***Review Article***

**Herbicide based weed management in blackgram (*Vigna mungo* L*.*) : A Review**

**ABSTRACT**

Blackgram (*Vigna mungo*) is a significant pulse crop grown in India, recognized for its nutritional value and contribution to soil fertility through nitrogen fixation. A major constraint to blackgram productivity is weed infestation, which can cause substantial yield reductions. Traditional weed control methods, such as manual weeding, are often labour-intensive, time-consuming, and becoming increasingly impractical due to labour scarcity and unfavourable weather conditions. Herbicide-based weed management provides a potentially more effective and economical solution. Various pre-emergence, early post-emergence, and post-emergence herbicides, as well as herbicide mixtures, are available for comprehensive weed management in blackgram. This review synthesizes recent research on the effectiveness of different herbicides and their combinations in managing weeds in blackgram cultivation.

Keywords: Blackgram, Chemical management, Herbicide combinations,Premixherbicides

**INTRODUCTION**

Blackgram (*Vigna mungo* (L.) Hepper) is a key crop among pulses in India, esteemed for its nutritional attributes. Its short growth cycle makes it valuable in intensive cropping systems. The importance of blackgram is evident in its widespread cultivation across 28.78 million hectares in India, yielding 25.46 million tonnes with an average productivity of 885 kg ha⁻¹ (1). Unfortunately, the average yield remains suboptimal, largely due to significant weed pressure. The limited competitive ability of blackgram against weeds renders it particularly vulnerable to their detrimental effects (2). High temperatures and frequent rainfall during the growing season exacerbate weed infestations, leading to significant reductions in crop productivity. Weeds impede photosynthetic efficiency, diminish dry matter production, and divert resources away from the development of economically valuable plant parts (3).

A two-year field investigation into the critical period of weed competition in irrigated summer-sown blackgram (*Vigna mungo* L.) demonstrated that uncontrolled weed growth throughout the crop cycle resulted in a 40.10 % decline in seed yield. Weed presence during the first 10 days after sowing did not significantly impact yield, and maintaining weed-free conditions beyond 40 days after sowing did not substantially improve yields. The critical period for weed control in irrigated summer-sown blackgram was thus determined to be between 10 and 40 days after sowing (4). In blackgram, unmanaged weed proliferation can diminish grain yield by 29% to 62% (5) and deplete essential soil nutrients (6). Another study reported loss in yield ranging from 27% to 100% in blackgram because of unchecked weed growth (7).

The extent of grain yield losses in blackgram can vary between 41.6% and 64.1%, depending on the species of weeds, their density, and the duration of competition (8). Weed competition throughout the growing season has been shown to cause a yield decline of 27% to 84%, dependent on the species and severity of the weed infestation (9). Unweeded control plots exhibited the lowest yields due to intense competition for nutrients, water, and light (10). Seed yield losses in blackgram through weed infestation have been reported to range from 50% to 87% (11). Prolonged crop-weed competition from 15 days after sowing (DAS) to crop maturity considerably heightened weed density and dry weight (12; 13). Manual weed control is labour-intensive, physically demanding, and often fails to provide time-bound suppression of weeds during critical periods of crop-weed competition (14). The process is further complicated by labour shortages and adverse weather. Therefore, the development of cost-effective, herbicide-based weed management strategies is vital to minimize weed-induced yield losses (15).

**Herbicide based weed management in blackgram**

The utilization of pesticides, encompassing herbicides, insecticides, and fungicides, has increased substantially since the green revolution of the early 1960s. Global pesticide consumption has risen considerably, reaching nearly four million tonnes recently, with herbicides (47.5%) representing the largest proportion of usage (16). Herbicides offer several advantages, including ease of application, cost-effectiveness, and superior weed control efficiency (WCE) compared to alternative methods. This leads to enhanced crop productivity and profitability, as well as reduced production costs (17). Numerous herbicides have been evaluated and recommended for controlling weeds in pulses, either as pre-emergence applications or through pre-plant incorporation (18). However, a thorough understanding of weed ecology is crucial before implementing specific management practices (19). While herbicidal weed control is generally economically viable, selecting the appropriate herbicide and ensuring its efficacy are critical for achieving optimal outcomes. Given these challenges, herbicides offer a valuable option for effective weed control. To improve weed control efficacy while minimizing application costs, the use of formulated or tank-mixed herbicide combinations has been suggested as a more efficient approach (20).

Herbicides approved for use in blackgram include fenoxaprop-p-ethyl (9.3% EC), imazethapyr (10% SL) with a surfactant, propaquizafop (10% EC), quizalofop-ethyl (5%EC), propaquizafop + imazethapyr (2.5%+3.75% w/w ME), and pendimethalin (30% EC) (21). The commonly used pre-emergence herbicides in blackgram are pendimethalin, imazethapyr, propaquizafop and quizalofop-ethyl. In contrast, commonly used post-emergence herbicides include imazethapyr, quizalofop-ethyl, cyhalofopbutyl, fenoxaprop ethyl and clodinafop-propargyl (22). Several herbicides have been employed for weed management in blackgram; however, their effectiveness in controlling diverse weed populations has been limited. Consequently, it is crucial to evaluate the efficacy of appropriate post-emergence herbicides, both individually and in combination, for effectively managing the predominant and varied weed flora associated with blackgram (23).

**1. Pendimethalin**

Pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitroaniline) is a dinitroaniline herbicide used as a pre-emergence treatment to control grass weeds in crops like maize, sorghum, cowpea, soybean, and various vegetables. This herbicide acts by inhibiting microtubulin synthesis, which is essential for microtubule formation required for cell wall development and chromosome movement during mitosis. The herbicide is primarily absorbed by young shoot tissues, such as the hypocotyl or coleoptile, rather than roots. It provides selective control of both grass and broadleaf weeds (24). Pendimethalin is widely applied as a pre-emergence herbicide in pulse crops, but its ability to control a broad spectrum of weeds over extended periods is limited.

For comprehensive weed management throughout the growing season, a combination of pendimethalin application and subsequent manual weeding at 30 to 35 DAS is often recommended for pulses. Alternatively, this practice is becoming less common due to labour shortages during critical weeding time and increasing labour costs (25). Adhikary (26) noted that pre-emergence pendimethalin spray @ 1.0 kg ha-1 followed by post-emergence application of quizalofop-ethyl @ 50 g ha-1 at 25 days after seeding reduced weed density, achieved a high weed control efficiency (WCE) of 92.10%, and produced a mean seed yield of 0.82 t ha-1, representing a 48.35% increase compared to control in rainfed blackgram. Pendimethalin (30 EC) applied @ 750 g ha⁻¹ as a pre-emergence treatment (2 DAS) has demonstrated selectivity in blackgram without causing phytotoxicity (27).

**2. Imazethapyr**

Imazethapyr is a selective systemic herbicide belonging to the imidazolinone group, offering broad-spectrum control with activity in both the soil and on the foliage. It provides versatility in application timing and exhibits low mammalian toxicity (28). This herbicide effectively controls a range of annual, perennial grasses, as well as broadleaf weeds (29). It can be utilized via pre-plant incorporation, pre-emergence, or post-emergence application techniques. It has low toxicity to mammals (30).

In rainfed blackgram, Nandan *et al*. (31) found that post-emergence imazethapyr application @ 25 g ha-1 did not negatively affect growth parameters and resulted in grain yields comparable to two hand weeding sessions at 20 and 40 DAS. Post-emergence imazethapyr application is suggested for rainy-season pulses like pigeonpea, blackgram, and greengram. Nevertheless, in winter-season pulses such as chickpea, lentil, and field pea, imazethapyr has exhibited toxicity even at reduced rates of 15 g ha-1(32).

In blackgram, post-emergence application of imazethapyr has yielded promising results (5). Late-emerging weeds were effectively managed with post-emergence spray of imazethapyr at 75 g ha-1. However, its prolonged half-life can result in carryover effects, negatively impacting subsequent cereal crops (33). Therefore, exploring alternative herbicides with different modes of action is essential to ensure effective, broad-spectrum weed control, as pre- or post-emergence applications can persist in the soil, altering enzyme activities (34).

Veeraputhiran and Chinnusamy (35) observed that post-emergence imazethapyr application at 0.09 kg ha⁻¹ was more effective than applications at 0.06 and 0.075 kg ha⁻¹, with applications at 21 and 28 DAS showing similar efficacy, followed by 14 DAS. Nirala *et al*., (36) opined that imazethapyr at 25 g ha⁻¹ yielded the lowest weed density, dry matter production, weed intensity, weed growth rate, and relative weed density, along with the greatest weed control efficiency in blackgram. As a systemic herbicide, imazethapyr is taken up by both the roots and leaves, moving through the xylem and phloem, and accumulating in the meristematic areas. As a post-emergence systemic herbicide, imazethapyr is absorbed by both roots and foliage, translocating through the xylem and phloem, and accumulating in meristematic regions (37). Currently, imazethapyr is recognized as a potent post-emergence herbicide for managing grass and broadleaf weeds in blackgram (38).

Singh *et al*. (39) stated that imazethapyr application @ 25, 40, and 75 g ha-1negatively affected various symbiotic parameters, including number, dry weight and leghaemoglobin content of nodule, in comparison to 2 hand weeding. Imazethapyr @ 75 g ha-1 applied as post-emergence effectively controlled late-emerging weeds. However, its use was limited by the selection of succeeding crops (40). The post-emergence application of imazethapyr @ 60, 75, 100, and 150 g ha-1 resulted in considerably greater seed yields than pre-emergence application of pendimethalin @1 kg ha-1, alachlor @1 kg ha-1, and the quizalofop-ethyl @75 g ha-1 (41). Imazethapyr, when used as a post-emergence herbicide shown remarkable effectiveness in broad-spectrum weed control in kharif pulses, including blackgram (42).

**3. Propaquizafop**

Propaquizafop has been used as a selective post-emergence herbicide and mainly advised for managing weeds of crops such as sugar beet, rapeseed, soybean, sunflower, vegetables, fruit trees, vineyards, and forest trees. Propaquizafop application @ 50 g ha-1 efficiently suppressed grass weeds of soybeans (43). Suryavanshi *et al*. (38) found that applying a mixture of propaquizafop + imazethapyr as post-emergence spray at rates of 53 + 74 and 56 + 78 g ha -1, 30 days after application, efficiently reduced the density and dry weight of different weed flora *viz*., grasses, sedges, and broadleaf weeds. This resulted in improved weed indices and yield-related traits (pods per plant), as well as seed and haulm yields, comparable to 2 hand weeding *viz.,* at 20 and 40 days after sowing. In another study, post-emergence treatment of propaquizafop @100 g ha-1 markedly decreased the density as well as the dry weight of grass weeds due to its selective action. It inhibited cell division and growth by disrupting the function of the enzyme acetyl-CoA carboxylase (44).

**4. Fenoxaprop-ethyl**

Fenoxaprop-ethyl is a post-emergence, selective herbicide belonging to the aryloxyphenoxypropionate group. It primarily targets grass weeds by inhibiting acetyl-CoA carboxylase (ACCase), an enzyme essential for lipid biosynthesis in grasses. Fenoxaprop-ethyl is absorbed through the leaves and stems of grass weeds, leading to their eventual death while sparing broadleaf crops like blackgram. Its ease of application and compatibility with other herbicides make it valuable for integrated weed management strategies. Fenoxaprop-ethyl has been shown to effectively control grass weed species such as *Echinochloa colona* (jungle rice), *Cynodon dactylon* (Bermuda grass), and *Dactyloctenium aegyptium* (crowfoot grass), which are commonly found in blackgram fields (6).

Rao (45) reported that herbicidal application of fenoxaprop-ethyl at 60 g ha-1 appreciably reduced weed density and biomass, resulting in 40% enhancement in blackgram yield compared to the untreated control. However, the efficacy of fenoxaprop-ethyl depends on its application timing and dosage. Applications made at 15 to 20 DAS are most effective, coinciding with the early vegetative stage of blackgram when weed competition is critical (2). Fenoxaprop-ethyl is primarily effective against grass weeds and does not control broadleaf weeds and sedges, necessitating its use in combination with other herbicides like imazethapyr or pendimethalin for comprehensive weed management. Also, frequent use of it will end up in the development of resistance in specific weed species of interest, reducing its long-term efficacy.

**5. Clodinafop-propargyl**

Clodinafop-propargyl is categorized under the aryloxyphenoxy class of herbicides. Its mode of action is by the inhibition of Acetyl-CoA carboxylase(ACCase), a crucial enzyme involved in synthesis of lipids. This disruption halts the development of susceptible grass weeds within 48 hours of application. It is specifically effective against annual grasses and does not impact broadleaf (dicot) weeds. When applied post-emergence at a rate of 30 to 60 g per ha, it successfully managed wild oats in winter wheat, with the tillering phase being the most responsive growth stage for treatment. According to Rao and Rao (46), applications of clodinafop-propargyl at rates of 52.5 to 75.0 g ha⁻¹ achieved weed control efficiencies ranging from 89% to 94%. This level of control was comparable to that obtained through manual weeding conducted 25 DAS in blackgram .

Post-emergence treatment with clodinafop-propargyl significantly curtailed the growth of *Echinochloa colona*, leading to yield increases in blackgram ranging from 27% to 42% (47). Jagadesh and Raju (48) noted that application of pendimethalin and subsequent, acifluorfen-sodium + clodinafop-propargyl could effectively suppress weed population and enhanced blackgram productivity. Thimmegowda *et al*. (49) reported that clodinafop-propargyl, when used in conjunction with sodium acifluorfen, led to a reduction in weed density and biomass, resulting in improved seed and haulm yields in blackgram. Furthermore, the post-emergence application of a mixture containing sodium acifluorfen at 16.5% and clodinafop-propargyl at 8% EC, applied at rates of 206.25 + 100 g ha-1, significantly enhanced both seed and haulm yields of blackgram during the summer and kharif seasons.

**6. Cyhalofop butyl**

Cyhalofop-butyl, a systemic and selective post-emergence herbicide within the aryloxyphenoxy family, acts by inhibiting ACCase, a key enzyme in fatty acid synthesis in grasses. Sasikala *et al*. (50) aimed to compare sowing methods and assess the efficacy of post-emergence herbicides for weed control in zero-tillage rice fallow blackgram, and found that imazethapyr at 100 g ha⁻¹ significantly enhanced growth parameters such as leaf area index, crop growth rate, net assimilation rate, and total biomass accumulation. Fenoxaprop-p-ethyl and cyhalofop-butyl exhibited closely comparable effectiveness.

Studies have indicated that post-emergence applications of cyhalofop-butyl can substantially reduce the proliferation of weeds like *Echinochloa colona*, leading to increased blackgram yield (30). Furthermore, Ramesh and Rathika (51) reported that cyhalofop-butyl did not induce any phytotoxicity in blackgram and proved effective for weed management in rice fallow systems. Dash *et al*. (27) found that applying pendimethalin (30 EC) @ 750 g ha-1 as a pre-emergence treatment 2 DAS, followed by cyhalofop-butyl (10 EC) @ 75 g ha-1, provided the most successful control of weeds with minimal herbicide-induced phytotoxicity, ultimately resulting in improved yields.

**7. Quizalofop ethyl**

Quizalofop-ethyl, a herbicide belonging to the aryloxyphenoxypropionate family, is a selective and systemic post-emergence treatment. Its mechanism of action involves inhibiting ACCase, a vital enzyme in the synthesis of fatty acids within grasses. As a result, it is highly effective in controlling grass weeds in broadleaf crops such as blackgram.

Quizalofop-ethyl is favoured for its ability to selectively control narrow-leaved weeds in broadleaf crops like blackgram. It is effective against both annual and perennial grass weeds and has been found safe for use in blackgram, without causing residual toxicity to succeeding crops. Mundra and Maliwal (52) demonstrated that applying quizalofop-p-ethyl @ 50 g ha⁻¹ achieved a reduction of density as well as dry biomass of narrow-leaved weeds, both at 30 DAS and at harvest. This treatment resulted in a weed control efficiency of 81.3%, which was slightly less than the 85.6% achieved with two manual weeding operations. Furthermore, plots treated with quizalofop-p-ethyl at the same rate showed enhanced values for key yield components, including an increase in the number of branches and pods per plant, more seeds per pod, and improved grain and stover yields.

Ramesh (53) reported that a tank mix of quizalofop-ethyl @ 31.25 g ha-1 combined with imazethapyr at 62.5 g ha-1, applied in 250 litres of water at 15DAS, provided effective weed control in irrigated blackgram. Adhikary (26) observed that a pre-emergence spray of pendimethalin @1.0 kg ha-1 followed by a post-emergence application of quizalofop-ethyl @ 50 g ha-1 25 DAS brought down the weed density and improved weed control efficiency compared to other herbicides tested. The efficacy of quizalofop-ethyl has also been attributed to the rapid absorption of the herbicide and its rapid translocation to the meristematic tissues of the plant.

**Herbicide combinations/ premix herbicides**

The restricted application flexibility and the increasing prevalence of herbicide-resistant weeds are diminishing the efficacy of various pre- and post-emergence herbicides, which significantly impairs crop productivity. Utilizing herbicide combinations or ready-mix herbicides presents a potential solution to these challenges (54). Selective herbicides, characterized by a narrow spectrum of activity, are only effective against specific types of weeds, such as grasses or broadleaf species, making them unsuitable for managing diverse weed populations (55). To overcome this limitation, herbicide mixtures, whether tank-mixed or pre-mixed, are recommended for achieving comprehensive weed control (56). Furthermore, these combinations can minimize or can defer the herbicide resistance build-up by reducing the selective pressure exerted by individual herbicides (57). Herbicide mixtures with differing modes of action contribute to a slower development of resistant biotypes within weed species. Such combinations typically result in a lower frequency of resistance compared to the use of a single herbicide (58).

**1. Pendimethalin + imazethapyr**

A substantial body of research has documented the numerous benefits of utilizing herbicide combinations in blackgram production systems. Chandrakar *et al*. (59) demonstrated that both the early post-emergence application of imazethapyr @ 40 g ha-1 (applied 15–20 DAS) and the pre-emergence application of a ready-mix formulation of pendimethalin + imazethapyr @1.0 kg ha-1 provided highly successful weed control in cultivated blackgram fields. Similarly, Rao *et al*. (60) reported that pre-mix applications of pendimethalin + imazethapyr consistently resulted in superior levels of weed control compared to a range of alternative treatments. Of particular significance was their key finding that both the standalone application of pendimethalin and the combined application of imazethapyr + pendimethalin were particularly successful in curbing the accumulation of weed dry matter and consistently maximizing overall seed yield.

Yadav *et al*. (10) opined that the use of premix herbicides, including imazethapyr + imazamox (applied as post-emergence) and pendimethalin + imazethapyr (applied pre-emergence), proved to be more effective in controlling the full spectrum of weed species present in blackgram cropping systems when compared to the individual applications of either pendimethalin (as a pre-emergence herbicide) or imazethapyr (as a post-emergence herbicide). Singh *et al*. (61) documented that the pre-mix combination of imazethapyr and pendimethalin applied at a rate of 1000 g ha-1 consistently accomplished the highest levels of weed control efficiency compared to the standalone applications of either herbicide. Importantly, this particular pre-mix combination also produced a substantial and economically considerable jump in blackgram seed yield, with an average of 63.3% improvement compared to untreated control plots where no weed control measures were implemented.

Singh *et al*. (40) further demonstrated that the carefully timed application of pendimethalin + imazethapyr @ 0.75 and 1.00 kg ha-1 gave rise to a significantly higher benefit-cost ratio compared to a range of alternative herbicide treatments. These improved benefit-cost ratios, alongside increased gross and net economic returns, were directly linked to improved grain yields and reduced overall cultivation costs. Providing even more specific details, Shashidhar *et al*. (62) affirmed that the pre-emergence spray of pendimethalin + imazethapyr (applied as a ready-mix formulation) at a rate of 1.0 kg ha-1 was the single most effective treatment in blackgram, resulting in a mean grain yield of 602 kg ha-1 and a corresponding stover yield of 1741 kg ha-1. Again, further emphasizing the robust efficacy of this specific herbicide combination, the study also highlighted that pre-emergent applications of pendimethalin 30 EC + imazethapyr 2 EC at relatively low doses of 0.75 kg and 1.0 kg ha-1 were exceptionally effectual in cutting down both weed density and overall weed dry weight in blackgram, especially when compared to a range of alternative post-emergent herbicide treatments. These specific pre-emergent applications exhibited comparable efficacy to intensive hand weeding performed at 20 and 40DAS, achieving a high weed control efficiency (WCE) of upto 83%.

Dhayal *et al*. (63) added yet another layer of support to these findings, reporting that the lowest overall weed density and weed index, in conjunction with the highest levels of crop growth parameters, were consistently observed with a system combining two well-timed hand weeding operations executed at 20 and 40 DAS in combination with a pre-emergence spray of pendimethalin @1.0 kg ha-1, subsequently, a post-emergent mixture of propaquizafop (2.5% w/w) and imazethapyr (3.75% w/w) @ 33.3 +50 g ha-1 applied at 20 DAS in blackgram. Finally, Reddy *et al*. (64) have definitively confirmed that pendimethalin + imazethapyr, when applied as a pre-mix formulation at a rate of 1000 g ha-1, is a highly effective method for reliably managing mixed weed populations in cultivated blackgram.

**2. Propaquizafop + imazethapyr**

The recent introduction of pre-mix post-emergence herbicides, such as propaquizafop + imazethapyr, has expanded weed control options in pulse crops. A post-emergence spray of propaquizafop + imazethapyr @ 53 + 74 g ha-1 and 56 + 78 g ha-1, applied at 30DAS, proved success in curtailing the density and dry weight of mixed weed flora in blackgram *viz*., grasses, sedges, and broadleaf weeds. This treatment also achieved a significantly higher number of root nodules per plant compared to untreated weedy checks, along with improved weed indices, yield attributes, seed yield, and haulm yields, which were comparable to results achieved by hand weeding twice (20 and 40 DAS) in soybean (37).

Tomar (65) documented that a post-emergence spray of quizalofop-ethyl @1000 ml per ha at 15 DAS efficiently suppressed grass weeds and enhanced blackgram seed yield. Rao (45) found that a post-emergence application of quizalofop-ethyl @ 50 g ha-1 resulted in the highest blackgram seed yield (1877 kg ha-1), net monetary returns (Rs. 35,625 ha-1), and a benefit-cost ratio of 3.15, which performed similarly to hand pulling at 15 and 30 DAS that recorded a seed yield of 1928 kg ha-1.

Post-emergence herbicides are imperative in curbing weed population during the advanced phases of crop development. Since there is a prevalence of grasses in many production systems, it is important to evaluate more grass-specific herbicides, as well as to explore newer-generation herbicides that can address evolving weed challenges. The post-emergence spray of propaquizafop (75 g ha-1) was confined to control of only grass weeds in black gram and its efficacy was found enhanced when combined with imazethapyr, with the highest effectiveness observed when the propaquizafop + imazethapyr mixture was applied at rates of 53 + 80 g ha-1 or higher (56 + 85 g ha-1). In addition, yield-attributing traits and overall yield were superior under the propaquizafop + imazethapyr mixture applied at 56 + 85 g ha-1 (66). Kewat *et al*. (67) found that the post-emergence application of propaquizafop combined with imazethapyr at 53 + 80 g ha-1 was the most cost-effective approach for bringing weed population under control in blackgram. In addition, the tank-mix application of propaquizafop + imazethapyr resulted in higher seed yield compared to other chemical treatments, and applying propaquizafop (50 g ha-1) + imazethapyr (100 g ha-1) at 20 DAS was found to be as effective as hand weeding in influencing seed yield in soybean (68).

While the application of propaquizafop alone as post-emergence @75g ha-1 effectively controls grass weeds, its overall effectiveness is significantly enhanced through combination with imazethapyr. The greatest weed control efficacy was observed with a mixture of propaquizafop + imazethapyr applied at 53 + 80 g ha-1 or at a slightly higher rates of 56 + 85 g ha-1. Panda (66) concluded that the post-emergence spray of a propaquizafop + imazethapyr mixture at 53 + 80 g ha-1 provided the most cost-effective approach for controlling a broad spectrum of weeds in soybean. The same study indicated that yield-related attributes and overall crop yields were superior when the herbicide mixture was applied at 56 + 85 g ha-1, followed closely by the application rate of 53 + 80 g ha-1. Both of these herbicide treatments provided levels of weed control and crop yield that were comparable to those achieved with a labour-intensive hand weeding regime involving two separate weeding operations conducted at 20 and 40 DAS.

In general, the combined application of compatible herbicides has proven to be more effectual than the use of any single herbicide in achieving comprehensive weed control in blackgram production (69). Reddy *et al*. (70) found that the combination of propaquizafop + imazethapyr at 127 g ha-1 was particularly effective in lowering total weed density and dry weight when assessed at 45 DAS and again at harvest, compared to a range of other post-emergence herbicides. The authors attributed this enhanced effectiveness to its dual mode of action in controlling weeds in blackgram cropping systems.

Dhayal *et al.* (63) in another study reported that the lowest weed density and weed index, and the highest crop growth parameters, number of nodules per plant, and nodule dry weight, were achieved with the pre-emergence spray of pendimethalin at 1.0 kg ha-1, followed by post-emergence spraying of propaquizafop 2.5% w/w (33.3 g ha-1) + imazethapyr 3.75% w/w (50 g ha-1) at 20 DAS. Supporting these findings, an experiment conducted to evaluate the effectiveness of pre- and post-emergence herbicides in blackgram revealed that, among the various post-emergence treatments evaluated, propaquizafop + imazethapyr at 127 g ha-1 proved to be the most efficacious in diminishing both weed density and overall weed biomass (64). Likewise, a study conducted at Jabalpur to evaluate the effect of propaquizafop and imazethapyr on weeds associated with blackgram found that a mixture of propaquizafop and imazethapyr at carefully chosen doses of 53+80 g ha-1 and 56+85 g ha-1 was highly successful in suppressing a wide range of common weeds (71).

**3. Acifluorfen sodium + clodinafop propargyl**

Research by Venkateswarlu (72) established that applying clodinafop-propargyl at 52.50 g ha-1 to blackgram at 20 DAS significantly boosted grain yield (922 kg ha-1), increasing pods per plant (33) and seeds per pod (6.2). Studies with varying doses of clodinafop-propargyl + acifluorfen sodium revealed that post-emergence application of 100.0+ 206.5 g ha-1 improved crop yield, leading to more pods per plant (31.48), higher seed yield of 1.22 t/ha, greater biological yield of 1.60 t/ha, and a better harvest index (43.3%).

In blackgram relay cropping, post-emergence acifluorfen + clodinafop-propargyl at 400 g ha-1 improved branches per plant (9.3), pods per plant (10.9), seeds per pod (6.3), economic yield (762 kg ha-1), and biological yield (1520 kg ha-1), comparable to two hand weeding (73). Harithavardhini (74) found that acifluorfen sodium + clodinafop-propargyl @ 0.3 kg ha-1 at 15 DAS substantially enhanced blackgram growth and yield, resulting in more pods per plant (28.9), seeds per pod (4.9), higher pod weight (4.92 g/plant), and better economic yield (10 quintals ha-1), similar to two hand weeding.

Mudalagiriyappa *et al*. (75) noted that post-emergence combination, sodium acifluorfen + clodinafop-propargyl (@ 206.25 + 100 g ha-1) appreciably increased blackgram yield in both summer and kharif seasons. The highest weed control efficiency (WCE) was at a higher dose (330 + 160 g ha-1), with 93.20% in summer and 91.0% in kharif, followed by 206.25 + 100 g ha-1 (89.51% and 90.24%). The yield increase resulted from effective weed suppression without harming the subsequent finger millet crop in semi-arid alfisols. A study by Basu *et al*. (76) on weed management in irrigated blackgram showed that post-emergence sodium acifluorfen + clodinafop-propargyl at 300 g ha-1 at 20 DAS remarkably reduced weed density and dry matter, leading to higher seed yields (1180 and 998 kg ha-1), maximum net returns (Rs. 43,227 and Rs. 32,915/ha), and a return per rupee investment of 1.99 and 1.50 during 2017-18 and 2018-19, respectively.

**4. Fomesafen + fluazifop-p-butyl**

In recent studies exploring broad-spectrum weed control in blackgram, Sreekanth *et al.* (77) found that the most effective approach for maximizing yield and minimizing weed growth involved two manual weeding sessions performed at 15 and 30 DAS. Notably, this labour-intensive strategy achieved results that were statistically comparable to those obtained with post-emergence applications of fluazifop-p-butyl + fomesafen @ 222 g ha-1 and sodium acifluorfen + clodinafop-propargyl @ 245 g ha-1, both sprayed at 20 DAS.

Marimuthu *et al*. (78) disclosed that, among different herbicidal treatments tested, the post-emergence application of a carefully optimized combination of fomesafen (220 g ha-1) + fluazifop-p-butyl (220 g ha-1) at 20 DAS provided superior weed control efficiency, achieving impressive values of 66.80% at 30 DAS and 68.53% at 45 DAS. This highly effective herbicide treatment also gave rise to a remarkably higher seed yield of 1088 kg ha-1, along with 8.1% increase in net income and 12.5% improvement in the benefit-cost ratio when compared to traditional hand weeding methods. These results indicated that this specific herbicide combination represents a cost-effective and labour-efficient strategy for maximizing blackgram productivity in modern agricultural systems.

However, research findings also indicated the potential for phytotoxicity associated with certain herbicide treatments. For example, Kalyani *et al*. (18) observed that flumioxazin-based weed control programs caused severe crop damage in grain legumes, with initial damage levels reaching 86% and 91% in some cases. The authors attributed this heightened level of crop damage to excessive rainfall occurring at the time of planting, which intensified the injury by allowing substantial pesticide seepage into the vulnerable seed zone. Interestingly, by mid-season, the level of crop injury had significantly reduced, dropping to below 10% in most cases. Similar patterns of initial crop damage followed by subsequent recovery were also observed with several sulfentrazone-based treatments, including fomesafen + S-metolachlor, as well as with both flumioxazin-containing treatments.

**Conclusion**

Herbicide-based weed management plays a major role in enhancing blackgram productivity by effectively controlling weed competition during critical growth stages. The amalgamation of different compatible herbicides, particularly premix formulations (having pre-and post-emergence activity or diverse mechanism of action), are future proof in achieving broad-spectrum weed control with minimal crop phytotoxicity. While herbicides provide a labour-efficient and cost-effective alternative to manual weeding, their repeated and unregulated use may lead to herbicide resistance, soil health deterioration, and residual toxicity concerns. Therefore, an integrated weed management approach that combines low dose high efficiency broad spectrum herbicide application together with cultural and mechanical methods is essential for sustainable weed management in blackgram.

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Option 1: I am hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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