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Seed priming with $CaCl_2$ and ridge planting for improved drought resistance in maize

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Abstract: Drought-induced losses in crop output have forced the scientific community to develop efficient management strategies to cope with the adversities of drought stress. This field trial was done to assess the role of seed priming techniques and planting methods for improving drought resistance in Pakistani hybrid maize in 2011. Maize seeds were soaked in an aerated solution of $CaCl_2$ (osmopriming; ψs –1.25 MPa) and distilled water (hydropriming), while untreated dry seeds were taken as controls. Primed and untreated seeds were sown on either ridges or a flat seedbed and were subjected to drought at vegetative and tasseling stages. Drought was imposed by stopping irrigation up to ~50% of field capacity (FC), while well-watered conditions (~75% FC) were taken as control. Drought at different phenophases, the tasseling stage in particular, impaired the root system, leaf score, yield-related attributes, and yield. Seed priming, osmopriming with $CaCl_2$, mitigated the damaging effects of drought on the root system, yield, and related traits. Moreover, ridge sowing helped to maintain its supremacy, securing a well-developed root system, i.e. greater root length and proliferation. This led to notable expansion in yield-related attributes compared with flat sowing under well-watered and stressed conditions. Interestingly, under vegetative drought, hydropriming performed better than osmopriming for 1000-grain weight; however, the supremacy of osmopriming over hydropriming was evident in all other yield-related attributes under vegetative and terminal drought stress. Net returns and benefit-cost ratio (BCR) declined under drought conditions; nevertheless, priming techniques over control and ridge sowing over flat sowing were helpful in improving the net returns and BCR of maize exposed to drought conditions. In conclusion, a combination of ridge sowing and osmopriming with $CaCl_2$ can play a vital role in mitigating the adverse effects of drought stress, increasing the production of maize and net returns under normal and deficit water conditions.

Key words: Drought, maize, osmopriming, resistance, ridge planting, seed priming

1. Introduction

Plants undergo drought stress either due to limited water supply to the roots or a high transpiration rate (Manivannan et al., 2007). Drought stress is a major threat to worldwide crop production, chiefly in areas where irrigation is an unavoidable aid to crop production. Drought stress is recognized as the most lethal abiotic stress disturbing crop metabolic activities such as cell division and expansion, leaf area, shoot growth and root development, stomatal oscillations and photosynthesis, plant water and nutrient relations connected with diminished growth, and the productivity of several arable crops (Bruce et al., 2002; Aslam et al., 2006; Hussain et al., 2008, 2009, 2013; Li et al., 2009; Farooq et al., 2012). It is a constraint to the sustainability of established agricultural production systems in developed countries around the globe (Rojas et al., 2011). Hence, an ample supply of irrigation water is essential to improve crop productivity and ensure future food supplies.

Maize (*Zea mays* L.) is the third most important cereal crop after rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.). It is a high-yielding cereal crop grown twice a year, and, therefore, it is capable of fulfilling the future dietary needs of ever-rising worldwide demographic pressure. Drought stress at any phenophase of maize crop production limits its growth and production potential (Shao et al., 2008); however, episodes of drought at critical phenophases pose more potential damage (Fenner, 1998). For instance, drought during the reproductive stage of maize is highly destructive, leading to a large yield tax (Borras et al., 2002; Hammer and Broad, 2003). It is more drought resistant during its early stages of growth, but severe water stress at any stage of crop growth reduces the yield markedly (Dhillon et al., 1995). Yield components of maize like cob length, grains per cob, and grain size are severely hampered due to drought stress at different critical growth periods resulting in lower grain outputs (Nouna et al., 2000; Panitnok et al., 2005; Moser et al., 2006; Hussain

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et al., 2013). Maize-grain yield is closely related with kernel number at maturity, and kernel number is determined by the physiological position of the crop around flowering (Otegui and Andrade, 2000). Water stress at flowering has a bad effect on the physiological status of the crop as a result of diminished photosynthetic rates, lower supplies of water, and lower plant growth rates. That, in turn, badly affects kernel setting during a critical reproductive period, and grain yield is negatively impacted (Andrade et al., 2002; Hussain et al., 2013).

Suitable sowing methods and seed priming are among several agronomic techniques used to cope with the adversities of drought-induced losses in maize (Harris et al., 2001; Farooq et al., 2013; Hussain et al., 2013). Roots elongate slowly due to hampered water supply and mechanical impedance under water-deficient soil conditions (Bengough et al., 2011), forcing the plants to explore a small volume of soil to get water and nutrients in dry soils (Chassot and Richner, 2002). Drought-induced growth inhibition of roots is even well reported in tolerant genotypes; the effect is very distinct in sensitive ones (Piro et al., 2003). Therefore, a well-developed root system seems a viable tool to improve plant growth, principally in soil conditions with low water and nutrients supplies. Results of several field trials elucidated that growing maize on ridges permits more efficient use of irrigation water and nutrients compared with other sowing methods due to the better rooting system produced, under both well-watered and drought conditions (Khan et al., 2012a, 2012b; Hussain et al., 2013). Ridges might provide a loose, fertile layer of soil with more aeration and easy supply of nutrients than a flat surface resulting in a well-developed root system (Khan et al., 2012a, 2012b). The furrow-ridge method provides better drainage and saves more water than border irrigation and provides maximum maize yield (Chaudhary and Qureshi, 1991).

Emergence, early stand establishment, growth, and yield attributes of field crops can be improved by different seed-priming techniques. Seed priming, a pre-sowing partial hydration of seeds, is often used to improve crop performance (Ashraf and Foolad, 2005). The cellular mechanism of seed priming as it relates to improved germination as well as stress-tolerance, however, is not fully understood. Among several osmotica, polyethylene glycol (PEG), KNO_3, K_3PO_4, $MgSO_4$, KCl, and $CaCl_2$ are used to direct the water potential of the solution during seed priming. The performance of crops under different abiotic stresses such as drought, chilling, and salinity can be improved by seed priming (Farooq et al., 2008). Farooq et al. (2006) reported that osmohardening with $CaCl_2$ improved germination and emergence in rice, while Rehman et al. (2011) reported better stand establishment and higher seedling vigor and yield in direct-seeded rice owing to osmopriming with $CaCl_2$. Seed priming led to better crop emergence and growth, earlier flowering, and greater yield for summer grown maize (Harris et al., 1999, 2001). It is evident from the above-mentioned literature that seed priming with Ca salts, especially $CaCl_2$, can improve vigor, growth, and development of cereals in stressful environments. Water stress is a growing problem around the globe, and seed priming with $CaCl_2$ may help to mitigate the adverse effects of drought stress.

Keeping the above-mentioned in view, it is evident that seed priming and ridge sowing are highly beneficial in improving maize performance under normal and deficit water conditions; however, information about the interactive effect of ridge planting and osmopriming with $CaCl_2$ to improve drought tolerance in maize has seldom been explored. Therefore, this field study was designed with the hypothesis that ridge sowing can mitigate the adversities of drought stress at different growth phases by encouraging a well-developed root system, and seed priming with $CaCl_2$ will further improve the performance of ridge-sown maize in water-limited environments.

2. Materials and methods

2.1. Experimental site description

The field study was carried out at the agronomic research area of the agronomy department, Bahauddin Zakariya University, Multan (71.43°E, 30.2°N, 122 m a.s.l.), Pakistan, during autumn 2011. The climate of this region is semiarid and subtropical. Before sowing, soil samples were collected from the experimental site and analyzed to estimate the fertility status of the soil. The analysis indicated that the soil was clay-loam (33.33%, 44.36%, and 22.31% sand, silt, and clay, respectively) with pH 8.30, EC 3.01 dS m^{-1}, organic matter 0.36%, available phosphorus 3.31 ppm, available potassium 190 ppm, and total nitrogen 0.06%. Weather is summarized in Table 1.

2.2. Experimental details

The seeds of maize hybrid Hi-Corn-11 Plus were collected from Pioneer Seeds, Sahiwal, Pakistan. For priming, seeds were soaked in an aerated solution of $CaCl_2$ (osmopriming) and distilled water (hydropriming), while the untreated dry seeds were taken as controls. To accomplish hydro- and osmopriming, seeds were fully immersed in aerated water and a solution of $CaCl_2$ (ψs –1.25 MPa) for 24 h at a 1:5 (w/v) ratio, respectively. After priming, the seeds were given three surface washings with tap water and redried near to their original weight with forced air under shade at 27 ± 3 °C. The seeds were then sealed in polythene bags and stored in a refrigerator at 5 °C until use. Primed and untreated seeds were planted on ridges and flat surfaces in rows 75 cm apart. Drought stress was imposed at the vegetative and tasseling stages by withholding irrigation up to ~50% FC level, while well-watered conditions (~75% FC) were taken as control.

Table 1. Weather data during the course of experiment.

Month	Mean monthly temperature (°C)	Mean monthly relative humidity (%)	Total monthly rainfall (mm)
August	31.50	66.50	70.40
September	29.00	74.00	68.20
October	26.20	67.60	9.50
November	18.00	60.70	0.00

Source: Agricultural Meteorology Cell, Central Cotton Research Institute, Multan, Pakistan.

2.3. Experimental design

The experiment was laid out in randomized complete block design (RCBD) with a split-split plot arrangement and three replications with a net plot size of 5 × 3 m. Water-stress levels, sowing methods, and seed-priming techniques were kept in main, sub, and sub-sub plots, respectively (Hussain et al., 2013).

2.4. Crop cultivation

Prior to seedbed preparation, a presoaking irrigation of 10 cm was applied. When soil attained feasible moisture, the seedbed was prepared by cultivating the field 2 times with a tractor-mounted cultivator, following each with planking. Primed and untreated seeds of maize were sown on 30 July 2011 on well-prepared land. Sowing was done by dibbling on a flat surface and manually on ridges, maintaining a plant-to-plant distance of 20 cm. Fertilizers were applied at 200 kg of nitrogen (N) and 150 kg of phosphorus (P) using urea and triple superphosphate as source, respectively. A full dose P and half of N were applied at the time of sowing, and the remaining half dose of N was applied with the 1st irrigation. Water stress was imposed at the vegetative and tasseling stages by withholding irrigation. After the 1st irrigation when the soil reached a workable moisture level, manual hoeing was done to keep the crop free from weeds. The crop was attacked by shoot fly 21 days after sowing. Furadan (10 kg ha^{-1}), with the active ingredient carbofuran 5% w/w, was applied for the control of shoot fly (2 grains per plant). The mature crop was harvested on 28 November 2011 manually by sickle.

2.5. Methodology for recording data

Ten randomly selected plants from each experimental unit were uprooted carefully, to avoid damage to the roots, fortnightly; number of lateral roots was counted and averaged to record the number of lateral roots. Similarly, primary root length of the uprooted plants was measured with a measuring tape and averaged to record the primary root length. The number of leaves present on ten randomly-selected plants from each treatment unit was counted at fortnightly intervals and averaged to get a leaf score. Plant population at maturity was obtained by counting the total number of plants from homogeneous 1 m^2 areas from each experimental unit. Ten plants at maturity from each treatment were randomly selected, measured for height with a measuring tape, and averaged to record plant height. Total number of cobs present on ten randomly selected plants from each experimental unit were counted and averaged to record number of cobs per plant. Ten cobs selected at random were measured for length with a measuring tape and averaged to record cob length. Total number of grain rows and grains present on each cob from ten randomly selected cobs were counted carefully and averaged to record the number of grain rows per cob and number of grains per cob, respectively. Three random samples of 1000 grains from each experimental unit were taken, weighed, and averaged to record 1000-grain weight. At maturity cobs were removed, sun dried, and threshed manually to calculate grain yield per plot which was converted to a per hectare basis by unitary method. The random grain samples were taken from each plot to find moisture content. Then, grain yield was adjusted to 10% moisture content and converted into kg ha^{-1}. At maturity all plants in each experimental unit were harvested manually and tied into bundles. The weight of all air-dried plants from each plot, except the cobs, was taken by spring balance and converted into kg ha^{-1}. The recorded weight was then added to the previously calculated grain yield (kg ha^{-1}) to record biological yield.

2.6. Statistical and economic analysis

Collected data regarding all parameters were analyzed by using Fisher's analysis of variance technique, and LSD test at 5% probability was used to compare the differences among treatment means (Steel et al., 1997). For the economic analysis, cost of seedbed preparation, seed and sowing, priming, irrigation, fertilizing, crop protection, weeding, earthing-up, harvesting, and land rent were summed to calculate total expenses. Gross income was calculated according the prevailing market price of maize grains in the country, while net income was determined by subtracting the expenses from gross income. Moreover, the benefit-cost ratio (BCR) was estimated by dividing the gross income by expenses (CIMMYT, 1988).

3. Results

Drought stress imposed at vegetative and tasseling stages notably decreased primary root length and number of lateral roots at 60 and 75 days after sowing (DAS) compared with the well-watered crops under both planting methods (Figures 1 and 2). However, both priming techniques mitigated the effects of drought and improved the root length and root proliferation at 45, 60, and 75 DAS under stressful and well-watered conditions, compared with untreated seeds (Figures 1 and 2). Moreover, ridge planting maintained its supremacy over flat seedbeds for primary root length and lateral roots under all priming techniques under drought stress and well-watered conditions (Figures 1 and 2). Although drought stress and seed priming did not affect the number of leaves per plant, ridge sowing frequently improved the number of leaves per plant compared to the flat sowing of maize (Figure 3). Plant height was extensively reduced by imposing drought at different phenophases, and terminal drought proved most damaging in this regard. The ridge-planted and osmoprimed seeds produced the highest plant height under well-watered conditions, while flat-sown maize using dry seeds under terminal drought produced the lowest plant height observed (Table 2; Figure 4).

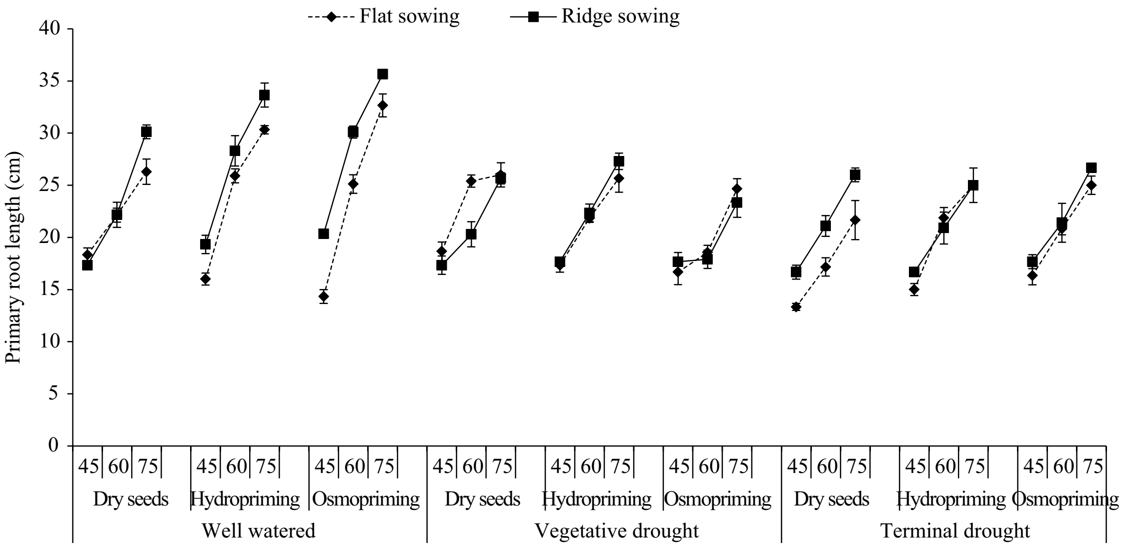

Figure 1. Effect of seed priming techniques and sowing methods on primary root length (cm) of maize grown under drought at different phenophases ± S.E.

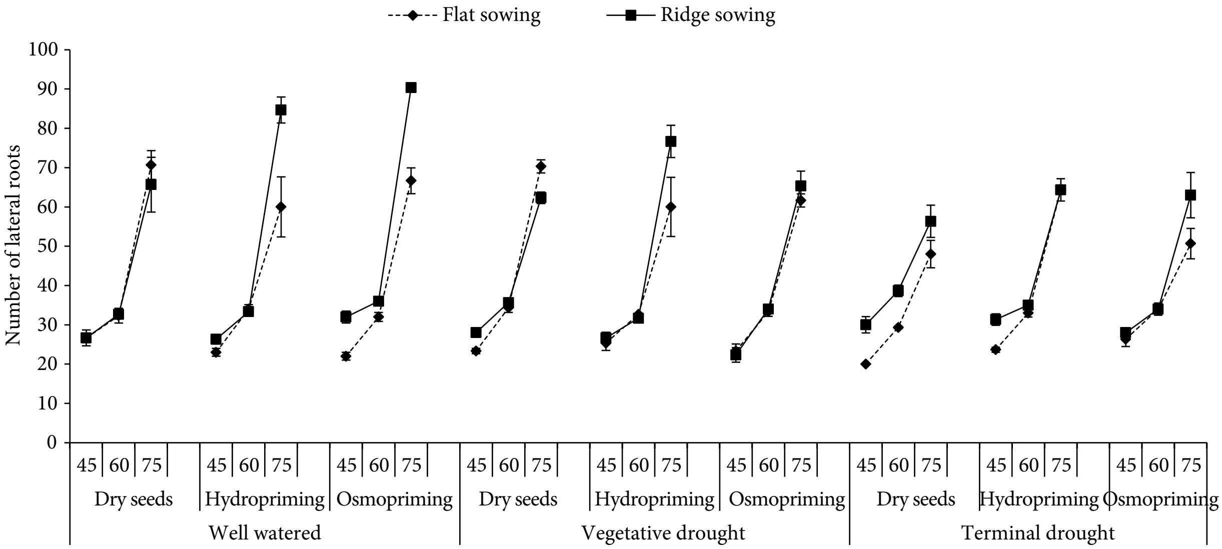

Figure 2. Effect of seed priming techniques and sowing methods on number of lateral roots of maize grown under drought at different phenophases ± S.E.

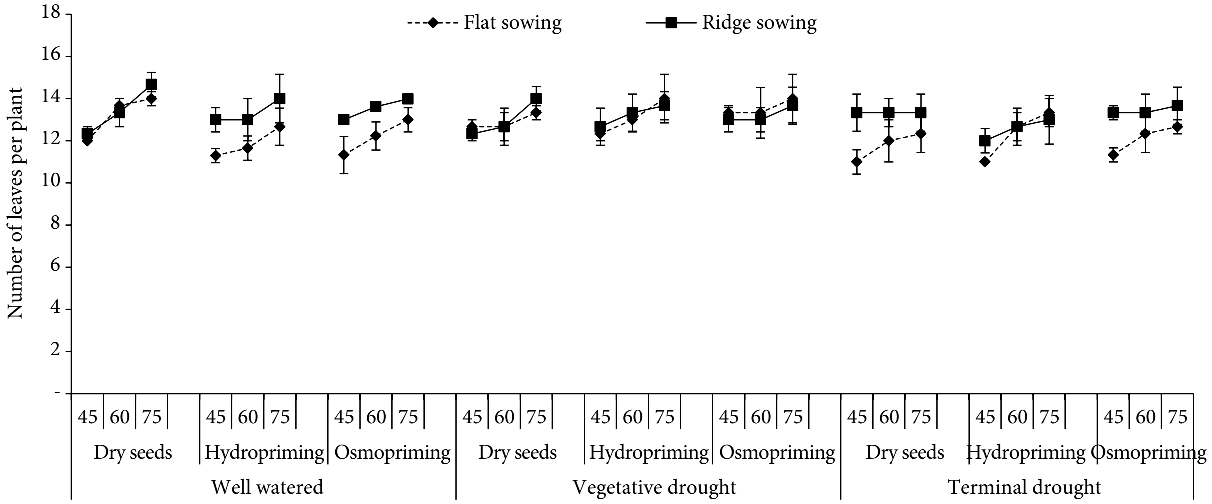

Figure 3. Effect of seed priming techniques and sowing methods on number of leaves per plant of maize grown under drought at different phenophases ± S.E.

Table 2. Analysis of variance (mean squares) for yield-related attributes of maize under different irrigation regimes and seed-enhancement techniques.

Sources of variation	DF	Sum of squares							
		Plant height (cm)	Number of cobs	Cob length (cm)	Number of grains per cob	1000-grain weight (g)	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
Water stress (WS)	2	1149.84*	0.00	9.41*	19,486.57*	16429.69*	89,475,650.50*	33,567,798.85*	1021.32*
Error (replication × WS)	4	55.45	0.13	0.98	262.57	143.91	870,279.96	414,122.30	32.45
Sowing methods (SM)	1	527.34*	0.07	0.71	3472.01*	20564.41*	1,483,049.46	644,236.10	85.05
WS × SM	2	14.01	0.29	17.97*	5350.46*	280.42	4,148,332.72	396,246.08	32.81
Error	6	38.58	0.22	0.35	570.14	1160.33	1,556,097.71	277,663.05	31.80
Seed priming (SP)	2	145.93*	0.16	1.37	4306.13*	274.56	5,260,238.03	166,468.14	37.13
WS × SP	4	26.46	0.16	2.57	264.88	3846.89*	658,482.03	1,385,974.48*	128.94*
SM × SP	2	43.62	0.24	4.89	692.35	459.71	2,475,780.24	480,852.35	46.63
WS × SM × SP	4	34.09	0.13*	2.66	1614.88*	1551.57	67,977,187.86*	2,083,494.90*	42.26
Error	24	16.15	0.33	1.51	441.50	915.26	2,167,321.30	371,747.47	49.35
C.V. (%)		1.97	23.62	6.84	4.07	11.80	10.71	14.85	23.39

DF = degree of freedom; C.V. = coefficient of variance; * = significance at P = 0.05.

Osmoprimed seeds sown on ridges under well-watered conditions possessed the highest number of cobs per plant (Table 2; Figure 5). All other plots had a statistically similar number of cobs per plant, except the dry seeds sown on flat land under well-watered conditions which had the lowest number of cobs per plant (Figure 5). Drought stress at both phenophases substantially decreased the cob length, while osmopriming significantly improved the cob length against untreated seeds (Table 2; Figure 6). However, ridge planting maintained its dominance over flat seedbeds in improving cob length under drought imposed at the terminal drought stage (Table 2; Figure 6). Numbers of grains per cob were significantly reduced by drought at different phenophases, in particular drought at tasseling under flat sowing (Table 2; Figure 7). Osmopriming with ridge sowing produced a higher number of grains per cob,

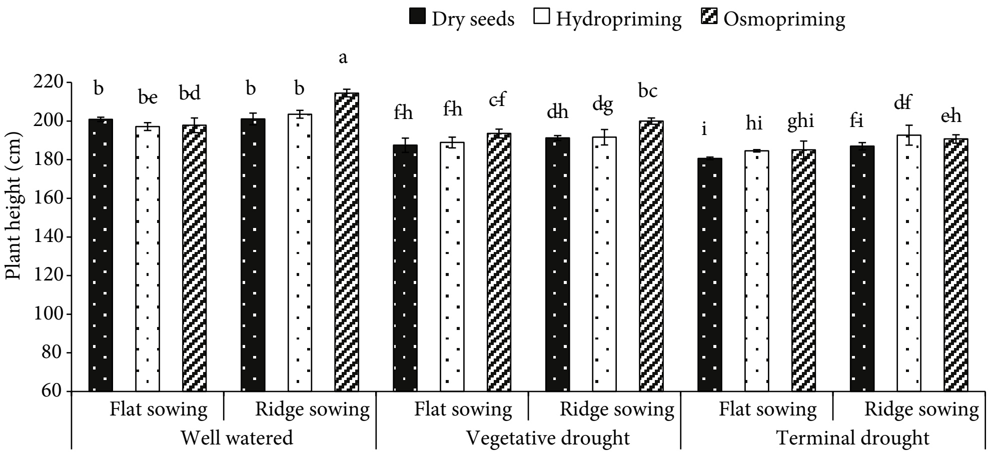

Figure 4. Effect of seed priming techniques and sowing methods on plant height (cm) of maize grown under drought at different phenophases ± S.E.; LSD 5% = 2.70.

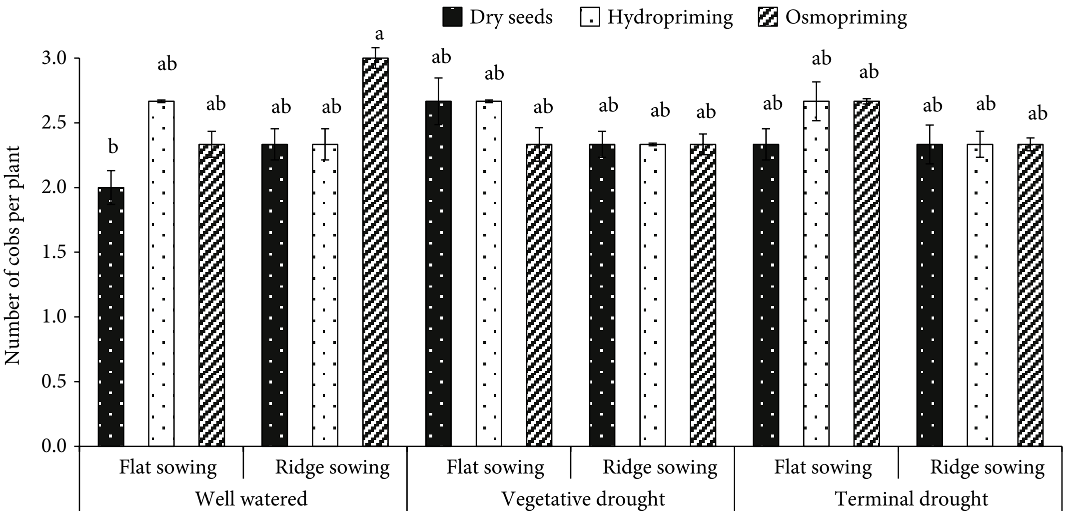

Figure 5. Effect of different seed priming techniques and sowing methods on number of cobs of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 0.96.

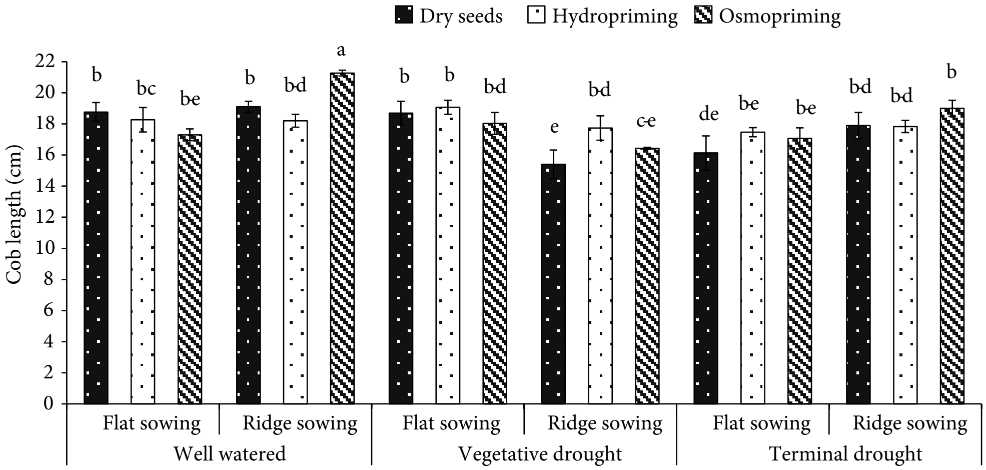

Figure 6. Effect of seed priming techniques and sowing methods on cob length (cm) of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 2.07.

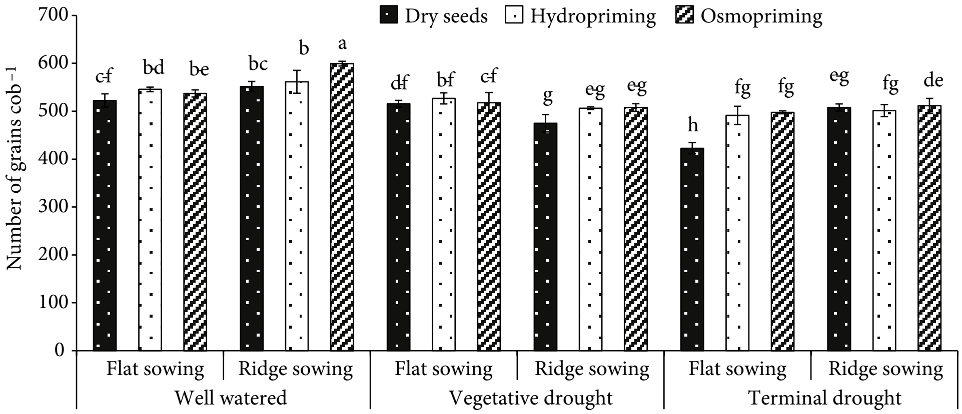

Figure 7. Effect of seed priming techniques and sowing methods on number of grains per cob of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 35.41.

not only under well-watered conditions but also under terminal drought (Figure 7).

Drought stress intensely decreased 1000-grain weight of maize, particularly in flat-sown crops, while ridge sowing helped to maintain a higher 1000-grain weight under drought stress (Table 2; Figure 8). Biological yield was rigorously reduced under drought stress, and terminal drought proved most dangerous (Table 2; Figure 9). Ridge-sown crops with seed priming produced higher biological yield in well-watered and vegetative drought conditions (Table 2; Figure 9). Drought stress substantially impaired the grain yield, particularly the terminal drought, when compared with a well-watered environment (Table 2; Figure 10). However, seed priming and ridge sowing improved the grain yield of maize under well-watered as well as drought conditions. Drought significantly reduced the harvest index, while seed priming improved the harvest index under well-watered conditions and under drought stress (Table 2; Figure 11). The highest harvest index was recorded for osmopriming in a well-watered environment (Figure 11).

Economic analysis (Table 3) indicated that a well-watered maize crop provided a higher gross and net income and BCR, while drought stress at the tasseling stage seemed poor in this regard. Likewise, ridge planting compared to flat seedbed and osmopriming compared with hydropriming and untreated seeds provided higher net income and BCR (Table 3).

4. Discussion

Drought both at vegetative and tasseling stages significantly impaired root system, yield, and related traits in maize; however, osmopriming and ridge sowing nullified the damaging effects of drought stress on maize performance (Table 2; Figures 1–11).

Possible reasons for drought-related decline in primary root length and number of lateral roots are reduced water

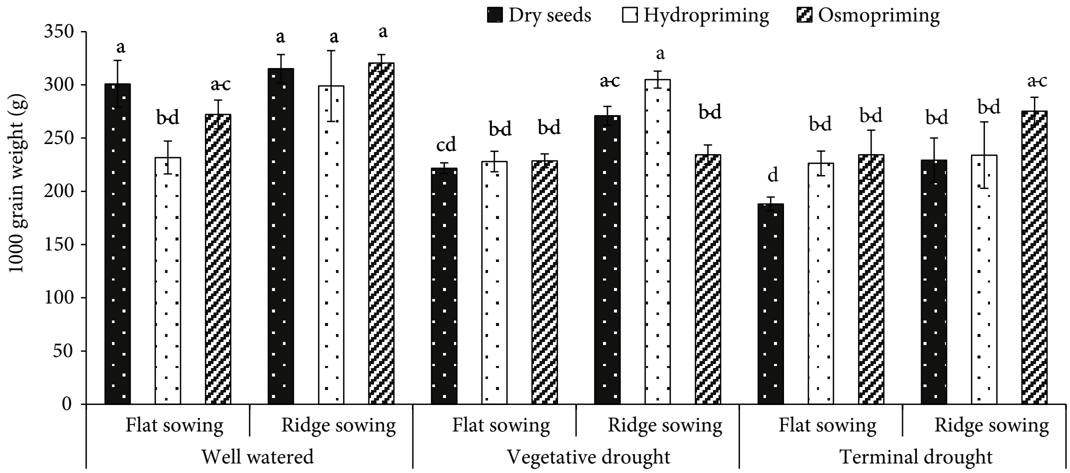

Figure 8. Effect of seed priming techniques and sowing methods on 1000-grain weight (g) of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 50.98.

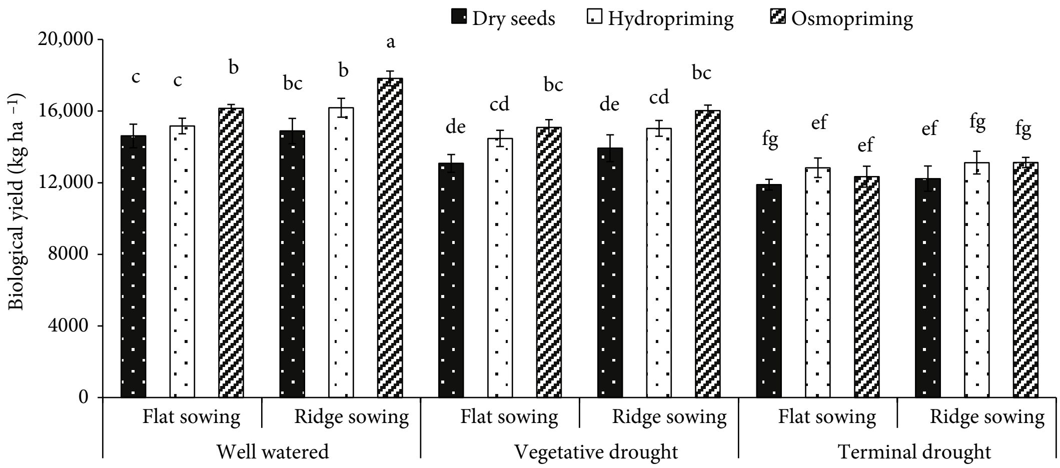

Figure 9. Effect of different seed priming techniques and sowing methods on biological yield (kg ha^{-1}) of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 1240.

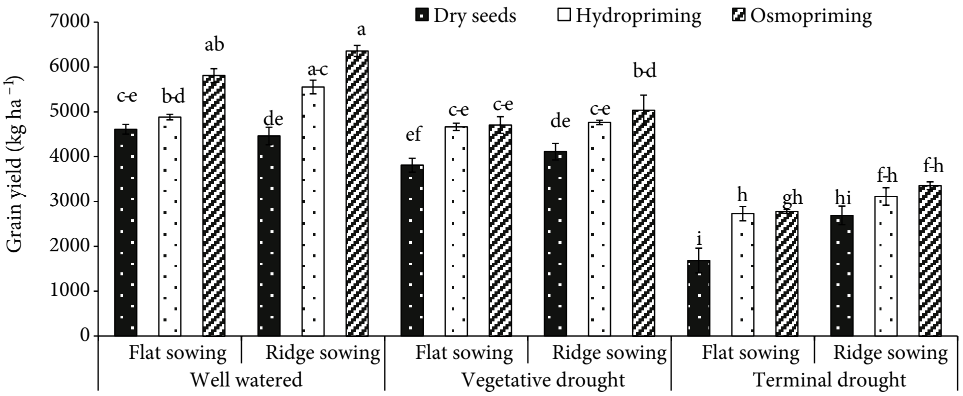

Figure 10. Effect of seed priming techniques and sowing methods on grain yield (kg ha^{-1}) of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 513.7.

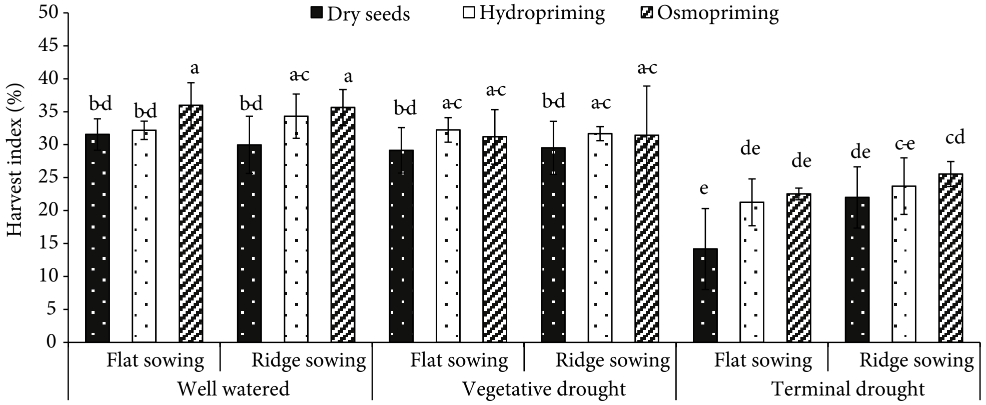

Figure 11. Effect of seed priming techniques and sowing methods on harvest index (%) of maize grown under drought at different phenophases ± S.E.; LSD at 5% = 11.84.

Table 3. Economic analysis of maize production under different irrigation regimes and seed-enhancement techniques.

Treatment	Total expenditure (US$ ha^{-1})	Gross income (US$ ha^{-1})	Net income (US$ ha^{-1})	Benefit-cost ratio (BCR)
Irrigation regimes (W)				
Well watered	573.41	1220.45	647.04	2.12
Vegetative drought	552.07	1024.80	472.73	1.85
Terminal drought	536.04	833.85	297.81	1.55
Sowing methods (S)				
Flat sowing	588.49	924.08	335.59	1.57
Ridge sowing	611.91	974.58	362.67	1.59
Seed-priming techniques (P)				
Dry seeds	571.51	875.53	304.02	1.53
Hydropriming	571.51	903.29	331.78	1.58
Osmopriming	587.06	974.32	387.25	1.65

supply to growing roots, which impairs cell division and expansion, mechanical hindrance to growing roots, diminished enzyme activities, and loss of turgor (Taiz and Zeiger, 2010; Zharfa et al., 2010; Farooq et al., 2012). Declines in root length and number of lateral roots have been observed under drought stress at different growth phases in maize (Ogawa et al., 2005). Improvements in root length and number of lateral roots by ridge sowing are the direct effect of the provision of a loose soil layer offering no resistance to root proliferation; the hard soil layer in the flat surface offers resistance, disturbing root growth (Khan et al., 2012a, 2012b). Drought-induced damage to rooting systems and the supremacy of ridge sowing for improving root systems in maize have been reported by Hussain et al. (2013), who noted that reduced water supply affects root growth, while ridges provide a loose surface layer to help the roots go deeper and extract moisture from deeper layers of soil. Similarly, priming-associated benefits for alleviating the damaging effects of abiotic stresses, drought in particular, have been reported (Farooq et al., 2008). Improvement in root length and seedling fresh weight by osmopriming with $CaCl_2$, compared with unprimed seeds, has also been reported (Farooq et al., 2006). Reduction in plant height under drought stress at different growth phases might be due to a decline in cell expansion and increased leaf senescence (Bhatt and Rao, 2005). Likewise Istanbulluoglu et al. (2002) also reported shortened plant height in maize under water deficit conditions. However, seed priming significantly improved plant height. There are contrasting reports in the literature indicating that priming-related benefits to crops only persist in earlier vegetative growth and have no effect on plant height (Basu and Choudhury, 2005).

Maize-grain yield is a consequence of the collective effects of all yield-related traits including number of cobs per plant, number of grains per cob, and grain size etc. under a given set of husbandry conditions. Drought imposed both at vegetative and tasseling stages substantially decreased the grain yield, although drought at tasseling was more damaging (Figure 10). Several researchers reported reduced grain yield of maize under drought stress, in particular drought at the reproductive phase (Cakir, 2004; Xin et al., 2011; Hussain et al., 2013). A substantial reductions in yield components (cob size, number of cobs per plant, number of grains per cob, and 1000-grain weight) were the key reasons for the yield penalty under drought stress at tasseling (Figures 5–10). Pollen sterility might be the cause of reduced grains per cob under water stress at the tasseling stage. Earlier, Sah and Zamora (2005) reported 18% and 40% fewer grains per cob due to exposure of the maize crop to drought at the vegetative and reproductive stages, respectively, compared with well-watered plants. Moreover, a short supply of water and nutrients due to poor root systems (Figures 1 and 2) under drought stress was also responsible for poor expansion of yield-related traits and led to the yield tax paid. Khan et al. (2012a) reported a positive relationship between root system and yield components of maize.

Ridge-sown maize produced a notably higher yield under well-watered and drought conditions due to a significant expansion in all yield-related traits (cob size, number of cobs per plant, number of grains per cob, and grain size) (Figures 5–10). In the case of ridge planting, ridges might provide a loose layer of fertile soil to growing roots, preventing resistance to root proliferation, and thus long roots with more lateral roots were observed (Figures 1 and 2). This well-developed root system, in the case of ridge sowing, ensured a greater water and nutrient supply by expanding into a larger area in a water-limited environment, compared with flat seedbeds (Khan et al., 2012a, 2012b; Hussain et al., 2013). Therefore, an elevated water and nutrient supply in ridge sowing enabled the plants to increase their photosynthetic activity to accumulate more dry-matter production and yield-related traits.

Seed priming, osmopriming with $CaCl_2$ in particular, not only improved the maize yield under well-watered conditions, it noticeably mitigated the detrimental effects of drought imposed at vegetative and tasseling stages on yield due to a substantial upgrading of yield-related traits (Figures 5–10). Higher water and nutrient supplies under deficit water conditions due to a well-developed root system, i.e. more root length with higher root proliferation (Figures 1 and 2), might be the cause of improvement in yield related traits (cob length, number of grains per cob, and 1000-grain weight) in maize subjected to osmopriming under drought stress (Figures 6–8). Better assimilate portioning and greater grains per cob in maize due to seed priming were also reported (Harris et al., 1999, 2001). Improvement in crop performance in terms of germination, early growth, yield, and yield components in different field crops under stressed environments has also been reported (Farooq et al., 2006, 2008).

Economic feasibility in monetary terms is prerequisite for adoption of any new innovation or technique on a large scale in the farming community. Economic analysis of the experiment clearly elaborated the dominance of well-watered conditions over drought, drought at tasseling in particular, to attain higher income and BCR (Table 3). Nonetheless, ridge sowing compared with flat seedbed and osmopriming compared with control (unprimed seeds) also proved their supremacy for achieving maximum net income and BCR (Table 3), due to the resulting expansion in maize production under normal and stressful conditions.

In conclusion, drought both at vegetative and tasseling phases severely hampered the root systems and productivity of hybrid maize; however, ridge sowing and seed priming with $CaCl_2$ were helpful in mitigating the adversities of drought stress. Maize can be sown on ridges and seed primed with $CaCl_2$ where it is subjected to drought stress in order to minimize the losses induced by drought stress. Further, it is suggested that the effects of priming with different Ca salts must be explored for improving maize productivity in water-limited environments.

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