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Managing Weedy Biotic Stress in Linseed (*Linum usitatissimum* L.) for Enhanced Production: A Comprehensive Review

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Abstract

Linseed is an oldest oilseed crops having multiplicity of uses, grown for yielding oil as well as fibre. Among the various biotic factors affecting linseed productivity, weeds are regarded as most disdain to crop production, because of the initial slow growth and relatively lower canopy spread, resulting in non-realization of desired level of productivity of the crop. Weed dynamics in linseed depends on agro-climatic situation, soil characteristics, cropping pattern, crop management practices and availability of soil moisture in the field. Manual weeding is labour intensive and is comparatively more time consuming, which necessitates a cost-effective chemical weed management practice for controlling weeds. Combination of pre-emergence herbicides followed by post-emergence herbicides provides an effective weed management since the pre-emergence herbicides does not allow the emergence of most of weeds through their action in inhibiting root and shoot growth, whereas, post-emergence application controls effectively the weed flush which germinates after getting the first irrigation. This article critically reviews the crop-weed competition, weed dynamics and their impact on linseed yield, including various research efforts taken by researchers in controlling the weeds. As very less research work is being conducted in India by various Agricultural Universities on weed management aspects of linseed, the future challenge should focus research on major areas of weed ecology, assessment of on-farm losses caused by weeds, bio-efficacy of post-emergence herbicides and on-farm assessment of available integrated weed management options in linseed for sustainable linseed production.

Keywords: Herbicide, linseed, weed dynamics, weed management

1. Introduction

Linseed (*Linum usitatissimum* L.), also known as flax, is one of the oldest oilseed and fibre crops having been cultivated since the beginning of civilization (Laux, 2011; Saleem et al., 2020). It belongs to the family Linaceae, comprising approximately 200 species worldwide (Novello and Pollonio, 2012). Although its exact origin is not clear, mediterranean countries have the oldest records of its cultivation (Vieira et al., 2012). Flax occupies an important position in global economy due to its wide industrial utility as well as regional and niche preferences (Yadav et al., 2022). Flaxseed is a rich source of α-linolenic acid, short chain polyunsaturated fatty acids, soluble and insoluble fibers, phyto-estrogenic lignans, proteins and antioxidants (Singh et al., 2011; Kajla et al., 2015; Xie et al., 2015). It contains 20%–25% protein and 40%–45% fatty acids, which has the ability in preventing heart diseases, cancer, strokes, and diabetes (Saleem et al., 2020a; Cloutier, 2016), besides having anti-inflammatory activity and laxative effect (Goyal et al., 2014; Sahoo, 2016). After flaxseed has been crushed for oil, flaxseed meal is a by-product, used to feed poultry and cattle, which has the ability to alter the level of omega-3 fatty acid in eggs and beef (Maddock et al., 2003; Muir and Westcott, 2003). Similarly, milk from dairy cattle fed rations including flax have shown increased α-linolenic acid content (Bork et al., 2010). A majority of seeds of linseed goes to industries for the manufacturing of paints, varnish, oil cloth, linoleum, pad-ink, printing ink, etc. The stem yields fibre of good quality having high strength and durability, lustrous and blends very well with wool, silk, cotton, etc. (Singh et al., 2011; Jhala et al., 2008; Mohammed et al., 2023). Besides the economic uses, linseed crop plays an important role in intensifying the rice fallows because of its potentiality to be grown under conserved moisture as paira/utera cropping, in rainfed areas (Jana et al., 2018).

Canada is the leading producer and exporter of flax worldwide over the past decade, while India ranks seventh in terms of production and eleventh in terms of export (Anonymous, 2022). Presently, it is cultivated in about 2.04 lakh ha, with a contribution of 1.35 lakh tonnes to the annual oilseed production of the country and average yield of 659 kg ha^{-1} (Anonymous, 2022). Though the major linseed growing regions in India are in Madhya Pradesh, Maharashtra, Uttar Pradesh, Chhattisgarh, Jharkhand and some parts of Odisha and Bihar, the areas of the crop are being replaced by the major staple foods and other important cash crops of the region. The poor yield of linseed is due to various biotic and abiotic factors affecting the productivity. Among the biotic factors affecting linseed productivity, weeds are regarded as most disdain to crop production, as it competes poorly with weeds, resulting in non-realization of desired level of productivity of the crop (Karimmojeni et al., 2013). Challenges in linseed production include better management of agronomic practices in the crop, particularly the control of weeds (Mankowski et al., 2015). Generally, for the weed management, farmers do manual weeding, but it is always laborious, expensive, time consuming and uneconomical (Puhup and Dwivedi, 2019; Mishra et al., 2016). Herbicides offer great scope for minimizing the cost of weed control irrespective of the situations and offer a good weed control alternative to cultural or mechanical methods in linseed (Choudhary et al., 2022). This article critically reviews the crop-weed competition, weed dynamics and their impact on linseed yield, including various research efforts taken by researchers in controlling the weeds.

2. Crop-weed Competition in Linseed

Weeds are a major concern in linseed, because of its initial slow growth and relatively lower canopy spread during the initial growth period leads to high weed infestation (Siddesh et al., 2016), making it a very poor competitor of weeds. According to Foulk et al. (2004) and Harker et al. (2011), flax does not compete well with other plants and yield along with quality is improved with weed control practices. The crop faces a season long weed competition, though an initial 25–45 days are very crucial, which accounts for 30–40% reduction in yield (Singh et al., 1992; Chhokar and Balyan, 1999; Mahere et al., 2000).

The composition and competition by weeds in linseed is dynamic and is dependent on soil, climate, cropping and management factors. The competitive ability of plant to utilize the growth determining resources such as light, water and nutrients plays a vital role in determining crop yield (Dwivedi and Puhup, 2019). They reported a nutrient mining of 30–32 kg N, 2–3 kg P and 11–12 kg K due to weeds in linseed crop. Sachin et al. (2022) reported that reduced weed population results in availability of more light, water and plant nutrients to the crop plant, which reflects in better plant growth. Rao and Nagamani (2010) opined that weeds generally have higher content of nutrients than crop plants. They grow and absorb nutrients faster than crop with the result that there could also be a scarcity of nutrient for the crop plants. Hussein et al. (2002) reported that weed competition caused a significantly lower seed, straw and oil yield.

3. Weed Dynamics in Linseed

Weed dynamics in linseed depends on agro-climatic situation, soil characteristics, cropping pattern, crop management practices and availability of soil moisture in the field. Acharya et al. (2017) observed broad leaf weeds like *Rumex dentatus*, *Chenopodium album*, *Polygonum plebejium*, *Alternenthera sesilis*, *Physalis minima*, *Medicago polymorpha* and *Solanum xanthocarpum*, grass like *Digitaria sanguinalis* and sedge like *Cyperus rotundus*, as the most predominant weed flora in the experimental field under Patna condition. Puhup and Dwivedi (2019) observed prevalence of weeds like *Medicago denticulata*, *Convolvulus arvensis*, *Parthenium hysterophorus*, etc. at different growth stages of linseed under Raipur condition. Similarly, Siddesh et al. (2016) reported major dicot weeds present in the field as *Euphorbia geniculata* L., *Euphorbia hirta* L., *Chrozophora rotleri* L., *Amaranthus viridis* L. etc. Among monocot weeds, *Brachiaria eruciformis* (Trin.) Griseb., *Eragrostis* sp., *Pennisetum pedicellatum* etc. were predominant, whereas *Cyperus rotundus* L. and *Cynodon dactylon* (L.) Pers. occurred in patches under Raichur condition. Devendra et al. (2016) reported the prevalence of dicot weeds under Tikamgarh condition, which constituted the higher relative density (67.7%) as compared to monocot weeds (18.0%). They reported highest relative density of *Chenopodium album*, followed by *Convolvulus arvensis* and *Melilotus officinalis*, among dicot weeds, whereas, *Cynodon dactylon* was found as dominant monocot weed in the field. This crop is also infested with parasitic weed like *Cuscuta campestris*, having slender, twining or thread like stems that vary from pale green to yellow or bright orange, which causes moderate to severe reductions of plant growth and in some cases complete loss of vigour and death. Mishra et al. (2006) reported that irrespective of the varieties, *Cuscuta* infestation reduced the growth and yield attributes and seed yield of linseed as compared to *Cuscuta* free conditions.

4. Effect of Weeds on Growth and Yield of Linseed

The competitive ability of a plant to utilize the growth resources such as light, water and nutrients plays a vital role in determining the crop yield. Several authors have assessed the influence of various weeds on plant growth and yield of linseed crop. Meleta et al. (2018) reported that weeds cause serious concern for growth and yield of linseed resulting in loss of yield and deterioration of oil quality because of severe competition for plant nutrients. Similarly, Acharya et al. (2017) recorded taller plants with more number of primary branches plant^{-1}, capsules plant^{-1} and seeds capsule^{-1}, when weeds were controlled by hand weeding as compared with control plots because of reduced crop-weed competition. Drastic reductions of linseed yield due to higher competition of weeds with crop for growth factors (moisture, light, nutrients and space) in weedy check have also been reported by Jain and Jain (2016). Devendra et al. (2016) have established the superiority of various weed control practices over weedy check plot with respect to yield and yield attributing characters of linseed. Mishra et al. (2006) reported a reduction in seed yield due to *Cuscuta campestris* in different varieties, varying from 7.26% to 44.29%.

5. Weed Management Methods

As linseed cannot compete with weeds at the early stages of the crop, owing to its slow initial growth and relatively lower canopy spread, hence, it is imperative to control the weeds as early as possible so that the crop plants can attain robust growth (Mohanty and Sahoo, 2022). Researchers have observed remarkable effect of various weed management practices on weed density, weed biomass and their influence on crop yield. Weeds can be controlled either manually or by application of herbicides or both. Manual weeding is labour intensive and is comparatively more time consuming, which necessitates a cost-effective chemical weed management practice i.e., herbicides. While working on non-chemical weed management, Dastgheib (2006) reported that under high weed pressure, a maximum of two tine weeding passes, one at cotyledon stage and another when average crop height is 5–7 cm, should be adequate. He also recommended higher sowing rate if tine weeding is in the plan to compensate for population loss. With regards to manual weeding, various researchers reported hand weeding around 20 to 40 days after sowing (DAS) controlled the weeds in linseed, which is significantly superior to any other methods of weed management (Siddesh et al., 2016; Acharya et al., 2017; Dwivedi and Puhup, 2019; Devendra et al., 2016)

6. Chemical Weed Management in Linseed

As compared to cost intensive manual weeding, chemical methods of weed control have been proven to control weeds more efficiently in linseed crop. For controlling weeds at the early growth stage and giving the crop a vigorous start, pre-emergence application of herbicides is more efficient. Generally, pendimethalin is widely used as pre- emergence herbicide for control of weeds in linseed crop, but its effectiveness varies depending upon type of soil and availability of soil moisture. Siddesh et al. (2016) reported that application of pre-emergence herbicide followed by post emergence herbicide or hand weeding around 20 to 40 DAS controlled the weeds in linseed and augmented the yield. Dwivedi and Puhup (2019) recorded lowest value of weed density and biomass with two hand weeding, which was statistically at par with pre-emergence application of pendimethalin @1.0 kg a.i. ha^{-1}. Several researchers reported significant reduction in weed density as well as weed dry weight under pre-emergence application of pendimethalin+imazethapyr @ 1.0 kg a.i. ha^{-1}. (Siddesh et al., 2016; Devendra et al., 2016). Oxadiazon can also be used as pre-emergence herbicide in linseed applied @ 0.5–1.0 kg a.i. ha^{-1} as reported by Mishra et al. (2021) and Mishra and Choudhary (2022). As there are a few number of experiments conducted with regards to the efficacy of pre-emergence herbicides in linseed, it needs the attention of researchers for evaluating some more pre-emergence herbicides in the crop. Mahere et al. (2000) reported that for controlling *Cuscuta* in linseed, pendimethalin @ 0.5–1.5 kg a.i. ha^{-1} can be applied as pre-emergence.

With respect to post-emergence herbicides, Amare et al. (2014) reported that there was significant reduction in weed density and weed dry weight with post-emergence application of isoproturon @ 1.50 kg a.i. ha^{-1}, due to its effective control of various types of weeds, whereas, Acharya et al. (2017) reported that herbicide-based weed management through post-emergence application of isoproturon @ 1.0 kg a.i. ha^{-1} was found to be the most effective and economic herbicide, in controlling weed flora and improving seed yield of linseed in Indo-Gangetic plain of Bihar. While reviewing weed management in oilseed crops, Choudhary et al. (2022) mentioned the use of propaquizafop @ 0.1 kg a.i. ha^{-1} and isoproturon @ 1.00–1.50 kg a.i. ha^{-1}, applied as post-emergence. Gaweda and Kwiatkowski (2012) reported that metribuzin @ 0.42 kg a.i. ha^{-1} registered the least weed population and biomass with highest weed control index in linseed. Punia et al. (2005) reported that tank mixture of clodinafop+sulfosulfuron (3:1) @ 60 g a.i. ha^{-1} and fenoxaprop+sulfosulfuron (4:1 and 5:1) @120 g a.i. ha^{-1} provided 85–90% control of *Avena ludoviciana* and *Phalaris minor* and 60% control of broadleaf weeds like *Chenopodium album*, *Melilotus indica* and *Rumex retroflexus*. They also reported highest grain yield obtained in weed free treatment, being at par with the said chemical combinations. Singh et al. (2014) reported that among the various herbicidal treatments, application of imazethapyr @ 100 g a.i. ha^{-1} was significantly superior in reducing the weed density, dry weight and recording higher weed control efficiency. Significantly higher linseed seed was recorded with hand weeding twice, being statistically at par with post-emergence application of isoproturon+metsulfuron-methyl @ (1 kg+4 g) a.i. ha^{-1} and metsulfuron-methyl @ 4 g a.i. ha^{-1} (Dwivedi and Puhup, 2019). They also recorded the highest benefit:cost ratio with metsulfuron-methyl @ 4 g a.i. ha^{-1} due to higher seed yield coupled with lower cost of chemical treatment. Choudhary et al. (2022) reported that sequential application of pendimethalin @ 1.0 kg a.i. ha^{-1} as pre-emergence followed by metsulfuron-methyl @ 4 g a.i. ha^{-1} or clodinafop+metsulfuron-methyl @ 60 g+4 g a.i. ha^{-1} in irrigated linseed, at 2–3 leaf stage of weeds, resulted in higher weed control efficiency, yield and economic returns.

Combination of pre-emergence herbicides followed by post-emergence herbicides provides an effective weed management since the pre-emergence herbicides does not allow the emergence of most of weeds through their action in inhibiting root and shoot growth, whereas, post-emergence application controls effectively the weed flush which germinates after getting the first irrigation, by inhibiting various physiological processes like photosynthesis, respiration, amino acid and lipid synthesis. Various researchers have reported that weed-free treatment produced the highest seed yield of linseed followed by two hand hoeing at 20 and 40 DAS. Sachin et al. (2022) revealed that application of pendimethalin @ 750 g a.i. ha^{-1} as pre-emergence followed by metsulfuron methyl @4 g a.i. ha^{-1} at 2–3 leaf stage of weeds was found effective in controlling the weeds with higher growth and yield component coupled with seed yield and net returns in linseed.

Mankowski et al. (2015) working on the effect of herbicides on quality of flax reported the lowest weed mass and the highest flax straw yield and fibre quality was obtained after the use of chlorsulfuron. Bentazon limited weeds more effectively than linuron but shortened the growing season of flax and reduced straw yield. The fibre mass was similar after the use of chlorsulfuron and linuron and higher than the mass from flax weeded with bentazon.

An over-reliance solely on herbicides as a weed management strategy poses several economic and environmental risks (Shekhawat et al., 2020), because of their long residual activity causing a significant weed shift and development of herbicide resistance either slowly or rapidly (Mahajan et al., 2013). The integrated weed management (IWM) approach, including crop-resource management practices compatible with herbicides become imperative in changing weed dynamics and crop-weed interference in linseed. IWM relies on weed management principles that use all the suitable techniques in a compatible manner to produce optimum yield at a minimum cost, by reducing weed population and maintaining them at levels below those causing economic injury level, without causing environmental degradation. It includes use of two or more methods like cultural, mechanical, biological and chemical for controlling weeds effectively and economically. However, herbicide is an important component of IWM for successful weed control in crops. IWM in linseed can be performed by a good crop husbandry along with pre or post-emergence herbicides and hand weeding at 30–35 days after sowing.

7. Conclusion

Weed interference causes substantial reduction in yield of linseed and relying on a single method of weed control may lead to shifting in weed flora, development of herbicide-resistance, emergence of perennial weeds, etc. The future challenge in weed management should include research on weed ecology, bio-efficacy of post-emergence herbicides and on-farm assessment of available IWM options in linseed. There is also need to educate farmers on judicious use of herbicides in India, in integration with other weed management methods.

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