.

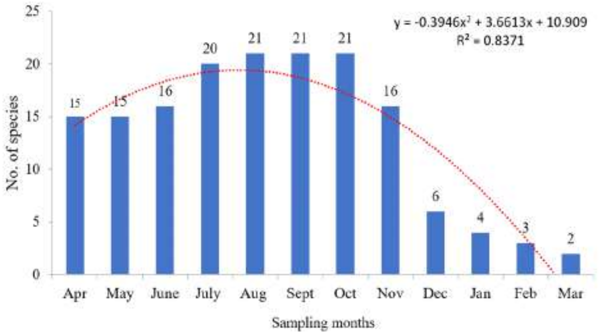

Figure 1. Temporal variation in the weed species across the study site

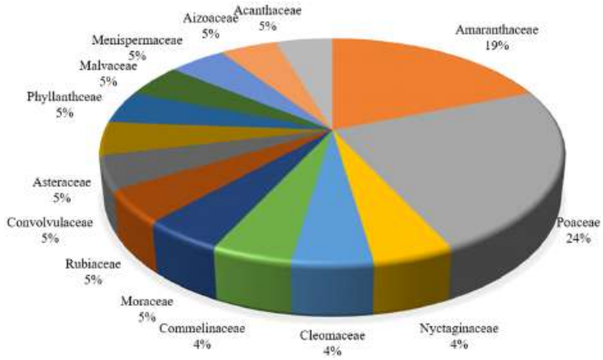

Figure 2. Family-wise distribution of weed species in the home garden agroforestry system of ICAR-CAFRI

Table 1. Monthly variation in species distribution in the home garden during 2022-23

Species	Family	Place of nativity	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Achyranthes aspera	Amaranthaceae	SE Asia and Africa	+	+	+	+	+	+	+	+	+	+	+	+
Atriplex prostrata	Chenopodiaceae	Africa and Europe	+	+	+	+	+	+	+	-	-	-	-	-
Boerhavia erecta	Nyctaginaceae	America	+	+	+	+	+	+	+	+	+	+	-	-
Brachypodium retusum	Poaceae	Africa, America	-	-	-	+	+	+	+	-	-	-	-	-
Celosia argentea	Amaranthaceae	India	-	-	-	-	+	+	+	+	-	-	-	-
Chenopodium album	Amaranthaceae	Asia, North America,	+	+	+	+	+	-	-	-	-	-	-	-
Chloris virgata	Poaceae	America	-	-	-	+	+	+	+	+	-	-	-	-
Cleome gynandra	Cleomaceae	Tropical Africa to Asia	+	+	+	+	+	+	+	+	-	-	-	-
Commelina communis	Commelinaceae	Europe to Japan and Indo-China	+	+	+	+	+	+	+	+	-	-	-	-
Ficus spp.	Moraceae	SE Asia and Australia	+	+	+	+	+	+	+	+	-	-	-	-
Gallium aparine	Rubiaceae	Europe, North Africa	-	-	-	+	+	+	+	+	-	-	-	-
Grass spp.	Poaceae	-	+	+	+	+	+	+	+	+	+	+	+	-
Ipomoea alba	Convolvulaceae	South-eastern USA	+	+	+	+	+	+	+	+	+	-	-	-
Lactuca serriola	Asteraceae	Europe to SW	+	+	+	+	+	+	+	+	-	-	-	-
Panicum sp.	Poaceae	Central America	-	-	+	+	+	+	+	+	-	-	-	-
Paspalum dilatatum	Poaceae	Central America	-	-	-	+	+	+	+	-	-	-	-	-
Phyllanthus nirurii	Phyllanthceae	Tropical & Subtro pical America	+	+	+	+	+	+	+	+	-	-	-	-
Ruellia geminiflora	Acanthaceae	Argentina and Brazil	+	+	+	+	+	+	+	+	-	-	-	-
Sida acuta	Malvaceae	Central America	+	+	+	+	+	+	+	+	+	+	+	+
Tinospora cordifolia	Menispermaceae	Indian subcontinent and China	+	+	+	+	+	+	+	+	+	-	-	-
Trianthema portulacastrum	Aizoaceae	Africa, North and South America	+	+	+	+	+	+	+	+	-	-	-	-

\+ showed presence of species and – showed absence of species

In the present study highest diversity was recorded during the rainy season, characterized by favourable environmental conditions conducive to weed growth and proliferation (Anwar *et al.* 2021). In contrast, species richness decreased during the cooler winter months, aligning with reduced moisture availability and suboptimal temperatures for weed development (Mhlanga *et al*. 2022). The monthly analysis highlighted specific periods of heightened weed diversity, with peak richness occurring during the months of August, September, and October, corresponding to the peak of the rainy season. This temporal distribution pattern, characterized by a distinct polygonal curve, reflects the strong association between moisture availability and weed proliferation (Fanfarillo *et al.* 2020).

Ecological status of weed species

A total of 21 distinct weed species belonging to 14 families and 17 genera were identified, reflecting the rich ecological tapestry present within the study area. Notably, the Amaranthaceae and Poaceae families emerged as predominant contributors, with 5 and 4 species, respectively, followed by representatives from diverse botanical families such as Nyctanginaceae, Clemaceae, Moraceae, and Rubiaceae, among others. The species diversity was maximum as recorded at Site-II (3.42) followed by

Table 2. Ecological status of recorded weed species during 2022-23

Species	Site-I		Site-II		Site-III	
	Density (no./m^2)	IVI	Density (no./m^2)	IVI	Density (no./m^2)	IVI
Achyranthes aspera	3.3	32.16	4.3	31.45	1.8	17.29
Atriplex prostrata	-	-	-	-	2.8	23.36
Boerhavia erecta	-	-	2.9	23.79	2.4	21.19
Brachypodium retusum	1	14.82	1	12.45	1	11.89
Celosia argentea	1.2	16.25	1.3	14.05	1.8	18.48
Ipomoea alba	-	-	-	-	2.1	19.58
Chenopodium album	1.5	18.82	1.9	18.02	-	-
Chloris virgata	-	-	1.4	14.83	1.8	17.24
Cleome gynandra	-	-	1.3	14.05	1.6	16.42
Commelina communis	2.2	24.12	-	-	2.7	22.67
Ficus sp.	1.3	17.49	-	-	-	-
Gallium sp.	2.8	28.55	2.9	23.79	1.8	18.47
Grass sp.	2.8	28.39	4	30.72	-	-
Lactuca serriola	1.4	17.97	1.5	15.38	-	-
Panicum sp.	2.9	29.27	2.9	23.79	2.7	23.13
Paspalum dilatatum	-	-	-	-	0.9	11.07
Phyllanthus niruri	2.7	27.8	2.7	22.65	2.1	19.2
Ruellia geminiflora	-	-	2.2	19.8	2.6	22.13
Sida acuta	-	-	-	-	2.4	22.59
Tinospora cordifolia	1.5	18.76	1.2	13.68	-	-
Trianthema portulacastrum	2.4	25.59	2.5	21.55	1.5	15.29
Total	27	299.99	34	300	32	300

Site-II (3.02) and minimum at Site-I (2.83). The study revealed variations in species richness, and density. The species density was maximum at Site-II (34/m^2), followed by Site-III (32/m^2) and minimum (27/m^2) at Site-I. Detailed analysis of quadrat-level data unveiled specific trends in weed density across the study area. The *Achyranthes aspera* emerged as the dominant species, at Site I and Site-II, exhibiting a maximum density of plants (3.3 and 4.3/m^2, respectively), However *Atriplex prostrata* was the dominant weed at Site-III (**Table 2**).

The study provided valuable insights into the diversity and distribution of weed species within the study area. A total of 21 distinct weed species spanning multiple families and genera were identified, showcasing the rich ecological tapestry present in the home garden agroforestry system. The dominance of families such as Amaranthaceae and Poaceae, along with contributions from diverse botanical families, underscores the heterogeneous nature of weed communities within the agroforestry context. Furthermore, the quadrat-based assessments revealed spatial variations in weed species richness, with differences observed across randomly selected quadrats. These variations highlight the heterogeneous distribution of weeds within the study area and emphasize the need for targeted management interventions tailored to specific locations (Joshi *et al.* 2024c) Detailed analysis of quadrat-level data further elucidated patterns of weed density and species composition, providing valuable insights into the dominant species and their spatial distribution within the home garden agroforestry system. These findings enhance our understanding of weed ecology in agroforestry and inform sustainable land management strategies.

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