STUDY OF PHYSIOLOGICAL QUALITY OF SEED ON THE BASIS OF GERMINATIVE PARAMETERS IN PEARL MILLET

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ABSTRACT

The investigation was carried out to study the physiological quality of seed on the basis of non-germinative parameters in pearl millet. A number of non-germinative parameters such as imbibition rate, germination percentage, germination index, root length, shoot length, seedling length, root shoot length ratio, root fresh weight, shoot fresh weight, seedling fresh weight, root shoot fresh weight ratio, root dry weight, shoot dry weight, seedling dry weight, root shoot dry weight ratio, root moisture, shoot moisture, seedling moisture, vigour index – I, vigour index – II, mobilization efficiency, field emergence and field emergence rate (index) were recorded at bimonthly interval in the seed lots stored for a period of time till the germination level fell well below Indian Minimum Seed Certification Standard. Seeds of four hybrids of pearl millet viz., GHB 719, GHB 905, GHB 744 and GHB 732 along with their parental lines, in all total 10 entries, were stored and utilized for this study. Relative loss of vigour in hybrids and their respective parents paralleled the loss of seed viability was not necessarily observed in all the parameters studied, but wherever it was observed might be due to dominance or over dominance type of genetic expression. Most of the germinative parameters except seedling moisture exhibited a significant decline with the deterioration in seed vigour due to storage, and the entries also differed significantly.

KEY WORDS: Germination, hybrid, pearl millet, physiological quality, viability, vigour

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is an important *Kharif* crop, which is known by various vernacular names such as *Bajra* (*Hindi, Punjabi and Urdu*), *Bajri* (*Rajasthan, Marathi and Gujarati), Sajje (Kannada), Gantilu (Telugu) and Kambu (Tamil)*. It is well adapted to drought prone areas, low soil fertility, and high temperature situation. It also performs well in soils with high salinity or low pH. It can be grown in all those soil and climatic conditions where other cereal crops, such as maize or rice, would not even survive. India is the largest producer of pearl millet in the world. In 2013-14, it occupied an area of 7.95 million ha with the production of 8.79 million tons per year and average productivity of 1106 kg/ha (Anonymous, 2014). Rajasthan, Maharashtra, Gujarat and Uttar Pradesh are the major pearl millet growing states of India. Gujarat has an area of 0.872 million hectares under pearl millet cultivation and production of 1.50 million tons with

1720 kg/ha productivity (Anonymous, 2013).

Seed viability and seedling vigour are dependent upon the extent of grain development. Selection of varieties with higher percentage of seed filling and larger seed size may lead to higher yields. The temperature at which the seed developed did not affect seed viability, but it did affect the vigour. Post-harvest dormancy has been reported for at least 14 days in pearl millet (Khairwal *et al.,* 1980). Germination and seed vigour characteristics are the vital components of physiological quality of seed necessary to ensure optimum plant population with good vigour. However, the standard germination test (SGT) usually over predicts the field performance of a seed lot. Hence, importance of seed vigour as a quality parameter is emphasized (AOSA, 1983). Aged seeds show decreased vigour and produce weak seedlings that are unable to survive once reintroduced into a habitat (Atici *et al*., 2007). As pearl millet is grown under hostile environment in marginal soils, the vigour aspects of seed quality become more important. Present study was conducted to evaluate physiological quality of pearl millet seeds using germinative parameters. The germinative criteria of physiological quality of seed are useful for evaluation of potential storage capacity of seed, seed viability and vigour, capacity to produce normal seedling and potential to develop a plant under favourable and adverse environmental conditions. Germinative evaluation, however, takes some time depending on the crop for assessment of physiological quality of seed. In pearl millet, standard germination test (SGT) takes seven days i.e. final count for germination percentage is taken at 7th day (ISTA, 1996).

MATERIALS AND METHODS

The experiment was conducted to study the physiological quality of seed on the basis of germinative parameters in pearl millet (*Pennisetum glaucum* (L.) R. Br.)" during 2014, at the Department of Seed Science and Technology and Department of Biochemistry, College of Agriculture, Junagadh Agricultural University, Junagadh. The seeds of parents (95222A, J 2454, 04999 A, 98444 A, J 2340 and 96222) of pearl millet hybrids (GHB 719, GHB 905, GHB 744 and GHB 732) were obtained from Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar and were multiplied as well as fresh seeds of hybrids were produced in the *kharif* 2013 at Sagadividi farm of Department of Seed Science and Technology, JAU, Junagadh. The harvesting was done in the month of November 2013 and ear heads were kept for air-drying. Threshing was done in the month of January 2014. Since pearl millet seeds have time bound dormancy, the seeds were stored in the month of February 2014, once the dormancy was released (Joshi *et al.,* 1996).

The seeds of each entry were stored in plastic containers kept in the laboratory under ambient conditions. The samples were drawn for evaluation of various germinative parameters at two months interval till the seed germination declined considerably below the Indian Minimum Seed Certification Standard. A number of germinative parameters such as imbibition rate (%), imbition rate index, germination percentage (ISTA, 1996), germination index (Maguire, 1962), root length (cm), shoot length (cm), seedling length (cm), root shoot length ratio, root fresh weight (mg), shoot fresh weight (mg), seedling fresh weight (mg), root shoot fresh weight ratio, root dry weight (mg), shoot dry weight (mg), seedling dry weight (mg), root shoot dry weight ratio, root moisture (%), shoot moisture (%), seedling moisture (%), seed vigour index – I, seed vigour index – II, mobilization efficiency (%) (Hageman *et. al.*, 1967), field emergence (%) and field emergence rate (index) were estimated in the dry seeds stored under ambient storage conditions employing CRD with four repetitions. The data were analyzed as per completely randomized design (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Imbibition

Germination commences with imbibition by the dry seed followed by a series of metabolic changes and ends with the protrusion of the radicle of the embryo through all the surrounding tissue. In the current investigation, imbibition rate at 0-4 hours, 4-10 hours and 10-16 hours of different entries at advancing storage period are presented in Table 1. The imbibition rate index is presented in Table 2. The imbibition rate 0-4 hours *i.e.* first phase of imbibitions, differed significantly among the entries, over the storage period along with its interaction (Table 1). The highest imbibition rate was recorded in female line 04999 A followed by GHB 905. In the second phase of imbibition *i.e.* 4-10 hours, the storage period did not differ significantly with regards to imbibition rate. The imbibition rate 10-16 hours *i.e*. third phase of imbitibiton differed significantly among entries and advancing storage period. Interestingly, during the advancing storage period *i.e.* seed ageing resulted in the decrease of this third phase of imbibition. With the advancement of the imbibition time, there was an increasing in the imbibition percentage, but an overall overview suggested that there were three distinct phases - the first one was fast, second one was comparatively steady and third one was again faster. Nonogaki *et al.* (2007) depicted that initial water uptake is a physical process, which occurs in both leaving and dead seeds. Thus, for viable and non-dormant seeds, there is a three phase pattern of water uptake. Phase first is characterized by rapid water uptake during which seed volume increases and some physiological activities are activated. Phase second is lag phase of imbibition. Physiological activities are speeded up, storage reserve mobilized. Although net water uptake is minimal, but major metabolic events take place in the seed. Only seeds that complete germination enters phase third of imbibition, which occurs due to cellular expansion associated with radical protrusion. Thus, water uptake during phase third is not proper imbibition *per se*, but rather the initial consequence of the completion of germination (Bewley *et al*., 2013).

Germination

Germination percentage recorded after 7 days (as per ISTA, 1996) had significant interaction effect (Table 2). Physiologically germination *sensu stricto* is associated with many metabolic, cellular and molecular events, rendering the radicle able to emerge from the seed (Bailly *et al*., 2004). Thus, it is worth noting that in the frame work of seed germination, cell division is not necessary for radicle emergence (Haber and Luippold, 1960). But recent transcriptomic analyses showed that the activation of the cell cycle in the *Arabidopsis* root meristem precedes the penetration of the seed envelop by the radicle and that D cyclines are limiting factors for this process (Masubelele *et al*., 2005). Although seed technology point of view, the germination percentage is considered on the basis of fully established normal seedlings. Overall, the hybrids GHB 744 recorded the highest germination percentage followed by GHB 905, GHB 719 and GHB 732, respectively. However, among the parents, female 96222 A recorded the highest germination percentage. Kulik and Yaklich (1982) reported significant decline in seed germinablity and deterioration under natural ageing and storage. The germination percentage recorded at different intervals was utilized in calculating germination index (GI), which reflected the overall performance of the seed lot and used for evaluation of the physiological quality of the seed. The simplest assessment of rate of germination can be made from the first count or preliminary count in germination test. The first count is indicative of quality of seed lot, the higher the percentage of normal seedlings, the higher the vigour (Powell and Matthews, 1992). More assessment of rate of germination can be made by including more frequent counts of germination. These assessments, therefore, also reflect the pattern of germination. The entries and storage period differed significantly while the interaction between them was not significant with regard to germination index (Table 2). Overall, the hybrid GHB 744 recorded the highest value followed by GHB 905, GHB 719 and GHB 732, respectively. Among parents female parents, 96222 A recorded the highest value of germination index.

Root length (cm)

The entries differed significantly with respect to root length, while the storage periods did not showed significant differences, though there was a numerical decline with the advancement of storage period (Table 3). The interaction between entries and storage periods was significant and the highest root length was recorded in the hybrid GHB 744 at the initiation of storage (Feb-2014), while the lowest root length was recorded in the female parent 96222 A at the end of storage period (Oct-2014). Use of linear measurement of growth as a vigour test was first suggested by Germ (1960) for cereals and sugar beets. The test was further developed by Perry (1977). The difference in germination percentage and length measurement has been reported *i.e.* a cultivar showing faster and high germination not necessarily recorded the greater seedling length (Joshi *et al*., 1997b). Hence, seedling growth test offers another dimension of seedling vigour.

Shoot length (cm)

The differences due to shoot length as influenced by storage periods and the entries were significant. The interaction between entries and storage periods was also significant (Table 3). Overall, there was a decline in shoot length with the increase in the storage period. Monira *et al*. (2012) reported the decline in root and shoot length due to storage period in soybean seeds. The hybrids GHB 905, GHB 744 and GHB 732 recorded higher shoot length.

Seedling length (cm)

The differences in seedling length were non-significant, but storage period showed overall a significant decline and interaction between entries and storage period was also significant (Table 3). Agrawal and Kharlukhi (1985) considering seedling length as one of the vigour parameters found that the length of seedling declined under all conditions of storage.

Root/shoot length ratio

Root/Shoot length ratio differed significantly among the entries and storage period along with interaction between them (Table 4). At the initial storage (Feb-2014), the root/ shoot ratio was minimum, while at later storage period, it increased significantly, but the differences among them were non-significant (April-2014 to Oct-2014). The highest root/shoot length ratio was recorded in female parent 04999 A. The minimum ratio was recorded in hybrid GHB 905.

Root fresh weight (mg)

The fresh weight measurements give a clue of vitality by way of water holding capacity of the living system. Roots are the organs through which water and minerals are absorbed, not only that but seedling establishment is mainly dependent on root growth as radicle is the first organ to emerge during seed germination. Particularly under adverse environmental condition seedling establishment has a great role to play. Root fresh weight in present investigation declined significantly with the advancement of the storage periods and it did differ significantly between the entries. The interaction effect was significant and the highest root fresh weight was recorded in the hybrid GHB 744 followed by GHB 719 at the initiation of storage (Feb-2014), while minimum was recorded by male parent, J 2454 at the end of storage period (Oct-2014) (Table 4).

Shoot fresh weight (mg)

Shoot fresh weight also showed declining trend over storage period and it differed significantly among the entries (Table 4). The interaction between two variables was also significant. In general, hybrid GHB 905 reported the highest value followed by GHB 744.

Seedling fresh weight (mg)

The seedling fresh weight showed the decreasing trend with advancement of storage periods. The entries differed significantly and the highest value was recorded by GHB 744 followed by GHB 905, respectively. The minimum value was observed in the male parent J 2340 (Table 5).

Root/shoot fresh weight ratio

Root/shoot fresh weight ratio, in general, declined with respect to increasing storage period. This signifies that root fresh weight was affected more than the shoot fresh weight influenced by storage period (Table 5). Overall, the hybrids recorded the higher root/shoot fresh weight ratio as compared to the parents.

Root dry weight (mg)

Vanangamudi and Natarajaratanam (1984) reported a relationship between roots and shoots dry weight and seedling vigour, which was reflected in the higher yields. The entries, storage period and their interaction were found statistically significant. There was a continuous declining in the root dry weight with advancement of ageing period (Table 5). All the hybrids recorded significantly higher root dry weight than their respective parents.

Shoot dry weight (mg)

Agarwal and Kharlukhi (1985) considered seedling dry weight as a measure of seed vigour. Shoot dry weight was decreased with storage under all the conditions. In the present investigation, also shoot dry weight recorded a significant decrease with the ageing period. The entries also registered significant differences among themselves. Hybrids were more vigorous as compared to parent considering the shoot dry weight (Table 6).

Seedling dry weight (mg)

Seedling dry weight differed significantly due to entries and decreased with the increase in the storage period (Table 6). Seedling dry weight was higher in hybrids as compared to parents. This parameter was influenced more by its component shoot dry weight than that of root.

Root/ shoot dry weight ratio

The root/shoot dry weight ratio decreased initially, but at later period of storage it remained steady. The differences in the entries were significant and overall hybrids recorded high root/shoot dry weight ratio except GHB 744 in comparison with their respective parents (Table 6).

Root moisture (%)

A critical appraisal of root moisture data indicated that entries, storage period and their interaction differed significantly. There was an increase in root moisture percentage with advancement of storage period. The highest root moisture was recorded in the hybrid GHB 744 followed by GHB 732 and female parent 04999 A, respectively (Table 7).

Shoot moisture (%)

Shoot moisture differed significantly due to entries as well on storage period. The interaction between entries and storage period was also significant. There was a consistent increase in the shoot moisture percentage with advancement of storage period (Table 7). The highest shoot moisture was recorded in hybrid GHB 905 followed by female parents 04999 A and 95222 A, respectively.

Seedling moisture (%)

Moisture of seedling as a whole differed significantly both due to entries and storage period. Seedling moisture also increased significantly as the storage period advanced (Table 7). The moisture content represents the vitality in terms of moisture holding capability of living system. The increasing seedling moisture percentage with seed ageing signifies that the dry weight accumulation was affected more adversely than the fresh weight.

Mobilization efficiency (%)

The mobilization efficiency represents the dry weight accumulation in embryo axis in comparison to reserve mobilization in the endosperm (Hageman *et al*., 1967). The mobilization efficiency decreased significantly with ageing of seeds. The entries also differed significantly with respect to mobilization efficiency and overall hybrids performed better than the parents (Table 8).

Seed Vigour Index

Looking to the importance of seed vigour in field performance of a seed lot, vigour indices are used to assay the physiological quality of the seed. Vigour index I is such an attempt to assess the seed quality which is a unit-less expression derived from the multiplication of germination percentage and mean seedling length (ISTA, 1976b). In the present investigation, the vigour index I recorded after 7 days differed significantly among entries, different storage period and their interactions (Table 8). Genotypic variations in vigour index have been reported and as it have been shown to be positively and significantly associated with the field emergence and establishment (Kumar *et al*., 1989 and Wanjari *et al*., 1992). There was a distinct decline in vigour index I as influenced by seed ageing.

Seed vigour index II was calculated based on integration of germination percentage and the seedling dry weight (ISTA, 1976a). A cultivar with greater speed of germination may not necessarily have the greater seedling length or seedling dry weight (Joshi *et al*., 1997a). Hence, an integration of germination percentage and seedling dry weight or length depicted as vigour index will give the better idea of physiological quality of seed in terms of seedling vigour. The seed vigour index II showed significant differences due to entries, storage period and their interaction (Table 8). There was a continuous decline in the seed vigour index II as influenced by the storage period. There are studies reporting reduction in germination, viability, dry matter and vigour index with response to period of ageing (Abdalla, F. H. and Roberts, 1969, Dharmalingam *et al*., 1976, Ravichandran, 1991, Singh *et al*., 2003, Varghese and Rai, 2005, Kumar and Rai, 2006, Kumar and Rai, 2009).

Field emergence count (%)

In peal millet, field emergence first count is taken at 3rd day after planting the seed (ISTA, 1993), which is an initial assessment of seed vigour under field conditions. In the present investigation, the differences with regard to field emergence first count due to entries and storage period both were significant along with significant interaction between them (Table 9). Increasing storage period resulted in significant reduction in first count field emergence percentage.

In pearl millet field emergence final count is taken after 7 days of planting the seed (ISTA 1993). Field emergence represents the actual physiological quality of a seed lot, since the field condition are always sub-optimal and the germination percentage recorded in standard germination test (SGT) taken under favoruable and optimal laboratory conditions are always higher than those obtained under field condition. This necessitates the development / identification of criterion which matches the actual field performance taking into consideration the seed vigour characteristics which are reflected directly or indirectly by some germinative criteria. Field emergence final count registered lower values when compared with the final count in laboratory germination taken under more congenial condition. The field emergence differed significantly due to entries. The storage period also had an adverse effect on the field emergence, obviously reflecting deterioration of physiological quality of seed lot (Table 9). The physiological quality deteriorates at three levels (Noli *et al*., 2008). Both seed and seedling vigour are influenced by genetic and non-genetic components, the latter being related to environmental conditions during seed production (Burris, 1977, Munamava *et al*., 2004), to timing of seed harvesting (Bochicchio *et al*., 1986, Ajayi *et al*., 2005), to drying (Tekrony *et al*., 1989) and to storage condition (Abba and Lovato, 1999). Producers rely on result of the standard germination test, which is printed on seed tag, to give them reliable information to use in making planting decisions. However, many seed weaknesses are not detected by standard germination test (Byrum and Copeland, 1995).

Field emergence index

Field emergence rate is again a reflection of seed vigour aspect of seed lot with special reference to its performance under field conditions. Field emergence index in the present investigation displayed significant differences among the entries as well as due to storage period. The interaction between entries and storage period was also significant. There was a distinct decline in the field emergence index discernible with seed ageing (Table 9).

CONCLUSION

On the basis of above results, it can be concluded that relative loss of vigour in hybrids and their respective parents paralleled the loss of seed viability was not necessarily observed in all the germinative parameters studied, but wherever it was observed might be due to dominance or over dominance type of genetic expression. Most of the germinative parameters except seedling moisture exhibited a significant decline with the deterioration in seed vigour due to storage, and the entries also differed significantly.

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Table 1: Imbibition rate 0-4 hours (%), 4-10 hours (%) and 10-16 hours (%) in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Imbibition rate 0-4 hours (%)						Imbibition rate 4-10 hours (%)						Imbibition rate 10-16 hours (%)					
GHB 719	13.45	12.60	11.48	11.33	10.41	11.85	7.60	6.40	6.11	5.76	5.33	6.24	18.04	16.09	15.84	16.03	16.28	16.46
95222 A	7.38	7.38	6.93	7.18	6.87	7.15	9.25	8.52	7.68	7.21	7.15	7.96	13.13	11.87	11.73	11.67	11.31	11.94
J 2454	12.21	11.90	10.88	10.41	10.31	11.14	7.19	7.14	6.24	6.17	7.26	6.80	18.99	19.93	18.30	17.10	17.16	18.29
GHB 905	16.59	19.13	17.46	18.23	18.71	18.02	5.45	6.48	6.37	6.25	5.75	6.06	10.37	10.05	9.59	7.79	7.90	9.14
04999 A	25.40	19.95	19.55	19.36	17.65	20.38	6.63	6.37	7.68	5.82	5.44	6.39	17.25	17.08	16.40	16.24	15.74	16.54
GHB 744	19.60	17.18	14.12	13.34	13.39	15.52	6.98	5.30	12.34	11.32	10.84	9.36	14.55	13.99	12.63	13.43	12.58	13.43
98444 A	21.88	15.72	14.64	14.31	14.48	16.20	7.47	12.14	12.62	11.08	11.84	11.03	13.61	14.07	12.57	11.65	11.50	12.68
J 2340	25.74	14.64	13.91	17.64	13.26	17.04	5.39	8.57	8.28	7.29	7.66	7.44	18.10	18.34	17.38	17.47	17.35	17.72
GHB 732	14.56	15.95	15.53	14.15	13.35	14.71	5.64	5.66	6.49	6.25	11.56	7.12	16.82	17.45	17.09	16.67	16.35	16.87
96222 A	15.67	11.90	12.19	12.49	13.55	13.16	6.89	5.95	6.19	5.98	13.85	7.77	15.62	15.15	15.42	14.77	14.46	15.08
Mean	17.25	14.63	13.67	13.84	13.20		6.85	7.25	8.00	7.31	8.67		15.65	15.40	14.69	14.28	14.06	
S.Em.±	1.21	0.53	0.42	1.32	1.32	0.87	0.40	0.29	0.49	0.31	0.31	0.83	0.96	0.41	0.23	0.70	0.70	0.28
C.D. at 5 %	3.48	1.52	1.22	3.80	2.27	2.49	1.16	0.85	1.42	0.90	1.57	2.37	2.76	1.19	0.67	2.02	1.71	0.79
C.V. %	13.99	7.18	6.18	19.01	11.93	12.72	11.68	8.08	12.32	8.53	12.57	11.03	12.22	5.37	3.17	9.79	8.42	8.49
D																		
S.Em.±						0.61						0.58						0.20
C.D. at 5 %						1.76						NS						0.56
D×E																		
S.Em.±						0.92						0.42						0.63
C.D. at 5 %						2.58						1.18						NS

Table 2: Imbibition rate index, germination percentage (7 days) and germination index in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Imbibition rate index						Germination percentage (7 Days)						Germination index					
GHB 719	7.64	6.90	6.53	6.47	6.21	6.75	87.75	84.75	78.75	71.00	64.75	77.40	600.36	576.05	539.62	520.93	492.86	545.96
95222 A	5.57	5.24	4.97	4.94	4.79	5.10	84.25	80.25	74.25	66.75	61.50	73.40	555.42	526.40	454.97	437.83	439.27	482.78
J 2454	7.41	7.49	6.81	6.48	6.65	6.97	81.00	84.00	70.50	67.50	63.25	73.25	506.54	474.56	512.55	495.30	484.35	494.66
GHB 905	6.78	7.54	7.02	6.90	6.95	7.04	93.25	90.75	85.25	80.00	73.50	84.55	626.75	559.22	559.50	521.18	507.17	554.76
04999 A	10.33	8.90	8.90	8.51	7.94	8.92	84.50	80.75	75.50	70.75	68.75	76.05	565.24	536.72	509.05	484.10	472.60	513.54
GHB 744	8.49	7.51	7.69	7.46	7.25	7.68	97.25	93.25	87.00	78.50	72.75	85.75	664.30	611.03	623.21	590.08	580.14	613.75
98444 A	8.98	8.30	7.86	7.36	7.51	8.00	87.50	84.25	77.75	73.25	69.00	78.35	591.30	562.98	526.11	473.72	476.53	526.13
J 2340	10.35	8.15	7.75	8.54	7.48	8.45	84.75	81.25	73.25	72.50	64.50	75.25	551.28	525.40	503.48	472.03	497.04	509.85
GHB 732	7.38	7.84	7.81	7.36	7.99	7.68	89.25	80.50	76.75	71.00	65.00	76.50	551.65	536.17	506.11	499.67	476.91	514.10
96222 A	7.67	6.49	6.65	6.58	8.11	7.10	89.00	84.50	79.00	68.75	67.50	77.75	616.43	577.10	550.94	513.37	507.55	553.08
Mean	8.06	7.43	7.20	7.06	7.09		87.85	84.43	77.80	72.00	67.05		582.93	548.56	528.56	500.82	493.44	
S.Em.±	0.47	0.22	0.20	0.42	0.42	0.23	1.30	1.05	1.15	1.43	1.43	0.82	11.43	18.22	18.15	15.35	15.35	8.14
C.D. at 5 %	1.37	0.65	0.56	1.22	0.98	0.65	3.75	3.02	3.32	4.12	3.76	2.36	33.01	52.61	52.42	44.34	NS	22.79
C.V. %	11.74	6.05	5.42	11.94	9.58	9.44	2.96	2.48	2.95	3.96	3.88	3.22	3.92	6.64	6.87	6.13	10.15	6.86
D																		
S.Em.±						0.16						0.58						5.75
C.D. at 5 %						0.46						1.67						16.11
D×E																		
S.Em.±						0.35						1.25						18.20
C.D. at 5 %						0.97						3.50						NS

Table 3: Root length (cm), shoot length (cm) and seedling length (cm) in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Root length (cm)						Shoot length (cm)											
GHB 719	8.26	9.84	10.54	10.51	8.79	9.59	5.90	4.50	5.14	5.68	5.36	5.31	14.18	14.32	15.80	16.19	14.28	14.95
95222 A	10.86	8.56	7.68	9.75	8.50	9.07	6.61	4.51	5.30	5.43	5.01	5.37	17.47	13.99	12.98	15.18	13.50	14.63
J 2454	10.20	8.87	8.68	9.43	8.48	9.13	7.41	4.95	4.17	5.16	4.55	5.25	18.94	13.82	12.85	14.59	13.03	14.64
GHB 905	6.78	6.01	9.56	9.97	8.81	8.23	8.80	10.73	5.41	6.25	5.74	7.38	15.58	16.49	14.97	16.21	14.77	15.60
04999 A	10.65	11.45	10.38	9.35	8.61	10.09	6.23	4.53	4.41	4.62	4.23	4.81	16.88	15.91	14.79	13.97	12.84	14.88
GHB 744	11.43	12.17	9.38	10.04	9.35	10.47	8.61	6.52	5.47	5.78	5.35	6.35	20.04	18.71	14.97	15.82	14.70	16.85
98444 A	11.17	11.63	8.68	10.10	9.46	10.21	7.47	5.51	4.74	5.98	5.38	5.81	17.67	17.16	13.23	16.08	14.84	15.79
J 2340	10.95	9.57	11.27	10.73	8.92	10.29	7.18	6.17	5.21	5.62	5.09	5.85	18.13	16.24	16.45	16.34	15.00	16.43
GHB 732	10.13	7.82	10.53	9.67	8.92	9.41	8.55	5.64	6.67	5.94	5.45	6.45	18.68	13.47	17.19	15.61	14.36	15.86
96222 A	11.35	8.10	6.18	8.38	7.78	8.35	8.87	6.40	4.26	4.82	4.46	5.76	20.22	14.35	10.44	13.20	12.24	14.09
Mean	10.18	9.40	9.28	9.79	8.76		7.56	5.95	5.08	5.53	5.06		17.78	15.44	14.37	15.32	13.95	
S.Em.±	0.68	0.49	0.18	0.33	0.33	0.54	0.34	0.23	0.12	0.16	0.16	0.39	0.81	0.66	0.24	0.43	0.43	0.66
C.D. at 5 %	1.96	1.42	0.53	0.96	0.86	1.56	0.99	0.66	0.36	0.47	0.58	1.11	2.33	1.89	0.71	1.23	1.21	NS
C.V. %	13.33	10.49	3.98	6.76	6.77	9.12	9.08	7.70	4.86	5.92	7.89	7.70	9.08	8.48	3.41	5.56	6.02	7.12
D																		
S.Em.±						0.38						0.27						0.47
C.D. at 5 %						NS						0.78						1.35
D×E																		
S.Em.±						0.43						0.22						0.55
C.D. at 5 %						1.21						0.63						1.53

Table 4: Root/shoot length ratio, root fresh weight (mg 10 root^{-1}) and shoot fresh weight (mg 10 shoot^{-1}) in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Root/shot length ratio						root fresh weight (mg 10 root^{-1})						Shoot fresh weight (mg 10 shoot^{-1})					
GHB 719	1.41	2.19	2.06	1.85	1.64	1.83	65.00	56.75	54.00	52.50	50.75	55.80	251.50	244.50	240.25	239.50	236.00	242.35
95222 A	1.63	1.88	1.45	1.79	1.69	1.69	47.00	37.75	34.00	35.75	33.50	37.60	239.75	234.75	233.50	229.50	225.75	232.65
J 2454	1.40	1.80	2.08	1.83	1.88	1.80	32.00	27.75	24.50	21.50	19.25	25.00	218.75	209.75	204.75	227.00	274.25	226.90
GHB 905	0.77	0.56	1.77	1.59	1.53	1.25	52.25	52.25	50.75	47.50	43.75	49.30	320.00	309.00	307.50	302.25	299.00	307.55
04999 A	1.71	2.53	2.36	2.03	2.04	2.14	49.75	44.75	42.50	40.25	36.50	42.75	252.25	239.25	237.75	235.50	231.00	239.15
GHB 744	1.33	1.86	1.71	1.74	1.76	1.68	75.50	78.75	67.00	67.75	64.25	70.65	307.50	302.75	301.00	297.25	294.75	300.65
98444 A	1.50	2.12	1.83	1.69	1.76	1.78	37.25	36.50	33.25	31.00	29.75	33.55	209.00	203.75	201.50	197.25	194.5	241.20
J 2340	1.54	1.55	2.16	1.91	1.75	1.78	33.75	27.75	24.50	22.50	23.25	26.35	232.25	215.50	212.00	207.75	203.50	214.20
GHB 732	1.18	1.39	1.58	1.63	1.64	1.48	53.75	57.25	54.50	52.00	48.75	53.25	263.50	259.00	256.75	251.75	249.25	256.05
96222 A	1.28	1.26	1.45	1.74	1.75	1.49	41.50	34.25	32.00	28.25	25.50	32.30	219.25	216.25	213.25	208.75	205.25	212.55
Mean	1.37	1.71	1.85	1.78	1.74		48.78	45.38	41.70	39.90	37.53		251.38	243.45	240.83	239.6	241.33	
S.Em.±	0.078	0.070	0.036	0.038	0.038	0.105	1.60	1.67	0.83	0.35	0.35	0.99	4.12	1.67	1.38	7.65	7.65	4.68
C.D. at 5 %	0.226	0.203	0.105	0.110	0.125	0.302	4.62	4.82	2.41	1.02	2.77	2.83	11.91	4.84	3.99	22.11	21.56	13.43
C.V. %	11.40	8.21	3.97	4.3	4.97	6.64	6.57	7.35	4.00	1.77	5.11	5.58	3.28	1.38	1.15	6.39	6.19	4.29
D																		
S.Em.±						0.074						0.70						3.30
C.D. at 5 %						0.213						2.00						NS
D×E																		
S.Em.±						0.056						1.19						5.22
C.D. at 5 %						0.157						3.33						14.61

Table 5: Seedlings fresh weight (mg 10 seedling^{-1}), root/shoot fresh weight ratio and root dry weight (mg 10 root^{-1}) in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Seedlings fresh weight (mg 10 seedling^{-1})						Root/shoot fresh weight ratio						Root dry weight (mg 10 root^{-1})					
GHB 719	316.50	301.25	294.25	292.00	286.75	298.15	0.26	0.23	0.22	0.22	0.22	0.23	12.75	12.00	11.00	9.81	9.81	11.08
95222 A	286.75	272.50	267.50	265.25	259.25	270.25	0.20	0.16	0.15	0.16	0.15	0.16	9.25	7.25	6.88	5.81	5.81	7.00
J 2454	250.75	237.50	229.25	223.50	318.50	251.90	0.15	0.13	0.12	0.10	0.07	0.11	7.50	5.60	4.82	3.93	3.91	5.15
GHB 905	372.25	361.25	358.25	349.75	342.75	356.85	0.16	0.17	0.17	0.16	0.15	0.16	12.25	9.25	8.56	7.85	7.85	9.15
04999 A	302.00	284.00	280.25	275.75	267.50	281.90	0.20	0.19	0.18	0.17	0.16	0.18	9.50	7.50	6.81	5.94	5.94	7.14
GHB 744	383.00	381.50	368.00	365.00	359.00	371.30	0.25	0.26	0.22	0.23	0.22	0.23	14.25	11.25	10.09	8.81	9.06	10.69
98444 A	246.25	240.25	234.75	228.5	224.25	274.75	0.18	0.18	0.17	0.16	0.15	0.15	10.25	8.63	7.84	6.91	6.91	8.11
J 2340	253.50	243.25	236.50	235.25	226.75	239.05	0.15	0.13	0.12	0.11	0.11	0.12	6.25	6.06	4.91	4.45	4.45	5.22
GHB 732	317.25	316.25	311.25	303.75	298.00	309.30	0.20	0.22	0.21	0.21	0.20	0.21	11.25	9.18	8.89	7.78	7.78	8.98
96222 A	260.75	250.50	245.25	237.00	230.75	244.85	0.19	0.16	0.15	0.14	0.12	0.15	8.75	6.82	5.91	4.75	4.88	6.22
Mean	298.90	288.83	282.53	277.5	271.35		0.192	0.182	0.169	0.158	0.149		10.20	8.35	7.57	6.61	6.64	
S.Em.±	2.00	2.32	1.55	2.56	2.56	9.78	0.005	0.005	0.003	0.003	0.003	0.006	0.39	0.34	0.17	0.17	0.17	0.19
C.D. at 5 %	5.78	6.70	4.48	7.38	6.27	28.08	0.015	0.01	0.010	0.009	0.013	0.017	1.12	0.99	0.50	0.50	0.48	0.54
C.V. %	1.34	1.61	1.10	1.78	1.49	1.48	5.660	5.69	4.35	4.28	6.24	5.34	7.59	8.20	4.58	5.21	5.05	6.77
D																		
S.Em.±						6.92						0.004						0.13
C.D. at 5 %						NS						0.012						0.38
D×E																		
S.Em.±						2.15						0.004						0.27
C.D. at 5 %						6.01						0.012						0.75

Table 6: Shoot dry weight (mg 10 shoot^{-1}), seedling dry weight (mg 10 seedling^{-1}) and root/shoot dry weight ratio in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Shoot dry weight (mg 10 shoot^{-1})						Seedling dry weight (mg 10 seedling^{-1})						Root/shoot dry weight ratio					
GHB 719	81.25	80.50	79.25	77.56	73.75	78.46	94.00	92.50	90.38	87.38	83.44	89.54	0.16	0.15	0.14	0.13	0.13	0.14
95222 A	60.75	58.00	56.00	53.75	51.25	55.95	70.00	65.25	62.88	59.56	57.06	62.95	0.15	0.12	0.12	0.11	0.11	0.12
J 2454	71.25	65.50	61.75	60.25	55.75	62.90	78.75	71.10	67.07	64.16	59.66	68.15	0.11	0.09	0.08	0.07	0.07	0.08
GHB 905	87.25	84.75	57.75	53.00	52.50	67.05	99.50	94.00	66.31	60.85	60.35	76.20	0.14	0.11	0.15	0.15	0.15	0.14
04999 A	60.50	57.75	56.75	52.75	50.75	55.70	70.00	65.25	63.56	58.69	56.69	62.84	0.16	0.13	0.12	0.11	0.12	0.13
GHB 744	91.25	88.50	87.25	83.75	81.50	86.45	105.50	99.75	97.34	92.56	90.31	97.09	0.16	0.13	0.12	0.11	0.11	0.12
98444 A	69.75	66.75	64.50	61.75	60.50	64.65	80.00	75.38	72.34	68.66	67.41	72.76	0.15	0.13	0.12	0.11	0.11	0.12
J 2340	69.25	69.25	67.75	64.00	61.00	66.25	75.50	75.31	72.66	68.45	65.45	71.47	0.09	0.09	0.07	0.07	0.07	0.08
GHB 732	80.25	79.25	77.75	74.00	66.25	75.50	91.50	88.43	86.64	81.78	74.03	84.48	0.14	0.12	0.11	0.11	0.12	0.12
96222 A	69.50	68.25	65.75	61.25	61.00	65.15	78.25	75.07	71.66	66.13	65.88	71.40	0.13	0.10	0.09	0.08	0.08	0.09
Mean	74.10	71.85	67.45	64.21	61.43		84.30	80.20	75.08	70.82	68.03		0.14	0.12	0.11	0.10	0.11	
S.Em.±	0.90	0.56	0.54	0.36	0.36	2.06	1.08	0.69	0.54	0.43	0.43	2.11	0.003	0.004	0.001	0.002	0.002	0.004
C.D. at 5 %	2.61	1.61	1.56	1.03	2.72	5.92	3.11	2.00	1.57	1.25	2.71	6.05	0.011	0.011	0.005	0.006	0.007	0.012
C.V. %	2.44	1.56	1.60	1.11	3.07	2.06	2.56	1.73	1.44	1.22	2.76	2.05	5.53	7.15	3.35	4.69	4.68	5.34
D																		
S.Em.±						1.46						1.49						0.003
C.D. at 5 %						4.19						4.28						0.087
D×E																		
S.Em.±						0.70						0.78						0.003
C.D. at 5 %						1.96						2.17						0.008

Table 7: Root moisture (%), shoot moisture (%) and seedling moisture (%) in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Root moisture (%)						Shoot moisture (%)						Seedling moisture (%)					
GHB 719	80.44	78.87	79.64	81.31	80.65	80.18	67.70	67.08	67.01	67.60	68.75	67.63	74.07	72.97	73.33	74.46	74.70	73.90
95222 A	80.32	80.85	79.68	83.75	82.65	81.45	74.66	75.29	76.01	76.57	77.30	75.97	77.49	78.07	77.85	80.16	79.97	78.71
J 2454	76.57	79.84	80.32	81.71	79.66	79.62	67.43	68.77	69.84	72.71	79.21	71.59	72.00	74.30	75.08	77.21	79.43	75.60
GHB 905	76.57	82.32	83.13	83.48	82.00	81.50	72.74	72.57	81.22	82.46	82.44	78.29	74.65	77.44	82.18	82.97	82.22	79.89
04999 A	80.91	83.25	83.97	85.24	83.70	83.41	76.02	75.86	76.13	77.60	78.03	76.73	78.46	79.55	80.05	81.42	80.86	80.07
GHB 744	81.10	85.66	84.93	86.99	85.89	84.91	70.33	70.77	71.01	71.82	72.35	71.26	75.71	78.21	77.97	79.41	79.12	78.09
98444 A	72.47	76.38	76.41	77.70	76.71	75.93	66.63	67.24	67.99	79.22	79.45	72.11	69.55	71.81	72.20	73.20	72.80	74.02
J 2340	81.42	78.15	79.94	80.26	80.62	80.08	70.03	67.87	68.04	69.19	70.02	69.03	75.72	73.01	73.99	74.72	75.32	74.55
GHB 732	79.00	83.98	83.69	85.03	84.03	83.15	69.55	69.40	69.71	70.60	73.43	70.54	74.27	76.69	76.70	77.82	78.73	76.84
96222 A	78.80	80.09	81.49	83.23	80.83	80.89	68.30	68.44	69.17	70.66	70.28	69.37	73.55	74.27	75.33	76.95	75.55	75.13
Mean	78.76	80.94	81.32	82.87	81.67		70.34	70.33	71.61	73.84	75.13		74.55	75.63	76.47	78.36	78.40	
S.Em.±	0.586	0.491	0.366	0.485	0.485	0.561	0.38	0.13	0.27	0.79	0.79	1.10	0.36	0.24	0.22	0.49	0.49	0.67
C.D. at 5 %	1.694	1.420	1.059	1.400	2.445	1.611	1.10	0.38	0.77	2.28	1.93	3.15	1.04	0.70	0.62	1.42	1.53	1.92
C.V. %	1.490	1.22	0.9	1.17	2.07	1.43	1.09	0.37	0.74	2.14	1.78	1.41	0.97	0.64	0.56	1.26	1.36	1.02
D																		
S.Em.±						0.396						0.78						0.47
C.D. at 5 %						1.139						2.23						1.36
D×E																		
S.Em.±						0.578						0.51						0.39
C.D. at 5 %						1.619						1.43						1.09

Table 8: Mobilization efficiency (%), vigour index I after 7 days of germination and vigour index II after 7 days of germination in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Mobilization efficiency (%)						Vigour index I after 7 days of germination						Vigour index II after 7 days of germination					
GHB 719	14.07	12.98	12.01	11.52	10.39	11.67	1249.76	1214.80	1245.18	1150.43	924.99	1157.03	8259.50	7844.50	7118.63	6204.88	5403.94	6966.29
95222 A	10.75	10.22	9.32	8.76	7.50	9.30	1475.03	1125.74	963.76	1016.10	831.80	1082.49	5898.75	5237.50	4669.75	3976.94	3510.50	4658.69
J 2454	11.47	9.96	8.89	8.77	7.48	9.31	1538.45	1162.17	906.56	987.31	825.45	1083.99	6382.25	5973.90	4729.43	4331.33	3777.94	5038.97
GHB 905	14.01	13.21	8.65	8.04	7.39	10.25	1453.33	1496.71	1276.66	1297.30	1086.10	1322.02	9280.00	8531.75	5654.38	4869.33	4438.68	6554.83
04999 A	9.62	8.70	8.25	7.42	6.85	8.16	1426.87	1285.06	1116.14	989.06	884.28	1140.28	5915.50	5269.50	4796.88	4152.52	3899.72	4806.82
GHB 744	15.50	14.33	13.22	12.57	11.54	13.43	1949.43	1746.90	1303.00	1242.45	1071.49	1462.65	10261.75	9304.25	8470.52	7267.38	6572.31	8375.24
98444 A	13.03	11.20	10.48	9.81	9.19	10.74	1548.22	1445.61	1028.87	1178.84	1025.38	1245.38	7001.25	6351.13	5625.24	5030.05	4653.04	5732.14
J 2340	11.17	11.15	9.86	9.25	8.36	9.95	1537.52	1321.19	1205.29	1187.76	968.65	1244.08	6404.50	6119.81	5324.42	4966.66	4222.24	5407.53
GHB 732	13.03	12.16	11.28	10.57	9.01	11.20	1669.88	1084.86	1320.13	1108.61	933.92	1223.48	8168.75	7119.75	6650.00	5807.46	4818.73	6512.94
96222 A	10.74	9.94	9.15	8.54	8.07	9.28	1801.08	1213.15	824.60	907.84	826.08	1114.55	6965.75	6344.69	5662.43	4548.38	4447.25	5593.70
Mean	12.34	11.38	10.11	9.53	8.32		1564.96	1309.62	1119.02	1106.57	937.81		7453.80	6809.68	5870.17	5115.49	4574.44	
S.Em.±	2.60	2.12	1.75	1.36	1.36	3.38	88.64	66.17	31.86	48.42	48.42	57.96	192.13	138.28	118.45	126.00	126.00	200.81
C.D. at 5 %	7.51	6.11	5.06	3.94	NS	9.70	255.98	191.09	92.00	139.84	123.24	166.37	554.84	399.32	342.06	363.87	393.71	576.44
C.V. %	4.21	3.72	3.46	2.87	19.50	8.00	11.33	10.11	5.69	8.75	9.10	9.77	5.16	4.06	4.04	4.93	5.96	4.85
D																		
S.Em.±	2.39						40.98						141.99					
C.D. at 5 %	6.86						117.64						407.60					
D×E																		
S.Em.±	4.13						59.02						144.59					
C.D. at 5 %	11.57						165.26						404.87					

Table 9: Field emergence first count (%) after 3 days, field emergence final count (%) after 7 days and field emergence rate index in seeds of pearl millet entries (four hybrids and their respective parents) after different periods of storage

Entries	Dates of sampling																	
	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled	Feb-14	Apr-14	June-14	Aug-14	Oct-14	Pooled
	Field emergence first count (%) after 3 days						Field emergence final count (%) after 7 days						Field emergence rate index					
GHB 719	78.00	64.00	62.00	37.25	32.75	54.80	83.75	81.00	76.50	75.00	47.50	72.75	27.44	25.58	24.29	21.85	14.60	22.75
95222 A	83.25	59.25	57.75	30.00	25.50	51.15	91.75	83.00	66.25	61.75	47.50	70.05	29.88	25.69	21.38	17.94	14.00	21.78
J 2454	81.50	63.00	54.50	35.00	32.00	53.20	81.50	81.00	66.50	62.00	49.75	68.15	27.17	25.50	21.17	18.42	15.10	21.47
GHB 905	83.00	70.75	66.00	38.25	34.75	58.55	95.25	82.50	67.25	60.75	51.25	71.40	30.73	26.52	22.31	18.38	15.71	22.73
04999 A	82.25	64.00	47.75	35.75	33.25	52.60	91.75	79.00	62.00	62.00	47.50	68.45	29.79	25.08	19.48	18.48	14.65	21.50
GHB 744	84.25	62.75	67.75	36.75	36.25	57.55	92.75	82.50	72.25	69.50	51.75	73.75	30.21	25.85	23.71	20.44	15.96	23.23
98444 A	86.25	60.00	48.00	35.00	28.75	51.60	91.75	83.75	63.00	59.00	47.50	69.00	30.13	25.94	19.75	17.67	14.27	21.55
J 2340	84.50	67.00	43.00	37.75	31.75	52.80	91.50	81.50	63.00	59.75	47.25	68.60	29.92	25.96	19.33	18.08	14.46	21.55
GHB 732	89.75	71.00	66.25	39.50	37.75	60.85	97.00	84.25	72.25	70.00	49.75	74.65	31.73	26.98	23.58	20.79	15.58	23.73
96222 A	82.75	67.00	40.75	33.50	30.25	50.85	88.75	80.75	57.25	54.50	41.75	64.60	29.08	25.77	17.71	16.42	12.96	20.39
Mean	83.55	64.88	55.38	35.88	32.30		90.58	81.93	66.63	63.43	48.15		29.61	25.89	21.27	18.85	14.73	
S.Em.±	1.03	1.03	1.39	1.55	1.55	2.10	0.88	0.68	1.08	0.93	0.93	1.70	0.30	0.24	0.38	0.34	0.34	0.53
C.D. at 5 %	2.99	2.96	4.02	4.47	2.51	6.02	2.55	1.96	3.12	2.69	2.45	4.89	0.86	0.68	1.08	0.98	0.79	1.51
C.V. %	2.48	3.16	5.03	8.63	5.39	4.42	1.95	1.66	3.24	2.94	3.53	2.55	2.02	1.83	3.53	3.62	3.70	2.80
D																		
S.Em.±						1.48						1.20						0.37
C.D. at 5 %						4.26						3.46						1.07
D×E																		
S.Em.±						1.20						0.89						0.31
C.D. at 5 %						3.36						2.50						0.86

[MS received: August 19, 2015] *[MS accepted September17, 2015]*