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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-

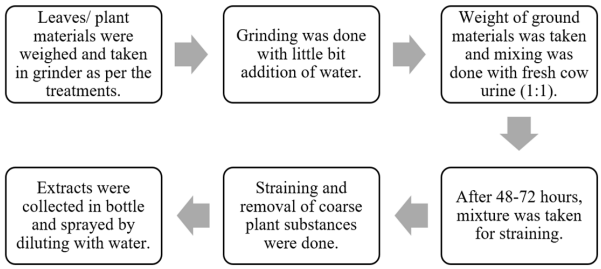

Figure 1. Botanical extract preparation process

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 (/m²) 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/ m² (grass: 31.3, broad-leaved weeds: 170.7 and total: 202.0) and biomass (g/m²) (grass: 6.85, broad-leaved weeds: 45.37 and total: 52.22) (**Table 1**). Among botanical weed control measures, the lowest weed density/m² (grass: 19.0, broad-leaved weeds: 147.7 and total: 166.7) and weed biomass (g/m²) (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/m²) 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 (/m²) and biomass (g/m²) in mustard field at 45 DAS

Treatment	Weed density/m²			Weed biomass (g/m²)		
	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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