Studies on Lodging Management in Grain Amaranth (*Amaranthus hypochondriacus* L.)

G. R. Siddesh[1], S. R. Anand[2], M. S. Dinesh[3], H. V. Ramegowda[4] and P. R Somashekarappa[5]
[1]Department of Agronomy, [4]Department of Crop Physiology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[2]AICRN on Potential Crops, UAS, GKVK, Bengaluru, [3]ICAR-Krishi Vignana Kendra, Magadi, Ramanagara District
[5]Agricultural Research Station, Arasikere, Hassan
e-Mail : anuagron80@gmail.com

Authors Contribution

G. R. Siddesh : Experimentation, recording observation, layout & designing and data analysis

S. R. Anand : Conceptualization, writing paper and paper correction

M. S. Dinesh ; H. V. Ramegowda & P. R Somashekarappa : Guidance, data analysis and reviewing

Corresponding Author :
G. R. Siddesh

Received : January 2025
Accepted : April 2025

Abstract

A field experiment was conducted at M block, field unit, AICRN on potential crops, University of Agricultural Sciences, GKVK, Bengaluru during *kharif* 2023 to study the 'Lodging management in grain amaranth (*Amaranthus hypochondriacus* L.)'. The experiment was laid out in factorial randomized complete block design consisting of two factors *viz*., three potassium levels (100, 125 and 150 % Recommended K_2O) and four mepiquat chloride levels (Control, 25 g *a.i.* ha^{-1}, 50 g *a.i.* ha^{-1} and 75 g *a.i.* ha^{-1}) with 12 treatment combinations which were replicated thrice. Among potassium levels, application of 150 per cent recommended potassium recorded significantly higher plant height (156.20cm), stem girth (5.01 cm), root length (24.95 cm), root to shoot ratio (0.278), panicle length (42.68 cm), grain yield (1708 kg ha^{-1}) and lower lodging percentage (14%). Among mepiquat chloride levels, application of mepiquat chloride @ 75 g *a.i.* ha^{-1} recorded significantly lower plant height (143.2 cm), lodging percentage (8.77 %) and higher stem girth (5.06 cm), root length (25.53 cm), root to shoot ratio (0.261), panicle length (43.47 cm), grain yield (1720 kg ha^{-1}). Higher gross returns (Rs.142720 ha^{-1}), net returns (Rs.105537 ha^{-1}) and B:C (3.83) was observed in 150 per cent recommended potassium with mepiquat chloride @ 75 g *a.i.* ha^{-1}. Significantly higher nitrogen, phosphorous and potassium uptake by the crop was observed under application of 150 per cent K_2O 67.84, 21.69 and 60.18 kg ha^{-1}, respectively as compared to 125 and 100 per cent recommended K_2O.

Keywords : Lodging management, Grain amaranth, Potassium levels, Mepiquat chloride, Grain yield, Nutrient uptake

Grain amaranth (*Amaranthus hypochondriacus* L.) is a versatile annual, small seeded, high-protein peudocereal cultivated for its edible seeds. It belongs to the family Amaranthaceae and is native to South America. It is an annual herb that can grow to a height of up to two meters. It has broad green leaves and produces vibrant, colourful flower heads that contain numerous small seeds. The seeds are the primary edible part of the plant and are often referred to as amaranth grain or pseudocereal. Pseudocereals are often referred to as 'false cereals' because, they are not true grasses like traditional cereal crops. However, pseudocereal grains are very similar to cereals and are rich in nutritional quality, especially protein and amino acids. Grain amaranth has been cultivated for thousands of years and its history can be traced to Mesoamerica and the Andean region of South America, where it was an important staple crop for the Aztecs, Incas and other indigenous civilizations. Gujarat is a major producer of grain amaranth in the country which is having an area of about 40-50 thousand hectares, especially in Banaskantha and Kheda districts of Gujarat state which covers more than 50 per cent area of our whole country (Raiger *et al*., 2023). In Karnataka, grain amaranth is being grown in Biligiri Rangana hills of Chamarajanagara and other districts like Bijapur, Bagalkot and Belgaum for seed purposes (Anand *et al*., 2020).

The seeds are highly nutritious and packed with all essential amino acids, fiber, vitamins and minerals. Seeds are particularly rich in protein (14-16%), making them a valuable source of high quality plant-based protein, a higher content of essential amino acids like lysine (Amare *et al*., 2015). It also contains a significant amount of oil (7-8%), calcium, phosphorus, iron, beta-carotene and most of its fat is unsaturated fatty acids (76%). Amaranth oil has 7 per cent squalene which is highly-priced and used in cosmetics and pharmaceutical industries (He *et al*., 2002 and He & Corke, 2003). Beyond their nutritional value, grain amaranth seeds contain bioactive compounds, including antioxidants and phytosterols which have been associated with numerous health benefits (Karamac *et al*., 2019). These compounds have been linked to reducing inflammation, promoting heart health and supporting overall well-being, contributing to the growing recognition of grain amaranth as a valuable addition to a balanced diet (Alvarez *et al*., 2010). In recent years, its popularity is gaining momentum because of its nutritional quality with gluten free option, which makes them suitable for individuals with gluten intolerance or celiac disease (Martķnez-Villaluenga *et al*., 2020). This is considered as versatile and can be cooked and used in various dishes including porridge, soups, stews, salads and baked foods.

Amaranth is a tall growing crop (1.5-2.5 m) with a single succulent stalk and bears heavy grain head at the top of the stalk makes highly susceptible to lodging resulting in poor yield and quality of the grain. Lodging in grain amaranth is noted predominant problem causing drastic reduction in yield and quality of grain. Plant height, especially stem length is considered to be one of the major factor associated with lodging sensitivity (Berry *et al*., 2000). Though, lodging can be effectively managed by manipulating the plant height and various agronomic practices, still lodging problem is found to be a debatable issue.

Studies have shown the use of plant growth regulators seems to be good intervention in reducing lodging losses. Plant growth regulators play an important role in the coordination of many plant growth and behavioral processes, regulating the amount, type and direction of the plant growth (Bari and Jones, 2009). The synthetic plant growth regulators (PGRs) such as mepiquat chloride have been found to reduce lodging risk by a reducing stem elongation (Rajala *et al*., 2002). Potassium leads to increased mechanical strength and improved plant height, inter-node length, fresh weight, bending moment, breaking resistance, lodging index and increased lodging resistance in crops. In this context, an experiment was designed to find out the effect of potassium and PGR levels on growth, yield and lodging index in grain amaranth.

MATERIAL AND METHODS

A field experiment was conducted on grain amaranth variety (KBGA 15) at the 'M' block of Gandhi Krishi Vignan Kendra, University of Agricultural Sciences, Bangalore, situated in Karnataka's Eastern Dry Zone (Zone 5) at 13°05' N latitude, 77°34' E longitude and 949 m altitude. The soil was neutral pH (6.39), low available nitrogen (252 kg ha^{-1}) and medium levels of phosphorous (41 kg ha^{-1}) and potassium (205 kg ha^{-1}). Total rainfall received during cropping period (September to December, 2023) was 416.8 mm with uneven distribution. Since crop was raised in protective irrigation condition, erratic rainfall did not influence on crop growth and development. The experiment laid out in Factorial Randomized Block Design (FRBD) with 12 treatments and three replications. The treatments comprised of three potassium levels as first factor (K_1: 100% Recommended K_2O, K_2: 125% Recommended K_2O and K_3: 150% Recommended K_2O) and four mepiquate chloride levels as second factor (M_1: Control, M_2: Mepiquat Chloride @ 25 g *a.i.* ha^{-1} (0.5 L ha^{-1}), M_3: Mepiquat Chloride @ 50 g *a.i.* ha^{-1} (1.0 L ha^{-1}) and M_4: Mepiquat Chloride @ 75 g *a.i.* ha^{-1} (1.5 L ha^{-1}). The gross plot size was 4.5 m × 3.0

m. The net plot size was 2.7 m × 1.8 m, with spacing of 45 cm × 15 cm. Potassium was applied as a full dose at sowing in the form of Muriate of Potash (MOP). Mepiquat chloride was applied at 30 days after sowing using a knapsack sprayer at a volume of 500 liters spray solution per hectare as per treatment. Leaf area was measured by using green leaves from the selected plants were fed to the leaf area meter and expressed as cm^2 per plant (Model Li-300 from Licor Co Nebraska). Stem girth was measured at harvest three points along the main stem *i.e.,* just below the basal node, at the middle and at the tip using a thread with the average value recorded and expressed in centimeters. Root length was then assessed by measuring the distance from the base of the stem to the tip of the main root in carefully uprooted plants and expressed in centimeters. The root-to-shoot ratio was calculated as the ratio of root dry weight to shoot dry weight, providing insight into the balance between underground and above ground growth. Finally, lodging percentage was determined at harvest by counting the number of lodged plants in each plot. This count was then converted into a percentage of the total plants per plot using the formula:

The experimental data collected on plant growth parameters, yield components were subjected to Fisher's method of 'Analysis of Variance' (ANOVA) as outlined by Panse and Sukhatme (1967). Wherever F-test was significant, for comparison between the treatment means, an appropriate value of critical difference (CD) was worked out. All the data was analyzed and the results were presented and discussed at a probability level of five per cent.

Results and Discussion

Growth Attributes of Grain Amaranth

The data on grain amaranth growth parameters at harvest under varying potassium and mepiquat chloride levels indicate a significant increase with higher potassium application (Table 1). Significantly higher plant height, number of leaves per plant, leaf area per plant and total dry matter production per plant were recorded with 150% K_2O (156.2 cm, 20.68, 2307 cm^2 $plant^{-1}$ and 84.88 g $plant^{-1}$, respectively) followed by 125% K_2O (148.7 cm, 20.03, 2226 cm^2 $plant^{-1}$ and 79.00 g $plant^{-1}$, respectively), as compared to 100% K_2O (145.6 cm, 17.30, 2091 cm^2 $plant^{-1}$ and 73.63 g $plant^{-1}$, respectively). This increase in growth with potassium application may be attributed to its role in promoting hormone synthesis, enhancing cell division and elongation and improving CO_2 assimilation, as reported in studies by Bhosale (2009), Ayub (2012), and Buriro *et al.* (2015) in mungbean. Similarly, Similarly, the increased total dry matter per plant is due to potassium which is known to promote cell growth and division, that increases the area of the leaf. However, potassium promotes an increase in photosynthates production and their subsequent translocation to the shoots and also potassium enhances the nitrogen uptake which results higher biomass. These results corroborate the findings of Golakiya *et al.* (2000) in groundnut and Bansal *et al.* (2001) in soybean.

Among the application of mepiquat chloride @ 75 g a.i. ha^{-1} significantly reduced plant height (143.2 cm) compared to the control (159.4 cm). This reduction is likely due to mepiquat chloride's anti-gibberellin effect and reduce gibberllin biosynthesis which restricts cell elongation but not cell division. These findings align with previous research by Elkoca and Kantar (2006) in pea, Fattah *et al*. (2013) in rice and Muhammad *et al*. (2018) in maize. These results corroborate the study of Golakiya *et al.* (2000) in groundnut and Bansal *et al.* (2001) in soybean.

Whereas, application of mepiquat chloride @ 75 g a.i. ha^{-1} recorded significantly higher number of leaves per plant, leaf area $plant^{-1}$ and total dry matter $plant^{-1}$ (20.63, 2357 cm^2 $plant^{-1}$ and 82.37 g $plant^{-1}$, respectively) which was on par with mepiquat chloride @50 g a.i. ha^{-1} (20.27, 2316 cm^2 $plant^{-1}$ and 81.20 g $plant^{-1}$, respectively) as compared to control. This could be due to mepiquat chloride may delay leaf senescence, inhibit protease activity and chlorophyll breakdown and promote the accumulation of soluble proteins and enzymes, thus enhancing leaf area. These effects, along with prolonged leaf retention, increase assimilation surface area over time, as reported by Prabhakar Reddy (2002) and Hanchinamath (2005).

TABLE 1

Growth attributes of grain amaranth as influenced by application of varying levels of potassium and mepiquat chloride at harvest

Treatments	Plant height (cm)	No. of leaves $plant^{-1}$	Leaf area $plant^{-1}$ (cm^2)	Total dry matter production $plant^{-1}$
Factor 1 : Potassium levels (K)				
K_1: 100 % Recommended K_2O	145.6	17.30	2091	73.63
K_2: 125 % Recommended K_2O	148.7	20.03	2226	79.00
K_3: 150 % Recommended K_2O	156.2	20.68	2307	84.88
S. Em. ±	0.79	0.10	11.61	0.41
C.D. (P= 0.05)	2.32	0.29	34.04	1.21
Factor 2 : Mepiquat Chloride 5% aqueous solution levels (M)				
M_1: Control	159.4	17.23	2015	75.20
M_2: Mepiquat Chloride @ 25 g *a.i.* ha^{-1} (0.5 L ha^{-1})	152.8	19.20	2145	77.90
M_3: Mepiquat Chloride @ 50 g *a.i.* ha^{-1} (1.0 L ha^{-1})	145.4	20.27	2316	81.20
M_4: Mepiquat Chloride @ 75 g *a.i.* ha^{-1} (1.5 L ha^{-1})	143.2	20.63	2357	82.37
S. Em. ±	1.06	0.13	15.48	0.55
C.D. (P= 0.05)	3.10	0.39	45.39	1.62
Interaction effect (K x M)				
S. Em. ±	3.17	0.40	46.43	0.65
C.D. (P= 0.05)	NS	NS	NS	NS

DAS : Day after sowing, NS: Non-significant, RDF: 60:40:40 N:P:K kg ha^{-1}

The interaction effects between potassium and mepiquat chloride levels was found non-significant with respect to growth parameters.

Lodging Traits of Grain Amaranth

The data on lodging traits of grain amaranth such as stem girth, root length, root-shoot ratio and lodging per cent at harvest under the application of varying levels of potassium and mepiquat chloride are presented in Table 2. Significantly higher stem girth, root length, root to shoot ratio and lodging per cent were recorded with application of 150% K_2O (5.01 cm, 24.95 cm, 0.278 and 14%, respectively) followed by 125% K_2O (4.70 cm, 23.20 cm, 0.252 and 17.33%, respectively). The lowest stem stemgirth, root length, root to shoot ratio and lodging per cent were observed with 100% K_2O (4.48 cm, 21.18 cm, 0.213 and 20.60%, respectively). This increase in stem girth may be due to potassium enhancing cell wall thickness in the cuticle and epidermis, as well as in sclerenchymatous cells by increasing lignin content, as reported by Kronzucker *et al.* (2003). Similar findings were noted by Magsi *et al.* (2023) in sunflower.

Increased potassium likely enhanced root length and root to shoot ratio by improving water uptake, cell expansion, enzyme activation and nutrient transport, promoting robust root growth. This finding aligns with Zizala (2000), who reported increased root length and volume in groundnut with higher potassium rates.

However, mepiquat chloride levels also had a significant impact on stem girth, root length, root to shoot ratio and lodging per cent at harvest. The highest

TABLE 2

Lodging traits of grain amaranth as influenced by application of different levels of potassium and mepiquat chloride at harvest

Treatments	Stem girth (cm)	Root length (cm)	Root : Shoot	Lodging %
Factor 1 : Potassium levels (K)				
K_1: 100 % Recommended K_2O	4.48	21.18	0.213	20.60
K_2: 125 % Recommended K_2O	4.70	23.20	0.252	17.33
K_3: 150 % Recommended K_2O	5.01	24.95	0.278	14.00
S. Em. ±	0.02	0.12	0.001	0.11
C.D. (P= 0.05)	0.07	0.36	0.004	0.31
Factor 2 : Mepiquat Chloride 5% aqueous solution levels (M)				
M_1: Control	4.36	19.67	0.240	27.87
M_2: Mepiquat Chloride @ 25 g *a.i.* ha^{-1} (0.5 L ha^{-1})	4.52	22.13	0.244	19.70
M_3: Mepiquat Chloride @ 50 g *a.i.* ha^{-1} (1.0 L ha^{-1})	4.99	25.10	0.246	12.90
M_4: Mepiquat Chloride @ 75 g *a.i.* ha^{-1} (1.5 L ha^{-1})	5.06	25.53	0.261	8.77
S. Em. ±	0.03	0.16	0.002	0.14
C.D. (P= 0.05)	0.10	0.47	0.005	0.42
Interaction (K×M)				
S. Em. ±	0.10	0.49	0.005	0.43
C.D. (P= 0.05)	NS	NS	NS	NS

DAS : Day after sowing, NS: Non-significant, RDF: 60:40:40 N:P:K kg ha^{-1}

stem girth, root length, root to shoot ratio and lodging per cent were noticed with 75 g a.i. ha^{-1} of mepiquat chloride (5.06 cm, 25.53 cm, 0.261 and 8.77%, respectively) which was on par with 50 g a.i. ha^{-1} (4.99 cm, 25.10 cm, 0.246 and 12.90%, respectively), both significantly exceeding the values recorded with 25 g *a.i.* ha^{-1} (4.52 cm, 22.13 cm, 0.244 and 19.70%, respectively) and the control (4.36 cm, 19.67 cm, 0.240 and 27.87%, respectively). This increase can be attributed to growth retardants that limit longitudinal growth while promoting lateral growth, as observed by Zidan *et al.* (2014). Similar results were obtained by Elkoca and Kantar (2006) in pea and Koutroubas *et al.* (2014) and Polat *et al.* (2017) in wheat, where mepiquat chloride application increased stem diameter. The increase in root length and root to shoot ratio could be due to mepiquat chloride directing growth hormones and photo synthates towards root development by suppressing vegetative growth, as observed by Raut *et al.* (2019). Mepiquat chloride also influenced on reduced lodging with the lowest percentage (8.77%) at 75 g a.i. ha^{-1}, attributed to improved stem strength and cell compaction, which aligns with Kamran *et al.* (2018) in maize and Zhipeng *et al.* (2025). The levels of potassium and mepiquat chloride interaction was non-significant with respect to stem girth, root length, root to shoot ratio and lodging per cent.

Yield Attributes and Yield of Grain Amaranth

The yield parameters of grain amaranth, including panicle length, number of fingers per panicle, finger length and 10 ml seed volume weight presented in Table 3, grain yield and stover yield per hectare illustrated in Fig. 1, were assessed under various levels of potassium and mepiquat chloride.

TABLE 3

Yield attributes of grain amaranth as influenced by application of different potassium and mepiquat chloride levels

Treatments	Panicle length (cm)	No. of fingers Panicle^{-1}	Finger length (cm)	10 ml seed volume weight (g)
Factor 1 : Potassium levels (K)				
K_1: 100 % Recommended K_2O	37.03	43.98	14.45	8.20
K_2: 125 % Recommended K_2O	41.13	48.98	15.68	8.36
K_3: 150 % Recommended K_2O	42.68	50.68	16.83	8.48
S. Em. ±	0.21	0.25	0.08	0.04
C.D. (P= 0.05)	0.62	0.74	0.24	NS
Factor 2 : Mepiquat Chloride 5 % aqueous solution levels (M)				
M_1: Control	35.23	43.20	14.10	8.14
M_2: Mepiquat Chloride @ 25 g *a.i.* ha^{-1} (0.5 L ha^{-1})	39.70	45.33	14.60	8.29
M_3: Mepiquat Chloride @ 50 g *a.i.* ha^{-1} (1.0 L ha^{-1})	42.70	51.07	16.80	8.44
M_4: Mepiquat Chloride @ 75 g *a.i.* ha^{-1} (1.5 L ha^{-1})	43.47	51.90	17.10	8.52
S. Em. ±	0.28	0.34	0.11	0.06
C.D. (P= 0.05)	0.83	0.98	0.32	NS
Interaction (K×M)				
S. Em. ±	0.85	1.01	0.33	0.18
C.D. (P= 0.05)	NS	NS	NS	NS

RDF : 60:40:40 N:P:K kg ha^{-1}

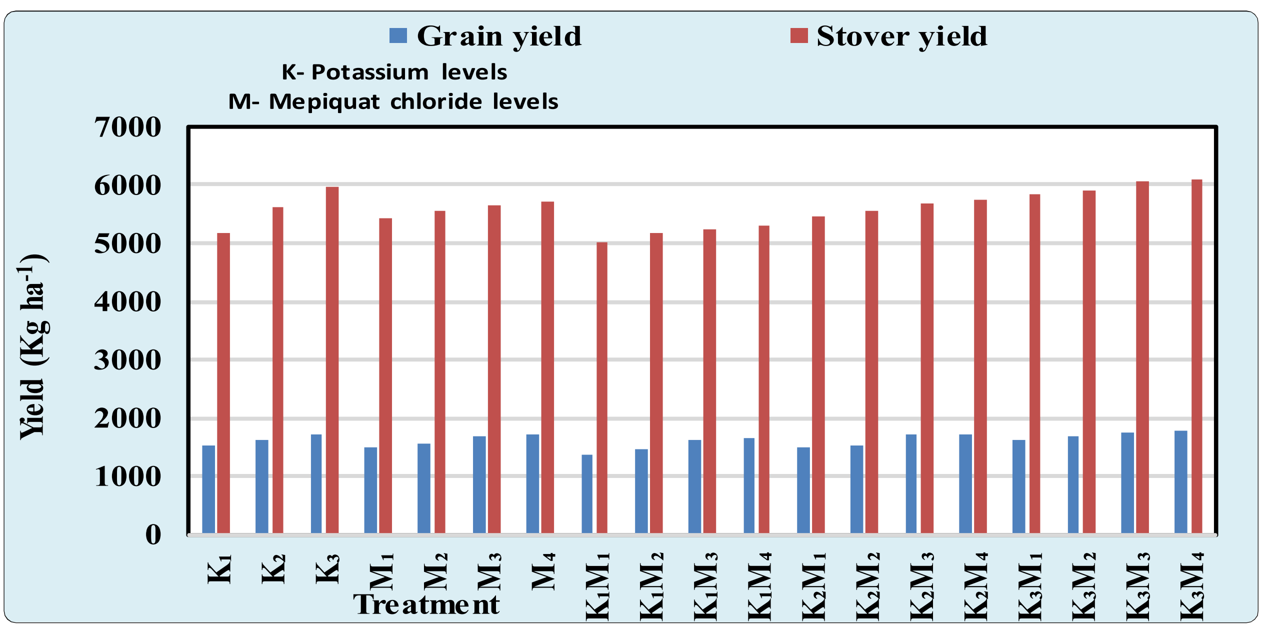

Fig. 1 : Grain yield and stover yield of grain amaranth as influenced by application of different potassium and mepiquat chloride levels

Higher potassium levels (150% K_2O) significantly increased panicle length, number of fingers per panicle and length of finger (42.68 cm, 50.68 and 16.83 cm, respectively) as compared to 125% K_2O (41.13 cm, 48.98 and 15.68 cm, respectively) and 100% K_2O (37.03 cm, 43.98 and 14.45 cm, respectively), likely due to enhanced growth and nutrient translocation, facilitating efficient source-to-sink movement, consistent with Islam *et al*. (2015) in rice, Jadav (2004) in sesame and Swetha *et al*., 2017 in baby corn. Whereas, 10 ml seed volume weight of grain amaranth was non-significantly influenced by different potassium levels. However, the highest value was recorded with 150% K_2O (8.48 g), followed by 125% K_2O (8.36 g) and the lowest was observed with 100% K_2O (8.20 g).

Among PGR levels, mepiquat chloride at 75 g *a.i.* ha^{-1} also significantly improved panicle length, number of fingers per panicle and finger length (43.47 cm, 51.90 and 17.10 cm, respectively) which was on par with Mepiquat chloride at 50 g *a.i.* ha^{-1} (42.70 cm, 51.07 and 16.80 cm, respectively) which could be attributed to more efficient photosynthates transfer due to reduced plant height. Mepiquat chloride likely enhanced finger length by redirecting assimilates from vegetative to reproductive growth, reducing abscission and increasing photosynthates availability. The potassium and mepiquat chloride interaction was statistically non-significant.

Whereas, mepiquat chloride levels did not significantly affect the seed volume weight. The highest seed volume weight was observed with mepiquat chloride at 75 g *a.i.* ha^{-1} (8.52 g), followed by 50 g *a.i.* ha^{-1} (8.44 g), compared to the control (8.14 g). Interaction effects between potassium and mepiquat chloride was found non-significant.

Grain Yield and Stover Yield

Grain yield of grain amaranth was significantly influenced by application of 150% K_2O recorded the highest grain yield and stover yield (1708 kg ha^{-1} and 5979 kg ha^{-1}, respectively), followed by 125% K_2O (1611 kg ha^{-1} and 5489 kg ha^{-1}, respectively), with the lowest yield under 100% K_2O (1520 kg ha^{-1} and 5179 kg ha^{-1}, respectively). Higher potassium likely enhanced growth and yield parameters as evidenced by Nasri and Khalatbary (2011) in beans and Buriro *et al*. (2015) in green gram. However, the stover yield increase is attributed to potassium's beneficial effects on photosynthesis and cell elongation, leading to taller plants and greater leaf production, as noted by Biswash *et al*. (2014) and Bhosale (2009). Among growth retardant levels, Mepiquat chloride @ 75 g a.i. ha^{-1} produced the highest grain yield (1720 kg ha^{-1}) as compared to 50 g *a.i.* ha^{-1} (1689 kg ha^{-1}). Similar results were obtained by Zhipeng *et al.* (2025) whos research findings indicates that spraying 200 mg L^{-1} mepiquat chloride at the three leaf stage and early flowering stage of soybean has the most favorable effect on both lodging resistance and yield improvement. Although the various mepiquat chloride levels did not significantly affect stover yield, the highest yield of 5716 kg ha^{-1} was observed with mepiquat chloride at 75 g *a.i.* ha^{-1}, compared to 5630 kg ha^{-1} at 50 g a.i. ha^{-1} and 5233 kg ha^{-1} in the control. The interaction effects were non-significant.

Economics of Grain Amaranth

The data on the cost of cultivation, gross returns, net returns and benefit-cost ratio for grain amaranth under the application of varying levels of potassium and mepiquat chloride are presented in Table 4. Application of 150% K_2O resulted in significantly higher gross returns (Rs.136,640 ha^{-1}), net returns (Rs.102,518 ha^{-1}) and BC ratio (4.0) compared to 125% K_2O (Rs.128,880 ha^{-1}, Rs.95,302 ha^{-1} and 3.83, respectively) and 100% K_2O (Rs.121,600 ha^{-1}, Rs.88,600 ha^{-1} and 3.68, respectively). Mepiquat chloride application at 75 g *a.i.* ha^{-1} resulted in significantly higher gross returns (Rs.137,600 ha^{-1}) and net returns (Rs.101,540 ha^{-1}), while 50 g *a.i.* ha^{-1} recorded the highest BC ratio (3.85). The combination of 150% K_2O and mepiquat chloride @ 75 g *a.i.* ha^{-1} produced the highest gross returns (Rs.142,720 ha^{-1}) and net returns (Rs.105,537 ha^{-1}), with 150% K_2O and mepiquat chloride @ 50 g *a.i.* ha^{-1} showing the highest BC ratio (3.89). The lowest returns and BC ratio were observed in 100% K_2O without mepiquat chloride (Rs.108,640 ha^{-1}, Rs.75,640 ha^{-1}, 3.29). The increased

TABLE 4

Economics of grain amaranth as influenced by application of different potassium and mepiquat chloride levels

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	BC ratio
Factor 1 : Potassium levels (K)				
K_1: 100 % Recommended K_2O	33000	121600	88600	3.68
K_2: 125 % Recommended K_2O	33578	128880	95302	3.83
K_3: 150 % Recommended K_2O	34122	136640	102518	4.00
S. Em. ±	-	-	-	-
C.D. (P= 0.05)	-	-	-	-
Factor 2 : Mepiquat Chloride 5% aqueous solution levels (M)				
M_1: Control	33000	118880	85880	3.60
M_2: Mepiquat Chloride @ 25 g *a.i.* ha^{-1} (0.5 L ha^{-1})	34020	124560	90540	3.66
M_3: Mepiquat Chloride @ 50 g *a.i.* ha^{-1} (1.0 L ha^{-1})	35040	135120	100080	3.85
M_4:Mepiquat Chloride @ 75 g *a.i.* ha^{-1} (1.5 L ha^{-1})	36060	137600	101540	3.81
S. Em. ±	-	-	-	-
C.D. (P= 0.05)	-	-	-	-
Interaction (K×M)				
S. Em. ±	-	-	-	-
C.D. (P= 0.05)	-	-	-	-

returns were attributed to better growth, yield, nutrient utilization and minimal lodging, particularly with potassium and mepiquat chloride treatments.

Total Nitrogen, Phosphorus and Potassium Uptake by Grain Amaranth (Kg ha^{-1})

Total nitrogen, phosphorus and potassium uptake by grain amaranth (Kg ha^{-1}) as influenced by application of different potassium levels and mepiquat chloride levels are presented in Table 5. The data reveals that nitrogen, phosphorous and potassium uptake by the whole plant was significantly influenced by application of different potassium levels and mepiquat chloride levels.

Among different potassium levels, significantly higher nitrogen, phosphorous and potassium uptake by the crop was observed under application of 150 per cent K_2O (67.84, 21.69 and 60.18 kg ha^{-1}, respectively). Significantly lower nitrogen uptake by the crop was observed under application of 100 per cent K_2O (59.87, 17.45 and 43.65 kg ha^{-1}, respectively) compared to other treatments. The increase in NPK content might be due to Potassium that might, have shown the synergistic effect in increasing the NPK uptake. These finding are in close agreement with those obtained by Anwar (2012) and Abbasi *et al.* (2012) in green gram. Similarly, increase in NPK uptake with increase in in P levels was reported by Revanth *et al.* (2024) in grain amaranth.

Among different mepiquat chloride levels, application of mepiquat chloride @ 75 g *a.i.* ha^{-1} recorded significantly higher nitrogen, phosphorous and potassium uptake by the crop (65.14, 19.96 and 54.80 kg ha^{-1}, respectively). Significantly lower nitrogen, phosphorous and potassium uptake by the crop was observed under control (62.30, 18.29 and 49.94

TABLE 5

Total nitrogen, phosphorus and potassium uptake by grain amaranth as influenced by application of different levels of potassium and mepiquat chloride

Treatments	Total uptake (kg ha^{-1})		
	N	P_2O_5	K_2O
Factor 1 : Potassium levels (K)			
K_1: 100 % Recommended K_2O	59.87	17.45	43.65
K_2: 125 % Recommended K_2O	63.81	18.42	52.70
K_3: 150 % Recommended K_2O	67.84	21.69	60.18
S. Em. ±	0.33	0.10	0.27
C.D. (P= 0.05)	0.98	0.29	0.79
Factor 2 : Mepiquat Chloride 5% aqueous solution levels (M)			
M_1: Control	62.30	18.29	49.94
M_2: Mepiquat Chloride @ 25 g *a.i.* ha^{-1} (0.5 L ha^{-1})	63.50	19.05	50.92
M_3: Mepiquat Chloride @ 50 g *a.i.* ha^{-1} (1.0 L ha^{-1})	64.43	19.44	53.04
M_4:Mepiquat Chloride @ 75 g *a.i.* ha^{-1} (1.5 L ha^{-1})	65.14	19.96	54.80
S. Em. ±	0.45	0.13	0.36
C.D. (P= 0.05)	1.31	0.39	1.06
Interaction (K×M)			
S. Em. ±	1.34	0.40	1.08
C.D. (P= 0.05)	NS	NS	NS

DAS : Day after sowing, NS: Non –significant, '*' indicates significant at 5% C. D. value, RDF : 60:40:40 N:P:K kg ha^{-1}

kg ha^{-1}, respectively) compared to other treatments. Chandewar *et al.* (2016) noticed that increased nitrogen, phosphorous and potassium uptake with application of mepiquat chloride in pigeonpea. Nitrogen, phosphorous and potassium uptake of the crop didn't vary significantly between the interaction effects due to K_2O and mepiquat chloride levels.

Based on the findings from the current investigations, it can be concluded that application of 150 per cent K_2O performed better as evidenced in increasing growth and yield parameters and finally grain yield. Application of mepiquat chloride @75 g a.i. ha^{-1} as growth retardant shown significant increase in lodging index and lowers in lodging percentage. As mepiquat chloride @50 g a.i. ha^{-1} found on par with mepiquat chloride @75 g a.i. ha^{-1} and higher economic returns in mepiquat chloride @50 g a.i. ha^{-1}, it can be concluded that mepiquat chloride @50 g a.i. ha^{-1} at 30 DAS is optimum for higher grain yield and lower lodging percentage in grain amaranth. These results underscore the importance of potassium and growth regulators in improving the overall performance and yield stability of grain amaranth.

REFERENCES

ABBASI, M. K., TAHIR, M. M., WALEED, A., ZAHEER, A. AND NASIR, R., 2012, Soybean yield and chemical composition in response to phosphorus, potassium nutrition in Kashmir. *American Soc. Agron*., **104** (5) : 1476 - 1484.

ALVAREZ, J. L., AUTY, M., AREND, E. K. AND GALLAGHER, E., 2010, Baking properties and microstructure of pseudocereal flours in gluten free bread formulations. *European Food Res. Technol.,* **230** (3) : 437 - 445.

AMARE, E., MOUQUET-RIVIER, C., SERVENT, A., MOREL, G., ADISH, A. AND DESSE HAKI, G., 2015, Protein quality of amaranth grains cultivated in Ethiopia as affected by popping and fermentation. *Food Nut. Sci.,* **6** (1) : 38 - 48.

ANAND, S. R., MURTHY, N. AND PRITHVIRAJ, S. K., 2020, Response of grain amaranth (*Amarant huscruentus* L.) genotypes to different levels of fertilizers (NPK) under eastern dry zone of Karnataka. *Mysore J. Agric. Sci.,* **54** (1) : 60 - 64.

ANWAR, R. A., 2012, Growth and yield response of chickpea to different rates of nitrogen and potassium. *Inter. J. Agric. Crop Sci*., **5** (17) : 1930 - 1933.

AYUB, M., NADEEM, M. A., NAEEM, M., TAHIR, M. AND AHMAD, W., 2012, Effect of different levels of P and K on growth, forage yield and quality of cluster bean (*Cyamopsis tetragonolobus* L.). *J. Animal Plant Sci.,* **22** : 479 - 483.

BANSAL, K. M., SINGH, S. P. AND NEPALIA, V., 2001, The Effect of potassium application on yield and quality of soybean and wheat in Madya Pradesh. Fertilizer News, **46** (11) : 45 - 49.

BARI, R. AND JONES, J. D., 2009, Role of plant hormones in plant defence responses. *Plant Mol. Biol*., **69** (4) : 473 - 488.

BERRY, P. M., 2013, New advances in PGRs. BCPC 50-year anniversary conference. Rothamsted, UK.

BERRY, P. M., GRIFFIN, J. M., SYLVESTER-BRADLEY, R., SCOTT, R. K., SPINK, J. H., BAKER, C. J. AND CLARE, R.W., 2000, Controlling plant form husbandry to minimize lodging in wheat. *Field Crop Res.,* **67** : 59 - 81.

BHOSALE, N. D., 2009, Effect of potash and sulphur on growth, yield and quality of sesamum (*Sesamum indicum* L.). *M. Sc. (Agri.) Thesis,* J.A.U., Junagadh.

BISWASH, M. R., RAHMAN, M. W., HAQUE, M. M., SHARMIN, M. SND BARUA, R., 2014, Effect of potassium and vermicompost on the growth, yield and nutrient contents of Mungbean (BARI Mung 5). *Open Sci. J. Biosci. Bioeng.,* **1** (3) : 33 - 39.

BURIRO, M., HUSSAIN, F., TALPUR, G. H., GANDAHI, A. W. AND BURIRO, B., 2015, Growth and yield response of mungbean varieties to various potassium levels. *Pakistan J. Agri. Agril. Engg. Vet. Sci.,* **31** (2) : 203 - 210.

CHANDEWAR, K. B., KHAWALE, V. S., JIVTODE, D. J., PAGAR, P. C. AND UPARKAR, A. L., 2016, Effect of fertilizer level and mepiquat chloride on growth, yield and uptake of pigeonpea. *J. Soil and Crops*, **26** (2) : 238 - 242.

ELKOCA, E. AND KANTAR, F., 2006, Response of pea (*Pisumsativum* L.) to mepiquat chloride under varying application doses and stages. *J. Agron. Crop Sci.,* **192** (2) : 102 - 110.

FATTAH, A. EL-EKHTYAR, A. M. AND KHOBY, W. M., 2013, Physiological effect of some growth retardants on performance of growth, lodging degree and yield of rice. *J. Plant Prod.,* **4** : 133 - 150.

GOLAKIYA, B. A., SHOBHANA, H. K., RAJANI, A.V. AND GUNDALIYA, J. D., 2000, Balanced nutrient management in groundnut-wheat sequence on LTFE basis proceeding. GAU-PRII-IPI National Symposium on '*Balanced Nutrition of Groundnut and other field crops grown in calcareous soil of India'* held at GAU, Junagadh, pp. : 124.

HANCHINAMATH, P. V., 2005, Effect of plant growth regulators, organics and nutrients on growth physiology and yield in cluster bean (*Cyamopsis tetragonoloba* L. Taub). *M. Sc. (Agri.) Thesis,* Univ. Agric. Sci., Dharwad, Karnataka, India.

HE, H. AND CORKE, H., 2003, Oil and squalene in amaranthus grain and leaf. *J. Agric. Food Chem.,***51** (27) : 7913 - 7920.

HE, H. P. Y., CAI, M., SUN AND CORKE, H., 2002, Extraction and purification of squalene from Amaranthus grain. *J. Agric. Food Chem.,* **50** (2) : 368 - 372.

ISLAM, A., CHANDRABISWAS, J., KARIM, A. J. M. S., SALMAPERVIN, M. AND SALEQUE, M. A., 2015, Effects of potassium fertilization on growth and yield of wetland rice in grey terrace soils of Bangladesh. *Res. Crop Ecophysiology J.,***10** (2) : 64 - 82.

JADAV, D. P., 2004, Effect of different levels of sulphur and potash on grain and oil yields of sesame. *M. Sc. (Agri.) Thesis,* J. A. U., Junagadh.

KAMRAN, M., AHMAD, I., WANG, H., WU, X., XU, J., LIU, T., DING, R. AND HAN, Q., 2018, Mepiquat chloride application increases lodging resistance of maize by enhancing stem physical strength and lignin biosynthesis. *Field Crop Res.,* **224** : 148 - 159.

KARAMAC, M., GAI, F., LONGATO, E., MEINERI, G., JANIAK, M. A., AMAROWICZ, R. AND PEIRETTI, P. G., 2019, Antioxidant activity and phenolic composition of amaranth (*Amaranthus caudatus*) during plant growth. *Antioxidants,* **8** (6) : 173.

KOUTROUBAS, S. D., VASSILIOU, G. AND DAMALAS, C. A., 2014, Sunflower morphology and yield as affected by foliar applications of plant growth regulators. *Int. J. Plant Prod*., **8** (2) : 215 - 230.

KRONZUCKER, H. J., SZCZERBA, M. W., SCHULZE, L. M. AND BRITTO, D. T., 2003, Non- reciprocal interactions between K+ and Na+ ions in barley (*Hordeumvulgare* L.). *J. Exp. Bot.,* **59** : 2793 - 2801.

MUHAMMAD KAMRAN, IRSHAD AHMAD, HAIQI WANG, XIAORONG WU JING, XUTIENING LIU, RUIXIA DING AND QINGFANG HAN, 2018, Mepiquat chloride application increases lodging resistance of maize by enhancing stem physical strength and lignin biosynthesis. *Field Crops Research,* **224** :148 - 159.

MAGSI, M. A., ANSARI, M. A., KALERI, A. A., MANGAN, B. N., LASHARI, M. S., AWAN, M. H., SHEIKH, Z. A., KUMAR, V., SARDAR, H., MANZOOR, D. AND MEMON, N. A., 2023, Effect of various levels of potassium on the growth and yield of sunflower (*Helianthus annuus* L.). *Jammu Kashmir J. Agric.,* **3** (2) : 167 - 171.

MARTINEZ-VILLALUENGA, C., PENAS, E. AND HERNANDEZ-LEDESMA, B., 2020, Pseudocereal grains: Nutritional value, health benefits and current applications for the development of gluten-free foods. *Food Chem. Toxicol.,* **137** : 111 - 178.

NASRI, M. AND KHALATBARY, M., 2011, Effect of nitrogen fertilizer, potassium and zinc on quantitative and qualitative characteristics of green bean genotypes. *J. Crop Ecophysiol.,* **3** (1) : 82 - 93.

PANSE, V. G. AND SUKHATME, P. V., 1967, Statistical methods for agricultural workers, ICAR Pub., New Delhi, pp. : 381.

POLAT, T., OZER, H., OZTURK, E. AND SEFAOGLU, F., 2017, Effects of mepiquat chloride applications on non-oilseed sunflower. *Turk. J. Agric. Forestry*, **41** (6) : 472 - 479.

PRABHAKAR REDDY, V., 2002, Effect of growth regulators on growth, physiology and yield in chickpea (*Cicerarietinum* L.). *M.Sc. (Agri.) Thesis*, Univ. Agric. Sci., Dharwad.

RAIGER, H. L., MISHRA, D., JAJORIA, N. K., DEEWAN, P. AND DHALIWAL, Y. S., 2023, Grain amaranth: Nutrient enriched grain of future. *Intensive Agric.,* **57** (1) : 4 - 13.

REVANTH, D., MURALI, K., ANAND, S. R., SATHISH, A. AND USHA RAVINDRA, 2024, Effect of phosphorous fertilizer levels and P solubilizers on growth, yield, economics, nutrient uptake and quality of grain amaranth (*Amaranthus hypochodriacus* L.). *Mysore J. Agric. Sci.,* **58** (2) : 237 - 247.

RAJALA, A., PELTONEN-SAINIO, P., ONNELA, M. AND JACKSON, M., 2002, Effects of applying stem shortening plant growth regulators to leaves and root elongation by seedlings of wheat, oat and barley, mediation by ethylene, *Plant Growth Regulators*, **38** : 51 - 59.

RAUT, S. A., MESHRAM, J. H. AND LAL, E. P., 2019, Effect of mepiquat chloride on cotton varSuraj shoot and root growth behaviour. *Int. J. Commun. Syst.,* **7** (3) : 946.

SWETHA, P., SOLANKI, D., KUMARI, S. AND SAVALIA, S. G., 2017, Effect of potassium and sulphur levels on yield and yield attributes of popcorn (*Zea mays* Var. Everta*). Int. J. Current Microbiol. Appl. Sci.,* **6** (8) : 646 - 655.

ZHIPENG QU, XINHE WEI, WEI ZHAO, XINYU ZHOU, XIYUE WANG AND SHOUKUN DONG, 2025, Effects of mepiquat chloride (MC) spraying on the lodging resistance and yield characteristics of soybean. *Int. Agrophys.,* **39** : 191 - 201.

ZIDAN, R., SULEIMAN, S. AND BORAS, M., 2014, Effect of the retardant 'dextril' on the quality of tomato seedlings grown at high temperature conditions. *Int. J. Plant Soil Sci.,* **3** (5) : 497 - 506.

ZIZALA, V. J., 2000, Root influx of nutrients in the groundnut cultivars as influenced by different levels of potassium. *M.Sc. (Agri.) Thesis*, Gujarat Agric. Univ., Junagadh.