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Effect of different post emergent herbicides on bio-efficacy, yield and economics of grain amaranth (*Amaranthus hypochondriacus* L.)

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Abstract
The field experiment was conducted at M block, field unit of AICRN on Potential Crops, University of Agricultural Sciences, Bengaluru to find out suitable post emergent herbicides for grain amaranth The experiment was laid out in a randomized complete block design (RCBD) with eight six post emergence herbicides along with hand weeding, weed free and weedy check treatments which were replicated thrice. The data indicated that at 30 and 45 DAS, early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} had significantly minimized weed density of sedges and grasses (1.60 and 1.82 m^{-2} and 1.22 and 2.81 m^{-2} at 30 and 45 DAS, respectively) and were on par with each other. However, lower weed density of broad leaved weeds (2.23 m^{-2}) were recorded with application of Clomazone 20% EC @ 750 g a.i ha^{-1}. Similarly, early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} was recorded lower weed dry weight of sedges and grasses (1.87, 2.51 and 1.81, 4.09 g m^{-2}, at 30 and 45 DAS, respectively) which was on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1}. Significantly higher weed control efficiency was witnessed with Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} (72.85% and 76.55% at 30 and 45 DAS, respectively) and found on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1} (68.70% and 74.07% at 30 and 45 DAS respectively) as compare to other treatments. Comparatively lower weed index (7.97%) was reported with Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} which was on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1} with 10.52%. Significantly higher grain yield was recorded with weed free check (2162 kg ha^{-1}) which was on par with herbicide treatments of early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} (1896 and 1805 kg ha^{-1}, respectively) and weedy check recorded significantly lower grain yield (1005 kg ha^{-1}) compared to all other treatments. However, higher gross returns, net returns and B:C were realized with early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} (Rs. 94800 ha^{-1}, Rs.68179 ha^{-1} and 2.56, respectively) followed by Propaquizafop 10% EC @ 12 g a.i ha^{-1} (Rs. 90250 ha^{-1}, Rs.63525 ha^{-1} and 2.38, respectively) and lower gross returns (Rs. 50250 ha^{-1}, Rs.25731 ha^{-1} and 1.05, respectively) were obtained in weedy check as compared to all other treatments.

Keywords: Grain amaranth, herbicides, bio-efficacy, yield, economics

Introduction
Grain amaranth (*Amaranthus* spp.) is a nutri-rich potential crop with C_4 pathway, quick growing, broad leaved and multipurpose crop which can be grown for grain, leafy vegetable, ornamental and forage purpose. It is a warm season crop belongs to Amaranthaceae family and characterized as a plastic plant due to its high adaptability to drought, heat stress, high soil acidity and salinity. It is known as "pseudo cereal" despite of producing significant amount of edible grain mainly to differentiate it from other cereal grain producing crops. It was originated from Central America and South America and comprise of 70 species (in the form of cosmopolitan weed or cultivated plant) which are widely spread in all tropical and subtropical regions of the world.

Presently, it is mainly cultivated and consumed in India, Nepal, China, Indonesia, Malaysia; whole of Central America, Mexico, Southern and Eastern Africa. In India, grain amaranth is mostly cultivated in Himalayan region at higher and lower hilly regions as a pure crop with some mixed cropping pattern too. This crop especially grown in few parts of Gujarat, Maharashtra and in various parts of Uttarakhand. In Gujarat, the Banaskantha district have approximately an area of 10,000 ha where this future potential crop replaced wheat and potato due to increasing problem of water scarcity. In Karnataka, grain amaranth is being grown by tribal communities in BR hills (Biligiri Rangana) of Chamarajnagara district. The statistical data on area and production in India is lacking. However, it is estimated to be grown in an area of about 40-50 thousand hectare (Raiger *et al.*, 2009) [20].

Its grain has higher protein (14%) with higher lysine and a good balance of other essential amino acids. Being an excellent source of iron and carotene, it can help in reducing iron and vitamin A deficiency especially among rural populations. The presence of higher amount of folic acid can help in increasing the blood hemoglobin (Gunjal, 2011) [7]. This can be consumed in various parts of the world due to its potential as a source of dietary rich protein (16.7%) with good amounts of lysine (0.5%) a limiting amino acid in cereals and methionine (0.5%) limiting in pulses and therefore is used largely for feeding children and adults to alleviate malnutrition (Mburu *et al.*, 2011) [17]. It can be utilized to manufacture products such as baby cereal foods, candies, snacks, protein drinks and hypoallergenic foods. Thus, value-addition can make this crop more attractive. Maurya *et al.* (2018) [16] reported that grain amaranth consists of 6 to 10 per cent of oil which is higher than most of other cereals and the lipid fraction is unique due to such high biologically active compounds such as squalene (8%), tocopherols (2%), phospholipids (10%) and phytosterols (2%).

Grain amaranth is very susceptible to weeds during its early growth period and it grows slowly after germination for the first few weeks and hence it is very susceptible to weed competition. Weeds are very high competitors to crop plants due to their analogous nature to growth resources of crop *viz.*, light, moisture, nutrients, space and carbon dioxide which not only diminish the yield, grain quality and impede harvest operations and surges the cost of production. The degree of damage by weeds relies upon the weed type, species density, period and extent of crop weed competition, soil type, soil moisture and soil fertility conditions.

Grain amaranth which is a broadleaved crop itself is a weed when it is with another crop. Hence, managing other weeds like sedges and grasses are the key concern. Grassy weeds are common in grain amaranth as compared to other group of weeds in majority of soils in *Alfisols*. Although it is obvious that effective weed control is important to ensure maximum yield, research on weed management in grain amaranth is very scanty in India. No herbicides are yet standardized to control weeds in grain amaranth. weed control is presently done by inter row cultivation but the shortage of labour is a setback. Suitable and economically feasible weed management practices for productive and effective suppression of weeds in grain amaranth is need of the hour. In this context, the current investigation was carried out to ascertain the effect of different post emergent herbicides on growth and yield of grain amaranth.

Materials and Methods

The field experiment was conducted at M block, field unit of AICRN on Potential Crops, University of Agricultural Sciences, Bengaluru which was located in Eastern Dry Zone (Zone V) of Karnataka at 12° 58' N latitude, 77° 35' E longitude with an altitude of 930 meters above mean sea level (MSL). The soil is red sandy loam in texture with slightly acidic in reaction (pH 6.25), normal electrical conductivity (0.24 dS m^{-1}), low in organic carbon (0.35%) and medium in available N, P_2O_5 and K_2O (252.7, 23.5 and 268.4 kg ha^{-1}, respectively). The experiment was laid out in a randomized complete block design (RCBD) with eight treatments which were replicated thrice. The stubbles and weeds were removed from the experimental area and the soil was brought to fine tilth. Before sowing, the plots were laid out (4.5 m × 3.0 m) as per the plan and bunds were formed around each plot. Sowing was done manually by opening shallow furrows with a row spacing of 45 cm. Recommended dose of FYM @ 7.5 t ha^{-1} was applied three weeks before sowing. The recommended fertilizer (60:40:40 NPK kg ha^{-1}) was applied as per the treatment plan in the form of urea, di ammonium phosphate (DAP) and muriate of potash (MOP), respectively. Half of the nitrogen and full amount of phosphorus and potash were applied as basal dose and remaining half of the nitrogen was applied at 30 DAS during intercultivation. Early post emergent herbicide application was done on 20 DAS as per the treatments. The required amount of herbicides for the experimentation was calculated by using the formula mentioned below.

$$F = \frac{R \times 100}{\text{Purity (\%)}} \times \frac{A}{10{,}000}$$

Where,
F = Formulated product required in kg or L ha^{-1}
R = a.i kg ha^{-1} to be sprayed (recommended rate)
A = Area to be sprayed m^2

Thus, calculated amount of herbicide was sprayed to each treatment using knapsack sprayer with a spray volume of 500 litre ha^{-1} for post-emergence herbicides. No insect pests were observed during the crop growth period. With regard to diseases, few plants were attacked with phyllody so they were uprooted and discarded carefully away from field. As the crop was raised during rainy season, the crop was given need based irrigation to avoid moisture stress during non-rainy days based on visual wilting symptoms**.** Species wise weed counts and weed dry weight (number m^{-2}) were recorded at 15, 30 and 45 DAS in two spots per plot. These weeds were categorized as sedge, grasses and broad leaf weeds and expressed as number m^{-2} and averaged over two random spots per plot.

Weed control efficiency denotes the magnitude of weed reduction due to the weed control treatment. The weed control efficiency was worked out based on the data from weed dry weight in the field and the formula used as suggested by Mani.

$$\text{WCE (\%)} = \frac{(X-Y)}{X} \times 100$$

Where,
WCE = Weed control efficiency expressed in percentage.
X = Total weed dry weight in weedy check.
Y = Total weed dry weight in the treated plot.

$$\text{WCE (\%)} = \frac{(X-Y)}{X} \times 100$$

Weed index is defined as the reduction in yield due to presence of weeds in comparison to weed free check. Weed index was calculated by using the formula as given by Gill and Kumar (1969) [5].

Where, WI = Weed index expressed in percentage. X = Yield of weed free check.

Y = Yield from treatment for which weed index is to be worked out

Five randomly selected plants were tagged and used for making observations on various growth and yield parameters in the net plot area on grain amaranth at harvest. As the data on weed density (no. m^{-2}) and weed dry weight (g m^{-2}) were not normally distributed, the data is transformed by using square root (x+1) transformation as given by Gomez and Gomez (1984) [6]. Later transformed data is analyzed statistically. All the experimental data recorded on yield and weed parameters were subjected to Fisher's method of "Analysis of Variance" (ANOVA) as outlined by Panse and Sukhatme (1954) [19]. Wherever F- test was significant, for comparison between the treatment means, an appropriate value of critical difference (CD) was worked out. All the data is analyzed and the results are presented and discussed at a probability level of 5%.

Results and Discussion

Influence of weed management practices on weed growth and weed density

Major weed flora observed in the experimental plots were *Cyperus rotundus* among sedges and *Cynodon dactylon, Echinochloa colonum, Eleusine indica and Panicum maximum* among grasses. Whereas, the major broad leaved weeds were *Ageratum conyzoides, Alternanthera spinosa, Amaranthus viridis,* and *Borreria aticularis*. While, the minor weeds observed were *Digitaria marginata, Commelina benghalensis, Legascea mollis* and *Chenopodium album.* Similar results were observed by Shukla *et al.* (2014) [23] at Uttarakhand hills in grain amaranth and Nagender (2014) in green gram. In the experimental field, grasses were dominant followed by broad leaved weeds and sedges based on the weed number in weedy check plots.

The weed density data reflects the efficiency of different weed management practices employed. The weed density of sedges, grasses and broad leaf weeds varied significantly at different growth stages of grain amaranth. At 15 DAS, all the treatments had non-significant differences in weed density of sedges, grasses and broad leaved weeds and it ranged from 8.52 to 10.75 m^{-2} as imposition of treatments was done after 15 DAS.

Whereas, at 30 and 45 DAS, early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} (1.60 and 1.82 m^{-2}, respectively) had significantly minimized weed density of sedges and grasses (1.60 and 1.82 m^{-2} and 1.22 and 2.81 m^{-2} at 30 and 45 DAS, respectively) and were on par with each other. Similarly, lower weed density of broad leaved weeds (2.23 m^{-2}) were recorded with application of Clomazone 20% EC @ 750 g a.i ha^{-1}. However, maximum weed density of grasses, sedges and broad leaf weeds (2.73, 4.50 and 4.70 m^{-2}, respectively) were relatively recorded lower with weedy check. The total density was significantly lower with early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} which was on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1} (3.43, 9.07 m^{-2} and 3.80 m^{-2}, 9.37 m^{-2}, at 30 and 45 DAS, respectively) and reported higher total weed density (7.04 m^{-2} and 11.93 m^{-2}, at 30 and 45 DAS, respectively) in weedy check. This might be due to effectiveness of the herbicide in controlling grassy weeds which were actually reported to be higher in number than sedges and broad leaf weeds in experimental field during crop critical period of 15 to 30 DAS. Weed leaves turned purplish / red within 5-8 days after application and within 10-15 days they are completely killed by inhibition of fatty acids synthesis through acetyl-CoA carboxylase (ACCase) inhibition. Even though it's effectiveness on broad leaved weeds was very less but they proved to be the best treatments which might be due to crop stature after critical period *i.e.*, after 30 DAS.

The grain amaranth has shown enormous plant growth with big broad leaves that gave shading effect analogous to self-mulching type character by filtering most of the light and very less light might fall on the soil. Therefore, totally the effective control of grasses by Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} paired with crops shading effect might have resulted in higher competitive ability of crop against weeds for resources. The above results were also in conformity with Idapuganti *et al.* (2005) [10], Billore *et al*. (2014) [3] and Jadhav *et al.* (2019) [11] in soya bean, Samant and Mishra (2014) [21] in ground nut, Gupta *et al.* (2013) [9] and Balyan *et al*. (2016) [15] in black gram. Similarly, weedy check recorded higher weed density of sedges, grasses, broad leaf weeds due to non-interruption of growth of the weeds.

Clomazone 20% EC @ 750 g a.i ha^{-1} was highly efficient in controlling major annual broad leaf weeds like *Ageratum conyzoides*, *Alternanthera spinosa* and *Borreria articularis.* Clomazone was a pro-herbicide that has to be converted to 5-keto clomazone in the plant to be active. 5-keto clomazone inhibits the isoprenoid biosynthesis pathway leading to blockage of the carotenoid biosynthesis which disrupts the synthesis of both chlorophyll and carotenes in susceptible plants. This results in chlorosis, bleaching of the target plants and death due to energy depletion. The results were on par with the findings of Westberg *et al.*, 1989 and Kudsk *et al.*, 2012 [12] in grain amaranth. But overall, it does not perform well as it was not much effective against grassy weeds which were actually dominated than broad leaf weeds in experimental field during crop critical period, thus they offer higher competition to crop and might resulted in poor performance of crop with Clomazone 20% EC @ 750 g a.i ha^{-1} treated plot.

Influence of weed management practices on weed dry weight

The data on weed density is a mirror of weed dry weight and in turn weed dry weight is a mirror of efficacy of different weed management practices. The herbicide applications have significantly influenced the weed dry weight in grain amaranth at different growth stages and data is presented in Tables 2. At 15 DAS, as in weed density, the weed dry weight of sedges, grasses and broad leaf weeds also didn't differ significantly in all the treatments. The non-significance might be due to non-imposition of treatments before15 DAS which recorded similar weed dry weight in all the treatments.

At 30 and 45 DAS, the early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} was found superior in controlling weeds which have recorded lower weed dry weight of sedges and grasses (1.87, 2.51 and 1.81, 4.09 g m^{-2}, at 30 and 45 DAS, respectively) among herbicide treatments which was on par with Propaquizafop 10% EC @ 12 g a.iha^{-1}. Further, significantly minimum weed dry weight of broadleaved weeds were recorded with application of Clomazone 20% EC @ 750 g a.i ha^{-1} (2.35 g m^{-2} and 4.09 g m^{-2} at 30 and 45 DAS, respectively), while weed dry weight of sedges, grasses and broad leaved weeds was maximum with weedy check. However, significantly lower total dry weight of weeds was reported with Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} (6.74 and 7.74 g m^{-2} at 30 and 45 DAS, respectively) which was on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1} (8.24 and 9.01 g m^{-2} at 30 and 45 DAS, respectively) and weedy check had maximum weed dry weight of (19.94 and 19.36 g m^{-2} at 30 and 45 DAS, respectively). Lower total weed dry weight was recorded with early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} and lower weed dry weight of broad leaf weeds with early post emergent application of Clomazone 20% EC @ 750 g a.i ha^{-1} was due to lower weed density registered in these treatments as a result of effective control of major weeds. The reason for lower weed density which resulted in lower weed dry weight was same as discussed above in weed density.

Weed control efficiency and weed index

The crop yield is directly proportional to weed control efficiency (WCE) and inversely related to weed index (WI). The data on weed control efficiency at 30 and 45 DAS as influenced by weed management practices is presented in Table 3.

At 30 and 45, significantly higher weed control efficiency was witnessed with Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} (72.85 and 76.55, respectively) and found on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1} (68.70 and 74.07, respectively) as compare to other treatments. Whereas, weed control efficiency (51.09 and 55.61%, respectively) was abysmal with Cyhalofop butyl 10% EC @ 150 g a.i ha^{-1} among herbicide treatments due to lower efficacy.

Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} recorded higher weed control efficiency might be a testimony for lower weed density and dry weight of total weeds as a result of effective control of grassy weeds which were dominant weed group among all weeds. This was also reported by Samant and Mishra (2014) [21]. Whereas, lower weed control efficiency with early post emergent application of Cyhalofop butyl 10% EC @ 150 g a.i ha^{-1} might be due to control of very narrow number of weed flora which resulted in higher weed density and weed dry matter among all herbicide treatments. The results obtained with Cyhalofop butyl 10% EC @ 150 g a.i ha^{-1} were not similar to results obtained in black gram by Sasikala *et al*. (2015) [22] and Deng *et al.* (2020) [4] in rice.

Weed index is an indicator of per cent yield reduction inflicted due to weeds competition with crop and also utters the efficiency of weed management practices. Among herbicide treatments, comparatively lower weed index (7.97%) was reported with Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} which was on par with Propaquizafop 10% EC @ 12 g a.i ha^{-1} with 10.52%. Whereas, the untrammeled growth of weeds resulted in significantly higher weed index (51.29%) in weedy check.

Lower weed index with early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} might be a result of discernible control of weeds which in turn lowered the reduction of yields due to weeds owing to increase in yields. This enabled the crop to utilize available resources like light, nutrients, moisture and space resulting in higher yield. Similar results were also reported by Kundu *et al.* (2011) [13] in green gram, Billore *et al*. (2014) [3] in soyabean, Samant and Mishra (2014) [21] and in ground nut, Gupta *et al.* (2013) [9] and Balyan *et al*. (2016) [15] in black gram, Jadhav *et al.* (2019) [11] in soyabean for Quizalofop ethyl 5% EC. However, the uncontrolled weed growth impinged heavy competition for resources and recorded higher weed index which implies to maximum yield reduction.

Yield and economics of grain amaranth as influenced by post emergence herbicides

Grain yield and economics in grain amaranth was significantly influenced by the weed management practices is presented in table 3. Significantly higher grain yield was recorded with weed free check (2162 kg ha^{-1}) which was on par with herbicide treatments of early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} (1896 and 1805 kg ha^{-1}, respectively) and weedy check recorded significantly lower grain yield (1005 kg ha^{-1}) compared to all other treatments. The yield increase in herbicide treatments of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} was in the tune of 88.65 and 79.60 per cent, respectively compared to weedy check. The higher grain yield among herbicide treatments was recorded with Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} could be due to effective control of grassy weeds which dominated high during the critical period of crop weed competition along with control of sedges and broad leaf weeds, which otherwise were quite notorious for imposing competition for light, space and nutrients with crop. These findings were also in accordance with Anon. (2004) [1], Anon. (2013) [2], Shukla *et al.* (2014) [23] and Mool *et al.* (2017) [18] in grain amaranth.

The economics of different weed management practices in grain amaranth is presented in Table 3. Higher cost of cultivation (Rs. 32179 ha^{-1}) were realized with weed free check followed by one hand weeding at 4 WAS (Rs. 28899 ha^{-1}) whereas, lower cost of cultivation (Rs. 24519 ha^{-1}) was recorded with weedy check followed by Fenoxaprop - p - ethyl 10% EC @ 25 g a.i ha^{-1} (Rs. 26551 ha^{-1}) and Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} (Rs. 26621 ha^{-1}). Higher cost in weed free check was buttressed with continuous employing of labours for maintaining weed free conditions. Whereas, no weeding or spraying which saved labour cost and chemical cost was resulted in lower cost of cultivation with weedy check. However, higher gross returns, net returns and B:C were realized with early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} (Rs. 94800 ha^{-1}, Rs.68179 ha^{-1} and 2.56, respectively) followed by Propaquizafop 10% EC @ 12 g a.i ha^{-1} (Rs. 90250 ha^{-1}, Rs.63525 ha^{-1} and 2.38, respectively) and lower gross returns (Rs. 50250 ha^{-1}, Rs.25731 ha^{-1} and 1.05, respectively) were obtained in weedy check as compared to all other treatments. This could be due to production of higher grain yield with early post emergent application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} and Propaquizafop 10% EC @ 12 g a.i ha^{-1} and lower returns with weedy check due to lower grain yield. The poorest performance of grain amaranth under weedy check with the lower yield level obviously resulted in the lower net returns and B:C ratio. The above results are in confirmatory with the findings of Chaudhari *et al*. (2019) [14].

Table 1: Weed density (No. m^{-2}) at different growth stages of grain amaranth as influenced by different post emergence herbicides during 2020-2022 (Pooled data of three years)

Treatments	Weed density at 15 DAS				Weed density at 30 DAS				Weed density at 45 DAS			
	Grosses	Sedges	BLW	Total*	Grosses	Sedges	BLW	Total *	Grosses	Sedges	BLW	Total*
T$_1$: Fenoxaprop - p - ethyl 10% EC @ 25 g a.i. ha^{-1}	3.51 (11.33)	3.02 (8.11)	3.70 (12.78)	10.23 (32.22)	2.33 (4.44)	2.29 (4.67)	3.13 (9.00)	7.75 (18.11)	1.74 (2.11)	4.41 (13.37)	4.37 (18.22)	10.52 (33.70)
T$_2$: Quizalofop ethyl 5% EC @ 50 g a.i. ha^{-1}	3.53 (11.44)	2.77 (6.67)	3.17 (9.22)	9.47 (27.33)	1.60 (1.56)	1.82 (2.33)	2.76 (6.89)	6.18 (10.78)	1.22 (0.56)	2.81 (5.37)	5.04 (24.44)	9.07 (30.37)
T$_3$: Clomazone 20% EC @ 750 g a.i. ha^{-1}	3.74 (13.00)	2.16 (3.67)	2.87 (7.33)	8.77 (24.00)	3.48 (8.67)	1.89 (2.67)	2.33 (4.40)	7.70 (15.54)	3.83 (13.89)	2.60 (6.07)	3.73 (13.04)	10.16 (33.00)
T$_4$: Propaquizafop 10% EC @ 12 g a.i. ha^{-1}	3.59 (11.89)	2.14 (3.56)	3.35 (10.33)	9.08 (29.78)	1.81 (2.33)	1.93 (2.78)	3.20 (9.33)	6.96 (14.44)	1.37 (1.00)	2.26 (3.67)	5.74 (32.19)	9.37 (36.86)
T$_5$: Cyhalofop butyl 10% EC @ 150 g a.i. ha^{-1}	3.79 (13.33)	2.14 (3.56)	3.53 (11.56)	9.46 (28.45)	2.87 (7.33)	2.87 (2.67)	3.59 (12.00)	9.33 (22.00)	2.18 (3.81)	2.30 (6.11)	4.41 (18.67)	8.89 (28.59)
T$_6$: One manual weeding at 4 weeks after sowing	3.96 (14.67)	1.67 (1.78)	3.55 (11.78)	9.18 (28.23)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	3.00 (0.00)	3.47 (11.07)	2.13 (2.93)	2.79 (7.52)	8.39 (21.52)
T$_7$: Weed free check	3.76 (13.11)	2.36 (4.56)	2.40 (5.00)	8.52 (22.67)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	3.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	3.00 (0.00)
T$_8$: Weedy check	4.08 (15.67)	3.04 (8.22)	3.61 (12.11)	10.73 (38.00)	4.50 (20.67)	2.73 (6.67)	4.70 (21.22)	11.93 (48.56)	4.82 (22.81)	2.59 (8.59)	4.52 (19.70)	11.93 (51.10)
S.Em ±	0.19	0.18	0.16	0.22	0.10	0.09	0.19	0.20	0.20	0.15	0.16	0.34
CD@ 5%	NS	NS	NS	NS	0.30	0.28	0.58	0.62	0.60	0.47	0.48	1.02

Note: Converted values SQRT of x+1,
* Data not converted
Figures in the parenthesis are original values

Table 2: Weed dry weight (g) at different growth stages of grain amaranth as influenced by different post emergence herbicides during 2020-2022 (Pooled data of three years)

Treatments	Weed dry weight at 15 DAS				Weed dry weight at 30 DAS				Weed dry weight at 45 DAS			
	Grosses	Sedges	BLW	Total*	Grosses	Sedges	BLW	Total *	Grosses	Sedges	BLW	Total*
T$_1$: Fenoxaprop - p - ethyl 10% EC @ 25 g a.i. ha^{-1}	2.29 (4.39)	2.12 (3.87)	2.15 (3.92)	6.56 (12.18)	2.88 (8.00)	2.86 (7.21)	3.40 (11.26)	9.14 (26.47)	2.73 (6.58)	3.62 (14.10)	2.36 (5.10)	8.72 (25.79)
T$_2$: Quizalofop ethyl 5% EC @ 50 g a.i. ha^{-1}	2.40 (4.93)	2.46 (5.50)	2.27 (4.28)	7.13 (14.70)	2.51 (5.37)	1.87 (4.12)	2.35 (4.76)	6.74 (14.25)	1.84 (2.58)	1.81 (2.70)	4.09 (18.43)	7.74 (23.71)
T$_3$: Clomazone 20% EC @ 750 g a.i. ha^{-1}	2.53 (5.53)	1.95 (2.94)	2.27 (4.28)	6.69 (12.75)	3.24 (9.53)	4.90 (7.79)	2.90 (9.09)	11.04 (26.41)	5.54 (31.83)	2.48 (5.65)	2.55 (6.32)	10.58 (43.80)
T$_4$: Propaquizafop 10% EC @ 12 g a.i. ha^{-1}	2.44 (5.16)	1.74 (2.31)	2.17 (3.92)	6.34 (11.39)	2.86 (7.28)	2.14 (4.03)	3.24 (10.90)	8.24 (22.21)	2.05 (3.42)	1.89 (3.22)	5.07 (24.97)	9.01 (31.61)
T$_5$: Cyhalofop butyl 10% EC @ 150 g a.i. ha^{-1}	2.17 (3.90)	2.01 (3.27)	2.14 (3.86)	6.31 (11.03)	3.46 (11.04)	2.70 (7.20)	3.36 (11.06)	9.52 (29.30)	2.70 (6.52)	2.66 (7.09)	3.57 (12.43)	8.93 (26.03)
T$_6$: One manual weeding at 4 weeks after sowing	2.12 (3.61)	1.98 (3.20)	2.12 (3.66)	6.22 (10.47)	1.53 (1.63)	1.47 (0.78)	2.24 (4.46)	5.23 (26.86)	1.61 (1.65)	1.77 (3.00)	1.56 (1.78)	4.93 (6.43)
T$_7$: Weed free check	2.19 (3.92)	1.00 (0.00)	2.12 (3.82)	5.31 (7.74)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	3.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T$_8$: Weedy check	2.04 (3.40)	2.01 (3.59)	2.68 (5.25)	7.73 (18.24)	6.03 (35.68)	9.10 (13.21)	4.80 (22.88)	19.94 (71.77)	10.72 (116.79)	3.36 (12.02)	5.28 (26.08)	19.36 (52.88)
S.Em ±	0.22	0.13	0.35	0.10	0.14	0.40	0.29	0.53	0.45	0.26	0.60	0.81
CD@ 5%	NS	NS	NS	NS	0.42	1.20	0.89	1.60	1.37	0.79	1.83	2.47

Note: Converted values SQRT of x+1,
* Data not converted
Figures in the parenthesis are original values

Table 3: Weed Control Efficiency, Weed Index, Yield and economics of grain amaranth as influenced by different post emergence herbicides during 2020-2022 (Pooled data of three years)

Treatments	Weed Control Efficiency (%)			Grain yield (kg ha^{-1})	Cost of cultivation (Rs.ha^{-1})	Gross returns (Rs.ha^{-1})	Net returns (Rs.ha^{-1})	B:C ratio
	30 DAS	45 DAS	Weed index (%)					
T$_1$: Fenoxaprop - p - ethyl 10% EC @ 25 g a.i. ha^{-1}	63.00	65.95	19.78	1654	26551	82700	56149	2.11
T$_2$: Quizalofop ethyl 5% EC @ 50 g a.i. ha^{-1}	72.85	76.55	7.97	1896	26621	94800	68179	2.56
T$_3$: Clomazone 20% EC @ 750 g a.i. ha^{-1}	61.52	64.41	34.04	1358	27019	67900	40881	1.51
T$_4$: Propaquizafop 10% EC @ 12 g a.i. ha^{-1}	68.70	74.07	10.52	1805	26725	90250	63525	2.38
T$_5$: Cyhalofop butyl 10% EC @ 150 g a.i. ha^{-1}	51.09	55.61	38.27	1274	26879	63700	36821	1.37
T$_6$: One manual weeding at 4 weeks after sowing	95.00	83.26	13.85	1878	28899	93900	65001	2.25
T$_7$: Weed free check	100.00	100.00	0.00	1962	32179	108100	75921	2.36
T$_8$: Weedy check	0.00	0.00	51.29	1005	24519	50250	25731	1.05
S.Em ±	-	-	-	98	-	-	-	-
CD@ 5%	-	-	-	297	-	-	-	-

Conclusion

Based on the results obtained during present investigation, it was found that early post-emergence application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} or Propaquizafop 10% EC @ 12 g a.i ha^{-1} in grain amaranth can be recommend for control of grassy weeds effectively as evidenced by higher weed control efficiency, productivity and profitability. Application of Clomazone 20% EC @ 750 g a.i ha^{-1} in grain amaranth can be recommended in broad leaf weeds infested area because it proved to be selective to grain amaranth with very slight phytotoxicity. Early post-emergence application of Quizalofop ethyl 5% EC @ 50 g a.i ha^{-1} or Propaquizafop 10% EC @ 12 g a.i ha^{-1} is recommended as it is evidenced higher yield and net monetary returns.

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