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Research Article

Effect of Quizalofop-p-ethyl + Bentazone and Pendimethalin Herbicides on Weeds, Yield Components, and Yield of Mung Bean (*Vigna radiata* (L.) Wilczek) in Guragie Zone, South Central Ethiopia

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Weeds significantly hinder mung bean production in Ethiopia. A field experiment conducted during the 2022 cropping season in Guragie Zone investigated the impact of pre- and post-emergence herbicides on weed control and mung bean (*Vigna radiata* (L.)) yield. The experiment utilized a randomized complete block design with three replicates and four treatments. The study revealed that the interaction between location and weed control methods significantly influenced weed density, dry weight, and control efficiency. Additionally, location and weed control methods significantly affected various mung bean growth parameters, including days to flowering and maturity, plant height, pod and seed numbers per plant, and grain yield. Meskan Wordea produced significantly higher pods per plant (14.4) and seeds per pod (9.73). Meanwhile, the weed-free check yielded the maximum number of pods per plant (20.38) and seeds per pod (11.68). Conversely, the weedy check exhibited the lowest values (7.17 pods and 6.43 seeds per pod). The weed-free check also achieved the highest grain yield (1412.9 kg ha^{-1}), aboveground dry biomass (3309.2 kg ha^{-1}), and harvest index (42.94%). Conversely, the weedy check yielded the lowest values. Financial analysis revealed that the combined application of Quizalofop-p-ethyl + Bentazone herbicide in Ezeha location resulted in the highest net profit (33602.3 ETB ha^{-1}). Therefore, for optimal mung bean growth and yield in the study area, we recommend planting the Rasa variety with Quizalofop-p-ethyl + Bentazone herbicide in Ezeha location.

1. Introduction

Mung bean (*Vigna radiata* (L.) Wilczek), also known as green gram or golden gram, is a globally important pulse crop belonging to the Leguminosae family. Native to the Indian subcontinent, it is widely cultivated in warm and dry regions of Asia (India, China, Thailand, Philippines, Indonesia, Myanmar, Bangladesh, and Cambodia) and increasingly in Europe, America, and Africa, including Ethiopia [1, 2].

Mung bean's historical significance extends to cultivation in various African and Southern United States regions [2]. Khan et al. [3] highlight its importance as a pulse crop grown across tropical and subtropical regions worldwide. Mondal [4] emphasizes its critical role in providing protein in subtropical zones, serving as a valuable source of human food, animal feed, and green manure. Mung bean thrives in hot climates due to its rapid growth, low water requirements, and ability to enhance soil fertility through nitrogen fixation [5]. Herbicides play a vital role in improving crop productivity, particularly in situations where labor is scarce and expensive. They are also beneficial where labor is readily available but manual weeding risks damaging crops due to morphological similarities between crop and weed plants. Additionally, herbicides often offer a more cost-effective solution compared to manual weeding [6].

Despite its potential, mung bean productivity growth has been hampered by biotic and abiotic factors, with weeds identified as the primary culprit in reducing yield. Weeds significantly decrease production by competing with crops for essential resources like light, nutrients, and space [7]. Yadav et al. reported mung bean yield losses due to weed competition ranging from 27% to 100% in specific regions [8].

Several herbicides, including Quizalofop-p-ethyl, Bentazone, and Pendimethalin, target a variety of weeds commonly found in agricultural settings [1]. Quizalofop-p-ethyl selectively controls grassy weeds, while Bentazone effectively tackles broadleaf weeds. Pendimethalin provides pre-emergent weed control, preventing weed seed germination [1]. Their combined application offers broad-spectrum weed management in crops like mung bean. Recognizing this importance, research efforts in various countries have explored and advocated for different weed management options in mung bean production systems. However, weed control practices remain inadequate in Ethiopia, with many farmers relying on minimal or no weeding. Implementing advanced weed management strategies is crucial to ensure sustainable mung bean production, meeting both domestic and market demands.

Limited research has been conducted specifically for the environmental conditions prevalent in the Guragie Zone and surrounding regions. Therefore, this experiment aimed to evaluate the impact of Quizalofop-p-ethyl, Bentazone, and Pendimethalin on broad-leaved and grassy weeds, as well as their influence on the grain yield of mung bean (*Vigna radiata* (L.) Wilczek).

2. Materials and Methods

2.1. Description of Study Area. The experiment was conducted during the 2022 main cropping season at two locations within the Guragie Zone: Meskan and Cheha Districts. The mung bean variety Rasa (N-26), released by the Melkasa Agricultural Research Center in 2011 [2], was chosen for this experiment due to its desirable characteristics. This drought-resistant, high-yielding, and early maturing variety was well-suited for the research. Seeds were obtained from the Melkasa Agricultural Research Center and used as planting material. As an early maturing variety (maturing in 65–80 days), Rasa is adapted to low-to-mid altitudes (1000–1650 meters above sea level) and areas receiving rainfall between 350 and 750 mm [2]. According to the same source, the yield potential of Rasa ranges from 800 to 1500 kg ha^{-1} in research fields and 500–1000 kg ha^{-1} in farmers' fields.

The experiment consisted of four treatments:

(i) Stomp 500 EC (Pendimethalin) applied at a rate of 3.0 L ha^{-1} (liters per hectare)
(ii) Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) applied at a rate of 1.0 L ha^{-1} (Table 1)
(iii) Weed-free check (plot kept free of weeds manually)
(iv) Weedy check (plot left unweeded)

Table 1: Description of herbicides used in the experiment.

Trade name	Common name	Content of A.I
Q-zone 300 EC	Quizalofop-p-ethyl + Bentazone	30 g/L + 270 g/L
Stomp 500 EC	Pendimethalin	500 g/L

Source: Pharmachem Enterprise Importer.

These treatments were arranged in a randomized complete block design (RCBD) with three replicates. Land preparation was carried out in mid-October 2022 using oxen for plowing, a suitable method for this crop. Each experimental plot measured 10 meters by 10 meters (100 square meters). Pathways between replications and plots were 1.5 meters and 1.0 meter wide, respectively, to allow for easy movement during field operations and data collection. Mung bean seeds were planted on October 26th and 29th, 2022, for Meskan and Cheha Districts, respectively, with a spacing of 40 cm between rows and 10 cm within rows. A uniform amount of fertilizer (100 kg DAP; 18 kg N + 46 kg P2O5 ha^{-1}) was applied at the recommended rate during sowing for each plot. The pre-emergence herbicide, Stomp 500 EC, was applied to the soil as per the treatment plan after sowing but before the emergence of both the crop and weeds. The post-emergence herbicide, Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone), was applied later. A knapsack sprayer with a flat nozzle was used, applying a spray volume of 200 L ha^{-}1. Hand weeding was conducted in the plots assigned to the weed-free check treatment. To account for border effects, the outermost row on one side and the two outermost rows on the other side (40 cm in total) were excluded from data collection, along with the three plants (10 cm) from each end of the rows. This ensured a consistent net plot area. Harvesting occurred on January 26, 2023, when the pods and leaves had turned yellow. The harvested crop was sun-dried for three days before manual threshing and winnowing.

2.2. Data Measurements and Measurement Method

2.2.1. Weeds. Weed populations within the experimental field were assessed at three critical stages during the mung bean growing period: 20 days after emergence (DAE), 55 DAE, and approximately 15 days before harvest. At each sampling point, weed density was determined using a quadrat sampling method. A randomly placed 1.0 meter × 1.0 meter quadrat frame was thrown twice within each plot. All weeds observed within the quadrat were identified, classified (broadleaved, grass, or sedges), counted, and expressed as the number of weeds per square meter (m^{-2}). For aboveground weed dry biomass, weeds within the sample quadrat were carefully cut near the soil surface immediately after weed counts were completed. Weeds from each plot were separated by treatment into paper bags. The weed samples were sun-dried for three to four days and then oven-dried at 65°C until reaching a constant weight. Finally, their dry weight was measured and expressed in grams per square meter (g m^{-2}).

Weed Control Efficiency (WCE) is the magnitude of weed reduction due to weed control treatment and expressed in percentage. It was calculated with the help of the following:

$$\mathrm{WCE} = \frac{(\mathrm{WDC} - \mathrm{WDT})}{\mathrm{WDC}} \times 100, \tag{1}$$

where WCE = Weed Control Efficiency; WDC = Weed dry matter in weedy check; and WDT = weed dry matter in a particular treatment.

2.2.2. Crop. Days to physiological maturity: the number of days taken for 90% of plants in each plot to senesce (leaves and pods turning yellow) was recorded from emergence until physiological maturity. Plant height: plant height (cm) was measured at physiological maturity from the base to the apex of the main stem on ten randomly selected and tagged plants in each net plot area, using a ruler. Number of pods per plant: the total number of pods on ten plants in each plot was counted at harvest and expressed as the average number of pods per plant. Number of seeds per pod: the total number of seeds from the pods collected from the ten plants per plot was counted to determine the average number of seeds per pod. Hundred seed weight: one hundred seeds were randomly selected from the collected seeds, and their weight was measured at 10.5% moisture content to determine the hundred seed weight (g). Harvest index: to avoid potential leaf shedding (common in pulses), ten plants were harvested from each plot at physiological maturity. Their dried aboveground biomass (grain and straw) was recorded. Harvest index (%) was then calculated as the ratio of grain yield to the total aboveground dry biomass yield. Grain yield: grain yield (kg ha-1) was measured after threshing the sun-dried plants harvested from each net plot.

Data on weed community composition, weed density, weed dry biomass, crop phenology, plant growth parameters, yield components, and grain yield were subjected to analysis of variance (ANOVA) using GenStat 15.0 software [9]. Fisher's protected Least Significant Difference (LSD) test ($p \leq 0.05$) was employed to compare treatment means and identify statistically significant differences [10].

A mixed analysis of variance (ANOVA) was used because the F-test is sensitive to homogeneity of error variances between the two locations (Meskan and Ezeha). This approach accounts for potential differences in error variances while still allowing for the assessment of treatment effects and location effects.

3. Results and Discussion

3.1. Weed Parameters

3.1.1. Weed Community. The experimental area was infested with exclusive kinds of weed species consisting of broad leaves, grasses, and sedge weeds (Table 2). In our observation, the experimental field consists of twelve weed species that belong to seven weed families. Within the experimental area, broad-leaved weeds were dominated and infested, especially than grassy weeds and sedge weeds. The recorded broad-leaved weeds were 9 in quantity while grass weeds and sedge weeds recorded were 2 and 1 in number, respectively. According to our findings, the fundamental weed species competing vigorously with mung bean had been *Ageratum conyzoides* L., *Emilia sonchifolia* (L.) DC. Ex Wight, *and Malvastrum coromandelianum* (L.) Garcke.

3.1.2. Weed Density. The analysis of variance revealed conflicting results regarding the interaction effect of location and weed control methods on weed density at harvest. While the initial finding suggested no statistically significant effect ($p > 0.05$) (Table 3), a further analysis showed a significant interaction effect ($p < 0.05$).

The highest weed density at harvest ($251.08\,\mathrm{m}^{-2}$) was observed in the unweeded plot at the Meskan district (Table 3). Conversely, the lowest weed density ($53.41\,\mathrm{m}^{-2}$) was recorded in the Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) treatment applied at $1.0\,\mathrm{L\ ha}^{-1}$ in the same Meskan district.

This finding aligns with the observations of Islam et al. [11], who reported the highest weed density in mung bean under the weedy check treatment and the lowest in weed-free plots. Similarly, Getachew and Mekdes [12] noted that uncontrolled weed infestation led to significantly higher weed density in cowpeas. These results suggest that weed management practices, particularly herbicide application, can effectively reduce weed populations by causing weed mortality.

3.1.3. Weed Dry Weight ($g{\cdot}m^{-2}$). The analysis of variance (ANOVA) revealed a significant interaction effect ($p < 0.05$) between location and weed control methods on weed dry weight at harvest (Table 4). The highest weed dry weight ($281.3\ \mathrm{g\ m}^{-2}$) was recorded in the weedy check treatment at the Meskan location. This value was not statistically different from the weedy check treatment in the Ezha District ($259.24\,\mathrm{g\ m}^{-2}$) (Table 4).

This finding suggests a potential link between higher weed density and increased weed dry weight. Improved plant growth within the weedy check plots may have also contributed to the overall higher dry weight of weeds. These results align with observations by Chaudhari et al. [13], who reported that the highest weed dry weight in most treatments was observed in the weedy check plot. Similarly, Nano and Sharma [14] attributed higher weed dry weight in the weedy check to increased weed density, allowing weeds to compete more vigorously for resources like nutrients, space, light, water, and carbon dioxide, leading to greater biomass production.

Further supporting this trend, Chaudhari et al. [13] also noted that the lowest weed dry weight across various weed management treatments occurred under weed-free conditions. This could be attributed to the effective weed control achieved through hand hoeing at the early crop growth stage, resulting in lower weed counts and ultimately reducing the overall weed dry weight at harvest.

Table 2: Weed flora recorded in the experimental field of mung bean in 2022 main cropping season.

Weed species	Family	Life form (category)
Ageratum conyzoides L.	Asteraceae	Annual (broad leaf)
Cassia pumila L.	Fabaceae	Annual (broad leaf)
Chromolaena odorata L.	Asteraceae	Perennial (broad leaf)
Chrozophora rottleri L.	Euphorbiaceae	Annual (broad leaf)
Commelina diffusa L.	Commelinaceae	Annual (broad leaf)
Commelina forskaolii Vahl.	Commelinaceae	Annual (broad leaf)
Cynodon dactylon (L.) Pers.	Poaceae	Perennial (grass)
Cyperus brevifolius Rottb.	Cyperaceae	Annual (sedge)
Emilia sonchifolia L.	Asteraceae	Annual (broad leaf)
Euphorbia thymifolia L.	Euphorbiaceae	Annual (broad leaf)
Malvastrum coromandelianum L.	Malvaceae	Annual (broad leaf)
Setaria glauca L.	Poaceae	Annual (grass)

Table 3: Interaction effect of location and weeding methods on weed density (m^{-2}) at harvest of mung bean in 2022 main cropping season.

Weeding methods	Location	
	Meskan	Cheha
Stomp 500 EC at 3.0 $L{\cdot}ha^{-1}$	80.17^{c}	80.25^{c}
Q-zone 300 EC at 1 $L{\cdot}ha^{-1}$	53.41^{d}	67.05^{d}
Weed-free check	0.00^{e}	0^{e}
Weedy check	251.08^{a}	208.2^{b}
LSD (0.05) LXT	10.74	
CV (%)	4.69	

LSD = least significant difference; CV = coefficient of variation; means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

3.1.4. Weed Control Efficiency (%). The analysis of variance (ANOVA) revealed a significant interaction effect ($p < 0.05$) between location and weed control methods on weed control efficiency (Table 5). The highest weed control efficiency (100%) was achieved under the interaction of the weed-free check treatment at all locations, followed by the interaction of Q-zone 300 EC applied at 1.0 L ha^{-1} with a specific location (Table 5).

Similar to the observations on weed density and dry weight, the highest standalone weed control efficiency (86.33%) was recorded in plots treated with Q-zone 300 EC at 1.0 L ha^{-1}. This was followed by applications of Stomp 500 EC at 3.0 L ha^{-1} (65.92%) when comparing herbicide-treated plots (Table 5). The weedy check treatment, with no weed control measures, displayed the lowest weed control efficiency (0.00%).

These results suggest that herbicide application plays a more significant role in reducing weed density and dry weight compared to the combined approach of herbicide application and hand weeding/hoeing methods (employed in the weed-free check). This finding aligns with Getachew and Mekdes [12], who reported that herbicide use combined with hand weeding resulted in lower weed infestation in cowpea compared to unweeded plots. Similarly, Fufa and Gebremariam [7] found the highest weed control efficiency (69.94%) achieved through the pre-emergence application of s-metolachlor 0.96 kg ha^{-1} combined with hand weeding at 45 days after sowing in haricot bean.

3.2. Crop Parameters

3.2.1. Crop Phenology and Growth

(1) Days to 50% Flowering. The analysis of variance (ANOVA) revealed a highly significant ($p < 0.01$) main effect of weed control methods on days to 50% plant flowering (Table 5). However, there was no significant interaction effect between location and weed control methods on this parameter (Table 5).

The weedy check treatment, with no weed control, exhibited the longest period (55 days) to reach 50% flowering, indicating delayed flowering. This can be attributed to the high weed infestation and density in unweeded plots during the mung bean growth season. The dense weed canopy likely shaded the mung bean plants, reducing sunlight interception and extending the vegetative growth stage, ultimately delaying flowering.

This finding aligns with observations by Sunday and Udensi [15] who reported that cowpea plants grown in unweeded plots took the longest time to reach 50% flowering. Conversely, the shortest period (52.11 days) to reach 50% flowering was observed in plots treated with the post-emergence herbicide Q-zone 300 EC (Quizalofop-p-ethyl- + Bentazone) at 1.0 L ha-1, followed by the pre-emergence application of Stomp 500 EC at 3.0 L ha-1 (54.11 days) (Table 5). The earlier flowering in these treated plots is likely due to reduced weed interference. By controlling weeds, these herbicides minimized competition for resources like light, leading to more efficient light penetration and interception. This, in turn, could have accelerated vegetative growth and resulted in earlier flowering. Supporting this notion, Nano and Sharma [14] also reported earlier days to 50% flowering in faba bean under weed-free conditions compared to other treatments.

(2) Days to 90% Physiological Maturity. The analysis of variance (ANOVA) revealed a significant main effect ($p < 0.01$) of weed control methods on days to reach 90% physiological maturity (Table 6). However, the interaction effect between location and weed control method was not statistically significant (Table 6). The weedy check treatment, with no weed control, exhibited the longest period (77.78 days) to reach 90% physiological maturity, indicating

Table 4: Interaction effect of location and weeding methods on weed dry weight (g m^{-2}) at harvest of mung bean in 2022 main cropping season.

Weeding methods	Location	
	Meskan	Cheha
Stomp 500 EC at 3.0 L·ha^{-1}	111.82^c	107.87^c
Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L·ha^{-1}	40.86^d	60.32^e
Weed-free check	0.0^f	0.0^f
Weedy check	281.38^a	259.24^b
LSD (0.05) LXT	17.34	
CV (%)	6.67	

LSD = least significant difference; CV = coefficient of variation; means in the same columns and rows followed by the same letters are not significantly different at 5% level of significance.

Table 5: Main effects of location and weeding methods on weed control efficiency (%) at harvest of mung bean in 2022 main cropping season.

Treatments	Weed control efficiency (%)
Location	
Meskan	46.59
Ezeha	45.75
LSD (0.05)	NS
Weeding methods	
Stomp 500 EC at 3.0 L·ha^{-1}	65.92^c
Q-zone 300 EC at 1 L·ha^{-1}	86.33^b
Weed-free check	100^a
Weedy check	0.00^f
LSD (0.05)	7.67
CV (%)	12.98

Means in the table followed by the same letter(s) are not significantly different to each other at 5% level of significance; NS = nonsignificant; LSD (0.05) = least significant difference at 5%; CV (%) = coefficient of variation.

delayed maturity (Table 6). This delay could be attributed to the shading effect of a dense weed canopy in unweeded plots. Reduced sunlight interception due to shading likely extended the vegetative growth stage of mung bean plants, leading to delayed physiological maturity. Conversely, the shortest period (74.56 days) to reach 90% physiological maturity was observed in plots treated with the post-emergence herbicide Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1} (Table 6). Earlier maturity in this treatment might be due to increased exposure to sunlight resulting from reduced weed competition. This improved light availability could have minimized excessive vegetative growth and accelerated the onset of physiological maturity. These findings support the observations of Sunday and Udensi [15] who reported that cowpea plants grown in unweeded plots took longer to reach both 50% flowering and 90% physiological maturity.

(3) Plant Height (cm). The analysis of variance (ANOVA) revealed a significant main effect ($p < 0.01$) of weed control methods on plant height but no significant effect of location or its interaction with weed control methods (Table 6). The tallest plants (35.53 cm) were observed in the weedy check treatment (unweeded plots), while the shortest plants (29.10 cm) were recorded in plots treated with the post-emergence herbicide Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1} (Table 6). The application of Stomp 500 EC at 3.0 L ha^{-1} resulted in statistically similar plant heights (30.47 cm) compared to Q-zone 300 EC.

The increased plant height in the weedy check treatment may be attributed to weed interference and competition for sunlight and nutrients. With limited resources available due to high weed density, mung bean plants may have responded by increasing their height in an attempt to capture more sunlight. These findings align with observations by Getachew and Mekdes [12] who reported taller cowpea plants in the presence of severe weed interference due to competition for light between weeds and the crop. Similarly, Chaudhari et al. [13] found that weed-free common bean plants were significantly shorter (79.5 cm) compared to plants in weedy check plots (95.5 cm).

3.2.2. Yield Components and Yield of Mung Bean

(1) Number of Pods per Plant. The analysis of variance (ANOVA) revealed a significant main effect ($p < 0.05$) of both weed control methods and location on the number of pods per plant in mung bean (Table 7). However, the interaction between these factors did not show a statistically significant effect ($p > 0.05$) (Table 7).

The highest number of pods per plant (14.4) was recorded in the weed-free check treatment at the Meskan location, with this value being statistically similar to the number of pods observed in the weed-free check treatment at the Ezha District (13.86) (Table 7). Notably, the Meskan location with the weed-free check treatment displayed the absolute highest number of pods per plant (17.27). This was followed by plots treated with the post-emergence herbicide Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1}.

The increased pod production in these treatments might be attributed to reduced weed competition. Both weed-free and herbicide-treated plots had significantly lower weed dry weight compared to other treatments. This likely resulted in a higher net assimilation rate, allowing the plants to conserve more resources for vegetative growth. Developing more and healthier leaves under low weed infestation can enhance the crop's photosynthetic efficiency, ultimately supporting the formation of a greater number of pods. These findings align

Table 6: Main effects of location and weeding methods on days to 50% plant flowering, days to 90% maturity, and plant height of mung bean in 2022 main cropping season.

Treatment	Days to 50% flowering	Days to 90% physiological maturity	Plant height (cm)
Location			
Meskan	53.22	75.72	31.71
Ezeha	53.00	75.89	31.33
LSD (0.05)	NS	NS	NS
Weeding methods			
Stomp 500 EC at 3.0 L·ha^{-1}	54.11^{ab}	76.22^{ab}	30.47^{bc}
Q-zone 300 EC at 1 L·ha^{-1}	52.11^{cd}	74.56^{bc}	29.1^{c}
Weed-free check	51.22^{d}	73.89^{c}	29.06^{c}
Weedy check	55^{a}	77.78^{a}	35.53^{a}
LSD (0.05)	1.17	1.86	3.55
CV (%)	2.32	2.56	11.76

Means in the table followed by the same letter(s) are not significantly different from each other at 5% level of significance; LSD (0.05) = least significant difference at 5%; CV (%) = coefficient of variation; cm = centimeter.

Table 7: The main effect of plant spacing and weeding methods of mung bean on number of pods per plant and number of seeds per pod in 2022 cropping season.

Treatment	Number of pods per plant	Number of seeds per pod
Location		
Meskan	14.4^{a}	9.73^{a}
Ezeha	13.86^{ab}	9.22^{ab}
LSD (0.05)	1.14	0.77
Weeding methods		
Stomp 500 EC at 3.0 L·ha^{-1}	11.04^{d}	8.22^{d}
Q-zone 300 EC at 1 L·ha^{-1}	17.27^{b}	10.21^{b}
Weed-free check	20.38^{a}	11.68^{a}
Weedy check	7.17^{e}	6.43^{e}
LSD (0.05)	1.61	1.09
CV (%)	12.36	12.4

WAE = weeks after crop emergence; LSD = least significant difference; CV = coefficient of variation; means followed by the same letters within each column are not significantly different at 5% level of significance.

with observations by Getachew and Mekdes [12] who reported that applying 1.0 kg ha^{-1} of pendimethalin or s-metolachlor, each combined with one hand weeding, resulted in a significant increase in the number of pods per plant in cowpea.

(2) Number of Seeds per Pod. The analysis of variance (ANOVA) revealed significant main effects ($p < 0.05$) of both location and weed control methods on the number of seeds per pod in mung bean (Table 7). However, the interaction between these factors did not show a statistically significant effect ($p > 0.05$) (Table 7).

Among herbicide-treated plots, the highest number of seeds per pod (10.21) was observed in plots treated with Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1}, followed by those treated with Stomp 500 EC at 3.0 L ha^{-1} (8.22) (Table 7). This increase in seeds per pod under reduced weed competition might be attributed to enhanced photosynthetic efficiency. With less competition for resources, plants likely developed more vigorous leaves, leading to better light capture and ultimately supporting the development of a greater number of seeds per pod.

Conversely, the lowest number of seeds per pod was observed in the weedy check treatment. This is likely due to significant weed competition. Intense competition with weeds for nutrients likely limited nutrient availability for seed development in mung bean plants. These findings align with observations by Nano and Sharma [14] who reported that poor seed filling in weedy check plots was likely caused by excessive weed competition with the crop. Similarly, Sunday and Udensi [15] reported the lowest number of seeds per pod in cowpeas grown under weedy check conditions.

(3) Hundred Seed Weight. The analysis of variance (ANOVA) revealed significant main effects ($p < 0.01$) of both location and weed control methods on hundred seed weight, but their interaction did not show a statistically significant effect (Table 8). Plants grown under weed-free conditions likely utilized available resources more efficiently, leading to increased hundred seed weight. Additionally, the larger and more vigorous leaves under weed-free conditions may have facilitated better assimilate transport for storage within the seeds, consequently increasing hundred seed weight (Table 8).

Table 8: The main effect of plant spacing and weeding method of mung bean on aboveground dry biomass (kg·ha^{-1}), grain yield (kg·ha^{-1}), and harvest index (%) in 2022 main cropping season.

Treatment	Aboveground dry biomass (kg·ha^{-1})	Grain yield (kg·ha^{-1})	Harvest index (%)
Location			
Meskan	2955.6	1040.83^{b}	34.18
Ezeha	3040	1096.89^{ab}	35.24
LSD (0.05)	NS	67.33	NS
Weeding method			
Stomp 500 EC at 3.0 L·ha^{-1}	2999.9^{b}	936.88^{d}	31.27^{c}
Q-zone 300 EC at 1 L ha^{-1}	3280.1^{ab}	1358.55^{a}	41.71^{ab}
Weed-free check	3309.2^{a}	1412.9^{a}	42.94^{a}
Weedy check	2118.7^{c}	493.34^{e}	22.53^{d}
LSD (0.05)	289.44	95.23	3.94
CV (%)	10.01	9.09	11.62

WAE = weeks after crop emergence; NS = nonsignificant; LSD = least significant difference; CV = coefficient of variation; means followed by the same letters within each column are not significantly different at 5% level of significance.

The lowest hundred seed weight (28.44 g) was observed in the weedy check treatment. This finding aligns with observations by Mohammadi et al. [16] who reported that prolonged weed interference in chickpeas is associated with reduced dry matter translocation to seeds, resulting in yield reduction, particularly in hundred seed weight per plant. Similarly, Sana et al. [17] reported the lowest hundred seed weights in untreated chickpea plots. These results are consistent with the findings of Yadav et al. and Mohammadi et al. [8, 18], who likely reported similar observations on the negative impact of weeds on seed weight.

(4) Aboveground Dry Biomass ($kg \cdot ha^{-1}$). The analysis of variance (ANOVA) revealed significant main effects ($p < 0.05$) of both location and weed control methods on aboveground dry biomass yield of mung bean, but the interaction between location and methods was not statistically significant (Table 9).

The highest aboveground dry biomass (3309.2 kg ha^{-1}) was recorded in the weed-free check treatment, followed by plots treated with Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1} (3280.1 kg ha^{-1}) (Table 9). The increase in aboveground dry biomass in these treatments might be attributed to more efficient utilization of growth resources by the crop, leading to a higher final crop stand. This aligns with the findings of Mizan et al. [19] who suggested that a longer weed-free period significantly influences the crop's dry matter weight.

It is important to note that high overall dry biomass production may not necessarily translate to high grain yield, as the grain weight represents only a portion of the plant. Additionally, aboveground dry biomass exhibited a significant variation across locations, with considerably higher biomass recorded at Ezha compared to Meskan.

(5) Grain Yield (kg ha^{-1}). The analysis of variance (ANOVA) revealed significant main effects ($p < 0.01$) of both location and weed control methods on grain yield, while the interaction between these factors was not statistically significant (Table 8). Grain yield was higher at Ezha (1096.89 kg ha^{-1}) compared to Meskan. Among different weed control methods, the application of Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1} resulted in a significantly higher grain yield (1358.55 kg ha^{-1}) compared to other treatments (Table 8).

Table 9: The main effect of plant spacing and weeding method of mung bean on thousand grain weight (g) and yield loss (%) in 2022 main cropping season.

Treatment	Hundred seed weight (g)
Spacing	
Meskan	34.06^{a}
Ezeha	32.17^{ab}
LSD (0.05)	2.18
Weeding method	
Stomp 500 EC at 3.0 L·ha^{-1}	29.78^{cd}
Q-zone 300 EC at 1 L·ha^{-1}	34.89^{ab}
Weed-free check	36.22^{a}
Weedy check	28.44^{d}
LSD (0.05)	3.08
CV (%)	10.01

WAE = weeks after crop emergence; NS = nonsignificant; LSD = least significant difference; CV = coefficient of variation; means followed by the same letters within each column are not significantly different at 5% level of significance.

These findings align with the observations of Mosisa et al. [20] who reported that herbicide application led to the highest grain yield in haricot beans. The increased yield in the Q-zone 300 EC treatment was likely due to a significant reduction in weed competition for essential resources like nutrients, sunlight, and water. This ultimately led to a greater number of pods per plant and higher hundred seed weight (Tables 7 and 9).

Reduced weed competition due to effective weed control in various treatments resulted in improved crop growth, development, and photosynthetic activity. Consequently, the higher yield in these treatments can be attributed to enhanced weed control, allowing the crop to better utilize resources, resulting in increased grain yield. This is consistent with the findings of Rao et al. [21] who also reported higher yields due to effective early stage weed control, which suppressed weed growth and accelerated the development and yield of black gram. Similarly, integrating hand weeding

Table 10: Effect of location and weeding method of mung bean on partial budget analysis in 2022 cropping season.

Location	Weeding methods	Average yield ($kg \cdot ha^{-1}$)	Adjusted yield ($kg \cdot ha^{-1}$)	Gross benefit ($ETB \cdot ha^{-1}$)	Variable total cost ($ETB \cdot ha^{-1}$)	Net benefit ($ETB \cdot ha^{-1}$)
Meskan	Stomp 500 EC at 3.0 $L \cdot ha^{-1}$	876.00	788.4	23652	1430	22222
	Q-zone 300 EC at 1 $L \cdot ha^{-1}$	1324.26	1191.83	35754.9	2860	32894.9
	Weed-free check	1384.81	1246.33	37389.9	10010	27379.9
	Weedy check	422.41	380.169	11405.07	0	11405.07
Ezeha	Stomp 500 EC at 3.0 $L \cdot ha^{-1}$	1125.00	1012.5	30375	1430	28945
	Q-zone 300 EC at 1 $L \cdot ha^{-1}$	1350.46	1215.41	36462.3	2860	33602.3
	Weed-free check	1424.63	1282.17	38465.1	10010	28455.1
	Weedy check	496.87	447.183	13415.49	0	13415.49

Currency: all costs are represented in Ethiopian Birr (ETB). Stomp herbicide: the cost of stomp herbicide for treating one plot of land is 16.00 birr. Qzone herbicide: the cost of qzone herbicide application per plot is 75 birr. Herbicide application service: applying herbicide across one hectare of land incurs a service cost of 300 birr. Mung bean selling price: locally, mung bean grain sells for 30 birr per kilogram.

at 5 WAE provided prolonged and efficient weed control, further reducing competition and benefiting yield.

Effective weed control likely increased nutrient availability for the crop, leading to a higher grain yield. In contrast, the weedy check treatment exhibited the lowest grain yield (493.34 kg ha^{-1}). This is likely due to intense weed competition for sunlight, moisture, and nutrients, ultimately reducing grain yield. This aligns with the observations of Prakash et al. [22] who reported that season-long weed competition reduced grain yield in peas.

Anwar et al. [23] further support these findings, suggesting that herbicides provided excellent weed control and significantly increased yield compared to weedy checks. Studies have shown that weeds can severely affect mung bean performance, with yield losses reaching up to 65.36% due to weed interference [24]. In field pea, Prakash et al. [22] found that long-season weed competition decreased yield by 44.6% to 55.6%. Similarly, weedy check plots resulted in the lowest yield as reported by various studies on chickpeas [8, 18, 25, 26]. Blackshaw et al. [27] even reported weed-induced yield losses exceeding 75% in cowpea crops. However, it is important to note that the extent of yield loss due to weeds can vary depending on environmental conditions, soil types, crop varieties, and the severity of weed interference at specific locations.

(6) Harvest Index (%). The analysis of variance (ANOVA) revealed a significant main effect of weed control methods on harvest index (Table 9). However, the location itself and the interaction between location and methods did not show statistically significant effects. Harvest index was significantly higher at Meskan than at Ezeha (Table 9). This suggests substantial variation in harvest index among the different weed control methods evaluated at each location.

The application of Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1} resulted in the highest harvest index (34.89%), while the weedy check treatment exhibited the lowest (28.44%) (Table 9). Increased weed interference likely led to higher shoot weight, potentially extending the vegetative growth period and lowering the root-to-shoot ratio. This, in turn, could explain the decreased harvest index in weedy plots.

Soltani et al. [28] support this notion, suggesting that harvest index in mung bean increases with greater seed production. Our findings are further corroborated by Akter et al. [29] who reported that herbicide application on mung bean increased the harvest index.

3.3. Partial Budget Analysis.

The results of the partial budget analysis, along with the data used for the calculations, are presented in Table 10. This analysis followed the methodology outlined by CIMMYT [30], focusing on variable costs that fluctuate with each treatment. These variable costs included the price of herbicides and their application fees. For simplicity, the analysis incorporated harvesting, threshing, winnowing, packing, and transportation costs into the variable input cost instead of accounting for them as separate field operation costs.

Yield variations observed across different treatments at each location translated into differences in gross revenue. The partial budget analysis revealed that Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) at 1.0 L ha^{-1} produced the highest gross benefit (36462.3 ETB ha^{-1}), followed by Stomp 500 EC at 3.0 L ha^{-1} (30375 ETB ha^{-1}). The lowest gross benefit was recorded in the weedy check plots at the Ezeha location.

4. Conclusion

This study identified the application of 1 L ha^{-1} Q-zone 300 EC (Quizalofop-p-ethyl + Bentazone) diluted with 200 L of water as the most effective treatment for enhancing mung bean (*Vigna radiata* (L.) Wilczek) yield in both studied locations with similar agroecology. This herbicide treatment provided better control of both grassy and broadleaf weeds compared to the alternative option of 3.0 L ha^{-1} Stomp 500 EC.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Getachew Mekonnen served as the supervisor of the research study. Worku Mengesha and Girma Wolde conducted the research study.

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