



Effects of Seed Priming on Growth and Yield of Sorghum (*Sorghum bicolor*) in Eastern Ethiopia

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ABSTRACT

Poor stand establishment is the major production constraint in semi-arid lowlands of Eastern Ethiopia and resulting low crop productivity. The objective of the study was to evaluate the effects of seed priming on growth and yield of sorghum (*Sorghum bicolor*). A factorial combination of three varieties (Dekeba, Melkam, and Teshale) and four priming media (water, N, Zn and unprimed control) replicated three times in RCBD. Results indicated that main effects of variety and media significantly ($P < 0.01$) influenced plant height, leaf area index (LAI), 1000-kernels weight, grain and biomass yields, while harvest index (HI) was affected only by priming media. Sorghum seeds primed with N media recorded the highest values in plant height (162cm), LAI (4), grain yield (3888 kg ha⁻¹) and HI (0.41), whereas, Zn primed seeds recorded the highest biomass yield (9457 kg ha⁻¹). The effect of interaction between variety and media was significant only on panicle weight where Zn priming in variety Melkam gave the highest panicle weight (82 g), while the lowest from Dekeba in unprimed seed (71 g). Among varieties, Teshale gave the highest grain (3713 kg ha⁻¹) and biomass (9400.64 kg ha⁻¹) yields, while the highest 1000-kernel weight recorded in variety Melkam. Overall, the results indicated nutrient priming with N or Zn performed better than hydropriming in all the traits studied. Therefore, it can be concluded that seed priming with either N or Zn was effective for better establishment, growth, and yield of sorghum under rainfed production of semi-arid lowlands of eastern Ethiopia.

Keywords: Hydro-priming, nutrient-priming, priming media, stand establishment, variety,

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is an important food and forage crop of arid and semiarid regions of the world. On a global basis, sorghum ranked fifth in total cereals grain production after wheat, maize, rice, and barley (FAO, 2014). Sorghum, in Ethiopia, is produced mainly for home consumption and is a key factor in household food security, particularly in marginal areas with low rainfall and poor soil fertility (EIAR, 2014).

In marginal, rainfed production in semi-arid areas, good stand establishment is of the utmost importance for farmers who grow annual crops from seed because poor (or patchy) plant stands often result from the failure of the crop to emerge quickly and uniformly. Sorghum yield under such

condition is constrained by frequent drought, poor quality seeds, and lack of appropriate improved technologies. On the other hand, wide ranges of the soils in semi-arid lowlands are deficient in macro nutrients like N and suffer from Zn deficiency, resulting in reduced crop growth, poor yields, and low zinc concentration in edible crop parts (Sadeghzadeh and Rengel, 2011). Seed priming with micronutrients such as Zn possibly offers a simple economical approach for enhancing micronutrient plant nutrition.

Seed priming involves the soaking of seeds either in water or fertilizer solutions to activate pre-germinative biochemical processes after water imbibition and re-drying back to its original moisture level before radical protrusion (McDonald, 2000). The triggered metabolic activities persist after re-drying (Asgedom and Becker, 2001). Moreover, primed seeds exhibit activation of cellular defense responses, due to which they can better tolerate subsequent biotic or abiotic stresses in the field (Beckers and Conrath, 2007; Moradi and Younesi, 2009).

Many seed priming treatments have been used to enhance seed quality, among which hydro-priming and osmo-priming are the most commonly used. Hydro-priming is simply the soaking of seeds in pure water, while osmo-priming is the soaking of seeds in osmotic solutions (Farooq et al., 2006a; Samad et al., 2014). Nutrient priming is a type of osmo-priming in which seed is soaked in nutrient solutions to improve the physiological quality of seed during early germination stage (Mousavi et al., 2012).

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On-farm seed priming simply involves soaking seeds in water overnight, surface drying them to facilitate easy handling, then sowing them in the normal fashion. On-farm seed priming hastens germination and seedling emergence and promotes vigorous early growth so that moisture and nutrient resources are captured and utilized effectively. Earlier seed priming studies showed the pre-soaking of seeds is beneficial in improve seedling emergence speed and uniformity, and increase yield of treated crops as reported in sorghum (Al-Mudaris, 1998), rice (Farooq et al., 2006a), barley (Abdulrahmani et al., 2007), maize (Foti et al., 2008), wheat (Ghiyasi et al., 2008), and soybean (Sadeghzadeh and Rengel, 2011).

The findings of the seed priming research have a practical importance for the farmers practicing crop production under dryland farming conditions to improve stand establishment and to increase yield. However, the results obtained so far with priming were variable depending on the climatic conditions, genotype, and priming techniques used. The information available at field scale with regard to the priming effect on sorghum stand establishment and yield for eastern semi-arid lowlands of Ethiopia are scanty. Therefore, this study was conducted to understand the possible benefits derived from seed priming technology especially on sorghum stand establishment, growth and grain yield of grain sorghum.

2. Materials and Methods

2.1. Description of the Study Area

A field experiment was conducted at the Babile (situated at 9°13' N and 42°20' E) research substations of the Haramaya University at an elevation of 1650 m above sea level. The second site was at the Errer research sub-station (situated at 8°50' N and 42°00' E) of Fedis Agricultural Research Center, at an elevation of 1295 m above sea level. The study sites represent typical semi-arid climate with mean annual rainfall ranging from 400 to 600 mm. The total precipitation during the growing season was 439 mm and 398 mm at Babile and Errer, respectively. The mean annual temperature is 20°C ranging from a mean minimum of 12°C to mean maximum of 27°C. The fertility status of the surface soil at both locations was low. The soil texture at Babile was sandy loam with soil pH (1:2.5 H₂O) of 6.8, organic carbon (OC) = 0.62%, total N = 0.19%, Av. P = 3.14 mg/kg, while soil texture at Errer was sandy clay loam with soil pH of 6.92, OC = 1.34%, Total N = 0.27% and Av. P = 6.34 mg/kg.

2.2. Plant Materials

Three sorghum varieties tested were Dekeba, Melkam, and Teshale. The seeds for these varieties were obtained from Melkassa Agricultural Research Center (MARC) Sorghum Improvement Program. These varieties were selected for their qualities of early maturity, high yield and good Injera (traditional Ethiopian flattened pan cake) making quality. The earliness allows the varieties to escape terminal drought. The varieties Dekeba and Melkam are also a stay green

genotypes and the residues are therefore suitable for feeding livestock (EIAR, 2014).

2.3. Experimental Design and Procedures

A field experiment was conducted during 2014 main cropping season. The treatments consisted of three sorghum varieties (i.e., Dekeba, Melkam, and Teshale) and three priming media [i.e., water, N (9 g L⁻¹ urea solution), Zn (0.2 g L⁻¹ ZnSO₄ solution) and unprimed seed as a control]. The experiment was laid out in randomized complete block design in 3×4 factorial arrangement and replicated three times.

The experimental land plowed with a tractor twice and then leveled manually. Each plot with 3.6 m length and 3.75 m width = 13.5 m² has consisted of five rows at 75 cm apart. Priming treatments were applied with the soaking of each variety seeds with water, N, and Zn for the duration of 10 h. The 10 h duration is the recommended priming time for sorghum. The soaking time was followed by rinsing three times with water to remove excess salts from the seed coat. Soaked seeds were then surface dried and dried briefly under shade and planted in the field. Three seeds per hill were planted at a spacing of 75 cm × 15 cm between rows and hills, respectively. Thinning of seedlings was done at 21 days after sowing by retaining one healthy and vigorous seedling per hill to attain the desired plant population of 88, 000 per ha.

Mineral fertilizers, 23 kg P₂O₅ ha⁻¹ in the form of triple-super-phosphate (46% P₂O₅) and 46 kg N ha⁻¹ in the form of urea (46% N) were applied uniformly for all the plots. The whole of phosphorus (23 kg P₂O₅) and half of the nitrogen rates (23 kg N) were applied at the time of sowing while the remaining half of N rate (23 kg N) was applied at 35 days after sowing. All other agronomic practices were applied uniformly for all the plots.

2.4. Data Collection

2.4.1. Stands Establishment and Phenology

Plants in the central three rows of each plot were counted at the establishment (after thinning) and at the harvest maturity to determine the number of plants per meter square. Days to 50% emergence and 50% flowering were recorded when 50% of plants in the net plot area showed these phenological parameters, while physiological maturity was defined as the date when basal grains in 90% of the five randomly selected and tagged plants attained a black layer (Eastin et al., 1973).

2.4.2. Growth Characters

Leaf number, leaf length, and maximum leaf breadth data were recorded from five randomly selected plants of the net plots (three rows = 8.1 m²) at heading stage. Leaf area (cm²) was determined by multiplying leaf length and width with a correction factor of 0.75 (Stickler et al., 1961). Leaf area index was determined as a ratio of leaf area to the land area covered by the sample plants. The plant height (cm) was measured from ground surface to the tip of a panicle of the five randomly selected plants at the time of physiological maturity with a graduated measuring stick.

Table 1: Mean squares of ANOVA for the effects of variety and priming media on stand count and phenology of sorghum

Source of variation	DF	Mean squares				
		Phenology (days)			Stand count m^{-2}	
		DE	DH	DM	ISC	FSC
Location	1	2.35	396.68	25.68	0.15	0.10
Rep(Location)	4	0.26	2.11	0.39	0.079	0.098
Variety	2	7.76**	8.17**	60.43**	0.13ns	0.019ns
Media	3	57.83**	38.13**	42.13**	2.44**	4.686**
Variety*Media	6	0.523ns	2.11ns	0.653ns	0.084ns	0.212ns
Error	55	0.408	0.788	0.459	0.07	0.1136
CV (%)		8.79	1.51	0.61	3.24	4.55

*, **, significant at $P < 0.05$ and $P < 0.01$, respectively; ns, non-significant at $P = 0.05$; DE, days to 50% emergence; DH, days to 50% flowering; DM, days to 90% physiological maturity; ISC, initial stand count at establishment and FSC, final stand count at maturity and CV, coefficient of variation.

2.4.3. Yield and Yield Components

Panicle weight (g) was determined from the averages of five randomly sampled plants from net plots at the time of harvesting. Grain yield (kg ha⁻¹) was determined from sorghum heads harvested in net plots and the yield was adjusted to 12.5% moisture content and converted to grain yield per hectare. Thousand kernels weight (g) was determined by counting 500 grains in duplicate and weighed on an electronic balance and the weight was adjusted to 12.5% moisture content. The above ground dry biomass yield (kg ha⁻¹) was determined by adding the stover yield and whole panicle (head) weight (kg ha⁻¹). The harvest index was computed as the ratio of the grain yield to the aboveground dry biomass yield per plot.

2.5. Data Analysis

All data were checked for homogeneity of the error variance for the two locations. When the error variances are found to be homogeneous, ANOVA procedure for combined analysis using SAS version 9.1 (SAS and Guide, 2004) was employed. Means were separated using LSD test at 5% probability level.

3. Results

3.1. Stand Establishment and Phenology

3.1.1. Stand Establishment

The number of plants m^{-2} at emergence and maturity time was significantly ($p < 0.01$) affected by priming media but not by the variety and their interaction (Table 1). When averaged over varieties, the primed seeds with hydro, N and Zn media recorded more plants m^{-2} compared to unprimed seeds. Hydro-primed seeds recorded the highest number of plants m^{-2} at the period of establishment and maturity, however, the mean differences among priming media were not significant ($p > 0.05$) (Table 2). Compared to unprimed seeds, hydro-priming increased the stand counts by 10 and 15.8% respectively at establishment and maturity stages.

3.1.2. Phenology

The 50% emergence, 50% flowering and 90% maturity time were significantly ($p < 0.01$) influenced by sorghum variety and priming media, but not by the interaction between variety and priming media (Table 1). Sorghum varieties Melkam and Teshale were the fastest to emerge and mature,

Table 2: Effect of seed priming treatments on crop phenology and plant stand parameters of grain sorghum.

Treatments	Crop phenology (days)			Stand count m^{-2}	
	DE	DF	DM	Initial	Final
Variety					
Dekeba	7.87	59.46	111.83	8.55	7.70
Melkam	6.75	58.54	110.75	8.65	7.69
Teshale	7.17	58.38	108.71	8.69	7.74
LSD (0.05)	0.3694	0.514	0.3921		
Priming media					
Unprimed seeds	9.55	60.83	112.61	7.64	6.64
Hydro-priming	7.72	58.83	110.28	8.41	7.69
N-priming	6.33	57.83	109.72	8.37	7.59
Zn-priming	5.44	57.67	109.11	8.34	7.68
LSD (0.05)	0.4266	0.5932	0.4527	0.177	0.2252
CV (%)	8.79	1.51	0.61	3.24	4.55

DE = days to 50% emergence, DF = days to 50% flowering, DM = days to 90% maturity, LSD = least significant difference at 5% and CV = coefficient of variation.

respectively, while variety Dekeba took the longest time to emerge, flower and mature (Table 2). Likewise, priming media significantly affected the phenology of sorghum ($P < 0.01$). Zinc primed seeds were the quickest to reach 50% emergence, 50% flowering, and 90% maturity dates. As compared to unprimed seeds, Zn priming had resulted in about 4, 3.2, and 3 days advantage of earlier emergence, flowering, and maturity, respectively. The time taken to reach 50% emergence by N-primed (6.3 days) seeds was the second quickest followed by hydro-primed (7.7 days) treatments in that order, while unprimed seeds took the extended time to 50% emergency (9.6 days) (Table 2). Seeds priming with Zn and N media didn't show significant variation with regard to 50% flowing but were significantly quicker than that of hydro primed and uprimed seeds.

3.2. Growth Characters

3.2.1. Plant Height

The main effect of variety and priming media on plant height were highly significant ($P < 0.01$), while their interaction effect was not significant ($p = 0.05$) (Table 3). When averaged over priming media, variety Teshale was the tallest (160.2 cm) followed by varieties Melkam and Dekeba (Table 4). Among priming media, seeds primed with N recorded the highest mean plant height (161 cm) though not significantly different with Zn, while unprimed seeds resulted in the lowest plant height (136 cm) (Table 4). Overall, the plant

Table 3: Mean squares of combined ANOVA for the effects of variety and priming media on growth parameters

Source of variation	DF	Mean squares		
		Plant height (cm)	Leaf number	Leaf area index
Location	1	2244.5	33.21125	2.48
Rep(Location)	4	28.37	0.188194	0.024
Variety	2	1435.17**	0.235139ns	0.38*
Media	3	2740.91**	3.386065***	5.02**
Variety*Media	6	96.79ns	0.074398ns	0.093ns
Error	55	43.23	0.16759	0.067
CV (%)		4.3	4.6	7.3

Table 4: Effect of seed priming treatments on crop phenology and plant stand parameters of grain sorghum.

Treatments	Plant height (cm)	Leaf number	Leaf area index
Variety			
Dekeba	144.83	9.03	3.40
Melkam	154.25	9.02	3.61
Teshale	160.17	8.85	3.63
LSD (0.05)	3.804		0.149
Priming media			
Unprimed seeds	135.89	8.37	2.84
Hydro-priming	152.39	8.94	3.49
N-priming	162.61	9.34	4.08
Zn-priming	161.44	9.22	3.79
LSD (0.05)	4.392	0.2735	0.173
CV (%)	4.3	4.6	7.3

LSD = least significant difference at 5% and CV = the coefficient of variation.

height increase achieved due to N priming was 19.6% higher over that of unprimed seeds.

3.2.2. Leaf Number and Leaf Area Index

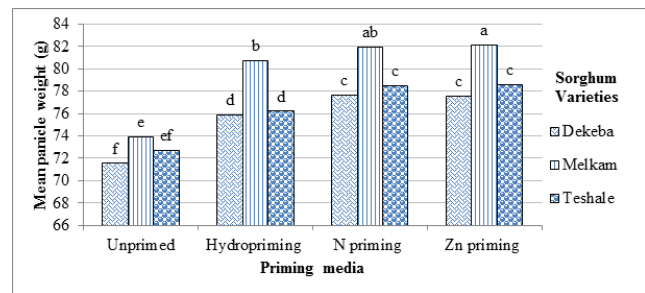
The result showed that seed priming media significantly ($P < 0.05$) affected the leaf number of sorghum, while the main effects of variety and the interaction between variety and priming media on leaf number were not significant ($p > 0.05$) (Table 3). Priming of sorghum seeds with N solutions recorded the highest leaf number (9 leaves per plant), although not significantly different with Zn it was higher than that of hydropriming (Table 4). Priming with N solution had resulted in about 11.6% higher leaves compared to unprimed control.

The main effects of variety and priming media on leaf area index (LAI) were significant ($p < 0.01$), while their interaction effect was not significant (Table 3). Leaf area index recorded for varieties Teshale and Melkam was at par but significantly higher than that of variety Dekeba (Table 4). Similarly, the N-primed seed had recorded the highest LAI (4.1) followed by Zn and hydro-primed seeds. The observed increase in LAI due to N-priming was 43.4% over unprimed seeds (Table 4).

3.3. Yield and Yield Components

3.3.1. Yield Components

The results indicated that main effects of priming media and variety on the weight of 1000-kernels were significant (p



* Bars with the same letter are not significantly different at $P = 0.05$.

Figure 1: Interaction effect of priming media and variety on mean panicle weight of grain sorghum

< 0.05), while their interaction effect was not significant ($p = 0.05$) (Table 5). All the three priming media gave similar kernel weight, while the lowest kernel weight was from unprimed seeds (Table 6). The highest 1000-kernels weight was for variety Melkam followed by varieties Dekeba and Teshale in that order (Table 6).

Both the main ($p < 0.01$) and interaction ($p < 0.05$) effects of variety and priming media on panicle weight were significant (Table 5). Variety Melkam with Zn-priming recorded the highest panicle weight (82 g), which was 11% higher over unprimed seeds, while the lowest panicle weight (72 g) was from variety Dekeba in unprimed seed (Fig. 1).

3.3.2. Grain and Biological Yield

Highly significant ($p < 0.01$) main effect of priming media and variety on grain and aboveground biomass yields, while their interaction effect was not significant ($p = 0.05$) (Table 5).

Variety Teshale recorded the highest sorghum grain yield (3713.4 kg ha⁻¹) which was 4.3% higher over that of variety Dekeba. The grain yield recorded for variety Melkam was significantly higher over that recorded in Dekeba (Table 6). The highest grain yield was obtained with N priming (3889 kg ha⁻¹) which was 19.6% higher over the unprimed seed; however, no significant difference between N and Zn primed seeds. Moreover, grain yield recorded with N and Zn nutrient solutions was significantly higher over that of hydro primed seeds, while unprimed seeds recorded the lowest grain yield (3252.56 kg ha⁻¹) (Table 6).

Variety Teshale recorded the highest sorghum above-ground biomass yield (9400.64 kg ha⁻¹) followed by variety Melkam, while variety Dekeba recorded the lowest aboveground biomass yield (9136.25 kg ha⁻¹). The above-ground biomass yield obtained from variety Teshale was about 3% higher over that obtained from variety Dekeba (Table 6). Similarly, Zn-primed sorghum seeds had recorded the highest aboveground biomass yield (9457.41 kg ha⁻¹) which was 6.8% higher over that of unprimed seeds, while its difference with that of N primed seeds was non-significant. Hydroprimed seeds, on the other hand, recorded significantly lower biomass yield than nutrient primed seeds (Zn and N) but higher over that of unprimed seeds (Table 6).

Table 5: Mean squares of ANOVA for yield and yield components of sorghum as a function of priming media and variety

Source of variation	DF	Mean squares				
		Grain yield (kg/ha)	Biological yield (kg/ha)	Harvest index	1000-kernels weight (g)	Panicle weight (g)
Location	1	472173.3	51053.44	0.0078	4.1	1.59
Rep(Location)	4	10173.2	40483.8	0.0001	0.07	1.45
Variety	2	138841.9**	424432.4**	0.0001ns	6.84**	108.2**
Media	3	1683784.4**	1407460.8**	0.0085**	2.33**	179.1**
Variety×Media	6	4906.7ns	28682.4ns	0.0001ns	0.06ns	3.28*
Error	55	11772.2	28041.3	0.00012	0.08	1.123
CV (%)		2.17	1.81	2.81	1.04	1.37

*, ** is significant at $P < 0.05$ and $P < 0.001$, ns is non-significant at $P = 0.05$ and CV = coefficient of variation.

Table 6: Mean values for main effects of variety and priming media on yield and yield components of grain sorghum

Treatments	Grain yield (kg ha-1)	Biomass yield (kg ha-1)	Harvest index	1000-kernels weight (g)
Variety				
Dekeba	3561.71	9136.25	0.391	27.16
Melkam	3646.91	9243.43	0.395	27.59
Teshale	3713.45	9400.64	0.395	26.53
LSD (0.05)	62.769	96.876		0.1633
Priming Media				
Unprimed seeds	3252.56	8859.01	0.368	26.56
Hydropriming	3539.48	9278.33	0.382	27.2
N priming	3888.8	9445.68	0.412	27.31
Zn priming	3881.9	9457.41	0.411	27.31
LSD (0.05)	72.48	111.86	0.0074	0.1885
CV (%)	2.98	1.81	2.81	1.04

LSD = least significant difference at 5% and CV = the coefficient of variation.

On the other hand, the effect of priming media on harvest index was highly significant ($p < 0.01$), while the main effect of variety and its interaction with media were non-significant ($p = 0.05$) (Table 5). The highest harvest index (0.412) was recorded with N priming which was 11.95% higher over unprimed seeds, although the difference with Zn priming was not significant. Moreover, the harvest index values recorded with nutrient priming with N and Zn solutions were significantly higher over that recorded with hydropriming, while the lowest harvest index (0.368) was from unprimed seeds (Table 6).

4. Discussion

4.1. Stand Establishment and Phenology

4.1.1. Stand Establishment

Optimum number of plants per unit area is an important index of seedling vigor that helps to attain the targeted plant population. In this study, the priming of sorghum seeds with nutrient solutions (i.e., Zn and N) and water had a profound effect on plant stands m^2 counted both at the establishment and physiological maturity stages, while the effect of variety on plant stand was not significant for both recording periods. For instance, as compared to unprimed seeds, hydropriming treatment recorded about 10% and 15.8% higher plant stands for both establishment and maturity periods, respectively.

The higher performance of primed seeds as compared to the unprimed control may be due to the fact that priming induces a range of biochemical changes in the seed that are required to initiate the germination process (Ajourri et al., 2004). All changes triggered by priming persist following re-drying of seeds back to original moisture level (Asgedom and Becker, 2001). (Beckers and Conrath, 2007) reported that hydro-primed seeds exhibited activation of cellular defense responses, due to which treated seeds had better tolerance to subsequent biotic or abiotic stresses in the field. The results are in harmony with (Mousavi et al., 2012) who reported about 11% and 13% increase in the emergence of Zn and urea primed maize seeds, respectively. Sudozai et al. (2013) also found higher emergence and seedling establishment in hydro-primed forage sorghum varieties. The results of this study also in accord with Afzal et al. (2013) who reported that maize hybrids and their interaction with the level of Zn priming were not significantly affected the germination count m^2 . In general, our findings revealed that nutrient priming (either with Zn or N) and hydro-priming were found useful techniques for enhancing establishment of sorghum, while no significant difference among varieties for a plant stands count.

4.1.2. Phenology

The duration of time the plant taken to complete emergence, flowering, and maturity are key attributes which reflect the uniformity and synchronization of seedling emergence, vigorous growth, and performance of plants in the field. Seeds that take less time to complete seed emergence are considered healthy and vigorous which result in good stand establishment and thus higher yield. In this study, seed priming had a significant influence on the number of days to 50% emergence, 50% flowering, and 90% physiological maturity than unprimed seeds. Better performance of priming treatments was probably due to the early completion of metabolic activities making the seed ready for radicle protrusion. After planting, primed seeds had germinated rapidly than unprimed seeds (Heydecker and Gibbins, 1977). Priming might also increase the activities of enzymes such as amylase, protease, and lipase, which have a great role in the breakdown of macromolecules and channeling of reserved food for growth and development of the embryo and ultimately this could result in early and higher seedling emergence (Yari et al., 2010).

The results show the priming of sorghum seed with a nutrient solution of N or Zn was important in reducing the duration of time required to complete seed emergence, flowering, and maturity in 4.2, 3.2, and 3.5 days earlier than those taken by unprimed seeds, respectively. The higher performance of nutrient priming than hydro-priming might be due to the nutritional effect of Zn and N in addition to priming. These nutrients deemed to be deficient in the soils of dry semi-arid regions dominated by sandy soils. The supply of which through priming, therefore, improves the rate of emergence, rapid seedling growth and enable to resist biotic and abiotic stresses.

The present results also indicated that varietal response was significantly variable on phenological characters. Variety Melkam has recorded the fastest seedling emergence time, whereas, variety Teshale has flowered and matured earlier than variety Melkam. This difference among varieties could be attributed to the genetic difference.

The current result agrees with Harris (1996) who reported the reduction of time to 50% emergence by 2-3 days due to on-farm hydro-priming compared to unprimed seeds. Similarly, faster emergence, early flowering, and maturity in hydro primed maize, rice, and chickpea were reported by Harris et al. (1999). Likewise, Murungu et al. (2004) reported earlier emergence with hydro-priming of cotton and maize.

4.2. Growth Characters

4.2.1. Plant Height

In this study, seed priming media significantly ($P < 0.05$) affected plant height. Nutrient priming with N solutions has resulted in longer plant height than with hydro-priming though the difference between N and Zn was non-significant. The results indicate that regardless of priming media, primed seeds recorded significantly longer plant height. The improved plant height might be the result of earlier emergence, uniform and vigorous seedlings that gave a stronger and more energetic start. These, in turn, might help the plant to utilize the available resources efficiently, grow rapidly, and resist moisture stress better than unprimed seeds (Farooq et al., 2006b).

4.2.2. Leaf Number and Leaf Area Index

The result indicated that priming media significantly influence leaf number of grain sorghum. Sorghum seeds primed with N followed by Zn have exhibited the highest number of leaves per plant than those hydro-primed seeds, while unprimed seeds performed poorly. The higher number of leaves with primed seeds than with unprimed seeds in this study might be attribute to priming effect which known to advance the rapid and vigorous growth of seedlings. This in turn allowed seedlings to extend roots deep into the soil and assisting utilize the available resources efficiently. Priming also reported in advancing resistance to abiotic and biotic stress better than unprimed seeds (Farooq et al., 2006b).

N-priming has resulted in the highest LAI (4.1) followed by Zn and hydro-priming while the unprimed seeds recorded the lowest LAI. The highest leaf area index with N priming

might be attributed to the significant increase in leaf expansion due to good germination and growth of plants. Leaf area development and growth are critical in determining the canopy leaf area index (LAI) to maximize the capture of solar radiation by the crop canopy for photosynthesis, leading to the accumulation of biomass, which finally defines crop yield. Hence, slow or inefficient development of the plant canopy may be critical in limiting the final yield produced by a crop. In agreement with this result, Yordanov et al. (2003) reported similar observations in maize with 1.5% ZnSO₄ priming. Similarly, N et al. (2005) also found higher growth rate of sorghum that ultimately resulted in high LAI with the priming of 1.5% ZnSO₄ solution while the least LAI is found in unprimed seeds. Afzal et al. (2013) also reported higher germination count per meter square, leaf area index, leaf area duration, crop growth rate, and net assimilation rate of hybrid maize to seed priming with different sources of zinc.

4.3. Yield and Yield Components

4.3.1. Yield Components

Thousand kernels weight is one of the important yield contributing attribute. In this study, results revealed that seed priming of grain sorghum has resulted in a significant increase in mean 1000- kernels weight. Increased kernel weight with seed priming was attributed to better dry matter partitioning to the developing grain that resulted from the greater crop growth rate and leaf area index exhibited at various growth stages. The result is in agreement with Farooq et al. (2006a) who reported higher kernels weight in rice due to osmopriming. Similarly, Bakht et al. (2010) reported that a hydro-primed maize seed has resulted in increased seeds weight and grains. Mousavi et al. (2012) also reported that seed priming of maize with tap water, urea, and zinc have increased ear diameter, ear length, grains per ear, and 100-grains weight. On-farm priming of corn with ZnSO₄, KH₂PO₄, KNO₃, and H₂O for different soaking durations increased 1000- kernels weight (Soleimanzadeh, 2013).

In this study, seed priming had a profound effect on mean panicle weight of grain sorghum varieties. Both main effects and interaction of priming media and varieties were significant on panicle weight. Soaking sorghum seeds in N and Zn solutions for the duration of 10 h had resulted in higher panicle weight than that of hydro-primed seeds. The maximum mean panicle weight recorded in variety Melkam with Zn followed by N and hydro-priming. The higher panicle weight observed in nutrient priming may be due to both priming and nutrient effect of zinc and nitrogen.

At germination and seedling growth period Zinc is involved in protein synthesis, cell elongation and greater resistance to environmental stresses (Cakmak, 2008). The supply of N during germination process is also important in the hydrolysis of starch to a usable form for germination process. These effects of Zn and N might have resulted in improved emergence, rapid growth, and higher LAI and panicle weight. The result was in agreement with the reports of Mousavi et al. (2012) who found that priming maize seeds

with tap water, urea, and zinc solutions have increased ear size and attributed this to the enhanced activity of enzymes in sucrose metabolism of the primed seeds.

4.3.2. Grain and Aboveground Dry Biomass Yield

The study revealed that seed priming media and variety significantly improved sorghum plant performance by increasing grain and aboveground dry biomass, although response varied with different priming media and varieties. Seed priming with nutrient solutions of N dramatically improved the grain (19.6%) although the differences with Zn was not significant. Likewise, seed priming of sorghum with Zn solution had resulted in the highest biological yield of sorghum, which was 6.8% higher over unprimed seeds. Moreover, nutrient priming either with N or Zn solution had performed better than hydro-priming with regard to grain and biomass yields of sorghum.

The observed increase in grain and aboveground dry biomass yield might be attributed to both effects of priming and nutrient effects of zinc and nitrogen. Seed priming has been found to improve speed and uniformity of germination, vigorous seedling establishment, rapid growth and yield compared to unprimed seeds. A vigorous seedling establishment enhances the competitiveness of plants against weeds, improves tolerance to environmental stresses and maximizes biological and grain yields (Farahani and Kasra, 2011).

It is apparent that in semi-arid areas with calcareous high pH and sandy soils has been deficient in zinc, resulting in hampered crop growth, poor yields, and low zinc density in edible crop parts (Sadeghzadeh and Rengel, 2011). Zinc deficiency in the soil can be treated effectively by soaking the seed with zinc solutions before sowing (Mousavi et al., 2012). Zinc mineral, during early seedling development, might be used for protein synthesis, cell elongation and greater resistance to environmental stresses (Cakmak, 2008; Sadeghzadeh and Rengel, 2011). Seed priming with nitrogen also reported to increase emergence rate, seedling establishment and yield significantly (Al-Mudaris, 1998; Basra et al., 2002).

Studies by Harris et al. (2001) shows that hydropriming of sorghum has caused yield increase up to 31%. Similarly, Ramamurthy et al. (2005) have shown about 9.5% grain yield increase in hydro-primed sorghum, although the differences among cultivars were non-significant. Furthermore, on-farm seed priming of corn with tap water for 17 h in semi-arid regions has improved corn establishment and its yield (Harris, 2006). Harris et al. (2001) also found higher grain yield with water and Zn priming of maize, whereas, the soaking of seed in ZnSO₄ (1.5%) solution found to increase maize biological, grain, and stover yields compared to hydro primed seeds (Shahid and Khan, 2007). Besides, on-farm seed priming has increased sorghum grain yield regardless of priming agents used (Mousavi et al., 2012). Arif et al. (2007) reported about 37%, 33.3% and 36% grain yield increase of maize over control under seed priming with water, 0.01% Zinc solution, and 0.02% Zinc solution, respectively. Afzal et al. (2013) also found maximum maize grain yield (5.35 t

ha⁻¹) and biological yield (16.6 t ha⁻¹) under priming with 1.5% ZnSO₄ solution. The results of this study, however, are not in line with Giri and Schillinger (2003) who found no significant effect of priming on the grain yield of wheat cultivars. Likewise, Subedi and Ma (2005) reported no effect of seed priming on the grain yield of corn despite some positive effects on seedling vigor and stand establishment.

In this study, variety Melkam tended to perform better than other varieties for the majority of yield traits studied despite the variation was non-significant. The variable responses of varieties to the applied treatment might have attributed to their inherent variability in morphology, physiology, and genetic makeup. Nagar et al. (1998) made a similar observation.

Harvest index is a key parameter that indicates the efficiency of a crop in transforming photosynthates into economic yield. The results indicated that soaking seeds in priming solutions of N, Zn and water had increased harvest index significantly compared to control. The increase in HI in primed seeds might be attributed to priming advance rate and uniformity of emergence, establishment, growth and ultimately grain yield. Other reports also showed that on-farm hydropriming increased HI of sorghum (Ramamurthy et al., 2005) and wheat (Bakht et al., 2010). Likewise, seed priming of maize with ZnSO₄ has increased HI as reported by Zeb and Arif (2008); Mousavi et al. (2012); Afzal et al. (2013).

5. Conclusion

The results of this experiment indicated that seed priming with N, Zn and water could improve some parameters of sorghum such as plant phenology, stand counts m^{-2} , plant height, leaf number, leaf area index, grain yield, stover yield, aboveground biomass yield, kernels weight, panicle weight and HI. The observed improvements in these studied traits were higher for nutrient-primed (with N and Zn solutions) than with the other treatments. Variety Teshale followed by Melkam had better performance than Dekeba for the majority of studied traits. Based on these results, therefore, it can be concluded that nutrient priming with either Zn or N could be an effective tool to improve the stand establishment, growth, and grain yield of sorghum in semi-arid areas of Ethiopia.

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Conflict of Interest

The author declares that they don't have conflict of interest.

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