Research Article

Journal of Agriculture

Seed Priming to Enhance Drought Tolerance of Pigeon Pea (*Cajaunus cajan* L.) under Dryland Conditions of Kenya

Chris Gikonyo Kahungu, Maurice E Oyoo*, Paul K Kimurto

Department of Crops, Horticulture and Soils, Faculty of Agriculture, Egerton University, P. O. Box 536-20115, Egerton, Kenya

*Author for correspondence: maurice.oyoo@egerton.ac.ke

Received: 10-Aug-2024, Manuscript No. JAGRI-24-145089; **Editor assigned:** 13-Aug-2024, PreQC No. JAGRI-24-145089 (PQ); **Reviewed:** 27-Aug-2024, QC No. JAGRI-24-145089; **Revised:** 06-Jan-2025, Manuscript No. JAGRI-24-145089 (R); **Published:** 13-Jan-2025, DOI: 10.37532/JAGRI.2025.8(1).255-264

Abstract

Drought is a major abiotic stress that affects plant growth and productivity. Poor seed emergence due to water stress is a key impediment to obtaining high pigeon pea yield. Seed priming has been used to accelerate synchronized seed germination, improve seedling establishment, stimulate vegetative growth and crop yield in many plants. Field experiments were conducted to determine the effect of different seed priming methods on yield and yield parameters of pigeon peas under drought conditions. The seeds of three pigeon pea genotypes, EUMDP 3, Egerton Mbaazi M1 and Kat 60/8 were primed with distilled water, 30% Polyethene Glycol (PEG), 1% Potassium Nitrate (KNO_3) and Gibberellic acid (GA_3) at 300 ppm. Unprimedseeds as the control was also incorporated. The trials were planted in Kerio Valley (37.7235°E, 2.2172°S) and agricultural training centre, Koibatek (10 35'S, 36°66'E) in a Randomized Complete Block Design (RCBD) split-plot arrangement, with three replicates for two seasons. Seed emergence, seedling growth, days to 50% flowering, number of branches, days to harvesting and grain yields were recorded. Data was subjected to analysis of variance at $p \leq 0.05$ level of significance using General Linear Model (GLM) procedure of Statistical Analysis System (SAS) and means separated by Tukeys' honestly significant difference test at 5%. Results showed that seeds treated with KNO_3 had higher significantly ($P \leq 0.05$) different effects on 50% germination, days to harvesting, seed yield, days to 50% flowering and plant height that any other seed priming agents. Distilled water and PEG showed less effect on yield and yield parameters compared to KNO_3 and GA_3. Seed priming treatment could serve to increase seed germination, early seedling establishment and yield of pigeon pea under drought stress conditions and 1% KNO_3 as a priming agent should be recommended for farmers in arid and semi-arid areas to ensure maximum productivity of pigeon peas.

Keyword: Seed priming • Seed emergence • Yield parameters

Introduction

Drought is one of the most damaging abiotic stresses in the world and has a significant negative impact on agricultural productivity. Global climate has become uncertain with unpredictable rainfall pattern being the primary cause of the frequent drought stress throughout the world [1]. FAO estimated drought induced economic losses to be about 28 billion dollars and it's predicted to become more extensive in the coming years [2]. Plants can experience drought at any stage of growth, but the biggest impacts are at seed germination. Drought at seed germination causes hydraulic reduction which impacts on all seed physiological and metabolic germination processes [3]. Yields and productivity of crops is significantly affected by inadequate supply of water during critical plant growing stages. Cell division, expansion and elongation are severely affected by circumstances of water deficit due to inadequate water flow in the xylem tissue [4].

Plants induce various physiological, morphological and molecular mechanisms to survive under drought stress. Some of the mechanisms include cell membrane stability, control of auxins and proline, and release of stress responsive proteins. The response to drought stress largely varies on the species, the stage of plant growth and other abiotic factors [5]. Breeding tolerant varieties, exogenous application of growth regulators, osmoprotectants, and plant mineral fertilizers, adjustment of cropping patterns are some of the practices being used to cope with drought stress [6]. The effects of drought stress have been reduced in recent years by a variety of biotechnological methods, including genetic mapping, drought-responsive gene characterization, and genetic engineering [7]. However, it has become challenging to breed for drought tolerance varieties due to the inadequate information on drought responsive gene and involvement of other abiotic plant stresses [8].

Plants response to drought stress conditions is classified into drought escape, drought avoidance, and drought tolerance. Drought escape involves regulation of the growth period and to avoid osmotic stress under drought conditions [9]. Through fast growth rate, high photosynthetic ability, high nitrogen level, and early flowering allows the drought escape plants to produce seeds before the onset of drought [10]. Drought avoidance involves the regulation of a morphological and physiological mechanisms that acts to cushion the plants from osmotic stress through rapid root growth, minimized stomatal counts and conductance, reduced leaf area, thickening of leaves, biosynthesis of cuticular wax on plant parts, and folding of leaves to limit the evapotranspiration [11]. Such plants also maintain the osmotic pressure through cellular, biochemical, and osmotic alterations and are capable of accumulating a variety of osmolytes in response to osmotic stress [12]. These osmolytes such as glycine betaine, proline, polyols sugars act as free-radical scavengers from the damaging effects of reactive oxygen species and also protect the structure and integrity of biomolecules and membranes [13].

Pigeon pea (*Cajanus cajan* L.) remains one of the most drought tolerant crop and can give some grain yield during dry spells when other legumes such as field beans will have wilted and dried up due to its deep roots and osmotic adjustment in the leaves [14]. The legume also maintains photosynthetic function during stress better compared to other crops in its class such as cow pea (*Vigna unguicultala* L.) [15]. Inspite of this, pigeon pea initial slow growth and seedling-stage sensitivity to drought stress reduces competition for light, water, and soil nutrients, resulting in low yield. Seed priming, a pre-germinative enhancement method induces early emergence of seedlings by regulating metabolic processes in the early phases of germination under drought stress [16]. Seed priming has been reported to increase uniform germination by reducing the imbibition time [17], increasing the pre-germinative enzyme repair of damaged DNA, and regulating osmosis [18,19]. Seed priming has been reported to improve stand establishment in many staple crops by inducing resistance against drought and heat stress through early initiation of germination, reduced risks rotting of seed and stunted seedling growth. This is a process that hydrates the seed to activate pre-germinative metabolic and biochemical activity without causing radical protrusion [20]. Seed priming increases the quantity of mitochondria and speeds up cell division, allows *de novo* synthesis of nucleic acids and proteins; adenosine tri phosphate production and activation of sterols and phospholipids [21]. There are a different types of priming treatments some of which include osmo-priming, hydro-priming hormonal-priming and biological priming. In the present study, the effectiveness of seed priming in mitigating against drought stress in pigeon pea was assessed.

Materials and Methods

Experimental site

This experiment was conducted at ATC-Koibatek, Baringo County and Kerio valley Research station, Elgeyo Marakwet County. Kerio valley Research station is a low attitude area and lies 975 m above sea level in agro-ecological zone UM4, with low agricultural potential. The station lies within longitudes 37.7235°E and latitudes 2.2172°S. It receives between 545 and 629 mm of rainfall. Long rains season is between April and July while the short rains season is between October and January. This is a hot dry region with a mean annual temperature of 22.6°C, mean annual maximum temperature of 28.6°C and mean annual minimum of 16.5°C. The soils are well drained, very deep, dark reddish brown to dark red, friable sandy clay to clay (Acri-RhodicFerrassols). Koibatek sub county lies 0°8'N 360 2'E in agro ecological zone iv and an altitude range of a between 1890 meters above sea level (m.a.s.l). It receives an annual precipitation of 700-900 mm per year with a mean daily temperature of 24.3°C. The soils are dark colored with high clay content and are classified as vertisols [22].

Plant materials

Three pigeon pea varieties: EUMDP 3, Egerton Mbaazi M1 and Kat 60/8 were used in the study. EUMDP 3, Egerton Mbaazi M1 (used as the check) were sourced from Egerton seed unit. Both are of medium maturity (105 to 129 days). Kat 60/8, a late maturing variety (135 to 150 days) was sourced from KALRO. Seeds for priming were surface sterilized with 5% NaOCl solution (household bleach diluted 1:1 with sterile water) for 30 min to avoid fungal infestation, and rinsed three times with sterile distilled water. Tetrazolium and germination tests were done on the seeds to determine seed viability and maximum germination potential of the seeds, respectively.

Seed priming techniques

Selected seed for priming were surface sterilized with 5% NaOCl solution (household bleach diluted 1:1 with sterile water) for 30 min to avoid fungal invasion, and rinsed three times with sterile distilled water. Priming was done by soaking the seeds into distilled water (hydro priming), 30% Polyethylene Glycol (PEG), 1% Potassium Nitrate (KNO_3) and 300 ppm Gibberellic Acid (GA_3) for 6 hours. Each of the 3 pigeon pea variety were subjected to the 4 priming treatments while control were left untreated in the dark at 25°C. Primed seeds were then sun dried for 24 hr at 25°C to original moisture contentof 12-13%. The treated seeds were then planted immediately in the field. Unprimed seeds were used as the control treatment.

The experiment was laid in Randomized Complete Block Design (RCBD) split-plot arrangement, with three replicates for two seasons. Primed seed were planted in 4 rows measuring 5 meters paced at 75 × 20 cm and a 1 m separation between the plots with the main plot being the variety and treatments being the subplots. All the seeds were hand sown (2 seeds per hill) as a pure stand at a seed rate of 12 kg/acre at a depth of 5 cm.

All treatments were subjected to the same recommend management practices from land preparation to weed control and harvesting. During planting DAP was applied as basal fertilizer at a rate of 50 kg/acre. 4-5 weeks after germination, top dressing with CAN was done at the rate of 75 kg/acre. Pest and disease management was done by use of pesticides as was required depending on the pest or disease that attack the crop. At maturity dry pods were picked individually.

Data collection

Stand count and germination percentage: The number of seedlings that emerged to the surface were taken every 24 hours for 7 days after start of emergence. Germination Percentage (GP) was then determined.

Yield and yield parameter: Data on physiological growth was collected from a sample of ten plants taken from each treatment. Days to 50% flowering was done by taking the mean of the ten randomly selected pigeon pea plants from the sub plot and counting the number of days from sowing to when 50% of the plant flowered. Days to maturity was measured by taking the mean of ten randomly selected pigeon pea plants from the plot and counting the number of days from sowing to when 90% of the fingers of the plants had matured. Number of pods per plant was taken by averaging ten randomly selected plants and counting the number of pods per plant. The number of branches per plant was taken every week for the first 3 months after emergence. Plant height (cm) was measured at maturity. Yield was determined by harvesting the four rows 100-seed weight of sun-dried seeds per plant was also taken after harvesting. The total yield from each plot was then weighed and converted into kilograms per hectare.

Data analysis: All data collected on germination and yield was first subjected to Shapiro Wilk test to check for normal distribution. Means were separated and compared using the Tukey's Minimum Significant Difference (MSD) test at $P \leq 0.05$. Data on yield, number of branches, height, 100-seed weight were subjected to Analysis of Variance (ANOVA) using the general linear model procedure in SAS (SAS institute version 9.4, 2002).

Results

Effects of seed priming agents on germination, stand count, days to flowering, number of branches, plant height, hundred seed weight and yield of pigeon peas under drought conditions.

Seasons had significant ($p \leq 0.001$) effects on number of branches and plant height. However, site had significant ($p \leq 0.001$) effects on plant height only. Number of branches and plant height were significant ($p \leq 0.01$, $p \leq 0.001$) due to varietal effects. Site × variety interaction had significant ($p \leq 0.05$) effects on both number of branches and plant height. Season × site × variety interaction had significant effects on plant height. Effects due to treatment, weeks, season × week, site × week, variety × week and treatment × week interactions had significant ($p \leq 0.05$, $p \leq 0.001$) effects on both number of branches and plant height.

Seasons and treatment effects were significant ($p \leq 0.001$) for all the traits except hundred seed weight. Site had significant ($p \leq 0.001$) effects on stand count and yield. Site and site × season effects were significant ($p \leq 0.001$) for only germination percentage and yield. Variety had significant ($p \leq 0.05$, $p \leq 0.001$) effects on all the traits measured. The site × treatment and variety × treatment interactions were only significant ($p \leq 0.05$, $p \leq 0.001$) for days to flowering.

Treatment with KNO_3 significantly influenced 50% germination, days to harvesting, seed yield, days to 50% flowering and plant height that any other seed priming technique as shown in Table 1. Seed priming with KNO_3 significantly accelerated plant germination time, reduced days to 50% flowering and harvesting and increased plant height thereby increasing yield. Seed priming KNO_3 resulted in yield of 2.39 t/ha which was significantly different from all other treatments except GA_3 (2.23 th^{a-1}).

All the seed priming techniques had an insignificant effect on the number of branches. However, these were significantly different from the control treatment. Seed priming as compared to the control significantly influenced all traits except for, days to 50% flowering and plant height. Seed priming treatments significantly differ from each other for their effect on the number of branches as given in Table 1. There was no significant difference between KNO_3, distilled water, GA and PEG on the number of branches recorded as shown in Table 1.

Control (untreated) had the least number of branches 64 (10^{-1}) which had a significant difference with all other treatments. Distilled water and PEG treatments showed did not differ on germination percentage as was the case between GA_3 and PEG (Table 1). Treatment with distilled water showed significant difference on yield to other treatments apart from GA (2.33 tha^{-1}) and PEG (1.95 tha^{-1}). Lastly on yield, treatments with PEG, distilled water and control showed no significant difference (Table 1). There was significant difference on days to 50% flowering among the treatments with PEG and GA_3.

Treatment	Germination %	Stand count	Days to flowering	Number of branches	Hundred seed weight	Yield (t/ha)
KNO_3	4.92^{d}	48.78^{a}	134.36^{a}	6.88^{a}	22.20^{a}	2.39^{a}
Distilled Water	5.86^{b}	47.58^{a}	130.81^{ab}	5.81^{b}	22.32^{a}	1.97^{bc}
GA_3	5.44^{c}	47.00^{a}	131.36^{ab}	6.24^{b}	22.36^{a}	2.23^{a}b
Control	7.94^{a}	38.78^{b}	126.08^{c}	4.61^{c}	22.51^{a}	1.81^{c}
PEG	5.64^{bc}	38.36^{b}	129.08^{bc}	5.85^{b}	22.30^{a}	1.95^{bc}
Tukey $MSD_{0.05}$	0.4	6.5	3.67	0.61	0.35	0.35

Note: Means followed by the same letter are not significantly different at $p \leq 0.05$.

Effect of variety on seed priming seed treatment on yield and yield components of pigeon pea: Variety KAT 60/8 which is a late maturing variety took most day to emerge. These was significantly different from those of EUMDP3 and Egerton Mbaazi M1 whose days to 50% emergence were not significantly different from each other. Variety KAT 60/8 had significant difference from EUMDP3 and Egerton Mbaazi M1 on germination with KAT 60/8 taking the longest to attain 50% germination at $p \leq 0.05$ (Table 2). Variety EUMDP3 and Egerton Mbaazi M1 had no significant difference on germination. The three varieties had significant difference on days to 50% flowering with KAT 60/8 taking the longest.

Egerton Mbaazi M1 and KAT 60/8 did not have any significance difference on the days to harvesting, but KAT 60/8 expressed a significant difference from EUMDP3 on the same. On hundred seed weight, the three varieties expressed significant differences among themselves. Lastly, KAT 60/8 recorded the lowest yield (1.89 t/ha) expressing significant difference with Egerton Mbaazi M1 and EUMDP3 (Table 2).

Variety	Germination %	Stand count	Days to flowering	Number of branches	Hundred seed weight	Yield (t/ha)
EUMDP3	5.78^{b}	46.82^{a}	129.28^{b}	5.56a^{b}	22.27^{b}	2.16^{a}
Egerton Mbaazi M1	5.72^{b}	46.32	129.88^{ab}	6.20^{a}	21.82^{c}	2.15^{a}
KAT 60/8	6.38^{a}	39.17^{b}	131.85^{a}	5.56^{b}	22.93^{a}	1.89^{b}
Tukey $MSD_{0.05}$	0.26	4.32	2.44	0.41	0.23	0.25
Note: Means followed by the same letter are not significantly different at $p \leq 0.05$.						

Effects of season and environment on germination, days to flowering, number of branches, plant height, hundred seed weight and yield: The two seasons had significance different on germination, days to 50% flowering, days to harvesting, number of branches, plant height and yield (Table 3). However, there was no significance difference on the weight of a hundred seeds due to the seasons (Table 3).

Season	Germination %	Stand count	Days to flowering	Number of branches	100 seed weight	Yield (t/ha)
1	5.74^{b}	37.08^{b}	121.72^{b}	4.53^{b}	22.35^{a}	1.03^{b}
2	6.18^{a}	51.12^{a}	138.96^{a}	7.22^{a}	22.33^{a}	3.11^{a}
Tukey $MSD_{0.05}$	0.18	2.94	1.66	0.28	0.16	0.17
Note: Means followed by the same letter are not significantly different at $p \leq 0.05$.						

The locations did not differ on germination percentage, number of branches and hundred seed weight (Table 4). However, locations differed on days to heading with crops in Kerio Valley had high stand count and flowered earlier than those in Baringo. On the other hand, pigeon pea in Baringo had higher yield than those in Kerio Valley as shown in Table 4.

Site	Germination %	Stand count	Days to flowering	Number of branches	Hundred seed weight	Yield (t/ha)
Kerio Valley	5.96^{a}	47.07^{a}	132.98^{a}	5.87^{a}	22.34^{a}	1.91^{b}
Baringo	5.97^{a}	41.13^{b}	127.70^{b}	5.88^{a}	22.33^{a}	2.23^{a}
Tukey $MSD_{0.05}$	0.18	2.94	1.66	0.28	0.16	0.17
Note: Means followed by the same letter are not significantly different at $p \leq 0.05$.						

The effect of weeks on number of branches and plant height in primed seeds of the 3 pigeon pea varieties across two seasons and sites: Number of branches and plant height were significantly different on weeks after sowing. Number of branches were significantly high 5 weeks after sowing as compared to 3 weeks after sowing. Similar observation was seen on plant height (Table 5).

Week after sowing	Number of branches	Plant height
3	1.13^{b}	23.21^{b}
5	10.62^{a}	119.74^{a}
Tukey $MSD_{0.05}$	0.28	1.93
Note: Means followed by the same letter are not significantly different at $p \leq 0.05$.		

Correlation coefficients of yield and yield components of pigeon peas: Germination percentage had significant positive correlation with 100 seed weight (r=0.94*) and days to flowering (r=0.96**) and negative significant correlation with plant height (r=0.99**) and number of branches (r=-0.97**). The 100 seed weight increased with decrease in plant height (r=0.90*) and number of branches (r=0.93*) and increased with increase in days to flowering (r=0.95*). Days to flowering had significant negative relationship with plant height (r=0.95**) and number of branches (r=-0.97**). Number of branches increased with increase in number of branches (r=0.92*) (Table 6).

Traits	Yield	Stand count	Germination %	100 seed weight	Plant height	Number of branches	Days to flowering
Stand count	0.77						
Germination %	-0.81	-0.65					
100 seed weight	-0.76	-0.6	0.94*				
Plant height	0.87	0.72	-0.99***	-0.90*			
Number of branches	0.92*	0.73	-0.97**	-0.93*	0.98212		
Days to flowering	-0.87	-0.56	0.96**	0.95*	-0.95**	-0.97**	
Note: *; ** and *** is $p \leq 0.05$; $p \leq 0.01$ and $p \leq 0.001$ respectively.							

Discussion

Pegeon pea production in arid and semi-arid ecosystems of the Kenya is under threat because of frequent drought under a changing climate. The current study was conducted to determine the effect of different seed priming methods on yield and yield parameters of pigeon peas under drought conditions in Kenya. The results indicated that priming techniques can enhance germination of pigeon pea under drought conditions and consequently result in enhanced yields. Seeds primed with KNO_3 showed a significant advantage over the other seed priming treatments. Priming with KNO_3 indicated the best germination rate and emerged to be the most effective as it took the least days to 50% flowering, had the best plant height, highest number of branches and the highest yield. These results are in confirmation with that of Fallah, et al. which indicated that KNO_3 is effective in increasing the rate and percentage of emergence in Nigella sativa under water stress condition [23]. The role of KNO_3 to improve seedling emergence, growth and other biochemical attributes under drought is well documented.

This study established that priming with KNO_3, GA, PEG and distilled water decreased the mean emergence time and improved emergence index substantially. This can be attributed to increased water imbibition by seeds, increased cell division and elongation, quick repair and synthesis of RNA and DNA, activation of seed reserve mobilizing enzymes like dehydrogenase, β-amylase and acid phosphatase among others [24]. Production of the hydrolyzing enzymes from stored resources, such as amylase, protease, and phosphatase, is necessary for germination to take place so that the hydrolyzed compounds can be employed in the germination stage to build the seedling tissues. The hydrolysis of stored resources to generate seedling tissue may be affected during drought stress because water availability to the seed reduces, which could result in a reduction in seedling length and weight [25]. Primed seedlings have the potential of increased superoxide dismutase, catalase and limit lipid peroxidation which is important for plants to resist water deficit [26]. Exposing the pigeon pea seeds to the priming treatment stimulates pre-germination processes that reduced mean emergence time and increased seedling establishment. Pigeon pea seedling establishment under adverse conditions of drought was accelerated by priming, which encouraged numerous germination processes including enhanced water uptake, cell division, and hydrolytic enzymes.

According to earlier research by Yuan-Yuan, et al. rice priming with water and Polyethylene Glycol (PEG) during drought significantly boosted the emergence percent, emergence index, and emergence time [27]. Zhang, et al. established that polyethylene glycol-primed sorghum cultivated under drought conditions displayed enhanced emergence percentage, emergence index, and vigor index [28]. In this study,

KNO_3, GA, PEG and distilled water stimulated pigeon pea seedling growth by acting as initiators of fundamental emergence and growth processes within the seed. This study found that priming substantially increased the height of pigeon pea under drought. This is in confirmation with a study by Zhang, et al. that established that priming sorghum with PEG increased shoot and root length, plant height, leaf area and panicle length. Increase in plant height was as a result of increased cell division and elongation, synthesis of nucleic acid and repair in the primed seeds. In a study by Tabassum, et al. hydro priming with distilled water and $CaCl_2$ increased plant height, leaf area and grain yield of wheat under drought conditions [29]. Priming with KNO_3 was reported to significantly change specific enzymatic activities within the seeds thus improving seedling establishment and plant growth [30]. GA_3 plays a key role in mapping and activation of gene encoding enzymes largely involved in germination. In a study by Li, et al. it was found that priming rapeseeds with GA_3 significantly improved levels of soluble sugars, soluble protein and proline that increase with increase with water stress [31]. The study further established increased levels of superoxide dismutase on primed seed indicating that the use of GA enhances germination improving its tolerance to water stress.

We established that priming pigeon pea seed with KNO_3, GA_3, PEG and distilled water substantially improved yields under drought stress. The difference of grain yield between the primed seeds and the control was significant. However, pre-exposing the seeds to KNO_3 solution was most effective. The difference in grain yield between the primed seeds and the control (unprimed) may be due to reduced mean germination time, better seedling establishment in primed seeds ultimately resulting in high yield. Similar results are documented by Chavan, et al. who noted increased seedling establishment and improved grain yields in soya bean seeds primed with PEG [32]. The improved seedling establishment as a result of priming can subsequently enhance plant drought tolerance and increase crop yield [33].

Sharma, et al. argues that under water stress, plants excessively produce ROS that potentially cause oxidative damages to plant cells [34]. In response, plants produce ROS-scavenging antioxidants such as SOD and POD. Priming induced drought tolerance has be closely associated with increased SOD and POD activity [35]. The results of this study are in confirmation to a study by Ali, et al. that established that FARO44 rice seedlings had significantly high carbohydrate and chlorophyll content when primed with KNO3 resulting in higher grain yield under drought condition.

Season and environment had significant variations of yield and yield parameters. We recorded better seed germination, shorter days to 50% flowering and harvesting, higher number of branches, better plant height and higher yields in season 2. This can be attributed to a better rainfall distribution experienced in season 2. This confirms findings of a study by Adamgbe and Ujoh that established a strong positive correlation between rainfall distributions with maize yield. They noted that rainfall account accounts for annual variations in in yields. In this case, relatively higher rainfall spread over the rain days led to better seed germination, higher number of branches, shorter days to flowering and harvesting and therefore higher yields in season 2. Lastly, EUMDP3 and Egerton Mbaazi M1 both being medium duration gave higher yields than KAT 60/8, this can be attributed to the ability of the two to quickly utilize the little rain water available as adopted and held by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Conclusion

Priming with KNO_3, GA_3, PEG and distilled water responded positively in reducing mean emergence time, seedling growth, reducing days to 50% flowering and subsequently increasing grain yield of pigeon pea grown under drought condition. Improved emergence, better stand establishment and early maturity as a result of priming points towards increased tolerance to drought. Priming seeds with KNO_3 and GA was established to be more effective in reducing mean emergence time, reducing days to harvesting and increasing yield than priming with PEG and distilled water. The increase in yield as a result of priming can be attributed to the stimulation of pre-germination enzymatic activities within the seeds; activation of reserve mobilizing enzymes and cell division that consequentially result to enhanced emergence and growth. The findings of this study justify seed priming as an affordable and easy practice to be adopted by pigeon pea farmers in dry areas. Farmers in drought pigeon pea growing areas can prime the seeds with KNO_3 and GA_3 before planting to confer the seed with a considerable advantage in water resources consumption for improved production.

Data Availability

The data supporting the results of this study are available.

Acknowledgements

The research was funded by Kenya climate smart agricultural program. This work was made possible through the collaboration of Kerio Valley research station and Koibatek farmers training centers. The institutional support offered by Egerton University is appreciated.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

1. Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. *Science*. 333, 616-620 (2011).

2. Bareke TJ. Biology of seed development and germination physiology. *Adv Plants Agric Res*. 8, 336-346 (2018).

3. Hussain M, Malik MA, Farooq M *et al*. Improving drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. *J Agron Crop Sci*. 194, 193-199 (2008).

4. Demirevska K, Zasheva D, Dimitrov R *et al*. Drought stress effects on Rubisco in wheat: Changes in the Rubisco large subunit. *Acta Physiol Plan*t. 31, 1129-1138 (2009).

5. Vurukonda SS, Vardharajula S, Shrivastava M *et al*. Enhancement of drought stress tolerance in crops by plant growth promoting rhizobacteria. *Microbiol Res*. 184, 13-24 (2016).

6. Liang C. Genetically modified crops with drought tolerance: Achievements, challenges, and perspectives. *Drought Stress Tolerance in Plants*. 2, 531-547 (2016).

7. Khan S, Anwar S, Yu S *et al*. Development of drought-tolerant transgenic wheat: Achievements and limitations. *Int J Mol Sci*. 20, 3350 (2019).

8. Manavalan LP, Guttikonda SK, Tran LSP *et al*. Physiological and molecular approaches to improve drought resistance in soybean. *Plant Cell Physiol*. 50, 1260-1276 (2009).

9. Kooyers NJ. The evolution of drought escape and avoidance in natural herbaceous populations. *Plant Sci*. 234, 155-162 (2015).

10. Liu Y, Li P, Xu GC *et al*. Growth, morphological, and physiological responses to drought stress in Bothriochloa ischaemum. *Front Plant Sci*. 8, 230 (2017).

11. Khan MS, Kanwal B, Nazir S. Metabolic engineering of the chloroplast genome reveals that the yeast ArDH gene confers enhanced tolerance to salinity and drought in plants. *Front Plant Sci*. 6, 725 (2015).

12. Liu HY, Yu X, Cui DY *et al*. The role of water channel proteins and nitric oxide signaling in rice seed germination. *Cell Res*. 17, 638-649 (2007).

13. Slavík L, Valenzuela-Ríos JI, Hladil J *et al*. Warming or cooling in the Pragian? Sedimentary record and petrophysical logs across the Lochkovian–Pragian boundary in the Spanish Central Pyrenees. *Palaeogeogr Palaeoclimatol Palaeoecol*. 449, 300-320 (2016).

14. Sarkar B, Chakravarthy VS, Varalaxmi Y *et al*. Genetic diversity among Pigeonpea (*Cajanus cajan* L. Millsp.) genotypes using genic SSRs with putative function for drought tolerance. Int *J Curr Microbiol Appl Sci*. 6, 1804-1814 (2017).

15. Hussain M, Farooq M, Lee DJ. Evaluating the role of seed priming in improving drought tolerance of pigmented and non-pigmented rice. *J Agron Crop Sc*i. 203, 269-276 (2017).

16. Brocklehurst PA, Dearman J. Interactions between seed priming treatments and nine seed lots of carrot, celery and onion. II. Seedling emergence and plant growth. *Ann Appl Bio*l. 102, 585-593 (1983).

17. Hussain S, Khan F, Hussain HA *et al*. Physiological and biochemical mechanisms of seed priming-induced chilling tolerance in rice cultivars. *Front Plant Sc*i. 7, 116 (2016).

18. Farooq M, Wahid A, Kobayashi NS *et al*. Plant drought stress: effects, mechanisms and management. *Sustain Agric*. 153-188 (2009).

19. Paparella S, Araújo SS, Rossi G *et al*. Seed priming: State of the art and new perspectives. *Plant Cell Rep*. 34, 1281-1293 (2015).

20. Padgham J. Agricultural development under a changing climate: Opportunities and challenges for adaptation. *SIDALC Alliance of Agricultural Information Services*. (2009).

21. Dingil M, Eren M, Kadir S *et al*. Andosols/Andosol-Like soils. *The Soils of Turkey*. 347-357 (2018).

22. Fallah S, Malekzadeh S, Pessarakli M. Seed priming improves seedling emergence and reduces oxidative stress in Nigella sativa under soil moisture stress. *J Plant Nutr*. 41, 29-40 (2018).

23. Ali LG, Nulit R, Ibrahim MH *et al*. Efficacy of KNO_3, SiO_2 and SA priming for improving emergence, seedling growth and antioxidant enzymes of rice (*Oryza sativa*), under drought.

Sci Rep. 11, 3864 (2021).

24. Ali LG, Nulit R, Ibrahim MH *et al*. Enhancement of germination and early seedling growth of rice (*Oryza sativa*) var. FARO44 by seed priming under normal and drought stressed conditions. *J Plant Nutr*. 43, 1579-1593 (2020).

25. Saed-Moocheshi A, Shekoofa A, Sadeghi H *et al*. Drought and salt stress mitigation by seed priming with KNO_3 and urea in various maize hybrids: An experimental approach based on enhancing antioxidant responses. *J Plant Nutr*. 37, 674-689 (2014).

26. Yuan-Yuan SU, Yong-Jian SU, Ming-Tian WA *et al*. Effects of seed priming on germination and seedling growth under water stress in rice. *Acta Agronom Sin*. 36, 1931-1940 (2010).

27. Zhang F, Yu J, Johnston CR *et al*. Seed priming with polyethylene glycol induces physiological changes in sorghum (*Sorghum bicolor* L. Moench) seedlings under suboptimal soil moisture environments. *PLoS One*. 10, e0140620 (2015).

28. Tabassum T, Farooq M, Ahmad R *et al*. Terminal drought and seed priming improves drought tolerance in wheat. *Physiol Mol Biol Plants*. 24, 845-856 (2018).

29. Farooq M, Gogoi N, Barthakur S *et al*. Drought stress in grain legumes during reproduction and grain filling. *J Agron Crop Sci*. 203, 81-102 (2017).

30. Li Z, Lu GY, Zhang XK *et al*. Improving drought tolerance of germinating seeds by exogenous application of Gibberellic Acid (GA_3) in rapeseed (*Brassica napus* L.). *Seed Sci Technol*. 38, 432-440 (2010).

31. Chavan NG, Bhujbal GB, Manjare MR. Effect of seed priming on field performance and seed yield of soybean (*Glycine max* (L.) Merill) varieties. *The Bioscan*. 9, 111-114 (2014).

32. Farooq M, Usman M, Nadeem F *et al*. Seed priming in field crops: Potential benefits, adoption and challenges. *Crop Pasture Sci*. 70, 731-771 (2019).

33. Sharma P, Jha AB, Dubey RS *et a*l. Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. *J Bot*. 2012, 217037 (2012).

34. Chen K, Arora R. Dynamics of the antioxidant system during seed osmopriming, post-priming germination, and seedling establishment in Spinach (*Spinacia oleracea*). *Plant Sci*. 180, 212-220 (2011).

35. Adamgbe, Msughter E, Ujoh F. Effect of variability in rainfall characteristics on maize yield in Gboko, Nigeria. *J Environ Prot*. 4, 36308 (2013).