Effect of Seed Priming on Germination and Seedling Growth of Grain Sorghum (*Sorghum bicolor* L. Moench) Varieties

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Abstract: Sorghum (*Sorghum bicolor* L. Moench) is one of the leading drought-tolerant crops often used to mitigate droughts for meeting household food security in Ethiopia. However, poor stand establishment is one of the major factors that constrain productivity of the crop. Poor stand establishment of sorghum is affected by certain conditions after sowing, which have a large influence on speed of germination and seedling emergence that determine successful establishment of the crop under adverse growing conditions. Therefore, an experiment was conducted to elucidate the effect of seed priming on germination and seedling vigor of seeds of six sorghum varieties under a laboratory condition. The experiment was conducted during the 2014 main cropping season on the campus of Haramaya University. The treatments consisted of six sorghum varieties (Abshir, Dekeba, Macia, Meko-1, Melkam and Teshale), three priming media (water, 9 g urea L^{-1}, and 0.2 g $ZnSO_4$ L^{-1}) and five priming durations (0, 5, 10, 15 and 20 h). The experiment was laid out as a completely randomized design (CRD) in a factorial arrangement and replicated four times per treatment. The results showed significant ($P < 0.05$) main effects of the treatments and interactions between priming media and duration, and variety and priming duration for all the traits studied. The highest improvements in final germination percentage (FGP) (6%), germination-index (GI) (8.4%), germination time (MGT) (4%), emergence-percentage (EP) (20%), seedling-length (SL) (12.5%), seedling-dry-weight (SDW) (26.5%), seedling-vigor-index-1 (SVI-1) (33.1%) and seedling-vigor-index-2 (SVI-2) (49.7%) were recorded in response to seed priming using $ZnSO_4$ followed by priming with Urea and water for 10 h priming over the unprimed seeds (control treatment). Likewise, the highest varietal performance was recorded for Melkam followed by Teshale and Dekeba with 10 h priming. The reduction in MGT and the increments in FGP, GI, EP, SL, SDW, SVI-1, and SVI-2 due to variety Melkam with 10 h priming respectively were 5.7, 7.7, 3.8, 22.7, 13.6, 30.2, 38.1, and 58.8% over the unprimed seeds. Therefore, the priming sorghum seeds for 10 hours with $ZnSO_4$ followed by Urea and water significantly improved germination, seedling growth, and seedling vigor under laboratory conditions, implying that the practice priming seeds with each of the media based on availability and affordability could be used by farmers to enhance sorghum seed germination, field stand establishment, and yield.

Keywords: Hydro-priming; Nutrient priming; Priming duration; Priming media; Vigor index

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the main staple crops for the world's poorest and most food-insecure people. It is one of the leading drought-tolerant crops and, therefore, used as a risk aversion and strategic crop for meeting household food security in most developing countries. It is one of the principal sources of energy, protein, vitamins, and minerals for millions of the poorest people in the semi-arid region (Stefoska-Needham *et al*., 2015). In Ethiopia, sorghum provides more than one third of the cereal diet and almost entirely grown by subsistence farmers to meet needs for food, income, feed, brewing and construction purposes. It is the third most important crop after *tef* and maize, in terms of area and production, in Ethiopia (CSA, 2014). The major use of sorghum in East Hararghe Zone is for making the traditional bread (*injera*) from fermented dough for human consumption. Stover of sorghum is also as important as grains and is used as cooking fuel, fodder and construction material (Wortmann *et al*., 2009).

Drought is one of the major yield-limiting factors that is often manifested by the delay in onset of rainfall, dry spell after sowing, drought during critical crop stages and too early stop. Over 80% of sorghum in Ethiopia is produced under moderate to severe drought stress conditions and complete yield loss was observed in some parts of the country in major drought years. Other constraints for sorghum production include soil fertility decline, diseases, insects, *striga* weed, and birds. Low purchasing power and limited use of fertilizer, improved seed, and other agricultural inputs such as agro-chemicals are also other major constraints for sorghum production (EIAR, 2014).

Poor stand establishment is one of the major constraints of crop production system in semiarid areas (Harris *et al*., 1999). The condition after sowing has a large influence on speed of germination and seedling emergence in sorghum and therefore is an important determinant of successful crop establishment under adverse growing conditions (Harris, 1996; Yazdani and Ghanbari-Malidarreh, 2011). Technology that enhances

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germination and emergence of the crop is thus important in mitigating deleterious effects of poor stand establishment due to drought. Seed priming is one such pre-sowing technology that is applied to enhance seed germination and growth by modulating pre-germination metabolic activities prior to the emergence of the radicle and thereby improving germination rate and plant performance (Bradford *et al.*, 1990). During priming, seeds partially hydrated to allow pre-germinative metabolic activities while preventing radicle protrusion followed by re-drying back to original moisture level (McDonald, 2000) and the processes triggered by priming persist following the re-drying of the seeds (Asgedom and Becker, 2001).

Several methods have been used to study effect of seed priming on germination and growth rate of field crops. The most common are osmo- and hydro-priming. Hydro-priming is the soaking of seed in pure water (Ashraf and Foolad, 2005; Farooq *et al.*, 2006), while osmo-priming, including nutrient priming is the soaking of seed in osmotic solutions such as polyethylene glycol, mannitol, and different salt and nutrient solutions. Nutrient priming is a novel technique that combines the positive effects of seed priming with an improved nutrient supply (Al-Mudaris and Jutzi, 1999). In nutrient priming, seeds are primed in solutions containing the limiting nutrients (such as N, P, Zn, etc) instead of being soaked just in water (Arif *et al.*, 2005).

The beneficial effect of seed priming has been demonstrated for many cereal crops like barley, maize, wheat, rice, and sorghum (Moradi and Younesi, 2009). The benefits from priming reflected in terms of higher germination percentage, rapid and uniform germination, higher seedling vigor, and growth thus higher yields over unprimed seeds. However, the level of effects achieved from seed priming studies varied depending on priming techniques, environment, and genotypes (Yari *et al.*, 2010; Khan *et al.*, 2014).

The exact relationship between these factors under different prevailing conditions is noteworthy for further investigation. After seeds sown in the field, seeds spend significant amounts of time absorbing water from the soil. By reducing this time to a minimum, seeds can be made to germinate and emerge more quickly. Farmers can prime their own seed if they know the "safe limits" (i.e., the maximum length of time for which seeds can be soaked safely). Safe limits of priming should be determined for each variety so that germination will not take place before sowing after seeds had removed from the water. Thus, the use of properly pre-soaked seeds in highly drought-prone environments can considerably decrease the risk of crop failure. Production of sorghum under low-inputs in marginal semi-arid is affect by drought and low availability of N, P, and Zn (Samad *et al.*, 2014). While increased seedling vigor via seed priming may improve sorghum plant establishment, possible benefits are likely to be limited when water, N and Zn are deficient. The present study, therefore, was carried out to determine the optimal priming duration and to determine the effect of seed priming on germination and seedling growth of major sorghum varieties developed for the lowlands of Ethiopia.

2. Materials and Methods

2.1. The experiment

A laboratory experiment was carried out at Seed Science and Technology Laboratory of Haramaya University during February to June 2014.

2.2. Seed Material

Seeds of six sorghum (*Sorghum bicolor* L. Moench) varieties viz., Abshir (P9403), Dekeba (ICSR24004), Macia, Meko-1 (M36121), Melkam (WSV387), and Teshale (3443-2-OP) were obtained from Melkassa Agricultural Research Center (MARC), National Sorghum Improvement Program. These varieties of sorghum were released for semi-arid lowlands due to their drought tolerance characteristic, high *injera* (national bread) making quality and some tolerance to *striga* weed (Adugna, 2007; MoARD, 2008).

2.3. Priming materials

Zinc sulphate monohydrate ($ZnSO_4.H_2O$) (36% Zn) and Urea (46% N) fertilizers were used as nutrient priming media for Zn and N priming of sorghum seeds, respectively. For hydropriming, distilled water was used as priming agent. Unprimed dry seeds were also used as control treatment.

Table 1. Description of grain sorghum varieties studied.

No.	Varieties	Year released	Adaptation	Seed color	Plant height (cm)	Maturity dates	Remark
1	Meko-1	1997	Lowland	White	132	108	Drought escape
2	Abshir	2000	Lowland	White	120-135	90-120	Striga tolerant
3	Teshale	2002	Lowland	White	196	108	Drought escape
4	Melkam	2009	Lowland	White	151	118	Drought escape
5	Dekeba	2009	Lowland	White	179	115	*Injera* making
6	Macia	2009	Lowland	White	167	120	*Injera* making

Source: Ministry of Agriculture and Rural Development (MoARD) (2008)

2.4. Treatment and Experimental Design

The treatments consisted of three priming media (i.e., water, 0.2 g $ZnSO_4$ L^{-1}, and 9 g urea L^{-1} solutions), five priming durations [i.e., 0, 5, 10, 15 and 20 h] and six sorghum varieties (i.e., Abshir, Dekeba, Macia, Meko-1, Melkam and Teshale). The experiment was laid out in a completely randomized design in a factorial arrangement and replicated four times per treatment.

2.5. Experimental Procedures

2.5.1. Priming of Seeds

Before priming of seeds, seeds were surface-sterilized in 1.5% sodium hypochlorite solution for two minutes and rinsed with distilled water three times. Seed samples of each sorghum variety were divided into three for each priming media and further sub-divided into five for priming durations. Seed sub-samples, except the to-be unprimed seeds (or control), were primed in different media (i.e., water, 0.2 g $ZnSO_4$ L^{-1} and 9 g urea L^{-1} solutions) for different durations (i.e., 0, 5, 10, 15 and 20 h) in an incubator adjusted to 25 °C under dark condition. For hydropriming, sorghum seeds were soaked in distilled water, while for N and Zn priming, seeds were soaked in urea (46% N) and zinc sulphate (36% Zn) solutions, respectively. The ratio of seed weight (g) to solution volume (mL) was 1:5 (Farooq *et al*., 2006). The primed seeds were surface-dried on moisture absorbent cotton sheet to their near original moisture content of about 11% at room temperature. After drying, all the primed and unprimed seeds were sealed in a polyethylene bag and stored at room temperature until further use.

2.5.2. Germination Test

A germination test using a top-of-paper method was performed in laboratory at room temperature (about 23°C). Four replicates of 100 seeds each taken from the primed and unprimed samples of each variety were arranged on a double layer of Whatsman filter paper No. 2 and moistened with 5 mL of distilled water in each sterilized Petri-dishes (11 cm diameter) and then Petri-dishes were completely randomized. Seedlings exhibiting 2 mm radicle and plumule were considered as germinated seed. Counts of germinated seed were made daily starting from the first day after sowing until there was no further germination (10 days after sowing). Assessment of final germination percent (FGP) was made based on counts of the normal seedling as prescribed in ISTA (ISTA, 2008) using Eq. 1 below.

FGP = [(Total number of normal seeds germinated)/(Total number of seeds sown)] × 100 (1)

Similarly, the assessment of germination index (GI) and mean germination time (MGT) were made by adopting Eq. 2 (AOSA, 1991) and Eq. 3 (Ellis and Roberts, 1981).

GI = [(No. of germinated seeds)/(Days of first count)] + …+ [(No. of germinated seeds)/(Days of final count)] (2)

$$MGT=\Sigma Dn/\Sigma n \quad (3)$$

Where: n is the number of seeds that germinated on day D and D is number of days counted from the beginning of germination.

2.5.3. Seedling Growth and Vigor Test

The second set of laboratory experiment was conducted to determine seedling growth and vigor parameters of sorghum varieties under room temperature. Four replicates of 20 seeds that were taken from the primed and unprimed seeds of each variety were germinated in plastic boxes (14 × 10 × 11 cm in length, width, and depth, respectively) filled with sterilized and moistened sand. The germinating boxes were completely randomized and watered as needed. At the end of the germination period of 14 days, the total numbers of normal seedlings were counted to determine the emergence percentage. From each planting box, five normal seedlings were randomly selected, and their length (root + shoot) was measured. Additionally, five normal seedlings were also randomly selected and oven-dried at 60 °C for 24 h to a constant weight to determine their mean dry weight (root + shoot). Seedling vigor indices were determined using mean values of emergence percentage, seedling length and seedling dry weight as indicated below in Eq. 4 and Eq. 5, respectively (AOSA, 1991).

SVI-1 = Seedling length (cm) × Emergence (%) (4)

SVI-2 = Seedling dry weight (mg) × Emergence (%) (5)

Where: SVI-1 and SVI-2 are seedling vigor index-1 and 2, respectively.

2.6. Statistical Analysis

Data collected were subjected to the analysis of variance (ANOVA) using SAS statistical software version 9.1 (SAS Institute Inc., 2004) as per standard procedures. Germination percentage values were transformed using Arcsine to fulfill the assumption of ANOVA whenever required but the results were presented in actual values. Least significant difference (LSD) test at 5% probability level was used to compare treatment means.

3. Results and Discussion

3.1. Germination Analysis

3.1.1. Final Germination Percentage

The main effect of variety and priming duration were highly significant ($P < 0.01$) on final germination percentage of grain sorghum seeds. Moreover, a highly significant ($P < 0.01$) interaction between priming media and duration and, between priming duration and variety on final germination percentage were observed. However, the three-factor interactions of varieties, priming media, and duration was non-significant ($P = 0.05$) on final germination percentage.

Final germination percentages due to the effects of interaction between priming media and duration were significant and ranged from 92 to 97.4%. Zinc and N primed seeds for the duration of 10 h had the highest germination percentage compared to other treatments followed by hydro-primed seeds, while the unprimed seeds exhibited the lowest germination percentage value (Table 2). The final germination percentage recorded for seeds primed with Zn and N for the duration of 15 and 5 h and that recorded for hydro-primed seeds for 10 h duration were in statistical parity (Table 2). Overall, the nutrient priming solutions of Zn and N led to significantly higher final germination percentage than hydro-priming while the least final germination percentage was recorded for unprimed seeds.

The higher final germination percentage of primed seeds with Zn, N, and water as compared to unprimed seeds found in this study might be because priming with these media induces a range of biochemical changes in the seed that are required for initiating the germination processes. These germination processes include breaking of dormancy, hydrolysis, or metabolism of inhibitors, imbibition, and enzymes activation (Ajouri *et al.*, 2004). The difference among treatments could also be due to efficient mobilization and utilization of seed reserves (Basra *et al.*, 2005) and better genetic repair (Ventura *et al.*, 2012). It may also be due to the osmotic effect of nutrients as priming agents and nutritional effects on germination. Consistent with this suggestion, Ventura *et al.* (2012) adequately reviewed the aspects of DNA repair and its mechanisms.

Table 2. Interaction effects of priming media and duration on germination behaviors of grain sorghum seeds.

Media	Duration (h)	Final Germination %	Germination Index	Mean Germination Time (day)
Hydro	0	92[f]	24.18[h]	3.9304[a]
	5	95[d]	25.23[g]	3.8533[c]
	10	96.5[b]	26.03[b]	3.7921[defg]
	15	96[c]	25.82[cd]	3.7933[def]
	20	94.6[d]	25.44[ef]	3.8008[de]
N	0	92[f]	24.27[h]	3.905[b]
	5	95.7[c]	25.71[d]	3.7975[def]
	10	97.3[a]	26.22[a]	3.7679[h]
	15	95.6[c]	25.82[cd]	3.7738[gh]
	20	94[e]	25.56[e]	3.7804[fgh]
Zn	0	91.8[f]	24.18[h]	3.9192[ab]
	5	95.7[c]	25.71[d]	3.8096[d]
	10	97.4[a]	26.22[a]	3.7692[h]
	15	95.8[c]	25.88[c]	3.7746[gh]
	20	93.7[e]	25.34[fg]	3.7854[efgh]
LSD (0.05)		0.5	0.211	0.016
CV (%)		1	1.5	0.7

Note: Means with the same letters in a column are not significant different at P = 0.05.

The results suggest that nutrient (Zn and N) primed seeds resulted in significantly higher final germination than water-primed seeds. The relative increments observed in final germination due to priming with Zn, N, and hydropriming for 10 hours as compared to unprimed seeds were 6.0, 5.8, and 4.9%, respectively. The result clearly indicated that prolonging the duration of priming from five to 10 hours tended to increase the final germination percentage in all priming media and the degree of this increment was higher for priming with Zn and urea than priming with water. However, a further increase in the duration of priming from 10 h to 15 h and to 20 h decreased the final germination percentage although it was significantly higher than the final germination percentage obtained from unprimed seeds (Table 2). The observed decrease in final germination percentage in response to prolonging the duration of priming might be attributed to build-up of inhibitors as a result of the prolonged time (Warren and Bennett, 1999; Ventura *et al.*, 2012). These results are in agreement with that of Mekonnen (2005) who found an increase in germination percentage of sorghum seeds in response to hydropriming for the duration of 13 and less.

The mean values of final germination percentage for the interaction of variety and priming duration are presented in Table 3. As priming durations increased from five to 10 hours, seeds of the sorghum varieties exhibited increases final germination percentages, although further increases in the duration of priming beyond 10 hours decreased final seed germination for all varieties except for seeds of variety Macia for which priming for the duration of 15 hours resulted in the highest germination percentages (Table 3).

Similarly, the highest final germination percentages were observed for seeds of Melkam (97.9%) and Dekeba (97.8%) followed by those of Teshale and Meko-1 in response to priming for the duration of 10 hours. Final germination percentages (FGP) of these four varieties in response to priming for the duration of 15 hours were in statistical parity and then FGP decreased with 5 and 20 h priming in that order, while the least FGP was obtained from unprimed seeds of variety Macia (91.2%) (Table 3). The physiological reasons for the observed decrease in final germination with the prolonged priming durations might be leakage of electrolytes and/or accumulation of toxic substances (Gracia and Lasa, 1991; Rowse, 1995). The relative increment achieved in the FGP with 10 h priming for variety Melkam was about 6.5% but only 3.2% for variety Macia as compared to unprimed seeds. However, the increment achieved in the final germination for variety Macia in response to priming for the duration of 15 hours was about 5.5% (Table 3). It is, therefore, clear that the requirement of priming differs with varieties, which might be due to varietal differences in sensitivity or resistance to the duration of exposure to priming (Ghana and Williams, 2003).

3.1.2. Germination rate

The main effects of variety, priming media and priming duration on germination index and mean germination time were significant ($P < 0.05$) on germination rate. Similarly, the interactions of priming duration and variety and, priming media and duration on germination index and mean germination time were also significant ($P < 0.05$). However, the effect of three-factor interaction among a variety, priming media, and priming duration on germination index was not significant ($P = 0.05$).

Seeds primed with N and Zn for 10 hours had a maximum germination index (26.2) followed by seeds that were primed with water for the same duration. However, the unprimed seeds had the lowest (24.2) germination index (Table 2). The germination indices obtained in response to priming sorghum seeds with N, Zn, and water for 15 hours were in statistical parity;

however, the indices were greater than that of seeds primed with the same priming media for five and 20 hours. However, priming the seeds with N, Zn, and water for five hours resulted in a significantly higher germination index than priming the seeds with the same media for 20 hours. On the other hand, for priming with water, the vice-versa was true for these two durations of priming (Table 2). The ineffectual response of germination to priming for a shorter duration (0-5 h) might be due to limited or inadequate activation of the germination process whereas that of priming for too long a duration (20 h) may be ascribed to over soaking which might cause damage of membranes and leakage of enzymes (Rowse, 1995). The increments in germination index due to priming with N, Zn, and water for the duration of 10 hours compared to the germination observed for unprimed seeds were 8, 8.4, and 7.6%, respectively. Overall, the reduction in mean germination time achieved in response to priming with N, Zn and water for 10 hours compared to the unprimed seeds was 3.6, 4, and 3.6%, respectively.

The higher performance of nutrient priming and hydropriming over unprimed seeds with regard to germination index and mean germination time might be due to the possibility that priming may have induced a range of biochemical changes in the seed that are required to initiate the germination process (Ajouri *et al*., 2004). In addition, building up of nucleic acids, increased synthesis of proteins, as well as the repairing of membranes might help the primed seeds to outperform unprimed seeds (Rowse, 1995). Moreover, early reserve breakdown and reserve mobilization might be the cause for significant reduction in mean germination time (Farooq *et al*., 2006; Shehzad *et al*., 2012). The results of this study are in agreement with that of Harris (1996) with hydropriming, Al-Mudaris and Jutzi (1999) with urea-based priming, and Kaurivi and Shilulu (2007) with osmo- and hydro- priming who reported reduced mean germination time of seeds of sorghum genotypes. Likewise, Shehzad *et al.* (2012) studied the response of three sorghum varieties to hydro- and halo-priming with KNO_3 and $CaCl_2$ (1% solution) for 10 h and found reduced mean emergence time for primed as compared to unprimed seeds.

Table 3. Interaction effects of variety and priming duration on germination behaviors of grain sorghum seeds.

Sorghum varieties	Duration(h)	Final Germination Percent	Germination Index	Mean Germination time (days)
Abshir	0	91.3^{p}	23.81^{p}	3.945^{a}
	5	94.4^{kl}	25.1^{kl}	3.853^{de}
	10	96.5^{ef}	25.72^{fg}	3.801^{f}
	15	94.6^{k}	25.46^{hi}	3.801^{f}
	20	94^{lm}	25.25^{jk}	3.799^{fg}
Dekeba	0	92.3^{no}	24.5^{mn}	3.913^{b}
	5	96.1^{fgh}	25.96^{bcd}	3.788^{fghijk}
	10	97.8^{ab}	26.46^{a}	3.759^{mn}
	15	96^{fghi}	25.94^{bcde}	3.773^{jklm}
	20	94.4^{kl}	25.5^{hi}	3.783^{hijk}
Macia	0	91.2^{p}	23.73^{p}	3.948^{a}
	5	94.3^{klm}	25.01^{l}	3.859^{d}
	10	95.4^{j}	25.77^{efg}	3.792^{fghi}
	15	96.2^{efg}	25.97^{bcd}	3.773^{klm}
	20	94.3^{kl}	25.61^{gh}	3.780^{ijkl}
Meko-1	0	92.2^{no}	24.16^{o}	3.915^{b}
	5	95.6^{hij}	25.44^{hi}	3.843^{e}
	10	97.2^{cd}	26.02^{bc}	3.789^{fghi}
	15	95.5^{ij}	25.73^{fg}	3.788^{fghij}
	20	93.8^{m}	25.36^{ij}	3.799^{fg}
Melkam	0	92.6^{n}	24.65^{m}	3.895^{c}
	5	96.3^{ef}	25.97^{bcd}	3.783^{hijk}
	10	97.9^{a}	26.55^{a}	3.753^{n}
	15	96.7^{de}	26.06^{b}	3.765^{lmn}
	20	94.2^{lm}	25.47^{hi}	3.787^{fghijk}
Teshale	0	92^{o}	24.42^{n}	3.894^{c}
	5	96^{fghi}	25.82^{def}	3.796^{fgh}
	10	97.3^{bc}	26.41^{a}	3.765^{lmn}
	15	95.7^{ghij}	25.87^{cdef}	3.783^{hijk}
	20	$94l^{m}$	25.48^{hi}	3.785^{ghijk}
LSD (0.05)		0.6	0.001	0.019
CV (%)		0.8	1.0	0.6

Note: Means with the same letters in a column are not significant different at 5% level of significance.

The response of variety to priming duration with regard to germination index and mean germination varied significantly. As illustrated in Table 3, all varieties except Macia had the least mean germination time and highest germination index in response to priming for 10 h hours. However, for variety Macia priming the seeds for the duration of 15 hours resulted in the highest germination index and least time required for germination. Moreover, the lowest germination index and the longest mean germination time were recorded for unprimed seeds distantly followed by seeds primed for 20 hours in most of the cases (Table 3). The variation among varieties in terms of performance in germination might be due to differences in the seed morphology and physiology (Yari *et al*, 2010). The physiological differences in genotypes with regard to seed size, resistance to water permeability and efficiency in mobilizing and utilizing reserve food had been reported (Bewley and Black, 1994). Kaurivi and Shilulu (2007) also observed these differences among sorghum varieties in response to hydropriming.

3.2. Seedling Growth and Vigor Analysis

3.2.1. Seedling emergence

The result showed that all main effects and the interactions of priming duration and variety as well as that of priming duration and media were significant ($P < 0.01$) on percentage emergence of sorghum seedlings. However, the interaction between priming media and variety, and among media, duration, and variety were non-significant ($P = 0.05$).

The mean difference for interaction of priming media and duration on mean emergence percentage indicated that the highest emergence (92.6%) was from nutrient priming (i.e., Zn and N) with 10 h duration. The improvement in final emergence percentage due to Zn priming for 10 h as compare to unprimed seeds was 19.9%. The second and third highest emergence percentages were from nutrient priming with 15 h and for hydropriming with 10 h duration, while the lowest emergence (77.8%) was from unprimed seeds (Table 4).

The mean difference for interaction of priming duration and variety showed the highest emergence percentage for variety Melkam (95.7%) with 10 h priming, while the second and third highest emergence percentages were from varieties Teshale and Dekeba with 10 h priming (Table 5). This result is in conformity with that of Chivasa *et al.* (2000) who found higher emergence percentage (13% higher over the control treatment) with 10 h hydropriming of sorghum varieties. Among the varieties studied, the minimum emergence for 10 h priming was recorded for variety Macia (86%). However, variety Macia had relatively higher emergence (90.2%) for 15 h priming. The emergence recorded for 20 h priming was lower as compare to that obtained from 10 h or 15 h priming duration (Table 5). This result is in agreement with that of Kaurivi and Shilulu (2007) who reported lower emergence percentage of variety Macia owing to hydropriming for 2 to 12 h as compared to the other two sorghum varieties. Moradi and Younesi (2009) also reported that osmo-priming sorghum seeds for 12 and 24 h enhanced emergence percentage from 87 to 95% while further soaking beyond 24 h decreased it. In general, the observed increase in the final emergence percentage of primed seeds could be due to efficient mobilization and utilization of seed reserves (Basra *et al.*, 2005) and better genetic repair in the primed seeds than in the unprimed seeds (Srivastava, 2002).

3.2.2. Seedling Height

Seedling height was significantly ($P < 0.01$) affected by the main as well as the interaction effects of priming media and duration as well as by that of priming duration and variety. However, the three-factor interaction of variety, priming media, and duration of seedling length was not significant ($P = 0.05$).

The interaction effect of priming media and duration was profound on seedling height and all priming media resulted in the tallest seedlings in response to priming for 10 hours followed by priming for 15 hours (Table 4). The increase in seedling height in response to priming with N, Zn, and water for the duration of 10 hours compared to unprimed seeds was 10.5, 11, and 12.5%, respectively.

The tallest seedlings were recorded for variety Melkam (29.5 cm) followed by Teshale and Dekeba seeds primed for 10 h duration (Table 5). The observed increments in seedling height due to Teshale, Dekeba and Melkam with 10 h priming as compared to the unprimed seeds were 13.6, 13.2, and 12.6%, respectively. The result indicates that increasing the duration of priming from five to 10 hours increased seedling height of all varieties; however, prolonging the duration of priming further from 10 to 15 h increased the seedling height of variety Macia but decreased that of the other varieties. Further increasing the duration of priming from 15 to 20 h decreased the mean seedling height of all varieties (Table 5). The better performance of varieties in response to priming for 10 hours could be attributed to the fact that water and nutrient solutions absorbed for the span of 10 h might be optimum to cause an increased cell division in shoots and roots. However, the shortest seedlings were recorded in response to priming for as long as 20 hours possibly because priming for too long a time might have resulted in excess water being trapped in the seeds, causing damage to the embryo due to lack of oxygen and also excess water uptake might have led to physiological seed damage (Murungu, 2011) due to leakage of electrolytes. Chivasa *et al.* (2000) who reported higher seedling length for 10 h hydropriming of sorghum varieties compared to unprimed seeds also found similar results. Mekonnen (2005) also reported that hydro-priming sorghum seeds for 10 and 13 hours led to growth of the tallest seedlings whilst a further increase in the duration of priming with water decreased seedling height.

Table 4. Interaction effect of priming media and duration on seedling growth and vigor parameters of grain sorghum seeds.

Media	Duration(h)	FEP	SL (cm)	SDW (mg)	SVI-1	SVI-2
Hydro	0	77.9i	24.8g	13.2f	1933.3i	1024.5h
	5	84.6gh	26.7d	14.8d	2265.4f	1254.1f
	10	90.8c	27.9b	16.5ab	2543.5b	1503.7b
	15	89.8d	27.3c	16c	2447.8d	1440.6d
	20	84.2h	26.1e	14.9d	2194.1g	1249.5f
N	0	77.9i	25.7ef	13.3f	2002.8h	1032.5h
	5	86.3ef	27.5c	14.5e	2370e	1251.8f
	10	92.3ab	28.4a	16.7a	2620.1a	1546a
	15	90.9c	26.8d	16.3b	2439.7d	1486.5bc
	20	85.5fg	25.8ef	14.8d	2201.7g	1266.8f
Zn	0	77.5i	25.5f	13.2f	1974h	1024.9h
	5	86.8e	26.8d	15d	2330.5e	1304.4e
	10	92.9a	28.3ab	16.7a	2628.3a	1556.1a
	15	91.7bc	27.3c	16.1c	2501.4c	1474.4c
	20	84.8gh	26.8d	14.3e	2272.7f	1217g
LSD (0.05)		1.45	0.54	0.35	77.46	48.66
CV (%)		3.0	3.5	4.1	5.9	6.5

Note: Means followed by the same letters in a column are not significant different at 5% level of significance; FEP = final emergence percentage; SL = seedling length; SDW = seedling dry weight; SVI-1 = seedling vigor index-1; SVI-2 = seedling vigor index-2.

Table 5. Interaction effect of variety and priming duration on seedling growth and vigor parameters of grain sorghum seeds.

Sorghum varieties	Duration (h)	FEP	SL (cm)	SDW (mg)	SVI-1	SVI-2
Abshir	0	77.3o	24.9mn	13.1op	1925.1o	1008.4pq
	5	84.7klm	26.6gh	14.5jkl	2247.5jk	1223.5kl
	10	89.4efg	27efg	16.3bc	2410.8hi	1456.8c
	15	89.7def	26.6gh	15.8de	2382.8i	1414.6de
	20	83.8lm	25.7kl	14.4kl	2150.9l	1211.2lm
Dekeba	0	78.1o	25.8jkl	13.4no	2010.1n	1044.9op
	5	87.4hi	27.7bcd	15.3fgh	2420ghi	1331h
	10	94.7a	29.2a	17.2a	2761.1b	1630a
	15	90.8cd	27.2d	16.6b	2472.8efg	1506.2b
	20	84.3klm	26.2hijk	14.7jk	2205.8kl	1238.6jkl
Macia	0	77.5o	24.5n	12.9p	1894.6o	1001.5q
	5	81.1n	25.6l	13.8m	2079.2m	1115.2n
	10	86j	26.6fgh	15.4fgh	2286.6j	1322.8h
	15	90.2cde	26.9efg	15.6ef	2422fghi	1397.8ef
	20	83.6m	26ijkl	14.2l	2175.6l	1185.5m
Meko-1	0	77.7o	25m	13.3nop	1941.9o	1031opq
	5	85.3jk	26.6fgh	14.6jk	2270.3j	1243.8jkl
	10	91.4bc	27.8bc	16.5b	2538.5cd	1511.4b
	15	90.3cde	27.1ef	16.6cd	2443efgh	1450cd
	20	85jkl	26.5ghi	14.8ij	2250.6jk	1256.8jk
Melkam	0	78o	26.2hij	13.4mn	2044mn	1046.1o
	5	88.8fg	27.9b	15.5efg	2475.9ef	1371.2fg
	10	95.7a	29.5a	17.4a	2822.8a	1661.2a
	15	92.5b	27.7bcd	16.6b	2560.6c	1534.2b
	20	86.3ij	26.3hi	15.1hi	2271.9j	1302.5hi
Teshale	0	78.1o	25.7kl	13.2nop	2004.2n	1032.1opq
	5	88.2gh	27.7bcd	15.2gh	2439fgh	1335.9gh
	10	94.8a	29.2a	17.2a	2764b	1629.3a
	15	91.3bc	27.3cde	16.4bc	2496.4de	1500.1b
	20	86j	26.5ghi	14.8ij	2282.2j	1272.1ij
LSD (0.05)		1.369	0.56	0.36	62.62	39.47
CV%		2.0	2.6	2.9	3.4	3.8

Note: Means followed by the same letters in a column are not significant different at 5% level of significance; FEP = final emergence percentage; SL = seedling length; SDW = seedling dry weight; SVI-1 = seedling vigor index-1; SVI-2 = seedling vigor index-2.

3.2.3. Seedling Dry Weight

The main effects of priming duration and variety and, the interactions of priming media and duration, and priming duration and variety on seedling dry weight were highly significant ($P < 0.01$). However, the three-factor interaction among variety, priming media and duration on seedling dry weight was not significant ($P = 0.05$). The maximum seedling dry weight (16.7 mg) was recorded in response to priming the seeds with N and Zn for the duration of 10 hours, followed by priming with water for the same duration. However, the least seedling dry weight was recorded for unprimed seeds (Table 4). Overall, the improvement achieved in seedling dry weight due to seed priming with Zn for the duration of 10 h was 26.5% higher than the seedling dry weight attained for the unprimed seeds.

The mean differences for interactions of variety and priming duration showed the highest mean seedling dry weight for variety Melkam (17.4 mg) with 10 h priming followed by varieties Dekeba and Teshale, while the lowest seedling dry weight (12.9 mg) was recorded from variety Macia with unprimed seeds (Table 5). The increment in seedling dry weight achieved with variety Melkam in response to priming for 10 h compared to unprimed seeds or at 0 h duration was 29.9%. Improved seedling dry weight due to priming might be attributed to increased cell division within the apical meristem of seedling roots, which cause an increase in plant growth and could also be due to physiological process and repair mechanism that occur during priming (Taylor and Harman, 1990).

The present results agree with that of Argerich *et al.* (1989) who reported that hydropriming enhance the speed of emergence and eventually, increase mean seedling size and biomass in some sorghum cultivars. Similarly, Chivasa *et al.* (2000) obtained a higher seedling weight for 10 h hydro-primed sorghum seeds than unprimed. Mekonnen (2005) also found the highest shoot and root dry matter weight for 10 and 13 h hydro primed sorghum seeds and observed variation among varieties. Accumulation of higher total dry weight due to priming of sorghum seeds with zinc sulfate as compared to unprimed and other treatments also reported by Yazdani and Ghanbari-Malidarreh (2011).

3.2.4. Seedling vigor indices

Both seedling vigor indices (SVI) (i.e., seedling vigor indices 1 and 2) were significantly ($P < 0.01$) affected by all main effects of the factors. Moreover, the interaction effect of priming media and duration and, priming duration and variety were also significant ($P < 0.05$) on this parameter. However, the three-factor interaction between treatments was not significant ($P = 0.05$).

Each priming media exhibited its respective higher SVI-1 and SVI-2 values for 10 h followed by those for 15 h priming. The result also indicated that sorghum seeds primed with Zn and N had higher SVI-1 and SVI-2 than that of hydropriming. Priming seed with zinc solution for five hours resulted in higher SVI-1 than that of 20 h priming. However, mean SVI-2 values from hydro- and N priming with 5 and 20 h durations were in statistical parity. In all priming media, the least SVI-1 and SVI-2 values were obtained from unprimed seeds (Table 4).

The increments in SVI-1 obtained due to N, Zn and hydro-priming with 10 h duration were 30.8, 33.1 and 17.2% over unprimed seeds, respectively, whereas the increments in SVI-2 with N, Zn and hydropriming for 10 h priming were 49.7, 51.8 and 46.8% over unprimed seeds, respectively. In line with this result, Basra *et al.* (2005) reported that hydro- and osmo-primed seeds exhibited increased germination rate, greater germination uniformity and total germination percentage. In this study, also seed priming improved seedling vigor indices of sorghum varieties as indicated by increased emergence percentage, seedling length, and seedling dry weight. It is apparent that primed seeds can rapidly imbibe and revive the seeds metabolism, enhancing germination rate that can lead to the production of large and uniform seedlings (McDonald, 2000).

The interaction effect of priming duration and variety on mean SVI-1 and SVI-2 of sorghum showed that the highest SVI-1 and SVI-2 were recorded for variety Melkam (2822.8 and 1661.2) followed by varieties Teshale and Dekeba with 10 h priming. Similarly, mean SVI-1 and SVI-2 obtained from variety Melkam with 15 h priming were higher over those from varieties Teshale and Dekeba with 15 h priming. Genetic differences existing among the varieties might have caused the differential responses to seed priming with regard to vigor indices. Moreover, for varieties except Macia, the mean SVI-1 and SVI-2 values recorded with five hour priming were higher than that recorded for 20 hour priming; however, the reverse was true for variety Macia. On the other hand, the lowest mean SVI-1 and SVI-2 values for varieties were from unprimed seeds (Table 5). These results indicate that variety Macia performed better, when the priming period was prolonged from 10 to 15 h although the performances of all other varieties beyond priming for the duration of 15 hours were reduced. For instance, the improvement achieved in SVI-1 for variety Melkam with 10 h and for variety Macia with 15 h priming was 38.1 and 27.8% over unprimed seeds, respectively. Likewise, an improvement achieved in SVI-2 for variety Melkam with 10 h and for variety Macia with 15 h priming was 58.8 and 39.6% over unprimed seeds, respectively.

The highest values with regard to seedling vigor indices for 10 h priming regardless of priming media in sorghum varieties might be the water and nutrients absorbed for the span of 10 h was optimum for activating the germination process and thereby resulting in maximum performance in seedling vigor indices. This improvement in vigor indices might also be due to enhanced reserve food mobilization to roots and shoots of seedlings, activation, and re-synthesis of enzymes, DNA and RNA, and some repairs of damage to the membrane (Arif *et al.*, 2008) in the primed seeds. In addition to the osmotic effect of fertilizers as priming agents, nutritional effects on germination, seedling growth and thereby on seedling vigor indices were available. Higher vigor index values due to priming of sorghum genotypes with $CaCl_2$ was also reported by Shehzad *et al.* (2012).

4. Conclusion

In this study, grain sorghum seeds responded well to priming treatments consisting of N, Zn solutions or water. Priming sorghum seeds with Zn solution for 10-hour duration dramatically improved the germination percent, germination index, and reduced mean germination time compared to the unprimed seeds. Priming seeds with Zn for 10 h had also a profound effect on vigor and seedling growth parameters and increased the seedling height, seedling dry weight (root and shoot), and seedling vigor index-1 and 2 as compared to unprimed seeds. Among sorghum varieties studied, varieties Melkam followed by Dekeba and Teshale with 10 h priming duration performed better than the other varieties with respect to the majority of the traits studied. Based on the results of this study, 10 h is an optimum priming duration for most of the varieties. Moreover, the use of limiting nutrients such as Zn as seed priming agent would be an excellent option to improve germination, seedling growth, and its vigor. However, in the absence of Zn or urea, farmers have the option to use water (easily available and affordable) to prime their seeds to enhance seedling germination and stand establishment. Future research should be geared towards studying the effect of priming duration with the three media at a narrower interval of about one hour particularly between the five- to fifteen-hour duration used in this study.

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