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Effect of Some Seed Physical Characteristics on Viability of Pearl Millet (*Pennisetum glaucum* (L.) R. Brown)

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ABSTRACT

To address the poor seed viability problem of pearl millet in Ghana, the influences of time of harvesting, some seed physical characteristic and moisture content relations on viability were evaluated. Harvesting was done on day 1, 3, 5, 7 and 14 from the physiological maturity or the hard-dough stage. The seeds were also fractionated into <2, >2 and 1-3 mm grades. Data on seed moisture content, bulk density and thousand seed weight were determined. Standard germination tests were carried out and counting was done from day 3 to 9. An analysis of the physical environment revealed that the extreme dry conditions (Temperature~18-42°C, RH%~20-54) which prevail during the period of seed storage may provide opportunity for seed drying. Gradual increases in seed weight, bulk density and thousand seed weight occurred from day 1 to 5 and peaked by 7 days after hard-dough stage. Consistently high germination rates were attained by harvesting at 7 days after hard-dough. The seeds harvested at day 1, 3 and sometimes 5 showed abysmal performances for most vigor traits evaluated. Within 9 months of storage, low germination rate of 53.3-65.8% was recorded. Four varieties, Arrow millet, Bongo short head, Bristle millet and Tongo yellow, which exhibited large seed characteristics consistently showed higher germination rates compared with their counterparts Salma-1, Salma-3, Indiana-05 and Langbensi millet. Across varieties, large seeds recorded higher germination rates compared with other grades. Seed vigor traits such as incidence of seedling abnormalities and days 3 to 5 leaf stages were positively related to early harvesting and large seed size.

Key words: Pearl millet, seed size, maturity, seed moisture, viability

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Brown) is a critical component of household food security in the northern savanna zone of Ghana; due to its adaptive ability to extreme limits of agriculture such as the marginal soils and erratic rainfall patterns (Afribeh *et al.*, 2006; Wilson *et al.*, 2008). In general, pearl millet displays better adaptation to marginal environments and gives higher yield under continuous cropping as compare to sorghum and maize (Wilson *et al.*, 2008; Abd El-Lattief, 2011). Under subsistence farming conditions, both crops have low grain yields (0.5-0.7 t ha^{-1} for pearl millet and 0.7-0.9 t ha^{-1} for sorghum), although improved hybrid cultivars give 3-4 t ha^{-1} of realizable grain yields in better-endowed environments (Rai *et al.*, 1999; Murungu *et al.*, 2006). In Ghana, the crop is cultivated on 176,600 ha with an average yield of 1.24 t ha^{-1} (SRID, 2010). However, an important constraint in pearl millet production is the irregular seed viability which leads to poor stand establishment and subsequent performance. Farmers have been found to use high seed rates (8-12 seeds per hill) because they are unsure of the germination capacity of their seeds (Kudadjie *et al.*, 2004). In many instances where laboratory tests show optimum viability (>70%), abysmal rates are recorded under field conditions.

Several pre-and-post-harvest factors affect seed viability and subsequent vigor. According to Sastry *et al.* (2008), even seeds stored under conditions optimal for long-term storage may decrease in viability as a result of deterioration processes. These may include increase in free radical content, changes in protein structure, depletion of food reserves, development of fat acidity, changes in enzymatic activity, membrane damage, chromosomal changes and increase of respiration. Such processes can manifest at different levels resulting in decrease in germinability, production of numerous abnormal seedlings or even complete loss of viability. In general, seed longevity depends on initial seed quality, moisture content and temperature and may be modified by the conditions and length of storage (Engels and Visser, 2003; Rao *et al.*, 2006). Their effect may be aggravated by factors such as mechanical damage to embryo, drying temperature, seed texture and size (Van Gastel *et al.*, 2002) as well as the intensity of rainfall, depth of sowing and soil edifice factors such as temperature (Kamkar *et al.*, 2006). Pearl millet also suffers from many seedborne pathogens that cause reduction in germination at the initial stage leading to poor crop stand as well as foliage and inflorescence diseases at the adult stage (Hussain *et al.*, 2009). The association of seedborne pathogens including *Alternaria alternata*, *Culvularia lunata*, *Fusarium* spp. and *Aspergillus* spp. has been reported on various pearl millet cultivars causing deterioration in seed germination as well as adverse effects on plants growth and development (Elisabeth *et al.*, 2008). In most pearl millet growing areas, the farmers obtain seed from their own harvest, neighbors or village markets (Ndjeunga, 2002; Kudadjie *et al.*, 2004). The farmers or farming communities manage variety selection, seed production and storage. The quality of seeds may therefore, be lower or at par with seeds produced from the formal systems.

In Ghana, the formal seed sector (government agencies, seed companies and donor seed projects) has achieved considerable success with the production and supply of hybrid seeds of maize, rice and other high-value crops such as the legumes (cowpea, soybean and peanut). However, myriad of seeds of small grains and indigenous crops grown by smallholder farmers in Africa, such as sorghum and millet, have been neglected (Ndjeunga, 2002; Kudadjie *et al.*, 2004). It is alleged that only Sudan, Egypt and South Africa have commercial production of hybrid sorghum seed in Africa (Bello, 2008). A review of crop storage systems and post-harvest losses in the upper east region of Ghana revealed that delay in harvesting, inadequate drying and use of grains as seed were limiting factors in pearl millet production (Sugri *et al.*, 2010). The seeds were stored in traditional granaries, polyethylene and jute sacs where quality deterioration can be excessive (Ihejirika, 2007). In addition, sporadic rainfalls and terminal droughts occurring toward the cessation of the wet season could influence seed maturity, moisture relations, texture and mould growth. To improve the seed viability of pearl millet under farmer handling conditions, the study explored the complexity of these abiotic stresses on seed viability. The specific objectives were to examine the influence of: (1) Seed maturity and time of harvesting and (2) Some seed physical characteristics and moisture content relations, on seed vigor of 8 pearl millet varieties during one year of storage.

MATERIALS AND METHODS

The study was conducted in 2009 and 2010 cropping seasons at the Manga Agricultural Station located in the Upper East Region of Ghana (longitude 1015'W to 005'E and latitude 10030' N to

1108' N). Seeds of eight varieties were obtained from the pearl millet germplasm of the Savanna Agricultural Research Institute (SARI). They consisted of 4 early maturing (Arrow millet, Bongo short head, Bristle millet and Tongo yellow), an intermediate variety (Indiana-05) and 3 late maturing (Salma-1, Salma-3 and Langbensi millet).

Time of harvesting: Sporadic rains, terminal droughts and delayed harvesting are recurrent constraints at the time of harvesting. The date of harvesting was varied from physiological maturity usually known as the hard-dough stage to simulate any occurrence of these limiting factors toward the harvest stage. Five replicates of 10 plants were randomly tagged at the booting stage and the first dates of milking were taken. The panicles were harvested from day 1, 3, 5, 7 and 14 after hard-dough stage. Harvesting on day 1 to 3 was planned to mimic the effect of terminal drought, day 5 to 7 as optimum whiles, day 14 represented some delay in harvesting or harvesting at farmers convenience.

Determination of seed physical characteristics: Thousand seed weight (g) was determined by counting and weighing 1000 seeds on a digital weighing scale. Seed size (mm) was determined by fractionating the seeds into three grades: large (>2 mm sieve range), small (<2 mm sieve range) and control (1-3 mm sieve range). The proportion of seeds in each grade was expressed as a percentage of seeds retained above each sieve to the total weight of sample. Bulk density of seed (kg m^{-3}) was determined as the ratio of seed weight to the bulk volume occupied as below:

$$\text{Seed size index} = \frac{\text{Weight of retained at each sieve}}{\text{Total weight of sample}} \times 100$$

$$\text{Bulk density} = \frac{\text{Weight of seed}}{\text{Volume occupied by seed}}$$

Seed moisture content (%): Average monthly temperature and Relative Humidity (RH) were obtained from the meteorological unit of the Savanna Agricultural Research Institute. With aid of psychometric chart, a generalized moisture isotherm was developed using ambient temperature and RH values, whilst the equilibrium moisture curves were obtained using the grain moisture contents at different months plotted against monthly temperature and RH values (Fig. 1). Using conventional hot oven-drying method, the Seed Moisture Content (SMC) on wet (% wb) and dry (% db) bases were determined as follows:

$$\text{SMC}(\%\ \text{wb}) = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight of sample}} \times 100$$

$$\text{SMC}(\%\ \text{db}) = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight of sample}} \times 100$$

Germination testing: The seeds were incubated between two layers of moist Hoffman paper towel in 9 cm glass petri dishes with close-fitting lids to prevent moisture loss. For field germination testing, 100 seeds were thinly drilled on 1 m rows of raised seed beds. Germination counts were

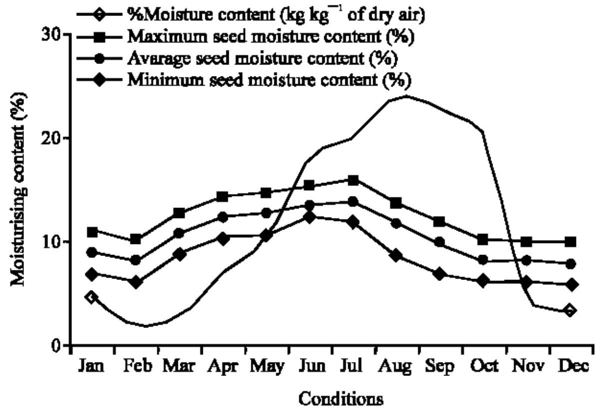

Fig. 1: Moisture characteristics of seed samples under farmer storage conditions

made on day 3 to 7 after incubation and up to day 9 for field test. The germination rate was expressed as the percentage of normal seedlings that emerged to the total seeds cultured.

$$\text{Germination perecent (\%)} = \frac{\text{No. of seeding emerged}}{\text{Total No. of seeds cultured}} \times 100$$

Seedling vigor: The number of days to 3 to 5 leaf stages were recorded when 50% of the seedlings attained 3 and 5 leaves stages, respectively. The incidence of seedling abnormalities was recorded using a three-point visual score: where score 1 = normal seedlings, 2 = root growth abnormalities such as decaying, stunted or stubby primary root and/or negative geotropism and 3 = shoot is constricted or twisted and glassy or decaying due to primary infection.

Data analysis: Data was subjected to analysis of variance (ANOVA) using GenStat Release 7.22 TE. Test for significance of treatment means was by Fisher Least Significant Difference (F-LSD) at 0.05 probabilities.

RESULTS

Effect of time of harvesting: Table 1 summarizes the main effect of varying dates of harvesting on the seed physical characteristics and subsequent influence on germination and establishment. Time of harvesting influenced seed quality components such as seed size, 1000 seed weight, bulk density as well as viability. Progressive increases in seed weight, bulk density and thousand seed weight were recorded from day 1 to 5 and peaked by 7 days after hard-dough stage. Though marginal differences existed for most traits studied, no significant difference ($p<0.05$) was noticed between 7 to 14 days. Across varieties, progressive increases in viability occurred up to day 7 and consistently high germination rates were attained at 7 days after hard-dough. A similar pattern was noticed for other seed vigor indices such as days to reach 3 leaf and 5 leaf stages. Seeds harvested from day 7 to 14 recorded relatively vigorous seedlings and fewer days to 3 and 5 leaf stages. On the contrary, the seeds harvested at day 1, 3 and sometimes 5 showed abysmal performances for seed vigor including days to 3 to 5 leaf stages. This may be attributed to morphological seed dormancy; where the seed embryo is not fully developed. In this case, the seed may be viable but could fail to germinate or may emerge but fail to establish under field conditions.

Table 1: Effect of time of harvesting on seed physical characteristics and vigor traits of pearl millet

Variety	Days after hard-dough	%>2 mm seed grade	Bulk density (kg m^{-3})	1000 seed weight (g)	Germination rate (%)	Number of days to 3 leaf	Number of days to 5 leaf
Arrow millet	1	56.7	87.6	4.8	42.7	7.0	12.5
	3	92.8	83.9	8.0	46.7	7.0	12.0
	5	96.4	59.5	10.8	58.8	6.3	10.3
	7	96.8	84.1	13.8	66.5	6.3	9.3
	14	97.7	82.0	13.2	60.0	7.5	9.8
Bougo short head	1	73.7	90.4	8.2	30.3	6.5	10.7
	3	91.5	88.1	10.6	53.8	6.2	9.2
	5	95.1	84.4	12.4	55.2	5.8	8.8
	7	96.0	85.7	15.2	59.0	6.0	8.8
	14	98.5	82.6	17.0	49.5	6.7	10.3
Bristle millet	1	42.5	91.1	4.8	17.5	12.7	16.3
	3	88.2	89.0	8.2	36.8	11.3	16.3
	5	97.8	86.2	12.9	53.7	6.7	10.8
	7	96.3	85.0	12.3	68.3	5.5	10.0
	14	98.2	82.9	16.3	58.5	5.5	10.0
Indiana-05	1	53.4	88.1	5.2	41.7	7.5	11.3
	3	51.5	86.3	6.6	45.2	7.2	10.7
	5	59.3	81.5	11.5	52.8	6.8	10.7
	7	76.9	78.7	12.3	57.8	6.5	8.3
	14	77.9	81.9	13.7	59.7	6.8	9.5
Langbensi millet	1	66.1	85.7	8.4	40.7	7.2	10.7
	3	86.9	79.1	10.8	43.7	6.7	10.3
	5	88.1	79.8	9.8	56.0	6.8	9.5
	7	94.4	79.9	11.7	65.3	6.2	8.0
	14	92.8	74.5	14.3	55.5	6.3	8.5
Salma-1	1	78.2	87.9	7.4	54.5	9.5	12.3
	3	88.0	85.0	11.2	52.8	9.3	12.0
	5	89.9	85.1	11.0	50.3	7.8	11.0
	7	94.8	81.8	12.5	52.5	6.5	12.0
	14	96.9	82.0	13.0	57.5	7.0	10.0
Salma-3	1	57.1	86.1	5.4	59.2	9.2	13.5
	3	78.2	84.3	7.1	52.8	8.5	13.3
	5	74.7	80.2	7.8	57.3	8.0	13.0
	7	91.1	80.2	10.1	61.3	7.8	11.5
	14	92.2	81.6	11.2	54.0	7.8	11.3
Tongo yellow	1	48.8	91.3	5.7	38.5	8.2	12.2
	3	95.5	84.9	10.8	58.7	7.7	9.8
	5	96.9	84.6	12.4	57.2	7.2	9.3
	7	96.0	84.7	14.0	57.3	6.3	9.3
	14	97.9	84.7	14.5	54.3	7.3	11.2
p-value		<0.05	0.001	00.001	00.001	0.001	00.001
LSD			2.9	1.3	12.3	1.1	2.1
CV (%)			3.0	10.8	20.7	12.9	1.9

Effect of physical characteristics: Four varieties, Tongo yellow, Arrow millet, Bristle millet and Bongo short head, were distinct for large seed size characteristics compared to Salma-1, Salma-3, Langbensi millet and Indiana-05 (Table 2). The former recorded less than 5% of the proportion of

Table 2: Seed physical characteristics of 8 pearl millet varieties for the viability test

Variety	<2 mm grade (%)	>2 mm grade (%)	Bulk density (kg m^{-3})	Thousand seed weight (g)	Moisture content (% db)	Seed purity (%)
Arrow millet	2.9	97.3	84.7	13.2	8.9	99.8
Bongo short head	3.9	95.7	82.2	14.9	8.2	99.8
Bristle millet	4.2	95.9	81.7	14.1	10.8	99.8
Indiana-05	10.8	89.4	74.9	11.2	12.3	99.7
Langbensi millet	18.0	82.3	80.6	9.0	10.7	99.6
Salma-1	8.4	91.5	76.0	11.6	12.5	99.7
Salma-3	30.1	71.2	78.1	7.8	13.9	99.6
Tongo yellow	0.3	99.6	81.8	17.9	10.7	99.9
Mean	8.8	91.5	80.0	12.5	11.0	99.7
$LSD_{(0.05)}$	0.8	1.6	1.5	0.6	0.8	NS
CV (%)	6.5	1.5	1.6	3.7	6.0	

seeds below 2 mm grade compared with the latter which recorded as high as 8 to 30%. Significant differences ($p<0.001$) existed between the two blocks of varieties for thousand seed weight and bulk density. The bulk densities of Arrow millet, Bongo short head, Bristle millet and Tongo yellow were 84.7, 82.2, 81.7 and 81.8 kg m^{-3} compared with Salma-1, Salma-3, Langbensi millet and Indiana-05 with 76.0, 78.1, 80.6 and 74.9 kg m^{-3}, respectively. Seed purity across varieties was 99.7% and fell within optimum range of not more than 1% of total seed lot; indicative that seed cleaning which is usually by threshing and winnowing can be efficient under local conditions. Somehow, the varieties with large proportion of small seeds, Salma-1, Salma-3 and Indiana-05, showed higher moisture contents.

An analysis of the physical environment (temperatures and Relative Humidity (RH)) showed that seemingly favorable conditions existed for seed storage (Fig. 1). The period of November to May was characterized by extreme dry conditions (Temperature ~ 18-42°C, RH% ~ 20-54 in 2009). The vapor pressure of seed exceeded the ambient conditions and the seeds lost moisture to the surrounding air becoming drier. A reverse conditions prevailed in the more humid periods of June to October (Temperature~ 21-37°C, RH% ~ 65-96 in 2009). The latter conditions can result in seed imbibitions of moisture from the air; though seed storage is not carried out within the latter period. In Fig. 1, the range of moisture content of seed samples was low (Min.~ 6.2-10.5%, Max.~ 9.9-14.7%) in the drier months compared with the range (Min.~8.7-12.6%, Max.~11.9-15.6%) observed in the humid periods of June to October.

Effect on seed viability and vigor: Both variety and seed size characteristics significantly ($p<0.001$) influenced seed viability. Four varieties, Arrow millet, Bongo short head, Bristle millet and Tongo yellow, which exhibited large seed characteristics showed higher germination rates compared with their counterparts Salma-1, Salma-3, Indiana-05 and Langbensi millet under field conditions (Table 3). Ironically, the former are early maturing varieties which are harvested during the humid months of August to September; which should greatly affect their viability. Across varieties, large seeds (>2 mm grade) recorded consistently high viability rates compare to other grades (Table 3). The overall viability rates (%) were control (86.4), <2 mm (85.5) and >2 mm (93.5). Viability rates (%) of the varieties were Arrow millet (95.8), Bongo short head (90.8), Bristle millet (90.8), Indiana-05 (80.7), Langbensi millet (91.2), Salma-1 (81.6), Salma-3 (89.3) and Tongo yellow (87.7). Under field conditions however, low germination rates as control (51.3), <2 mm (39.3) and

Table 3: Effect of seed size on the viability of eight pearl millet varieties (%)

		Laboratory viability test				Field germination test		
		Seed grade				Seed grade		
Variety	Control	<2 mm	>2 mm	Mean (variety)	Control	<2 mm	>2 mm	Mean (variety)
Arrow millet	94.2	96.0	97.2	95.8	55.3	42.0	65.7	54.3
Bongo short head	88.3	87.0	97.0	90.8	53.3	40.5	60.3	51.4
Bristle millet	89.3	87.0	95.7	90.8	57.0	44.3	65.3	55.2
Indiana-05	73.8	77.3	90.8	80.7	51.3	34.0	62.5	49.3
Langbensi millet	90.0	89.2	94.3	91.2	51.0	36.2	62.8	50.0
Salma-1	80.0	77.2	87.7	81.6	34.2	30.2	53.3	39.2
Salma-3	88.2	85.2	94.7	89.3	50.5	40.7	57.2	49.4
Tongo yellow	87.7	84.7	90.7	87.7	58.3	46.2	65.8	56.8
Tongo yellow	87.7	84.7	90.7	87.7	58.3	46.2	65.8	56.8
Mean	86.4	85.5	93.5	88.8	51.3	39.3	61.2	50.8
	$LSD_{(0.05)}$ = 4.7, CV (%) = 4.6				$LSD_{(0.05)}$ = NS, CV (%) = 11.9			

Table 4: Effect of seed size on seedling establishment (days to 3-leaf stage)

	Control			<2 mm seed grade			>2 mm seed grade			
Variety	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Mean
Arrow millet	6	6.8	8	6	6.3	7	6	6.7	7	6.1
Bongo short head	5	6.3	8	5	5.7	7	6	6.7	7	6.2
Bristle millet	10	12.8	14	5	6.5	8	5	5.5	6	8.3
Indiana-05	9	9.3	10	7	7.8	8	6	7.2	8	8.1
Langbensi millet	6	7.5	9	6	6.9	8	6	6.5	7	7.0
Salma-1	9	9.3	10	7	7.8	9	6	7.2	8	8.1
Salma-3	8	9.7	12	7	8.0	10	7	8.2	9	8.6
Tongo yellow	7	8.3	9	6	7.0	8	7	7.3	8	7.6
Mean	8.8				7.0			6.9		7.6
$LSD_{(0.05)}$ = 1.1, CV (%) = 12.4										

>2 mm (61.2) across seed grades were recorded. The overall germination rates (%) of were Arrow millet (54.3), Bongo short head (51.4), Bristle millet (55.2), Indiana-05 (49.3), Langbensi millet (50.0), Salma-1 (39.2), Salma-3 (49.4) and Tongo yellow (56.8). By 3 months after storage, overall viability was above 85% across varieties (Fig. 2). However, sharp reductions to 65-75, 53.3-65.8 and 34.2-58.3% were recorded by 6, 9 and 12 months after storage, respectively. These ranges are indicative that highly inconsistent germination rates would be recorded under farmer conditions.

The number of days to 3 to 5 leaf stages (Table 4, 5) as well as incidence of seedling abnormalities (Table 6) showed direct relationships between seed size and initial vigor across varieties. Thus, large seeds (>2 mm grade) were more vigorous and recorded less incidence of root and shoot growth abnormalities than the other grades. Using the range (Table 4, 5), seedlings of the 1-3 mm, <2 mm and >2 mm seed grades took 5-14, 5-10 and 5-9 days to reach 3 leaf and 9-21, 8-17 and 8-15 days to reach 5 leaf stages, respectively. The proportion of seedlings showing normal growth was 85.9, 81.8 and 86.8% for the 1-3 mm, <2 mm and >2 mm seed grades, respectively which is indicative of a fairly good seed-quality (Table 6). Across varieties, small seeds

Table 5: Effect of seed size on seedling establishment (days to 5-leaf stage)

	Control			<2 mm seed grade			>2 mm seed grade			
Variety	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Mean
Arrow millet	10	12.7	14	8	10.2	12	9	10.0	12	10.9
Bongo short head	9	10.5	13	8	8.3	10	9	10.0	12	9.8
Bristle millet	14	17.3	21	9	11.0	13	9	10.0	12	12.8
Indiana-05	11	12.8	14	10	11.3	13	9	9.8	10	11.3
Langbensi millet	10	10.7	12	9	9.5	10	8	8.7	10	9.6
Salma-1	11	12.8	14	10	11.3	13	9	9.8	11	11.3
Salma-3	11	13.3	18	11	12.0	17	10	11.0	15	12.1
Tongo yellow	10	12.5	14	8	9.5	12	10	10.8	11	10.9
Mean		12.8			10.9			10.0		11.1
$LSD_{(0.05)}$ = 0.75, CV (%) = 16.6										

Table 6: Effect of seed size on the incidence of seedling growth abnormalities in pearl millet (%)

	Normal growth			Root abnormalities			Shoot abnormalities		
		Seed grade			Seed grade			Seed grade	
Variety	Control	<2 mm	>2 mm	Control	<2 mm	>2 mm	Control	<2 mm	>2 mm
Arrow millet	90.3	90.0	93.3	5.3	4.2	2.5	2.5	1.7	1.7
Bongo short head	85.8	80.0	87.5	8.3	7.5	4.2	3.3	2.5	2.5
Bristle millet	86.7	79.2	87.5	7.5	7.5	5.0	3.3	3.3	3.3
Indiana-05	80.8	75.8	80.8	10.8	15.0	11.7	5.0	7.5	6.7
Langbensi millet	85.8	79.2	86.7	7.5	12.5	7.7	5.0	7.5	4.2
Salma-1	82.5	80.0	80.7	9.3	13.3	11.5	2.7	5.5	5.0
Salma-3	88.3	81.7	86.7	7.5	10.8	6.7	4.2	5.0	5.8
Tongo yellow	86.7	88.5	91.7	6.7	8.3	5.0	2.5	2.6	1.7
Mean	85.9	81.8	86.8	7.9	9.9	6.8	3.6	4.4	3.9
	$LSD_{(0.05)}$ = 5.2, CV (%) = 5.3			$LSD_{(0.05)}$ = 4.4, CV (%) = 8.2			$LSD_{(0.05)}$ = 3.7, CV (%) = 20.2		

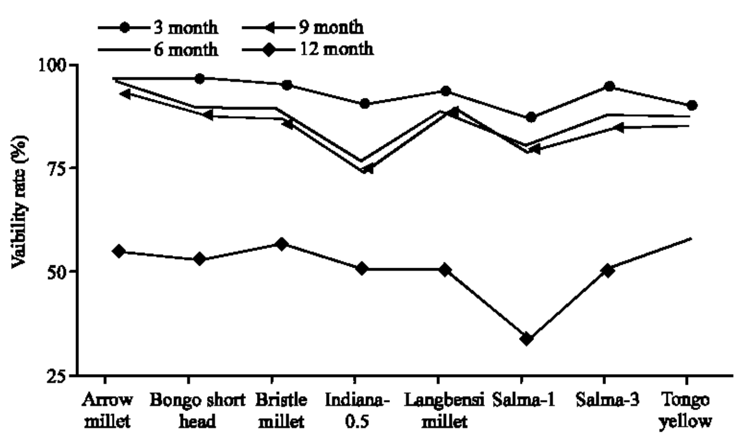

Fig. 2: Viability rates of pearl millet varieties during 12 months of storage

(<2 mm grade) recorded high incidence of root and shoot growth abnormalities (Table 6). Overall, 8.2% of seedlings recorded root and 4% recorded shoot growth abnormalities. Large seeds showed lower incidence of root (6.8%) and shoot (3.9%) abnormalities compared with small seeds which recorded higher incidence of root (9.9%) and shoot (4.4%) abnormalities. Indices of root growth abnormalities were decaying, stunted or stubby primary root and/or negative geotropism whiles the shoot abnormalities included constricted or twisted and/or glassy-decaying shoot due to primary infection.

DISCUSSION

Seed quality is an essential component in crop production as vigor and yield are strongly influenced by initial seed quality (Manga and Yadav, 1996; Ramanadane and Thirumeni, 2001; Van Gastel *et al.*, 2002). High-quality seed will produce vigorous seedlings under a wide range of environmental conditions (Murungu *et al.*, 2006). Although seed quality, vigor and viability are used interchangeably, the meaning of seed viability is narrower and often embedded in the definition of vigor, both of which are considered aspects of seed quality. Seed quality encompasses genetic purity, physiological quality, sanitary quality and physical quality (Ndjeunga, 2002; Van Gastel *et al.*, 2002). Vigor connotes the physiological condition of the seed that governs its ability to produce vigorous seedlings from the soil and tolerate a range of environmental factors (ISTA, 2005). An appreciable understanding of factors that influence seed quality would be essential for local seed producers who lack adequate knowledge and access to complex storage systems.

This study explored the influence of genotype, seed maturity, pre-and-post-harvest factors as well as the seed physical characteristics on the viability of pearl millet. Significant interactions among early harvesting, seed size characteristics, moisture content and seed vigor were observed for most traits studied. Vigor traits such as days to 3 to 5 leaf stages (Table 4, 5) and incidence of seedling growth abnormalities (Table 6) were positively related to early harvesting and large seed size. The effect of seed size on vigor may partially be due to the differential nutrient reserves in larger seeds. Results of this study relate favorably to other studies on seed size and pearl millet viability (Manga and Yadav, 1996; Ramanadane and Thirumeni, 2001). Larger seeds exhibited superiority over other grades in all the physiological traits except speed of germination where medium-grade seeds performed better (Ramanadane and Thirumeni, 2001). According to Manga and Yadav (1996), both seed size and genotypes influenced early vigor, tillers per plant, plant height, days to wilting initiation, days to permanent wilting and dry matter production. Larger seeds produced vigorous seedlings, taller plants with greater tillering and higher dry matter. Plants from large seeds took longer days to initiate wilting and permanent wilting compared with plants from smaller seeds. Also, 1000 seed weight was positively correlated with all traits studied except plant height. Therefore, seed size is major component influencing vigor in small-seeded crops like pearl millet and thus size grading is an essential operation before planting to obtain vigorous and uniform stand establishment as well as increase yield and good quality seeds.

The equilibrium moisture curves (Fig. 1) showed that extreme dry conditions prevailed around the period of seed storage, which could provide opportunity for further drying. Thus, if the seeds can be harvested by 7 days after hard-dough stage and dried to safe moisture content (10.5±1), subsequent loss of viability, grain heating, pest infestation and fungal growth may be less consequential within one season of seed storage. Undue delay in harvesting can lead to mould development and a myriad of other seedborne pathogens such as *Alternaria alternata, Fusarium semitectum, Curvularia lunata, Penicillium* spp., *Rhizopus* spp. and *Aspergillus* spp. (Elisabeth *et al.*, 2008; Hussain *et al.*, 2009). In addition, seeds are hygroscopic and their moisture content comes to equilibrium with the relative humidity of the atmosphere around them. At a given relative humidity and temperature, seed that has high protein or starch content and low oil content will have much higher moisture content than seed with high oil content (Sastry *et al.*, 2003, 2008). The environmental conditions influence the chemical composition during seed development and any change in the percentage of oils or proteins or thickness of the seed coat will result in a different moisture equilibrium value. Variations in seed size will change the proportion of the compounds and therefore give different moisture equilibrium values. The moisture equilibrium value at a given humidity may vary as much as 1.5% with extremes in storage temperature. Higher temperatures result in rapid seed deterioration at any given moisture level and low temperatures (0-5°C) are best for seed storage (Engels and Visser, 2003; Rao *et al.*, 2006) but this is not attainable under farmer conditions. As per earlier postulate known as the Harrington rule of the thumb, seed life is doubled for every 5°C decrease in temperature between 0-50°C and for every 1% decrease in moisture content between 5-15%.

CONCLUSION

Given that pearl millet seed production is done by largely peasant farmers, efforts to achieve higher germination should concentrate on prompt harvesting, adequate drying and appropriate storage; since these are within their capacity. The complex interrelationships among seed size, moisture content and good storage need to be understood by farmers. Thus, the capacity of farmers to store seeds at or near optimum conditions would be critical to increasing their seed viability. Based on the role of seed size on viability, an indigenous farmer practice where large millet heads are selected for seed may yield dividend. Though sporadic rainfalls at harvest are a major abiotic stress, early harvesting by 7 days after the hard-dough stage could improve seed viability. Where undue delay in harvesting is anticipated due to farmers' busy schedule, selective harvesting for seed can be adopted. In all cases, adequate drying of seed to around 10.5±1 moisture content should be emphasized. In the long term, an effective seed programme outlining measures to guarantee the production and supply of seeds of prescribed quality and quantity for pearl millet and sorghum would be essential as current emphasis is put on rice, maize and the legumes.

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