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Weed management in lowland rice

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ABSTRACT

Lowland rice ecosystem in India is infested with complex weed flora including semi-aquatic and aquatic weeds. Recently weeds having mimics with rice, perennial and other weeds which propagate by vegetative means are emerging as major threat. Weeds cause yield losses from 15 to 76% in rice crop. Besides, weeds remove about 21-42 kg N, 10-13.5 kg P and 17-27 kg K/ha in transplanted rice. Research on weed management in lowland rice in India has been reviewed in this paper with respect to weed flora and their impact, biology and ecology of weeds, weed management methods and future thrust areas of research and management. The weed flora in lowland rice is very much diverse and dynamic over times and places. Very limited information is available on biology and ecology of major weeds. Studies have been carried out on cultural, manual, mechanical, chemical means of weed management. Shortage of labours, lack of suitable weed control implements and problem of specific weeds have compelled the farmers to think for alternative strategies and herbicides have been the obvious choice to the farmers. Many herbicides either alone or in combinations as ready or tank mixed have been recommended in India. Studies on integrated weed management have also been undertaken. But majority of researches focused on herbicide based IWM. Future research and weed management in lowland rice should be focused on ecophysiology and biology of major weeds, HR genetically modified rice, integrated weed management, exploring biocontrol agents and screening and use of allelopathic and weed competitive rice cultivars.

Key words: Lowland rice, Weed ecology, Weed flora, Weed management

Rice is a staple for more than 60% of the world's seven billion people and more than 90% of this rice is consumed in Asia (Mohanty 2013, Chauhan *et al.* 2014). Based on the hydrology and topography of land, the rice area is divided into various ecologies *viz.*, rainfed upland (16%), irrigated medium land (45%) and rainfed low land (shallow, intermediate, semi deep and deep) (39%), with a productivity of 0.87, 2.24 and 1.55 t/ha, respectively. Out of 61.3% of total rice area in eastern India 20% (5.2 Mha) are rainfed upland, 28.5% (7.8 Mha) medium land and 51.5% (14.0 mha) are rainfed low land (Mahapatra *et al.* 2012). Lowland rice is grown generally under rainfed situations in which soil is puddled for transplanting or wet seeding. The rainfed ecology is characterized by frequent drought and/or submergence and flood depending on rainfall distribution and nature of monsoon. Depending upon topography and rainfall pattern, lowland rice experiences drought, flooding and intermittent submergence at different stages of crop growth.

In India, low land rice area is mostly locate in the eastern region comprising of Assam, Bihar, Madhya Pradesh, Eastern Uttar Pradesh, Odisha and West Bengal. Area under rainfed lowland has been classified into three major ecosystems based primarily on surface hydrology during cropping period. These are shallow lowland (30-50 cm water), semi-deep lowland (50-75 cm water) and deep-water lowland (>75 cm water). India needs to produce 120 million tons of rice by 2030 to feed its one and a half billion plus population (Adhya 2011). However, to meet this demand the crop should perform to its full potential.

Many weeds which propagate by vegetative means are becoming dominant due to increased use of tractor and power tiller. Weeds like *Echinochloa crusgalli, E. colona* and *Sacciolepis* sp. having mimics with rice crop are appearing as major weeds in many rice growing areas of Eastern India. Moreover, shortage of labours, increased wages and lack of suitable weed control implements have compelled farmers to think for alternative strategies of weed management. Herbicides have been the obvious choice to the farmers, which has resulted incresed use of herbicides in India. But most of them are specific and work against narrow range of weed species (Mukherjee and Singh 2005) besides leading several problems in long run. Therefore, appropriate and economic weed management technology has to be developed for sustainable rice cultivation under

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low land ecosystem. In the present paper, an attempt has been made to review the weed flora and their impact, biology and ecology of weeds, weed management methods, future thrust areas of research for the lowland rice ecosystem in India.

Weeds and their impact on lowland rice

Weed flora

Weed composition is dynamic over times and places and its competition depends on soil, climate and management practices. The weed flora in lowland rice is very much diverse and consists of grasses, sedges, broad-leaved and algae. In India, rice is grown under a wide variety of cultural practices in different agro-ecological systems. In irrigated and shallow depth of water *Echinochloa* spp., *Paspalum* spp., *Cyperus iria* and *Fimbristylis miliacea* predominates while with more than 2.5 cm of water *Sphenoclea zeylanica, Monochoria vaginalis, Ammania baccifera, Hydrolea zeylanica* are the most predominant. In coastal belt of West Bengal and Odisha,where rice–rice cropping system is followed under lowland, the problem of algae weeds like, *Nittella hyaline, Hydrodictyon reticulatum, Chara zeylanica, Spirogyra condensate etc.* are reported. The predominant weed flora associated with lowland rice in Eastern India were *Ammania baccifera, Fimbristylis miliacea, Cyperus microiria, Ludwigia parviflora, Monochoria vaginalis, Echinochloa crus-galli, Echinochloa colona, Lindernia ciliata, Marsilea quadrifolia, Spilanthes acmella, Cyperus difformis* and *C. iria* (Anonymous 2003, Kundu *et al.* 2003, Mondal *et al.* 2005, Mahapatra *et al.* 2012). *Ludwigia parviflora* was observed with highest frequency (Duary and Mukherjee 2013). The wet-seeded rice was infested with composite weed flora comprising of grasses, sedges and broad-leaved weeds majority of which was under grasses (Singh *et al.* 2007a, Ravisankar *et al.* 2008). *Echinochloa crusgalli, E. colona, Panicum repens, Sacciolepis interrupta* and *Paspalum distichum* among the grasses, *Cyperus difformis, C. iria, C. microiria, F. dichotoma, F. miliacea,* S*cirpus acutus* and *Scripus grossus* among sedges and *Alternanthera philoxeroides, Ipomoea aquatica, Nymphaea odorata, Monocharia vaginalis, Sphenoclea zeylanica, Eclipta alba, Aeschenomene indica* L., *Ludwigia parviflora, L. octovulvis, Cyanotis axillaris, Ammania baccifera, Marsilia quadrifolia, Lemna minor, Aeschenomene aspera, Potamogeton distinctus* and *Eichhornia crassipes* among broad-leved were the predominant weeds under puddled medium lowland conditions during rainy season (Mondal *et al.* 2005, Mondal and Duary 2009, Pal *et al.* 2009a, Ghosh 2010, Mishra *et al.* 2012, Teja *et al.* 2015a, 2015b). Much of the rainfed rice in lowland plains was dominated by *Echinochloa crussgalli* and *Paspalum scorbiculatum* among annual grasses, *Cyperus iria, C. difformis* and *F. miliacea* among sedges and *Sphenoclea zeylanica* and *Monochoria vaginalis* among broad-leaved weeds (Malik *et al.* 2014).

Weed competition

Weeds are recognized as major biological constraints that hinder the attainment of optimal rice productivity (Kumar and Ladha 2011, Rao and Nagamani 2013) and quality. It is estimated that every year, weeds cause yield losses from 15 to 76% in rice crop (Singh *et al.* 2004, Mondal *et al.* 2005, Rao and Nagamani 2010, Mishra *et al.* 2012, Mandal *et al.* 2013). Direct yield loss has been estimated to the range from 16-86% depending on type of rice culture, cultivars, weed species and density, cropping season, plant spacing, fertilizer rate, duration and time of weed infestation and climatic and environmental conditions (Duary *et al.* 2004, Kolay 2007). It is well established that weeds remove considerable quantities of nutrient from rice crop field. Estimate showed that weeds can deprive the crops by 47% N, 42% P, 50% K, 39% Ca and 24% Mg of their nutrient uptake thereby reduce the yield potential of rice (Balasubramaniyan and Palaniappan 2001). Hence, timely and effective weed control was essential for obtaining higher yield of rice (Sathyamoorthy *et al.* 2004, Kumar *et al.* 2007). Nutrient removal by weeds has been reported to be about 21-42 kg N, 10-13.5 kg P and 17-27 kg K/ha in transplanted rice depending upon the soil, condition of cropping and location of growing rice (Sudhalakshmi *et al.* 2005, Puniya *et al.* 2007b, Gowda *et al.* 2009). In rain fed lowland rice, a period of 30-60 days after sowing was considered as critical period for crop weed competition to avoid grain yield losses (Moorthy and Saha 2005). The critical period of crop-weed competition in lowland transplanted and direct-seeded rice were 30-60 DAT and 40-60 DAS respectively (Das *et al.* 2012).

Biology and ecology of major weeds

Ecological and biological studies of major weed species in lowland system help identifying the susceptible stage in life cycle to make better strategy for effective weed management. *Ludwigia parviflora* is one of the most dominant species in different rice ecosystems throughout rice growing areas in Eastern India. The probable reason for its wide ecological amplitude might be the adaptation by special structure like periderm and pneumatophores as reported by Mukhopadhyay and Duary (1999) and Duary and Mukherjee (2013). Recently, the increased use of tillage implements (power tiller and tractor-drawn) has aggravated the problem of weeds by cutting into pieces which further grow and multiply as separate individuals (Duary and Mukhopadhyay 2004, Duary 2014b). In nursery bed, *Echinochloa crusgalli* emerges simultaneously with rice and owing to mimicry, it is transplanted simultaneously with rice seedlings in main field.

Most of the weeds are angiospermic plant except *Marsilea* which is a pteridophyte. It creeps through rhizomatous stems just below the surface of the soil and reproduce through the structure "Sporocarp" which is capable of retaining viability for several years. Current information about weed biology and ecology is very limited. More research efforts are needed on the biology and ecology of major weeds in order to prepare better strategy for their management in low land rice in India.

Weed management methods

Cultural methods

Cultural practices greatly alter the competitive relationship between rice and weeds. Proper agronomic management practices like suitable crop establishment method, efficient fertilizer use, proper crop stand, selection of competitive crop cultivars play important role providing competitive advantages to low land rice against weeds. The risks of crop yield loss due to competition from weeds in direct-seeded rice is greater than in transplanted rice because the weeds emerge concurrently with rice and farmers are not usually able to use standing water to suppress weeds at the early growth stages (Chauhan and Johnson 2010a). Transplanting of rice experiences lowest weed competition thereby records the lower weed population and dry weight (Prasad *et al.* 2001, Singh *et al.* 2007a, Mishra *et al.* 2009) as compared to sowing of sprouted seeds in puddled condition and dry drilling of seeds and SRI. Intensive puddling with continuous submergence was very effective in reducing the weed dry weight (Subramanyam *et al.* 2007). *Azolla* intercropping (dual cropping) significantly reduced the weed density (Singh 2000, Biswas *et al.* 2005). Flooding is one of the most important weed management options in lowland rice as many weeds will not germinate in anaerobic conditions. It is the timing, duration and depth of flooding that determines the extent of weed suppression by flooding (Mortimer *et al.* 2005). But its effect on weeds is species specific (Chauhan and Johnson 2010b, Singh 2010). However, it is hardly possible to maintain water depth in rainy season. Two cultural practices which are often not given adequate attention in most of the farmer's field are through land preparation and proper land leveling. Land leveling should be an integral part of tillage operations because it is extremely important for good drainage in lowland rice ecosystems. An uneven field results in poor rice emergence in low spots and enhanced weed growth in high spots. In many areas, farmers do not take much care in leveling the land. Weed competitive rice cultivars are one of the integral parts of integrated weed management in transplanted rice. But little information is available in this aspect in India. Rice cultivar '*Prabhat*' and *'PR 108'* exhibited greater smothering effect on weeds grown under puddled transplanted conditions (Singh *et al.* 2004, Ghuman *et al.* 2008). Stale seedbed technique, a cultural-cum-preventive measure has been found very effective against weeds during *Kharif* season in lowland rice (Sindhu *et al.* 2010, Duary and Mukherjee 2013).

Manual weeding

The traditional method of weed control practice in India is manual weeding by hoe and hand pulling. Usually, hand weeding is practiced two or three times for growing a rice crop depending upon the nature of weeds, their intensity and the method of rice establishment. Hand weeding twice at 20 and 45 DAS/DAT for broadcast or transplanted crop has been found superior to the chemical weed control for all the growth and yield attributes (Chander and Pandey 2001, Prasad *et al.* 2001, Dutta *et al.* 2005, Pal *et al.* 2009b). Manual weeding is ineffective for weeds having mimicry with rice in early stage of crop. The presence of perennial weeds and other weeds propagated vegetatively that fragment over hand pulling also renders hand weeding ineffective and uneconomic. At the time of the peak period of the labor crisis and unfavorable weather condition, weeding sometimes becomes late. But delay in weeding beyond 15-25 days sharply reduces the yield to the tune of 43 kg/ha/day between 25 to 45 days (Mahapatra *et al.* 2012). With the use of rotovator and power tiller, the weeds like *Jussiaea, Marsilea, Cardenthera*, *Paspalum* are fragmented and floated after land preparation. Before transplanting, these fragmented parts should be collected using proper screen.

Mechanical weeding

In view of the increasing labour scarcity, negative impact of indiscriminate herbicide use, weed management strategy needs to be reoriented towards mechanical means for satisfactory monetary benefits. Rotary weeder was effective in controlling the weeds present in inter row space, but failed to control the weeds in intra row space or those in the vicinity of the crop (Choubey *et al.* 1998). The use of cono weeder resulted in 10-17% increase in grain yield during wet season (Thiyagarajan *et al.* 2002, Mandal *et al.* 2013). Cono weeder reduced man-days required for weeding from 30 to 10 (Mrunalini and Ganesh 2008) thus helped saving labour and time. The cost of weeding for labours could be reduced by 6.6 and 7.6 times by using rotary weeder and cono weeder, respectively, compared to hand weeding (Remesan *et al.* 2007). However, the problem of incorporation of perennial weeds and vegetatively propagated weeds may result in faster regeneration of those under mechanical weeding (Sudhalakshmi *et al.* 2005, Duary and Mukherjee 2013).

Chemical method

Herbicide usage is one of the most labour saving innovations (Moody 1993). Herbicide application has increased significantly over the last decade due to labor shortages, low herbicide prices, increased herbicide effectiveness and other advantages. A number of herbicides has been tested since last two and half decades for the management of weeds in transplanted rice with different times of application like pre-emergence, early post-emergence or post-emergence in India. Wide range of herbicides are available for the management of grassy weeds (pretilachlor, butachlor, anilofos, fenoxaprop and oxadiargyl)as well as broad-leaved weeds (metsulfuron, chlorimuron, ethoxysulfuron and 2, 4-D). Pre-emergence herbicides in rice have very narrow application window and need continuous stagnation of water for their efficacy. Many times due to various constraints at farm level, the application of herbicides in the early growth stages is not possible and continuous use of same herbicide might cause resistance in weeds. Under such situation, the post-emergence herbicides are another option (Puniya *et al.* 2007a). Sulfonylurea group is one of the most important classes of herbicide that has become popular all over the world which represent high level of activity, application flexibility, excellent selectivity and low mammalian toxicity even at very low dose with broad spectrum of weed control (Mukherjee and Singh 2005, Saha 2006, Saha and Rao, 2009, Duary, 2014a). Application of metsulfuron-methyl (10%) + chlorimuron-ethyl (10%) as early post-emergence showed better weed control efficiency against broad-leaved and sedges as compared to grasses (Singh *et al.* 2007b, Saha and Rao 2009, Pal *et al.* 2009b, Mandal *et al.* 2013). In lowland transplanted wet season rice, glyphosate as pre-planting, followed by pyrazosulfuron-ethyl, pretilachlor, butachlor as pre-emergence or metsulfuron-methyl + chlorimuron-ethyl (Almix), sodium bispyribac, ethoxysulfuron to a limited extent as early post-emergence are applied in rice fields in eastern India (Duary and Mukherjee 2013). But *Leptochloa chinensis*, *Dactyloctenium aegyptium* and *Eragrostis* spp. are not controlled by bispyribac–sodium (Malik *et al.* 2014). Bispyribac-sodium has been found effective in rice nursery as well as main field where *E. crusgalli*, *E. glabrescens* are major problem (Duary and Mukherjee 2013). Application of oxadiazon as pre-emergence on puddle soil in lowland conditions where direct-seeding has been done is quite effective against annual grasses particularly on *Commelina benghalensis* (Das 2008). The lowland rice condition is very often encountered with algal infestation in a luxuriant way, which cause suffocation and prevent root growth and tillering of rice. The application of copper sulphate effectively controlled the algae (Mishra and Mishra 2008, Das 2008, Mishra *et al.* 2012). Butachlor, pretilachlor, oxadiazon, bentazon, oxadiargyl, pyrazosulfuron-ethyl, bispyribac-Na, metsulfuron-methyl, metsulfuron-methyl+chlorimuron-ethyl, imazosulfuron, anilofos, 2,4-D, azimsulfuron, bensulfuron-methyl, ethoxysulfuron, cyhalofop-butyl are the herbicides, which have been found quite effective in transplanted rice in India (Saini and Angiras 2002, Saini 2003, Mondal *et al.* 2005, Yadav *et al.* 2008a, 2009, Saha 2009, Duary *et al.* 2009, Pal *et al.* 2009a, Kiran *et al.* 2010, Saha and Rao 2010a, 2010b, 2012, Das *et al.* 2012, Soren 2011, Mandal *et al.* 2013, Duary, 2014a). Penoxsulam either as pre- or early post-emergence controlled all categories of weeds in transplanted rice (Singh *et al.*, 2007c, Mishra *et al.* 2007, Yadav, *et al.* 2008b, Malik *et al.* 2011, Prakash *et. al.* 2013).

Repeated and injudicious use of same herbicide or herbicides having similar mechanism of action may lead to shift of weed flora, development of herbicide resistance and buildup of herbicide load in the environment (Duary and Yaduraju 1999, Das and Duary 1999, Duary 2008). Continuous use of butachlor and anilofos in rice, particularly in North-West India, has led weed flora shifting to sedges, such as *Cyperus* sp., *Scirpus* sp., *Fimbristylis* sp. and *Eleocaris* sp. and broad-leaved weeds, such as *Caesulia auxillaris* (Chauhan *et al.* 2014). Herbicide rotation and mixture herbicide use are two major strategies to prevent shift of weed flora and development of herbicide resistance in weeds. More recently use of mixture herbicides is increasing due to the benefits of managing complex weed flora with mixture- either tank or ready mix. In addition to metsulfuron-methyl + chlorimuron-ethyl (Almix) ready mix product of bensulfuron + pretilachlor at 60 + 600 g /ha and tank mixed application of azimsulfuron with metsulfuron + chlorimuron or metsulfuron-methyl,bispyribac +Almix, fenoxaprop + ethoxysulfuron has also been found quite effective against complex weed flora (Jayadeva 2010, Sunil *et al.* 2010, Chauhan and Abugho 2012, Anonymous 2012, Parthipan *et al.* 2013, Teja *et al.* 2015a, 2015b). To improve herbicide use efficiency and avoid the problem associated with herbicide use, emphasis should be given on use of herbicide mixture and rotation and to impart training and awareness to stakeholders.

Integrated weed management

The aim of integrated weed management (IWM) is not to eliminate the use of herbicides but to improve their efficiency through their rational usage by combining with better crop management options and other methods which give an advantage to the crop. Combination of SRI method of crop establishment with alternate wetting and drying method of irrigation and cono weeding recorded lower weeds and higher growth attributes of rice (Vijayakumar *et al.* 2006). Pretilachlor with safener as pre-emergence and chlorimuron + metsulfuron at 21 DAS/DAT followed by hand-weeding or cono weeding or two way rotary weeder weeding could effectively control most of the weeds (Singh *et al.* 2008, Babar and Velayutham 2012, Sridevi *et al.* 2013). Combination of stale seedbed technique with pre-emergence spray of herbicides or with hand weeding or concurrent growing of green manure crops gave better control of weeds and higher grain yields (Sindhu *et al.* 2010). Several research publications have proved that integration of herbicides with hand weeding is the most effective and economical method of weed management (Rao 2011). Integrated use of herbicide azimsulfaron or pyrazosulfuron-ethyl with hand weeding at 40 DAT or butachlor and anilofos along with closer planting was effective for reducing weed population and dry weight (Gogoi *et al.* 2001, Mondal *et al.* 2005, Mondal and Duary 2009). Effective weed control in terms of reduced weed density and dry weight was achieved by pretilachlor with safener combined with *Sesbania* intercropping and *Azolla* dual cropping in wet-seeded rice (Subramanian and Martin 2006). In India, the information like effect of changes in plant geometry (transplanting in a triangular or paired row manner), performance of rice genotypes under different plant geometry is not available (Chauhan *et al.* 2014). However, this aspect may be exploited as a component of IWM in lowland rice. The strategies for integrated weed management should be developed and evaluated considering all the available options in the region.

Future thrust areas and strategies of weed management

Herbicide–resistant genetically modified rice

Herbicide resistant (HR) rice technologies have the potential to control a wide range of weeds including grasses, broad-leaved and sedges which cause serious problems in lowland rice, including problematic weeds like *Echinochloa* spp. and weedy rice (Rodenburg and Demont 2009). The ability to control problem weed species efficiently makes HR rice an attractive technology and farmers may rapidly adopt it in many cases. Three HR systems have been developed in rice: imidazolinone, glufosinate and glyphosate -resistant varieties (Gealy *et al.* 2003). Glyphosate and glufosinate are considered as relatively environmentally benign and, as post-emergence herbicides, the application rates can be adjusted to the weed population, and the technology has wider herbicide application time window compared to conventional technologies. Despite the possible advantages of HR options, there are concerns regarding the likelihood of gene flow from HR rice to wild and weedy rice species. In India, *O. sativa f. spontanea* is considered as weedy species in cultivated rice. In Eastern India (*e.g.* Eastern Uttar Pradesh, Bihar, Odisha, Manipur, and West Bengal) and Southern India, wild and weedy relatives are common and gene flow may occur from HR rice to these species (Kumar *et al.* 2008). The reliance on HR technology for effective weed control in rice will depend thus on careful introduction and management.

Eco-physiology and economic threshold

Simulation of competitive relationship between major weeds and rice in terms of economic yield loss and development of economic threshold (ET) may be useful in taking decision for initiation of weed management -specially use of herbicides. Very limited information is available for threshold levels of predominant weeds species in India. Threshold levels for a few weed species like *Cyperus iria* (30/m^2), *Echinochloa crus-galli* (20/m^2) has been worked out (Singh and Angiras 2003, 2008). Grass weed seedlings of rice nursery are unintentionally transplanted with rice seedlings and average rice yield reductions from transplanted *E. glabrescens* ranged from 6 at the 5% infestation level to 73% at the 40%

infestation level (Rao and Moody 1992). *Ludwigia parviflora* density of only 5/m^2 reduced the grain yield of rice about 10.2%. Single season economic threshold density varied from 1.4 *Ludwigia* /m^2 for 2, 4-D to 6.74 /m^2 for hand weeding under low land transplanted rice (Kolay 2007). More emphasis should be given on ecophysiological aspects of rice and major weeds.

Exploration of potential bioagents

In some developed countries several biocontrol agents have been used successfully in specific situations. In India also few attempts have been made for application of some fungal pathogen and insect biocontrol agents over rice weeds. However, very low abundance of these biocontrol agents at specific situation has resulted in failure of wider application and commercial success. In lowland rice *Ludwigia parviflora* was reported to be completely defoliated in lowland transplanted rice by Halticid beetle (Mukhopadhyay and Duary 1999) indicating its potentiality as a biocontrol agent against the weed. The possibilities of such biocontrol agents should be explored by identifying natural enemies through autecological studies of major weeds in lowland rice.

Developing allelopathic rice and C_4 rice

Some rice lines or wild rice species have been found to be allelopathic and can inhibit the growth of some weeds like barnyard grass and broad-leaf weeds (Fujii 1992, Olofsdotter *et al*. 1995). A number of compounds such as phenolic acids, fatty acids, phenylalkanoic acids, hydroxamic acids, terpenes and indoles have been identified as potential rice allelochemicals. The momilactone B secreted from rice seedlings appears to be the major contributor to the allelopathic activity of rice crops at least against barnyard grass (Kato-Noguchi 2013). Similar attempts may be made in India and rice cultivars are to be screened for their allelopathic potentials. Rice scientists are aiming for a second Green Revolution by developing a C_4 rice through traditional breeding or transgenic methods (Gunawardana 2008). At present rice being a C_3 plant is less competitive than C_4 weeds like *E. crusgalli* and *C. rotundus*. A C_4 rice will be more competitive against weeds, more efficient in photosynthesis and will yield high even with less water, since water requirement of C_4 plants is much lower than that of C_3 plants (Baltazar and Johnson 2013).

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