Impact of Moisture Deficit on Physiological Quality of Maize Seeds

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Summary

There is limited empirical information on the physiological basis of the development of seed quality despite the awareness that vigorous seeds provide a basis for solving crop-establishment problems. To address this problem, seeds of 16 maize (*Zea mays* L.) genotypes were planted in the dry season and the crop was grown entirely under irrigation. In one of the blocks, irrigation was suspended from five weeks after planting to harvest, whereas the control plot received irrigation from planting to physiological maturity. The seeds produced under the irrigated and moisture deficit conditions were harvested and subjected to seed viability and vigor tests as well as to seedling-evaluation tests. High-yielding genotypes did not necessarily produce seeds with high vigor. Moisture deficit resulted in 34% loss in germination potential, whereas vigor loss was between 40% and 220%, depending on the type of vigor test used. The seeds produced under moisture deficit had slow and non-uniform germination and seedling growth, with poor storage potential. Water availability to the crop affected seed vigor more than the genotypic effect, suggesting an inelastic limit to the extent that genotype can compensate for inadequacy of moisture of a maize plant.

Key words

accelerated aging, maize, moisture deficit, physiological quality, vigor

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Introduction

Farming under rain-fed conditions is vulnerable to the effects of climate change. Empirical evidences suggest a negative impact of climate change on crop productivity in sub-Saharan Africa. Odjugo (2010) analyzed mean air temperatures recorded between 1901 and 2005 and reported that mean air temperature across Nigeria alone had steadily increased, especially since the 1970s. The results were corroborated by Oguntunde et al., (2012), who analyzed trends and variabilities in evaporation and other climatic variables at Ibadan (Nigeria) from 1973 to 2008 and concluded that Ibadan had experienced colder nights and warmer afternoons during the study period, i.e. almost four decades. The potential long-term implications of these changes for agricultural productivity warrant development of climate-smart agricultural systems and climate-resilient crops (McCarthy et al., 2011; Wollenberg et al., 2011; Neufeldt et al., 2011; Banga and Kang, 2014). Multiplication and distribution of seeds of climate-resilient crop varieties is the first step in improving such systems and in providing food security assurance because the success of all the subsequent stages in crop production is dependent on availability of high-quality seeds of adapted crop varieties.

Moisture deficit affects almost every developmental stage during maize growth. However, the most devastating effects of this stress occur during germination, establishment and flowering (Khayatnezhad et al., 2010; Queiroz et al., 2019). The effect of drought on seed quality is dependent on the developmental stage at which the plant encounters moisture deficit, mostly during the interval between pollination and physiological maturity (Bradford, 1994; Champolivier and Merrien, 1996). Also, the effect of drought on seed vigor will be the cumulative effects of moisture deficit on several physiological processes preceding seed formation, development and maturation. When moisture deficit occurs, the rate of photosynthesis is reduced (Siddique et al., 1999), thereby causing a reduction in the level of assimilates produced and eventually stored in the endosperm. Therefore, the endosperm, which contains primarily starch, becomes shrivelled, causing a reduction in seed size, weight and physiological quality (Quattar et al., 1987; Heatherly, 1993; Bradford, 1994). Awosanmi et al., (2016) reported that accumulation of assimilates terminated much earlier during seed development in moisture-stressed maize plants, which could have also been enhanced by high atmospheric temperature and evapotranspiration rate, leading to the production of smaller seeds. Zehtab-Salmasi et al., (2006) found a positive correlation between heavier seeds and seed vigor. In carrot (*Daucus carota* L.), water deficit enhanced seed quality by restricting the development of subsequent inflorescences and by a reduction in intra-plant competition for photosynthates and reserves (Steiner et al., 1990). In contrast, Smicklas et al., (1992) observed no effect on germination percentage, accelerated aging percentage or seedling axis dry weight when drought was imposed on soybean during flowering. According to Sinniah et al., (1998), terminal drought on rapid-cycling brassica (*Brassica campestris* [rapa] L.) resulted in the development of high seed quality. On the other hand, a reduction of both germinability and vigor of groundnut (*Arachis hypogea*) was reported by Dornbos and Mullen (1991).

Considering the predicted effect of climatic changes on crop production and food security, knowledge of the genotypic differences regarding vigor of maize seeds produced under drought is important to ensure selection of genotypes with consistent production of high-quality seeds to maintain good plant stand in marginal production environments. The objective of this study was therefore to investigate the effects of exposure of maize seeds of different genotypes from two contrasting moisture regimes on seed viability and vigor.

Materials and Methods

Sixteen maize hybrids (Table 1), developed at the International Institute of Tropical Agriculture (IITA), Ibadan, were evaluated at Ikenne experiment station (latitude 60° 53' N, longitude 3° 42' E and altitude 60 m above sea level) in Nigeria. The genotypes were planted in a single 3 m row with 0.75 m between rows and 0.25 m between hills. Two seeds were planted in a hill and later thinned to one after emergence, to an approximate density of 53,333 plants per hectare. The experimental design was a split-plot arrangement (Main plot – Treatment; Sub-plot – Genotype) with three replications. The experimental fields in the station were flat and fairly uniform. Planting was done in the dry season and the crops were completely dependent on sprinkler irrigation. The field was divided into two blocks. The first block was watered adequately every week from planting till physiological maturity while irrigation was withdrawn five weeks after planting in the second block to impose moisture deficit.

Table 1. Pedigree of the maize genotypes evaluated under irrigated and moisture deficit conditions

Genotype Code	Pedigree
1	9071/LATA-26-1-1-1-B-B
2	9071/P43SRC9FS100-1-1-8#1-B1-13-B1-B-B
3	9071/CML373
4	9071/DT-SR-W-3-3-2-1-1-B-B-B-B-B
5	9071/1368xHIx4269-1x1368-4-1-B-B-B-B
6	9071/1368xHIx4269-1x1368-7-2-B-B-B-B
7	1368/Obantapa-33-5-1-B-B
8	1368/(TZMI50xKU1414x501)-1-4-3-1-B-B
9	1368/(9071xBabamgoyo)-3-1-B-B
10	1368/EV8749-SR-25-1-B
11	1368/LATA-26-1-1-1-B-B
12	1368/DTPL-W-C7-S2-1-2-1-1-4-B-1
13	1368/ACR-86-8-1-2-1-1-1-B-1
14	1368/Tux-DT-STR-1-3-2-2-1-1-1-1
15	Oba Super 1
16	Oba 98

Weeds were controlled by applying both paraquat and atrazine at the rate of 5 L ha^{-1} of each formulation. NPK compound fertilizer at the rate of 60 kg N, 60 kg P and 60 kg K per ha was applied four weeks after planting.

Harvested seeds from both plots were subjected to viability and vigor tests as follows:

Standard germination test: The standard germination test was conducted for each maize genotype with 400 seeds tested in four equal replicates on moistened, sterilized sand for 7 days in plastic bowls. Germination counts were taken daily from the 4^{th} to the 7^{th} day after sowing (DAS). Germination was assessed as percentage of seeds producing normal seedlings as defined by ISTA (2018) rules as follows:

$$Germination\ Percentage\ (GPCT) = \frac{100\ \times Number\ of\ seedlings\ that\ emerged\ 7DAS}{Total\ number\ of\ seeds\ planted}$$

Germination index was also calculated as proposed by Fakorede and Agbana (1983):

$$Germination\ Index\ (GI) = \frac{\Sigma((number\ \ of\ plants\ that\ emerged\ in\ a\ day) \times (DAS)}{Total\ number\ of\ plants\ that\ emerged\ on\ the\ 7th\ day}$$

Evaluation of seedling traits: One out of every 10 normal seedlings, that is, 10% of the total number of normal seedlings, in each replicate, at the final germination count, was used to obtain data on the following seedling-vigor parameters:

Seedling shoot length (SLT): The length from the base of the plant to the node bearing the first leaf was measured and expressed in cm.

Number of roots (RNO): This was the number of roots on each seedling.

Root length (*RLT)*: This was the length of the primary root measured in cm.

Accelerated aging test: Fifty seeds of each genotype in four replicates were weighed and placed in wire mesh suspended over 40 ml distilled water in accelerated-aging boxes. Aging of the seeds was done by placing the aging boxes in an accelerated aging chamber set at 43 °C for 72 h. Standard germination test was then conducted with the aged seeds, as described above. Accelerated aging germination percentage (AAT) and accelerated aging index (AAI) were calculated by substituting the germination counts after accelerated aging into the formula for germination percentage and germination index given above, respectively.

Bulk conductivity test: Four replicates of 50 pre-weighed seeds from each genotype were soaked for 24 h in 100 mL distilled water in 200 mL conical flasks covered with aluminium foil to prevent contamination. The flasks were shaken intermittently. The conductivity of water was first measured using a flask with 100 ml distilled water without seeds. This conductivity was measured using a conductivity meter (Mettler Toledo Mc 126, GmbH Schwerzenbach, Switzerland), and expressed as $\mu Scm^{-1}g^{-1}$:

$$Bulk\ conductivity = \frac{Conductivity\ for\ each\ flask\ - conductivity\ of\ distilled\ water}{Dry\ weight\ (g)\ of\ seed\ sample\ for\ each\ flask}$$

Ranking of genotype means across all vigor tests was done to identify stable, adapted and outstanding genotypes. The stability of the genotypes across the vigor tests was evaluated using a vigor index (VI), which was calculated as an average performance in each of the tests across treatments, as shown below:

$$VI = \frac{(GPCT + AAT + COND\ (\%))}{3}$$

where GPCT = Germination percentage, AAT = Accelerated aging germination percentage, COND = Bulk conductivity. The higher the VI, the more stable the genotype.

Conductivity values were converted to % as follows:

$$COND\ (\%) = 100\ X\ (\frac{30-COND}{30})$$

Given that lower conductivity values indicate higher quality, the factor 30 was used on the basis of the interpretation of conductivity values in relation to field emergence, as suggested by Hampton and TeKrony (1995). Therefore, seedlots with conductivity values greater than 30 $\mu Scm^{-1}g^{-1}$ were regarded as not suitable for sowing, especially under adverse field conditions.

Statistical Analysis

The data were subjected to analysis of variance using the General Linear Model procedure of SAS version 9.1 (SAS 2003). The means of the genotypes for the vigor tests were determined for both treatments and compared. Stepwise multiple regression analysis was also carried out.

Results

Mean square attributable to genotypes was significant (P < 0.01) for all the parameters, except number of roots (Table 2). In addition, the treatment (moisture level) significantly affected all the parameters measured, except germination index, number of roots and root length. The genotype × treatment interaction was significant for all the parameters, except germination index and amount of water imbibed during the aging process (WIA). Moisture deficit significantly reduced standard germination percentage by 34%, accelerated aging germination percentage by 40% and amount of water imbibed during the aging process by 34%, whereas it significantly increased accelerated aging index (AAI) by 7% and bulk conductivity by 220% (Table 3).

When expressed as a percentage of the total sum of squares, the contribution of genotype to the observed variability was greater than that of the treatment (the moisture condition of the mother plant) for germination index, accelerated aging germination index and the seedling traits (Table 4). On the other hand, the treatment contributed more to the observed variability in standard germination and accelerated aging germination percentages, bulk conductivity and the amount of water imbibed during accelerated aging. The contribution of the interaction effect was moderately high for the seedling traits. Generally, the proportions of the observed variations that were not accounted for by the sources of variation, that is, error, were very high for all traits, except for the amount of water imbibed. Marked differences were detected among genotypes for all the characters measured under both fully irrigated and moisture deficit conditions and the genotypic differences were greater under moisture deficit than under irrigated condition (Table 5). Genotypes did not rank consistently across the three tests, namely, standard and accelerated aging germination and conductivity tests. Across the two conditions, the genotypic means for standard germination percentage ranged between 27% and 94%, whereas a larger range

Table 2. Mean squares from the combined analysis of variance of maize vigor tests for irrigated and moisture deficit conditions

Tests	Rep (df = 3)	Treatment, (T) (df = 1)	Error A (df = 3)	Genotype (G) (df = 15)	G x T (df = 15)	Error B (df= 90)	C.V (%)	R^2 (%)
GPCT	235.18	23331.09**	766.69	1097.17**	513.45*	266.39	25.38	65.06
GI	0.27	0.08	0.33	0.50**	0.17	0.14	8.10	43.24
AAT	416.69	22889.74**	40.15	887.23**	641.94**	246.29	27.94	68.70
AAI	0.07	2.79**	0.10	0.50**	0.22**	0.09	6.21	62.79
WIA	0.00	27.35**	0.37	0.18**	0.07	0.04	9.74	87.03
COND	33.12	4607.90**	31.88	41.42**	33.45**	16.03	35.27	79.51
RNO	0.38	0.99	0.44	0.53	0.87*	0.28	10.91	47.40
SLT	0.56	8.30**	0.77	2.38*	3.47**	0.86	10.23	58.79
RLT	3.59**	12.31	0.81	10.89**	10.72**	2.48	14.64	68.36

Note:
*Significant at $P < 0.05$
**Significant at $P < 0.01$
GPCT = Germination percentage
GI = Germination index
AAT = Accelerated aging germination percentage
AAI = Accelerated aging germination index
WIA = Amount of water imbibed during accelerated aging
COND = Conductivity value
RNO = Average number of roots per seedling
SLT = Seedling shoot length
RLT = Root length

Table 3. Mean, range, standard deviation (SD) and percent variation in the mean of vigor tests performed on maize seeds produced under different field moisture conditions

Vigor	Irrigated				Moisture deficit				Percent variation in the mean of the two moisture conditions
	Mean	Min.	Max.	SD	Mean	Min.	Max.	SD	
GPCT	79.59	36.67	98.00	15.05	52.49	4.00	93.00	24.39	34.05
GI	4.79	4.23	5.84	0.33	4.73	4.00	6.44	0.52	1.25
AAT	68.79	20.00	94.67	16.38	41.57	6.00	94.00	21.95	39.57
AAI	4.72	4.08	5.52	0.36	5.03	4.17	6.16	0.43	6.57
WIA	2.79	2.10	3.39	0.29	1.85	1.40	2.39	0.23	33.69
COND	5.51	2.98	8.58	1.18	17.65	9.12	33.26	6.55	220.33
RNO	5.11	3.67	6.33	0.55	4.81	3.67	6.00	0.75	5.87
SLT	8.89	6.33	11.90	1.23	9.60	8.20	11.20	1.04	7.99
RLT	11.17	7.03	17.63	2.34	9.92	6.80	12.80	1.93	11.19

Note:
GPCT = Germination percentage
GI = Germination index
AAT = Accelerated aging germination percentage
AAI = Accelerated aging germination index
WIA = Amount of water imbibed during accelerated aging
COND = Conductivity value
RNO = Average number of roots per seedling
SLT =Seedling shoot length
RLT = Root length

Table 4. Percentage of relative contributions of the sources of variation to the total sum of squares

	Rep	Treatment(T)	Error A	Genotype (G)	G*T	Error B
GPCT	0.96	31.67	3.12	22.34	10.45	31.82
GI	3.41	0.32	4.15	31.60	10.85	52.60
AAT	1.80	32.87	0.17	19.11	13.83	31.12
AAI	0.96	12.46	1.33	33.51	14.72	35.88
WIA	0.02	75.91	3.05	7.33	3.07	9.92
COND	1.34	62.02	1.29	8.36	6.75	19.20
RNO	3.60	3.08	4.12	25.07	21.78	46.64
SLT	1.34	6.68	1.85	28.74	22.37	37.61
RLT	2.42	2.81	0.55	36.73	19.29	30.07

Note:
GPCT = Germination percentage
GI = Germination index
AAT = Accelerated aging germination percentage
AAI = Accelerated aging germination index
WIA = Amount of water imbibed during accelerated aging
COND = Conductivity value
RNO = Average number of roots per seedling
SLT = Seedling shoot length
RLT = Root length

Table 5. Performance of individual maize genotypes among vigor tests compared in the irrigated and moisture deficit conditions

G	GPCTIR	GPCTMS	AATIR	AATMS	CONDIR	CONDMS	V. I	RANK
1	90.00	63.50	75.67	41.00	79.66	20.07	61.65	9
2	81.33	52.22	56.67	50.44	81.60	68.00	65.05	6
3	76.00	68.50	83.00	56.67	79.10	34.53	66.30	4
4	73.83	37.08	53.67	44.00	80.70	54.93	57.37	12
5	73.67	77.83	70.67	53.00	78.47	43.33	66.16	5
6	71.67	27.33	47.33	13.33	78.27	17.43	42.56	16
7	91.33	70.33	80.33	64.22	85.07	42.83	72.36	2
8	93.00	79.00	62.00	70.00	85.40	59.90	74.88	1
9	82.00	42.67	71.33	21.67	82.00	18.30	53.00	14
10	70.50	37.83	54.67	44.33	80.60	37.13	54.18	13
11	94.17	30.50	90.00	26.33	88.13	41.47	61.77	8
12	68.17	41.83	74.67	39.00	80.63	52.17	59.41	10
13	88.33	76.33	73.33	48.67	81.90	34.87	67.24	3
14	76.17	38.25	63.67	16.67	82.97	40.23	53.00	14
15	76.75	54.00	77.67	40.67	79.37	46.30	62.46	7
16	66.58	39.00	66.00	43.00	82.20	53.80	58.43	11

Note: GPCTIR = Germination percentage of the seeds from the irrigated plot; GPCTMS = Germination percentage of the seeds from the moisture deficit plot; AATIR = Accelerated aging germination percentage of the seeds from the irrigated plot; AATMS = Accelerated aging germination percentage of the seeds from the moisture deficit plot; CONDIR = Conductivity values of seeds from the irrigated plot; CONDMS = Conductivity values of seeds from the moisture deficit plot; V. I. = Vigor index was observed for accelerated aging germination percentage, which ranged from 13% to 90%. With the exception of genotypes 9071/CML373, 1368/DTPL-W-C7-S2-1-2-1-1-4-B-1 and Oba Super 1, all genotypes had a higher standard germination percentage than accelerated aging germination percentage under irrigated condition, whereas genotypes 9071/DT-SR-W-3-3-2-1-1-B-B-B-B-B, 1368/EV8749-SR-25-1-B and Oba 98 had a higher standard germination percentage than accelerated aging germination percentage under moisture deficit condition. Genotypes 9071/P43SRC9FS100-1-1-8#1-B1-13-B1-B-B and 9071/1368xHIx4269-1x1368-7-2-B-B-B-B had the least (13.60%) and the widest (60.84%) variation in conductivity values between the irrigated and moisture deficit conditions. This significantly contributed to their final ranking in vigor index.

Accelerated aging test was a good predictor for the ranking of the genotypes, as it accounted for 74% and 92% of the vigor tests to the vigor index, for the irrigated and moisture deficit conditions respectively (Table 6). Genotypes 1368/(9071xBabamgoyo)-3-1-B-B, 1368/LATA-26-1-1-1-B-B, 1368/EV8749-SR-25-1-B, 1368/Tux-DT-STR-1-3-2-2-1-1-1-1 and 1368/ACR-86-8-1-2-1-1-1-B-1 ranked best across the two treatments with respect to seed yield, while genotypes 9071/P43SRC9FS100-1-1-8#1-B1-13-B1-B-B, 1368/(TZMI50xKU1414x501)-1-4-3-1-B-B, Oba Super 1, 9071/LATA-26-1-1-1-B-B and 9071/CML373 ranked worst (Table 7).

Table 6. Stepwise multiple regression for the vigor tests in predicting the genotypic ranking under irrigated and moisture deficit conditions

Step	Irrigated condition		Moisture – stress condition	
	Vigor Test	Partial R-square	Vigor Test	Partial R-square
1.	AAT (%)	0.743***	AAT (%)	0.918***
2.	GPCT (%)	0.246***	COND (%)	0.026*
3.	COND (%)	0.011***	GPCT – COND (%)	0.055***

Note:
*Significant at $P < 0.05$
*** Significant at $P < 0.0001$)
GPCT – Germination percentage
AAT – Accelerated aging germination percentage
COND – Conductivity value

Table 7. Ranking of maize genotypes by seed yield (ton ha^{-1})

Genotype code	Well- watered	Rank	Moisture-stressed	Rank	Rank Summation	Overall Ranking	Rank Deviation (%)	Genotype Stability Ranking
1	6.82	4	1.25	9	13	7	76.92	13
2	8.10	1	1.14	11	12	5	166.67	16
3	7.10	2	1.40	4	6	1	66.67	12
4	6.39	8	1.03	13	21	12	47.62	11
5	6.73	6	1.38	5	11	4	18.18	6
6	6.81	5	1.26	7	12	5	33.33	8
7	5.59	12	1.25	8	20	10	40.00	9
8	6.69	7	1.95	1	8	3	150.00	15
9	6.85	3	1.43	3	6	1	0	1
10	5.06	15	0.55	16	31	15	6.45	3
11	6.20	10	1.15	10	20	10	0	1
12	6.24	9	1.37	6	15	8	40.00	9
13	5.15	14	1.07	12	26	14	15.38	5
14	4.84	16	0.57	15	31	15	6.45	3
15	5.57	13	1.48	2	15	8	146.67	14
16	6.07	11	0.74	14	25	13	24.00	7

Genotypes 3 and 9 had the same and least rank summation and were found to be the most stable across moisture regimes. Only genotypes 9071/DT-SR-W-3-3-2-1-1-B-B-B-B-B, 9071/1368xHIx4269-1x1368-4-1-B-B-B-B, 1368/DTPL-W-C7-S2-1-2-1-1-4-B-1 and 1368/ACR-86-8-1-2-1-1-1-B-1 had comparable ranking for seed yield and seed vigor across the two contrasting moisture regimes (Table 8). Although genotype 1368/LATA-26-1-1-1-B-B was ranked as the overall second best, its ranking for seed vigor was poor. Similarly, genotype 1368/Obantapa-33-5-1-B-B that had the same rank summation as genotype 5 had a low seed yield ranking.

Table 8. Comparison of maize genotype rank summation index for seed yield and vigor

Genotype code	Genotype Ranking for seed yield	Genotype Ranking for seed vigor	Rank Summation	Ranking
1	13	9	22	13
2	16	6	22	13
3	12	4	16	6
4	11	12	23	15
5	6	5	11	3
6	8	16	24	16
7	9	2	11	3
8	15	1	16	6
9	1	14	15	5
10	3	13	16	6
11	1	8	9	2
12	9	10	19	11
13	5	3	8	1
14	3	14	17	9
15	14	7	21	12
16	7	11	18	10

Discussion

The impact of moisture deficit on seed vigor varies among species within the same genus and the stage of growth at which moisture deficit occurs. Events occurring within the seed are influenced by the maternal environment (Sinniah et al., 1998; Demir et al., 2008). The physiological quality of seeds that relates with vigor and viability is very important because of its direct and immediate effect on field establishment. The results of this study clearly demonstrated that viability and vigor traits that relate to germination of maize seeds were negatively affected by moisture deficit during seed development. The broader ranges and standard deviations of traits measured under moisture deficit relative to those produced under full-irrigation also suggest that the physiological processes affecting seed quality traits are expressed differently under drought stress (Hampton et al., 1994; Akinwale et al., 2017) and ultimately result in physiologically non-uniform seeds. Therefore, the variation in physiological quality of seeds could result not only from variations in seed size, chemical composition, and the maturity of seeds at the time of harvest but also from inadequate moisture condition of seed-bearing plants.

The detection of significant genotype and, genotype × treatment interaction for vigor and the resultant seedling indicated that the ranking of the genotype performance varied from the irrigated to the moisture deficit condition. However, there is the possibility of identifying genotypes that will perform well under both adequate and limiting moisture conditions during seed development. The contribution of the water status of the mother plant environment to the vigor of seeds produced, as measured by accelerated aging germination and bulk conductivity was high, suggesting an inelastic limit to the extent that genotype could compensate for inadequacy in moisture availability in maize (Awosanmi et al., 2016). The interaction between genetic characteristics and moisture conditions determined the quality of the seed and seed performance, as earlier reported by Delouche (2005) and Elias (2006).

According to Woltz and Tekrony (2001), seed lots of high quality showing 70% to 80% germination after the aging test can be considered to have met acceptable minimum level. While this was not achieved in the seeds produced under moisture deficit for all the genotypes, three genotypes had more than 80% germination after the aging test under well-watered condition. The loss in vigor also revealed the level of pre-harvest deterioration that had already taken place within the seed lots. This corroborates the fact that standard germination test alone is not sufficient to detect quality and that vigor is gradually lost in seeds prior to the loss of viability (Hampton and Tekrony, 1995). This assertion became more pronounced in the seeds produced under moisture deficit. Powell (2006) attributed the rate of loss in vigor of seeds to environmental factors. Although seeds are believed to possess repair mechanisms, these mechanisms seemed inadequate to compensate or counter the drought-induced deteriorative processes that resulted in the apparent low vigor of the moisture deficit-produced seeds across all the genotypes.

The rapidity of the loss of vigor, as measured by the conductivity test, was both influenced by the environmental condition in which the seeds developed and the genetic make-up of the seeds. Kilen and Hartwig (1978) reported that impermeability of seed coat was a heritable trait and was apparently derived from differences in seed-coat thickness and composition that are affected by drought (Nooden et al., 1985). The higher the conductivity value, the lower the vigor and vice versa (ISTA, 2018). Seeds produced under the moisture deficit conditions leaked more ions when soaked, depicting a low vigor and a less likelihood of producing a healthy plant stand when sown in the field. According to Bewley and Black (1994), leaked solutes stimulate the growth of fungi and bacteria in the soil, which, in turn, invade the seed and lead to its deterioration. Although a significant percentage of the seeds produced under moisture deficit condition germinated, the vigor was compromised prior to harvesting.

However, the genotypes showed a differential seed yield response to moisture deficit. The extent to which genotypic differences contributed to the variability in mean values for the two moisture regimes was quite minimal, as most of the variability was attributed to differences in the moisture condition of the mother plant. These results unequivocally reinforce the thinking that seed mother plants require adequate moisture (Quattar et al., 1987; Bankole et al., 2018) not only during flowering and post-flowering stages but also throughout the entire growing season. As the quality of seeds is an important end result of all seed production efforts (Boko et al., 2007), the results of this study showed that such seeds could best be produced with supplemental irrigation in drought-prone areas.

The vigor tests notably accelerated aging germination percentage, provided a fair assessment of the stability of the genotypes for high seed vigor production under adverse weather and the results revealed wide genetic differences that could be exploited for the development of varieties with high seed vigor, even though this had rarely been a breeding objective. Interestingly, the genotypes ranked differently for seed yield and vigor to the extent that no single genotype was among the best five for seed yield and for seed vigor. The lack of consistency in the ranking of the genotypes for seed yield and seed vigor puts plant breeders and commercial seed producers in a dilemma because of its significant implications for selection during varietal development and for large-scale profitable seed production. A newly developed and adapted genotype with high vigor rating will be considered an ideal candidate for release and large-scale seed multiplication for food production. This is because, with such a ranking, the genotype will be expected to tolerate adverse field conditions and give reasonable yield. From a commercial point of view, however, a high seed-yielding genotype will be expected to give a high profit margin for seed producers, because seeds are often sold on a weight basis. The moisture condition of the mother plant that produced this result notwithstanding, this conflicting situation could arise under any condition for plant growth and development. But in reality, plant breeders are rarely confronted with this challenge because seed vigor is rarely considered a selection criterion during varietal development and because viability, measured by standard germination percentage, is often used as index of vigor presuming that viable seeds will be vigorous. Hence, the inclusion of high seed vigor as a selection criterion during evaluation and selection of maize varieties will increase the yield and range of adaptation of maize varieties.

In conclusion, moisture deficit has a profound, measurably negative effect on physiological quality of maize seeds and this has been observed as slow and non-uniform germination and seedling growth, with reduced vigor potential. Therefore, the production of high quality seeds is dependent on adequate moisture supply to the mother-plant, which then makes irrigation and adequate rainfall very essential in production of high quality maize seeds.

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