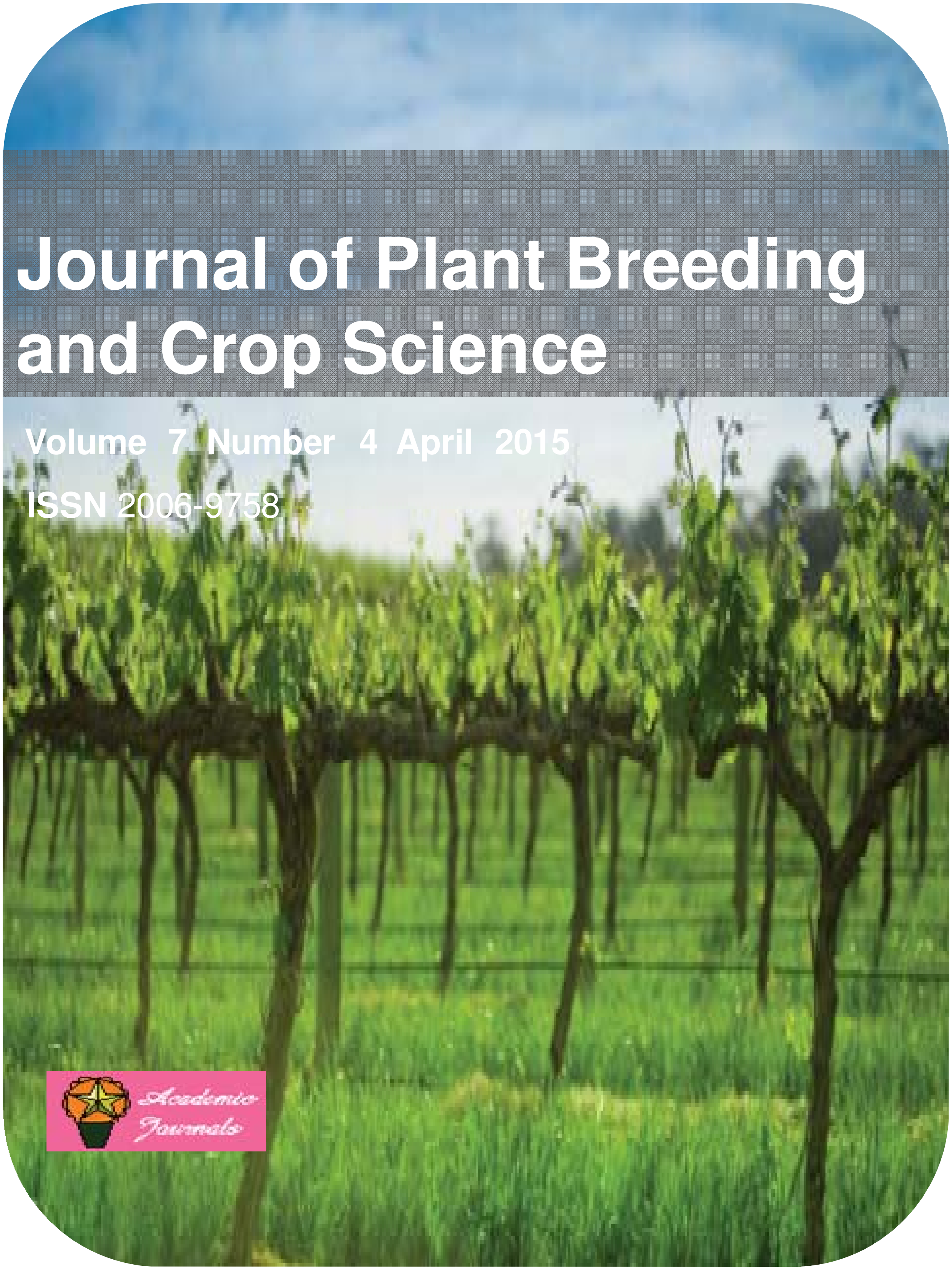

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Full Length Research Paper

Combining ability and heterosis estimate of extra-early quality protein maize (QPM) single cross hybrids

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Six extra-early quality protein maize (QPM) inbred lines from IITA were investigated using a partial diallel cross design. The objectives were to assess the hybrids and their parents for their agronomic performance. The six parents along with their hybrids (15) were evaluated using a Randomized Complete Block Design (RCBD) with three replications per site in four locations. General combining ability (GCA) and specific combining ability (SCA) effects as well as mid-parent heterosis were determined. Results of combined analysis of variance (ANOVA) revealed significant environmental effect for all the traits studied. Significant additive effect was observed for only grain yield whilst non-significant GCA and SCA effects were identified for all other traits. The GCA estimate identified parental lines P1, P3 and P5 as the high combiners for grain yield. The GCA estimates identified parental lines P1, P3 and P5 as the best combiners for grain yield. Again, P1 was the most suitable parent for increased cob length, cob diameter, number of rows per cob and reduced anthesis-silking interval; P3 for thousand-grain weight and reduced days to flowering (anthesis and silking days), and P5 for number of kernels per row, and reduced plant height and ear height. Hence, these parents may be used in hybridization programmes as donors of the superior traits indicated. The highest values for SCA and mid-parent heterosis for grain yield were observed in the crosses P1xP4, P5xP6, P1xP5 and P4xP6.

Key words: Quality protein maize (QPM), diallel, combining ability.

INTRODUCTION

Maize is an important staple cereal crop in the world (Michael et al., 1999; Vivek et al., 2007; Moaveni et al., 2011). It is estimated that 94 countries depend on maize for at least 30% of their total daily calories (CIMMYT and IITA, 2011). In sub-Saharan Africa, about 12 countries depend on maize for at least one fifth of their total daily calories intake, and up to 60% for their total daily protein intake (Krivanek and Vivek, 2006). Although, maize plays an important role in global food systems, there is some nutritional deficiency present in the normal maize (NM) varieties. These varieties do not have enhanced protein level and are considered as low quality protein maize. There is paucity of two specific essential amino acids - lysine and tryptophan, which are prerequisite to human

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dietary protein requirement. The intervention for mitigating protein deficiency from low protein quality maize has led the maize improvement programme of International Institute of Tropical Agriculture (IITA) to develop quality protein maize (QPM) inbred lines through combining ability studies to establish heterotic patterns among inbred populations and to maximize their yields for hybrid development.

Falconer and Mackay (1996) defined heterosis as the difference in performance of hybrid and the mean performance of the two parents. This difference is often called mid-parent heterosis. In effect, heterosis restores reduced vigour associated with inbreeding and leads to higher performance of progenies over the parents. Heterosis has been found to be controlled by dominance complementation, locus-specific over-dominance (Shull, 1908; Crow, 1948) and epistasis effects (Lippman and Zamir, 2006). Combining ability study via diallel crosses is an important tool used by many plant breeders for developing hybrid maize varieties and offers an opportunity in identification and selection of potential inbred lines and parental combinations (Hallauer, 1990).

The method used to analyse crosses, or parents and the crosses on the basis of general combining ability (GCA) and specific combining ability (SCA) concepts is diallel mating design (Griffiths, 1956). Hayman (1954) and Stoskopf et al. (1993) defined “diallel cross” as the set of all possible matings between several genotypes. The estimates from GCA and SCA provide an assessment of relative merits of the individual genotypes in cross combinations to guide in selection and testing schemes. Thus, diallel analysis is among the genetic-statistical approaches developed to assist in selection of parents based on their combining ability and the potential to produce promising segregating populations (Okello et al., 2006). Combining ability for yield and other traits such as disease resistance and high protein concentration play significant role in the identification of appropriate parents for hybrid development. Diallel mating designs have been extensively used in breeding programs for the evaluation of genetic potential of parents that range from inbred lines to wide genetic base varieties (Hallauer and Miranda, 1988; Stoskopf et al., 1993; Bernardo, 2002).

The advent of changes in climatic conditions coupled with unpredictable rainfall pattern and incidence of pest and disease pose threats to crop production especially grains (FAO, 2007). These demand the development of an adapted extra-early maturing QPM hybrid with improved nutritional qualities and high yield potential in Ghana to improve livelihood of farmers. These lines would be a valuable genetic material to enhance extra-early QPM hybrid development in Ghana. The goal of this study was to assess the relative importance of SCA and GCA of six extra-early IITA QPM inbred lines and their single cross hybrids. The specific objectives were to estimate the GCA and SCA effects for grain yield and other agronomic traits and to identify cross combinations expressing high hybrid vigour.

MATERIALS AND METHODS

The genetic materials (Table 1) used were made up of six extra-early QPM F_6 inbred lines obtained from International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. These lines were crossed in the major season of the year 2011 in incomplete diallel mating design to form 15 F_1 hybrids. F_1 single crosses were made by hand-pollination using bulk pollen from each line. The harvested ears were dried and shelled manually. The F_1 single cross hybrids and their parents were processed and stored in cold room prior to field evaluation.

In major season of 2012, field evaluation of 15 F_1 single crosses and their parents was conducted at Crops Research Institute (CRI) – Fumesua which is located at the forest ecological zone of Ghana with coarse sandy-loam soil. The experiment was replicated in three other out-stations of the Institute. These were Ejura in the forest transition zone with fine coarse sandy-loam soil, Pokuase and Akomadan in the coastal savannah and semi-deciduous forest ecological zones respectively with coarse sandy-loam soil for both locations (Sallah et al., 2004).

The entries were arranged in randomized complete block design (RCBD) with three replications. A plot consisted of two-rows of 5 m long each with planting interval of 75 cm x 40 cm was used. Hills were overplanted and thinned after emergence until a final planting density of approximately 66,000 plants ha^{-1} was achieved in each trial. Cultural practices such as fertilization, weeding, pest and disease control were accomplished using normal field management practices.

Data collection

Data for days to flowering (anthesis and silking) was taken and anthesis–silking interval (ASI) was calculated as the difference between number of days to silking and anthesis (SD–AD). Plant height (from the ground level to the flag leaf node) and ear height (from the ground level to the node bearing the uppermost ear) were recorded using a graduated measuring pole. Root and stalk lodging (RL and SL) parameters were taken at physiological maturity determined as the percentage of plants leaning at an angle greater than 45° from the vertical and percentage of plants with broken stalks at or below the main ear at maturity respectively. After harvest, data for cob length, cob diameter, number of rows cob^{-1}, number of kernels row^{-1}, thousand grain weight and grain yield plot^{-1} were taken.

Individual analyses of variance (ANOVA) per location or environment and across environments for agronomic traits were carried out using Genstat version 9.2. Genotypes were considered as fixed effects whilst environments and replications were treated as random effects. For each agronomic and morphological trait, an individual ANOVA was conducted to determine the statistical significance for parents and their crosses at each environment and across environments. Combining ability test involving parents and their F_1 progenitors were used to assess their performance.

Diallel analysis was conducted using the DIALLEL-SAS program (Zhang and Kang, 1997). Griffiths (1956) linear Model 1 and Method 2 (Table 2) was used for analysis of variance as follows: $X_{ijk} = \mu + r_k + g_i + g_j + s_{ij} + e_{ijk}$; where X_{ijk} is the observed performance of the cross between ith and jth parents in the kth replication, μ the population mean, r_k the replication effect, g_i the GCA effect for the ith parent, g_j the GCA effect for the jth parent, s_{ij} the SCA effect for the cross between ith and jth parents, and e_{ijk} is the experimental error for the X_{ijk} observation (Hallauer and Miranda, 1988). Means were compared using the least significant difference (Steel and

Table 1. List of parental inbred lines and their pedigrees.

Name	Pedigree	Designation
TZEEQI 1	TZEE-W Pop × 1368 STR S7 Inb 40 × Pool 15 SR QPM BC1S5 (18) 2-5-1-1	P_1
TZEEQI 2	TZEE-W Pop × 1368 STR S7 Inb 40 × Pool 15 SR QPM BC1S5 (3/4) 3-7-3-7	P_2
TZEEQI 7	TZEE-W Pop × 1368 STR S7 Inb 40 × Pool 15 SR QPM BC1S5 (7) 4-10-1-1	P_3
TZEEQI 6	TZEE-W Pop × 1368 STR S7 Inb 40 × Pool 15 SR QPM BC1S5 (7) 1-10-1-10	P_4
TZEEQI 8	TZEE-W Pop × 1368 STR S7 Inb 40 × Pool 15 SR QPM BC1S5 (7) 6-10-4-5	P_5
TZEEQI 12	TZEE-W Pop × 1368 STR S7 Inb 40 × Pool 15 SR QPM BC1S5 (7) 10-10-10-10	P_6

Table 2. Format of ANOVA for GCA and SCA according to Griffiths' Method 2.

Source	Degrees of freedom (d.f.)	Sum of squares (S.S.)
GCA	$\mathrm{n}-1$	$\frac{1}{\mathrm{n}+2}\left[\sum(\mathrm{y_i}+\mathrm{y_{ii}})^2-\frac{4}{\mathrm{n}}\mathrm{y}^2_{..}\right]$
SCA	$\frac{\mathrm{n}(\mathrm{n}-1)}{2}$	$\sum\sum \mathrm{y}_{\mathrm{ij}}^2-\frac{1}{\mathrm{n}+2}\sum(\mathrm{y_i}+\mathrm{y_{ii}})^2+\frac{2}{(\mathrm{n}+1)(\mathrm{n}+2)}\mathrm{y}^2_{..}$
Error	$\left[\frac{\mathrm{n}(\mathrm{n}+1)}{2}-1\right]\times(\mathrm{r}-1)$	$\frac{\text{Total S.S.}-\text{Treatment S.S.}-\text{Replication S.S.}^*}{\mathrm{r}}$

S.S. out of base ANOVA (Aliu et al., 2009).

Torrie, 1980).

The estimates of heterosis over the mid parent heterosis was calculated using Aliu et al. (2009) Mid Parent Heterosis

$$(\mathrm{MPH}) = \frac{\mathbf{F_1} - \mathbf{M_P}}{\mathbf{M_P}} \times 100$$

Where: F_1 is the mean of the F_1 hybrid performance and MP = mid parent value of the particular F1 cross $\left[\frac{P_1+P_2}{2}\right]$, where P_1 and P_2 are the means of the inbred parents.

RESULTS

When the genotypic sum of squares was partitioned into general combining ability (GCA) and specific combining ability (SCA), only GCA was found to be significant ($p < 0.01$) and for only grain yield. Estimates of GCA effects indicated parental performances of the traits across all the locations (Table 3). For days to flowering (anthesis and silking), the highest and lowest GCA values were observed for P4 and P3, respectively. However, P4 had the least GCA values for grain yield, thousand grain weight, cob diameter, plant height and root lodging whilst P3 had the least for stem lodging. P5 had the highest parental GCA value for grain yield, number of kernels per row and root lodging. P1 was the best general combiner for plant height, ear height, cob length, cob diameter and number of rows per cob but exhibited the least and negative value for anthesis-silking interval. P6 had the least GCA effect for cob length and number of kernels per row but had the highest observed GCA value for anthesis-silking interval. The crosses P1×P4 and P5×P6 had the highest SCA effect for grain yield but P1xP4 had the highest negative SCA effects for both days to anthesis and silking (Table 4). Similarly, P5×P6 had the highest SCA effects for anthesis-silking interval, plant height, cob length and number of kernels per row. The cross combinations P1×P5 and P1×P6 had the least SCA values for anthesis-silking interval with the latter combination emerging as the least for grain yield. P1×P3 gave high negative SCA effects for both plant and ear heights and high positive value for root lodging. P4 also produced negative SCA effects for stem lodging in all crosses except for P2×P4, which had positive SCA effects for both stem and root lodging. P1×P4 however had a high positive SCA effect for cob length, cob diameter, number of rows per cob and number of kernels per row. Similarly, P5×P6 had positive SCA effects for all the traits estimated with the exception of stem and root lodging.

The mid parent heterosis estimates for the respective 15 hybrid combinations are shown in Table 5. For grain yield, the highest positive mid-parent heterosis was observed in the hybrid P1×P4 followed by P4×P6, P1×P5, P5×P6, P2×P4, P4×P5, P2×P3 and P1×P3 whilst the remaining hybrids had negative estimates. Mid-parent heterosis for grain yield ranged from -15.16 to 26.15% with an average estimate of 0.99% for the 15 hybrids (Table 5). For days to flowering, it ranged between -2.41% and 2.08% for DTA, and -3.24 to 1.94% for DTS with an averages of 0.21% and 0.25% for days to anthesis and silking respectively. The average estimate

Table 3. Estimates of general combining ability (GCA) effects of each parental line for traits.

Parent	GY	DTA	DTS	ASI	PHT	EHT	TGW	CL	CD	NRC	NKR	SL	RL
P1	0.122	-0.128	-0.122	-6.875	1.783	1.019	-0.001	0.173	0.034	0.135	0.361	-0.135	0.076
P2	-0.003	-0.045	0.014	-2.875	0.225	-0.547	0.000	-0.061	0.020	0.021	-0.087	0.104	0.191
P3	0.084	-0.253	-0.247	0.000	0.760	0.911	0.003	-0.086	-0.024	-0.177	-0.139	0.156	0.264
P4	-0.247	0.424	0.337	2.000	-2.215	-0.249	-0.003	0.055	-0.073	-0.042	-0.045	-0.052	-0.747
P5	0.134	0.017	0.024	3.375	-0.544	-0.674	0.001	0.029	0.028	-0.042	0.372	-0.052	0.576
P6	-0.091	-0.014	-0.007	4.375	-0.010	-0.460	-0.002	-0.110	0.015	0.104	-0.462	-0.021	-0.361

(GY) grain yield, (DTA) days to 50% anthesis, (DTS) days to 50% silking, (ASI) anthesis-silking interval, (PHT) plant height, (EHT) ear height, (TGW) thousand grain weight, (CL) cob length, (CD) diameter, (NRC) number of rows per cob, (NKR) number of kernels per row, (SL) stem and (RL) root lodging.

Table 4. Specific combining ability (SCA) effects for the hybrids in their respective combinations.

Hybrid	GY	DTA	DTS	ASI	PHT	EHT	TGW	CL	CD	NRC	NKR	SL	RL
P1P2	-0.218	0.420	0.100	0.750	-1.542	-3.395	-0.005	-0.263	-0.030	0.237	-0.743	0.519	-2.906
P1P3	0.028	0.461	0.527	-1.125	-9.794	-8.254	0.012	0.095	0.065	-0.232	-0.774	0.217	1.604
P1P4	0.360	-0.799	-0.973	-2.125	2.715	-1.543	0.001	-0.037	-0.011	0.299	0.382	-0.491	0.198
P1P5	0.220	0.274	0.423	-2.500	1.260	1.299	0.002	0.047	0.013	0.132	1.299	-0.074	-1.125
P1P6	-0.255	0.305	0.621	-2.500	1.394	2.417	0.001	0.136	-0.016	-0.180	0.216	0.478	1.479
P2P3	0.153	0.628	0.808	-0.125	5.631	-0.695	0.002	-0.130	-0.072	-0.451	1.007	-0.606	0.573
P2P4	0.093	-0.716	-0.775	-1.125	5.223	2.580	-0.004	0.438	0.127	0.164	0.997	1.103	0.917
P2P5	-0.155	-0.143	-0.046	-1.500	3.819	1.624	0.000	0.022	-0.040	0.164	-1.003	-0.231	1.427
P2P6	-0.138	-0.362	-0.348	-1.500	-5.331	2.915	0.004	-0.306	-0.069	0.018	-1.170	0.321	0.698
P3P4	0.005	-0.591	-0.432	0.000	-4.679	-2.333	0.001	-0.279	-0.053	-0.055	-0.868	-0.033	1.844
P3P5	-0.184	-0.435	-0.536	-0.375	1.500	-4.718	-0.009	-0.120	0.013	0.278	0.132	0.884	-0.979
P3P6	-0.118	0.597	0.329	-0.375	-10.650	1.607	0.004	0.044	-0.050	-0.034	-0.618	0.686	-0.708
P4P5	-0.020	0.305	0.214	0.625	2.492	-3.558	-0.003	0.031	0.037	-0.190	0.039	-0.574	-1.552
P4P6	0.122	0.003	-0.004	0.625	-3.675	6.236	0.000	0.053	-0.009	-0.336	-0.628	-0.189	-0.948
P5P6	0.257	0.409	0.225	1.250	8.888	4.744	0.002	0.488	0.040	0.164	1.455	-0.356	-0.021

(GY) grain yield, (DTA) days to 50% anthesis, (DTS) days to 50% silking, (ASI) anthesis-silking interval, (PHT) plant height, (EHT) ear height, (TGW) thousand grain weight, (CL) cob length, (CD) diameter, (NRC) number of rows per cob, (NKR) number of kernels per row, (SL) stem and (RL) root lodging.

of mid-parent heterosis for anthesis-silking interval was -6.96% and ranged from -85.19 to 10.55%. Most of the hybrids had negative mid-parent heterosis for plant height except for P1×P5, P2×P3, P2×P4, P2×P5, P3×P5, P4×P5, and P5xP6. Similarly except for 7 hybrids (P1×P2, P1×P3, P1×P4, P2×P3, P2×P6, P3×P4 and P3×P6). The average estimate of mid-parent heterosis for plant height was -0.36% and ranged from of -9.99 to 6.70%. A range of -12.71 to 14.56% with an average of 1.25% was observed for the ear height (Table 5). For thousand grain weight, the range was -2.33 to 6.98% with 0.47% as the average for 15 hybrids. Cob length and cob diameter had 0.41 and 0.42% for average mid-parent heterosis estimate for 15 hybrids and ranged from -2.58 to 5.66% and -3.08 to 3.59% respectively. The mid-parent value for number of rows per cob also ranged from -4.09 to 6.55% with an average of 0.47%, whilst number of kernels per row had an average of -0.12% and ranged from -5.54 to 6.51%. Stem and root lodging respectively had a mid-parent heterosis range of -54.26 to 137.71% and -66.06 to 85.81% with averages of 45.09 and 6.15%, respectively (Table 5).

DISCUSSION

The significance of general combining ability (GCA) and specific combining ability (SCA) plays a vital role in developing appropriate breeding approaches. As proposed by Hallauer and Miranda (1988), general and specific combining ability estimates respectively provide relative genetic effects of additive gene and non-additive gene actions (dominance and epistasis). The results indicated highly significant additive gene action for grain yield indicating that further progress can be achieved in these genotypes through recurrent selection methods. This result corroborates the finding of Musila et al. (2010), who also found significant GCA and non-significant SCA effects for grain yield. Baker (1978) and Ojo et al. (2007) suggested that the non-significant differences in SCA estimate permit maximum utilization of GCA in predicting the performance of single cross hybrids. Again, Mhike et al. (2011) suggested possibility of exploring early testing of the genotypes due to the predominance of additive gene to non-additive gene actions. This method becomes more efficient and effective for selecting promising hybrids based on their predictions from GCA effects. This presupposes that, early testing of the selected genotypes from the testcrosses from the studied population can be done for grain yield because of the predominance of GCA variances to SCA variances. The application of early testing becomes necessary since additive gene action is not affected by inbreeding depression. Hence traits that are under control of additive gene action will not suffer from inbreeding.

This assertion reflected in grain yield where the best performing hybrids (P1×P5 and P1×P3) were crosses between three inbred lines (P1, P3 and P5) with the highest GCA estimates for grain yield (0.122, 0.084 and 0.134 t/ha^{-1}, respectively) suggesting that these parents are potentially superior (Woyengo et al., 2001). These parental lines had positive GCA effects for grain yield, indicating the presence of favourable alleles for grain yield. In addition, P1 was a good combiner for reduced days to flowering (both anthesis and silking), anthesis-silking interval, stem lodging and increased number of rows per cob, number of kernels per row, cob length and cob diameter. Consequently, P1 proved to be the best combiner for early maturity and high yields. Similarly, P3 had reduced days to flowering whilst P5 had reduced plant height, ear height and stem lodging suggesting that they have good potentials to be used in maize improvement programmes. Although P4 and P6 were poor combiners for grain yield, both parents exhibited negative GCA effects for plant height, ear height, root and stem lodgings which suggests that these parents can be used for reduced plant height and lodging tolerance improvement. For increased grain yield, it is desirable to make selection based on yield components (Zare et al., 2011). Hence P1 was the suitable genetic resource for cob length, cob diameter and number of rows per cob; P3 for thousand-grain weight, and P5 for number of kernels per row. In similar studies, non-significant GCA effects have been identified for plant height and cob length (Zare et al., 2011). As suggested by Simmonds (1979), GCA effects of parental lines also provide substantive information for selecting outstanding parents to make desirable crosses for advance breeding programmes.

The non-significant SCA effects observed in this study is possibly due to the use of parental lines that are related as proposed by Hill (1983). Similarly, non-significant SCA has been reported for grain yield (Filho et al., 1981; Ojo et al., 2007). To exploit the genetic potentials of these parents, they could be crossed with distantly related inbreds or populations. The SCA estimate gives heterotic response of parental interaction (heterosis) for specific traits (Zare et al., 2011). The high SCA and mid-parent heterosis values for grain yield observed in the following combinations: P1×P4, P5×P6, P1×P5 and P4×P6 suggests that these crosses are suitable for increased grain yield. This was manifested in yield components such as number of kernels per row, number of rows per cob, cob length and diameter where positive SCA and mid-parent heterosis values were observed. The mid parent heterosis for some crosses were negative for days to anthesis and silking indicating earliness in maturity. The maximum negative heterosis for days to flowering recorded for P1×P4, P3×P4, P2×P4, P2×P5, P4×P6 and P4×P5 suggests that the parental lines involved in these crosses may be useful for producing extra-early maturing QPM hybrids. The advent erratic climatic conditions also poses serious threat to existing early maturing varieties there by making them susceptible to biotic and abiotic factors hence the promising hybrid combinations can be useful germplasm to replace them. Earliness in maturity also offers opportunity to utilize minor season cropping where the short rainy periods can efficiently be used for maize cultivation. High negative mid-parent heterosis for plant height was exhibited in the crosses P1×P3, P1×P4, P3xP4 and P3×P6 which also means that the parents

Table 5. Heterosis estimate for respective hybrid combinations.

Hybrids	GY	DTA	DTS	ASI	PHT	EHT	TGW	CL	CD	NRC	NKR	SL	RL
P1P2	-10.32	1.11	0.40	-11.82	-0.64	-7.11	-2.33	-2.55	-1.29	2.51	-3.01	120.25	-66.06
P1P3	1.44	1.97	1.71	2.90	-8.97	-12.71	6.98	-0.11	1.04	-2.22	-3.32	79.64	48.84
P1P4	26.15	-2.18	-2.47	-7.75	-0.15	-3.89	0.00	-0.04	0.40	2.51	3.35	-39.58	3.53
P1P5	11.80	1.11	0.40	4.66	2.57	2.91	2.33	1.21	0.77	6.55	6.51	0.00	-33.81
P1P6	-11.31	1.46	1.94	10.39	-1.41	2.60	0.00	1.81	-1.03	0.92	0.44	122.54	35.97
P2P3	2.50	1.55	-3.24	-85.19	1.80	-0.21	0.00	-2.23	1.30	-4.09	1.73	-4.17	34.10
P2P4	8.95	-2.41	-0.56	-1.57	4.72	4.10	-2.33	3.33	3.32	1.28	2.61	123.04	36.57
P2P5	-6.49	-0.16	-0.89	1.57	6.23	9.38	0.00	0.91	-1.03	2.56	-2.62	-0.03	19.55
P2P6	-10.76	-0.33	-0.41	10.55	-3.40	-0.16	-2.33	-2.07	-3.08	-0.30	-5.54	100.00	27.25
P3P4	-6.15	-1.76	-1.44	4.43	-5.09	-8.95	0.00	-2.58	-1.48	-1.59	-4.03	18.22	85.81
P3P5	-15.16	-0.34	-0.57	-4.30	0.89	2.33	-2.33	-0.79	0.00	2.19	0.87	93.13	-19.35
P3P6	-7.89	2.08	1.39	-10.39	-9.99	-6.33	2.33	0.36	0.94	-0.75	-3.79	137.71	-0.15
P4P5	7.73	-0.09	-0.39	-6.18	4.70	9.36	2.33	1.58	2.01	-0.65	1.75	-54.26	-45.25
P4P6	12.92	-0.41	-0.55	-2.91	-3.29	12.94	4.76	1.63	3.59	-3.42	-2.93	0.00	-25.22
P5P6	11.45	1.54	0.96	-8.83	6.70	14.56	-2.33	5.66	0.78	1.54	6.19	-20.19	-9.49
Mean	0.99	0.21	-0.25	-6.96	-0.36	1.25	0.47	0.41	0.42	0.47	-0.12	45.09	6.15

(GY) grain yield, (DTA) days to 50% anthesis, (DTS) days to 50% silking,(ASI) anthesis-silking interval, (PHT) plant height, (EHT) ear height, (TGW) thousand grain weight,(CL) cob length, (CD) diameter, (NRC) number of rows per cob, (NKR) number of kernels per row, (SL) stem and (RL) root logging.

could be used as germplasm source for developing short varieties.

Conclusion

The study identified valuable genetic materials which can be exploited for subsequent breeding activities. The GCA estimates identified parental lines P1, P3 and P5 as the best combiners for grain yield. Again, P1 was the most suitable parent for increased cob length, cob diameter, number of rows per cob and reduced anthesis-silking interval; P3 for thousand-grain weight and reduced days to flowering (anthesis and silking days), and P5 for number of kernels per row, and reduced plant height and ear height. Hence, these parents may be used in hybridization programmes as donors of the superior traits indicated. The crosses P1×P5, P5×P6, P1×P3, P2×P3 and P1×P4 were the best performing hybrids as well as for exploiting hybrid vigour. Therefore, they can be further evaluated for possible release for commercial production by farmers.

Conflict of Interest

The authors have not declared any conflict of interests.

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Breeding for dual purpose attributes in sorghum: Identification of materials and associations among fodder and grain yield and related traits

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In view of the pressing need for both grain and fodder of sorghum as source for food and feed, a study was conducted during 2010 and 2011 to investigate the possibility of developing high yielding dual (grain/fodder) sorghum cultivars. A replicated breeding nursery comprising 122 genotypes was screened for dual grain/fodder attributes. 21 sorghum genotypes were selected and tested against 3 checks in Alpha lattice design with 3 replicates. Association study between grain and forage yields and some related traits was carried out. Sorghum genotypes with high capacity for dual grain/fodder production were identified. It was concluded that high levels of grain and fodder yields coupled with some desirable related traits could be incorporated in one sorghum cultivar as suggested by the favorable associations shown in the study.

Key words: Abjaro, Abu Sabein, Ankolib, correlation, shambat, Sudan grass, variability.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a crop of world-wide importance, ranking fifth among the important cereal crops (Chantereau and Nicou, 1994). In the sub-Saharan Africa, it is arguably the most important cereal crop. The world production of grain sorghum amounted to 63.4 million tonne resulting from growing an area of about 47 million ha 63% of which in the African continent (FAO, 2009). The major uses of sorghum have been for food, feed, starch, and for fuel alcohol. Initially, sorghum grain is used primarily for food; however, its use as a feed now exceeds its use as food especially in developed countries. In view of the pressing demand for fodder coupled with the fact that grain sorghum is the stable diet for millions of people in the sub-Saharan Africa and India, it is imperative to reconsider the present mono-commodity breeding strategy of sorghum. Kelly et al (1991) questioned the current strategy of strictly adopting grain-yield criteria in evaluating sorghum genotypes arguing that fodder's contribution to the total value of sorghum production has increased considerably.

Being a possible centre of origin, Sudan is endowed with a wealth of genetic variability in sorghum (Yasin, 1978) enabling selection for most economic traits. The sorghum germplasm of Sudan has been utilized extensively all over the world especially in the USA to improve yield of both grain and fodder (Mahmoud et al,,

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1996). In contrast, local efforts to exploit such variability to develop dual sorghum types have been very limited and mostly directed towards developing improved grain types. Simultaneous improvement of sorghum for both fodder and grain attributes will help in meeting the demand for feed and food and allow maximum utilization of the limited farmer's resource. Research efforts of such kind were very few or lacking in the Sudan. The objectives of this investigation were: To assess the magnitude of variability among some local and exotic sorghum for some traits that aid in developing dual forage/grain sorghum cultivars and to investigate associations between the major forage and grain attributes contributing to developing of dual purpose sorghum cultivars.

MATERIALS AND METHODS

The experimental site

The study was conducted in Shambat (lat.15° 39 N; Long.32° 31 E) in the Experimental Farm of Agricultural Research Corporation (ARC) during 2010- 2011. The soil is heavy clay, non-saline, non-sodic with pH 7.8. The climate is hot and dry. Average Min-Max temperature was 14 and 40°C. The rainy season is short extending from July to September with scant and fluctuating precipitation.

Plant materials

The breeding nursery

The source population of materials used in this study was based on a breeding nursery established in 25/11/2010 in the Experimental Farm of Shambat Research Station (Sh. R.S.). The material grown consisted of 122 entries comprising 34 Sudan grass, 33 Abu Sabein, 29 grain sorghum, 17 sweet sorghum and 9 Ankolib genotypes. All materials other than grain sorghum were developed or kept by the Forage Improvement Program (FIP) at Sh. R.S. The grain sorghum genotypes were collected from different parts of the country, or donated by local research programs. Each entry was represented by one 5 m - ridge replicated twice. Sowing was done manually on the eastern side of the ridge by placing 3 to 5 seeds in holes spaced at 20 cm. Nitrogen fertilizer (urea) was added at the second irrigation at rate of 55 kgN/ha..Irrigation water was applied at 10 to 12 days interval. Weed population was kept at minimum by hand weeding.

Selection criteria

The major criteria used to select for dual purpose (fodder/grain) genotypes included but not limited to: Early to semi early flowering time, high regrowth and tillering capacity, medium to tall plant stature, large panicle size (thick diameter), leafiness, stay green, juicy sweet stems, bold white grains with no testa color. Panicle and grain characteristics were evaluated in the laboratory from five heads randomly chosen from each genotype. Based on the above attributes, 21 genotypes comprising 7 Sudan Grass, 5 each Abu Sabin and grain sorghum and 2 each Ankolib and sweet sorghum were selected. Selection was firstly based on high dual grain / forage yield then on related attributes with more emphasis given to earliness, regrowth and leaf to stem ratio (Table 1).

The trial

The 21 selected genotypes plus 3 standard checks (totaling 24) were arranged in α lattice design (Patterson and Williams, 1976) with 12 incomplete blocks (iblock) and 4 complete blocks. The iblock composed of two plots each having two 5 m ridges. Planting date was effected on 11/10/201. Sowing method and planting density were similar to those of the breeding nursery. In each incomplete iblock, forage and grain attributes were evaluated from the two outer and the two inner rows, respectively. Data collected for forage attributes included: Green (GMY) and dry (DMY) matter yields (t/ha), days to 50% flowering, plant height and stem diameter. Leaf to stem ratio: Measured on dry weight basis by dividing the weight of the leaves by the total weight of leaves and stems taken from five randomly chosen plants from each plot. Regrowth (g): Measured two weeks following the date of cutting of each entry, new immerging shoots from 5 competitive plants randomly chosen from each harvested plot were collected, air dried and the dry weight was determined in grams. Data collected for grain attributes included seed yield /plant (g), head circumference (cm), head length (cm), 1000 seeds weight (gm) and seed number/head.

Statistical analysis

The data was subjected to analysis of variance (ANOVA) following the procedure of alpha lattice design (Patterson and Williams, 1976). Correlation between different characters was worked out. The statistical software packages Agrobase Gen II (2008) was used to run alpha lattice whereas GenStat (2011) was used to run correlation analysis.

RESULTS

Agronomic performance

The analysis of variance (Table 2) revealed highly significant differences among genotypes for forage and grain yields and all related traits.

Forage yield

The overall mean for DMY was 7.34 t/ha (Table 3). SG33 gave the highest DMY (11.35 t/ha) followed by Abjaro (9.85 t/ha), S.25Abu70 (9.80 t/ha), SG8 (9.74 t/ha) and S.03Abu70 (9.74 t/ha). The lowest DMY was shown by Abnaffain (3.78 t/ha). The grain checks (WadAhmed, and ArfaaGadamak) and Ankolib types gave below average DMY. The overall mean for GMY was 33.8 t/ha. Generally, the genotypes kept similar trend as in DMY. The highest GMY was shown by S.25Abu70 (47.97 t/ha) and SG33 (47.72 t/ha) whereas the lowest GMY was shown by Abnaffain (17.95 t/ha).

Seed yield per plant

The overall mean for seed yield per plant was 31.61 g

Table 1. The 21 selected sorghum genotypes (Shambat, 2011).

Entry	Genotype	Type	Source	Seed color
1	SG33	Sudan grass	FIP. Shambat	Dark brown
2	SG08	Sudan grass	FIP. Shambat	White
3	SG54	Sudan grass	FIP. Shambat	White
4	SG53-1	Sudan grass	FIP. Shambat	Dark brown
5	SG12-1	Sudan grass	FIP. Shambat	White
6	SG51	Sudan grass	FIP. Shambat	White
7	SG32-1	Sudan grass	FIP. Shambat	White
8	S.25Abu70	Abu sabein	FIP. Shambat	White
9	S.24Abu70	Abu sabein	FIP. Shambat	White
10	S.26Abu70	Abu sabein	FIP. Shambat	White
11	S.134Abu70	Abu sabein	FIP. Shambat	White
12	S.03Abu70	Abu sabein	FIP. Shambat	White
13	ANKSenar	Ankolib	FIP. Shambat	Dark brown
14	ANKNiyala	Ankolib	Nyala Res. Station	Dark brown
15	E-35-1	Sweet sorghum	USDA-ARS U .of Nebraska	White
16	Atlas	Sweet sorghum	USDA-ARS U .of Nebraska	White
17	ArfaaGadamak	Grain sorghum	ARC National Prog.	White
18	HagaBanet	Grain sorghum	Niyala Res. Station	White
19	FakiMustahi	Grain sorghum	ARC National Prog.	White
20	Hemasi	Grain sorghum	FIP. Shambat	Yellow
21	Abjaro	Grain sorghum	FIP. Shambat	White
22	Abnaffain	Grain/Forage (dual check)	U. of Bakht Alrida	White
23	SG32-2A	Sudan grass (forage check)	FIP. Shambat	Dark brown
24	WadAhmed	Grain sorghum (grain check)	ARC National Prog.	White

Table 2. Mean squares from ANOVA for yield and yield-related traits of 24 sorghum genotypes (Shambat, 2011).

Source of variation	DF	Green matter yield (t/ha)	Dry matter yield (t/ha)	Seed yield/plant (g)	Regrowth weight (kg/ha)	Days to flower	Plant height (cm)	Stem diam. (cm)	Leaf/stem ratio
Block	3	113.00*	4.845^{ns}	86.856^{ns}	6.394^{ns}	20.427**	700.260**	0.013^{ns}	0.000^{ns}
Genotype	23	275.862**	15.254**	815.573**	70.534**	75.565**	2757.597**	0.104**	0.004**
Residual†	69	30.428	2.004	67.697	13.352	4.007	129.311	0.009	0.001
iBlock ♣	44	36.190^{ns}	2.014^{ns}	78.527^{ns}	15.933^{ns}	5.009^{ns}	157.543^{ns}	0.010 ^{ns}	0.001^{ns}
Error ‡	25	20.285	1.987	48.63777	8.810	2.244	79.623	0.007	0.001

**, ^{ns}, Highly significant and not significant at 0.01 and 0.05 probability level, respectively; †, RCBD residual; ♣, incomplete block; ‡, Intra block error.

(Table 3). Abjaro showed the highest seed yield (72.50 g) followed by S.134Abu70 (57.54 g), S.26Abu70 (49.10 g), Hemasi (45.58 g) and S.25Abu70 (44.13 g). S.03Abu70 and E-35-1 averaged 41.85 and 36.92 g, respectively. SG53-1 and SG51 gave the best seed yield among Sudan grass group averaging 30.1 and 28.83 g, respectively. Abnaffain, ArfaaGadamak and WadAhmed gave below average seed yield amounting to 25.65, 23.60 and 21.72 g, respectively. The lowest seed yield was shown by the Sudan grass genotypes SG33 (18.39 g), SG32-2A (13.69 g) and SG32-1(12.89 g).

Growth traits

The genotypes SG12-1 and Abnaffain were the earliest with respective flowering time of 52.3 and 53.2 days (Table 4). In contrast, Abjaro and E-35-1 were the latest taking 71.3 and 66.0 days to flower. The flowering time for Abu Sabein genotypes ranged from 55.9 to 58.7 days. The average performance for plant height was 182 cm. Abjaro was the tallest (217 cm) whereas ArfaaGadamak and WadAhmed showed the shortest stature (122 cm).

Abu Sabein genotypes showed above average plant

Table 3. Green (GMY) dry (DMY) matter yields and seed yield of sorghum genotypes evaluated for dual fodder/grain yield (Shambat, 2011).

Genotype	GMY	DMY		Seed yield		Rank average
	(t/ha)	(t/ha)	Rank	(g/plant)	Rank	
SG33	47.7	11.4	1	18.4	22	12.5
SG08	41.1	9.74	4	24.0	16	10
SG54	36.9	8.85	7	27.1	13	10
SG53-1	30.8	6.73	17	30.1	9	13
SG12-1	32.7	6.66	18	23.9	17	17.5
SG51	31.8	7.08	15	28.8	10	12.5
SG32-1	36.8	7.71	9	12.9	24	16.5
S.25Abu70	48.0	9.80	3	44.1	5	4
S.24Abu70	39.3	7.64	11	37.9	7	9
S.26Abu70	42.4	8.19	8	49.1	3	5.5
S.134Abu70	45.1	8.86	6	57.4	2	4
S.03Abu70	43.7	9.19	5	41.9	6	5.5
ANKSenar	27.8	5.25	21	25.7	14	17.5
ANKNiyala	26.6	5.43	19	19.1	21	20
E-35-1	32.7	7.39	12	36.9	8	20
Atlas	33.1	7.12	14	27.7	12	13
ArfaaGadamak	20.4	4.32	22	23.6	18	20
HagaBanet	30.1	7.67	10	22.5	19	14.5
FakiMustahi	19.0	4.26	23	28.2	11	17
Hemasi	28.6	6.79	16	45.6	4	10
Abjaro	42.1	9.85	2	72.5	1	1.5
Abnaffain	18.0	3.78	24	27.7	15	18.5
SG32-2A	34.0	7.18	13	13.7	23	18
WadAhmed	23.4	5.35	20	21.7	20	20
Mean	33.8	7.34		31.6		
S.E±	2.6240	0.7079		3.9725		
LSD (5%)	7.6429	2.0618		11.5705		
C.V (%)	15.51	19.28		25.14		

height. The average performance for stem diameter was 0.95 cm. Abjaro was the thickest (1.57 cm) whereas SG32-2A was the thinnest (0.65 cm) in stem diameter. Abu Sabein genotypes, apart from S.24Abu70 showed above average stem diameter.

The highest leaf to stem ratio was shown by ArfaaGadamak (0.45), WadAhmed (0.44), FakiMustahi (0.44), Abjaro (0.43) and Atlas (0.43). The highest regrowth weight was given by the Sudan grass genotypes SG32-2A (33.8 g/plant) and SG8 (30.6 g/plant). Abnaffain Fakimustahi and All of the Abu Sabein genotypes gave below average regrowth weight whereas Abjaro gave above average regrowth.

Grain yield components

Mean performance for number of seeds per head was 1098 seeds (Table 4). Abjaro gave the greater number of seed per head (1879). Abu Sabein genotypes gave above average number of seed per head whereas the opposite is true for most of Sudan grass genotypes. Mean performance for 1000 seed weight was 28.5 g. The greater seed weight was expressed by the genotypes: Hemasi, S.26Abu70, S.134Abu70, S.25Abu70, Abjaro and Abnaffain, showing seed weight ranging from 36.8 (for Abnaffain) to 40 g (for Hemasi).

Mean performance for panicle length was 20.5 cm. The largest value for panicle length was shown by ArfaaGadamak (26.9 cm) and FakiMustahi (25.0 cm) whereas the smallest value was shown by Abjaro (15.7 cm) and E-35-1(15.8 cm). Mean performance for panicle circumference was 14.9 cm. Abjaro gave the largest panicle circumference (24.2 cm) whereas the smallest value was shown by SG32-2A (10.9 cm). All of the Abu Sabein genotypes and Abnaffain showed above average panicle circumference ranging from 15.8 to 17.3 cm.

Table 4. Forage and grain yields related traits of different sorghum cultivars (Shambat, 2011).

Genotype	Days to flower	Plant height (cm)	Stem diam. (cm)	Re-growth (g/plant)	Leaf /stem ratio	Panicle length (cm)	Panicle circum. (cm)	No. of seeds /head	1000 seed wt. (g)
SG33	60.2	206	1.02	27.8	0.35	24.47	12.66	734	26.66
SG08	59.3	201	0.96	30.6	0.34	19.18	14.13	850	28.01
SG54	61.0	214	0.97	19.3	0.38	25.82	13.92	1058	25.81
SG53-1	56.6	178	0.94	20.3	0.38	21.63	14.75	1116	27.29
SG12-1	52.3	191	0.82	22.1	0.36	22.94	13.78	731	33.65
SG51	62.5	206	1.00	23.1	0.36	24.15	14.14	1223	23.77
SG32-1	56.2	202	0.94	23.5	0.36	19.01	14.44	458	30.43
S.25Abu70	57.4	195	0.97	18.3	0.38	18.01	16.88	1159	38.64
S.24Abu70	55.9	189	0.93	17.0	0.37	18.60	15.83	1253	31.16
S.26Abu70	56.4	187	0.97	19.5	0.40	16.40	16.05	1232	39.15
S.134Abu70	57.8	201	0.98	17.8	0.37	16.76	17.30	1465	38.73
S.03Abu70	58.7	187	0.97	19.6	0.38	18.94	17.19	1267	33.25
ANKSenar	54.1	167	0.80	19.5	0.40	22.57	11.57	988	25.57
ANKNiyala	56.9	167	0.88	18.9	0.40	24.63	11.05	788	23.26
E-35-1	66.0	154	1.10	22.7	0.41	15.77	15.92	1595	22.71
Atlas	62.3	177	0.95	18.5	0.43	21.39	14.09	1615	17.10
ArfaaGadamak	57.7	122	0.85	23.9	0.45	26.90	11.84	1234	19.46
HagaBanet	64.0	176	0.87	28.0	0.38	16.12	13.88	977	21.61
FakiMustahi	55.3	154	0.82	19.4	0.44	24.96	13.92	931	29.97
Hemasi	58.2	178	1.01	19.1	0.38	17.18	19.05	1127	39.82
Abjaro	71.3	217	1.57	22.3	0.43	15.73	24.16	1879	38.47
Abnaffain	53.2	171	0.89	18.2	0.38	16.65	15.34	719	36.78
SG32-2A	60.7	211	0.65	33.6	0.38	24.09	10.87	744	16.24
WadAhmed	59.5	123	0.92	21.8	0.44	20.92	13.78	1216	16.46
Mean	58.9	182	0.95	21.9	0.39	20.53	14.86	1098	28.50
SE±	0.914	5.315	0.045	1.734	0.012	0.766	0.564	97.993	2.102
LSD (5%)	2.662	15.480	0.136	5.052	0.035	2.232	1.642	285.416	6.121
CV%	3.10	5.83	9.81	15.87	6.19	7.46	7.59	17.85	14.75

Association study

Table 5 shows correlation among different grain and forage sorghum attributes. Positive highly significant correlations were observed between green matter yield (GMY) and each of seed yield (R = 0.402), 1000 seed weight, head circumference, plant height and stem diameter. Negative highly significant correlations were detected between GMY and leaf to stem ratio. GMY has week and insignificant correlation with days to flowering and regrowth. Seed yield has positive highly significant correlation with each of plant height, stem diameter. Correlations were weak and insignificant between seed yield and each of days to flowering and leaf to stem ratio. Plant height was positively and significantly correlated with 1000 seed weight and head circumference but has weak and insignificant correlation with days to flower, regrowth and number of seeds/ head. Plant height has negative significant correlation with leaf to stem ratio. Days to flowering has significant positive correlation with number of seeds/ head, stem diameter, head circumference and leaf to stem ratio, but has negative significant correlations with 1000 seed weight and head length. Weak and insignificant correlation was observed between days to flowering and regrowth.

DISCUSSION

Agronomic performance

Abjaro and the Abu Sabein selections: S.25Abu70, S.134Abu70, S.26Abu70, S.03Abu70 were the best genotypes ranking top in dual forage and grain yields (Table 3). However, of the 4 Abu Sabein genotypes, only S.25Abu70 and S.03Abu70 would be advanced due to their good performance in one or more of other attributes including regrowth, earliness and leaf to stem ratio (Table 4). Among the Sudan grass genotypes, SG08 , SG54 and SG51 averaged the best score for dual grain forage yield,

Table 5. Correlation among different grain and forage attributes in sorghum (Shambat, 2011).

1	Regrowth										
2	Seed No/ head	-0.2173*									
3	Seed yield	-0.3118**	0.7541**								
4	Stem diameter	-0.1078	0.5252**	0.5900**							
5	Plan height	0.1456	-0.0381	0.2765**	0.2593*						
6	1000 seed wt	-0.3134**	0.0998	0.6994**	0.3063**	0.3949**					
7	Days to flowering	0.1359	0.4322**	0.1893	0.4936**	0.0772	-0.2536*				
8	Green matter yield	0.0894	0.1725	0.4018**	0.3506**	0.6901**	0.3732**	0.1038			
9	Head circumiference	-0.3068**	0.6098**	0.8569**	0.6820**	0.2997**	0.6650**	0.3309**	0.3340**		
10	Head length	0.1589	-0.2666**	-0.4711**	-0.3559**	-0.1455	-0.4453**	-0.2226*	-0.2850**	-0.5969**	
11	Leaf to stem ratio	-0.1432	0.2666**	0.0153	0.0436	-0.6258**	-0.2480*	0.2157*	-0.4521**	-0.0087	0.1042
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

*, **, Significantly different from zero at 0.05 and 0.01 probability level, respectively.

however, the former has got brown seed color which is undesirable for food consumption whereas the latter showed the lowest regrowth value among Sudan grass genotypes (Table 4). SG51 has desirable seed color and can be considered for advanced testing. SG51 has been reported to have stable agronomic performance with high forage yield (Mohammed, 2010). E-35-1 was the best among sweet sorghum group showing desirable performance in dual purpose attributes.

Abnaffain is a traditional cultivar grown for dual production of grain and fodder. The literal translation of the Arabic name “Abnaffain” (*Father of two benefits*) implies the dual utility of this cultivar. It was included here as a check for dual fodder / grain production. In this study, all of the advanced materials outperformed the check Abnaffain in dual forage and grain yields. Its low fodder and grain yields could be attributed to its reduced plant height and seed number / head (Table 4). However, none of the studied materials was earlier in flowering than Abnaffain. Earliness is a key factor in dual cultivations systems with limited moisture and other resources of production. ArfaaGadamak and WadAhmed exhibited below average performance in both grain and fodder yields. Their low forage yield could be attributed to their short stature. Both cultivars are the outcome of the national breeding program that emphasizes developing high grain yielding types at the expense of fodder yield, that is, dwarf combinable types suitable for mechanized harvesting. Abjaro belongs to the landraces of Northern Sudan. It was the best genotype combining the highest fodder and grain yields (Table 3). Its high fodder yield could be explained by its unique tallness and stem thickness (Table 4) whereas the high grain yield is attributable to the high number of seeds per head coupled with high weight of the seed (Table 4). Unexpectedly, Abjaro was among the best genotypes in leaf to stem ratio (Table 3). Usually leaf to stem ratio correlates unfavorably with forage yield and plant height as proved by this study (Table 5) or reported by other workers (Rashida and Mohammed, 2012). This trait represents a good measure for fodder quality as the greater part of the nutritive value is stored in leaves which also have better intake potential and digestibility (Mohammed and Zakaria, 2014). Unfortunately, Abjaro was the latest to flower (Table 4). However, being highly productive along with leafiness justify its advancement as a candidate for dual fodder/grain production. Some of Abu Sabein genotypes, that is, S.25Abu70 and S.03Abu70 were comparable to Abjaro in high fodder/grain productivity. Though less leafy, they were however, excelling Abjaro in earliness. Abu Sabein is basically a grain cultivar more probably derived from the palatable ‘Dibekri’ (Kambal 2003). Dibekri is a land race variety widely grown in Northern Sudan (Nile State). Driven by the need for fodder around cities, the farmers opted to Abu Sabein as a dual grain/fodder cultivar. However, Abu Sabein had been gradually devoted to forage production in response to the increasing demand for fodder.

Association study

The highly significant positive correlation revealed by this study between green matter yield (GMY) and grain yield (Table 5) points to the possibility of simultaneously combining high levels of grain and fodder yields in one cultivar. Similar results with grain and stover were reported by a number of workers (Ross et al., 1983; Blümmel et al., 2009; Reddy et al., 2005). Ross et al (1983) reported that grain yield had no extremely strong negative phenotypic correlations with any forage residue trait. They concluded that, the correlations obtained do not suggest any formidable barriers to simultaneous improvement of agronomic, grain, and forage traits. Their results go well with our finding that GMY was positively or favorably correlated with and 1000 seed weight, head circumference and seed number per head. Furthermore, this was strongly supported by the positive and highly significant correlation shown in this study between plant height and each of grain and fodder yields. Positive significant association between grain yield and plant height was also reported by Kumar et al. (2012).

Correlations of days to flower with each of forage and grain yield in this study were weak and insignificant permitting development of early and improved dual grain fodder cultivars. Disagreeing results for week correlation between grain yield and days to flower were reported by Patil et al. (1995).

Conclusion

The study revealed the possibility of selecting sorghum cultivars with high capacity for dual grain/fodder production. Six genotypes were identified as having the best dual grain/fodder excelling the standard checks, these included Abjaro (a land race cultivar), S.25Abu70 and S.03Abu70 (Selections from the land race cultivar Abu Sabein), SG08 and SG51 (Selections from Garawi, traditional Sudan grass cultivar) and E-35-1 an introduced sorghum cultivar.

High levels of grain and fodder yields coupled with some desirable traits could be incorporated in one sorghum cultivar as suggested by the favorable associations shown in the study.

Conflict of Interest

The authors have not declared any conflict of interests.

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Breeding for dual purpose attributes in sorghum: Effect of harvest option and genotype on fodder and grain yields

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A study was conducted across different seasons during 2012 to 2013 to investigate the effect of harvest options and genotype on the dual fodder and grain yield in sorghum. The treatments were arranged in split–split plot design with the harvest options assigned to the main plot and the genotypes to the sub plot. The study revealed that performance of dual sorghum genotypes differed across harvest options and seasons. To maximize the benefits gained from dual sorghum genotypes, different harvest options for fodder and grain need to be investigated. When the option is to harvest the main crop as forage and the ratoon as grain crop, the cultivars Abjaro during winter and S.25Abu70 during summer were suggested. If the option is to harvest the grain and stover from the main crop, either Abjaro or S.25Abu70 could be suggested, depending on what is favored by farmers: Earliness of S.25Abu70 or the high stover yield of Abjaro.

Key words: Abjaro, Abu Sabein, main crop, ratoon, shambat, Sudangrass, stover.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important cereal grain crop in the world. It is thought to have been originated in north-eastern Africa around Ethiopia, Sudan and East Africa (Dogget, 1988; Acquaah, 2007). Sorghum is unique in its ability to produce under a wide array of harsh environmental conditions. Thus, it is undoubtedly the crop of poor people providing cheap sources for food and feed specially in the sub-Saharan Africa, and India.

Initially, sorghum grain is used primarily for food; however, its use as a feed exceeds its use as food since the mid of 1960s, especially in developed countries (Dendy, 1995). In view of the pressing demand for fodder coupled with the fact that grain sorghum is the stable diet for millions of poor people, it is imperative to reconsider the present mono-commodity breeding strategy of sorghum. Kelly et al. (1991) questioned the strategy of strictly adopting grain-yield criteria in evaluating sorghum genotypes arguing that fodder's contribution to the total value of sorghum production has increased considerably. Residues of sorghum are becoming important feed sources for livestock raised by resource-poor smallholders in

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Table 1. The selected sorghum genotypes used in the study (Shambat, 2012 - 2013).

Genotype	Group (population)	Initial usage	Grain color	Mid-rib color
Abjaro	Abjaro	Grain	White	White
Abnaffain	Dual check	Grain/forage	White	White/green
E-35-1	Sweet sorghum	Forage	White	Green
S.25Abu70	Abu Sabein	Forage	White	Green
S.03Abu70	Abu Sabein	Forage	White	Green
SG08	Sudan grass	Forage	White	Green
SG51	Sudan grass	Forage	White	Green

southern Asia and sub-Saharan Africa (Mohanraj et al., 2011). However, attributes relating to crop residue improvement has been largely ignored, with emphasis being placed on grain yield. Thus, dwarf high-yielding grain cultivars with fewer residue has been released in the early days of cereal improvement programs (Reddy and Sanjana., 2003). The same situation exists in Sudan, where breeding objectives were set to develop short statured combinable grain cultivars. Since recognition of crop residues as a viable source of feed, emphasis has been shifted to dual-purpose cultivars for grain and forage. Stover traits can be easily incorporated into existing breeding programs to generate superior dual-purpose (grain/fodder) sorghum varieties suited to smallholder farmers.

Sudan is endowed with a wealth of genetic variability in sorghum (Yasin, 1978) enabling selection for most economic traits. Local efforts to exploit such variability to develop dual sorghum types have been very limited and mostly directed towards developing improved grain types. Simultaneous improvement of sorghum for both fodder and grain attributes will result in developing dual cultivars that maximize grain and fodder yields and reducing costs of productions by saving time, labor and inputs under the constraints imposed by the environment and the prevailing production systems. Hence, the end result will be increasing the incomes of poor-resource farmers and sustaining their food security. Therefore, a breeding program has been launched to develop dual purpose fodder/grain sorghum genotypes and we are able to identify some of the elite genotypes. Further investigations are, however, needed to explore different factors required to increase the benefits gained from developing dual purpose varieties.

The objectives of this work were to investigate the performance of dual purpose (grain/fodder) sorghum genotypes under different harvest options required to maximize the benefits gained from combining grain and fodder attributes in one cultivar.

MATERIALS AND METHODS

The experimental site

The study was conducted in Shambat (lat.15° 39 N; Long.32° 31 E) in the Research Farm of the Collage of Agricultural Studies, Sudan University of Science and Technology during the summer season of 2012 and the winter season of 2012/2013. The soil is heavy clay, non-saline, non-sodic with pH 7.8. The summer season has short rainy period extending from July to September with scant and fluctuating precipitation. The min-max temp during summer averaged 26 to 39°C. The winter is dry with 16 to 35°C average min-max temperature.

Treatments and experimental design

Six sorghum genotypes (Table 1) selected for their high performance dual purpose ability were used in the study. The selection criteria and the steps followed to develop these genotypes are presented in the companion paper. The genotypes were tested against the check Abnaffain, a traditional dual grain/forage cultivar. The performance of the 7 genotypes was assessed under two harvest options viz:

1. Option 1 (HOP1): The crop was cut at heading time to evaluate forage production and the ratoon (regenerated crop) was evaluated for grain production
2. Option 2 (HOP2): The crop was left to grow up to grain maturity to evaluate both grain and stover yield

The treatments were replicated 4 times in split- split plot design with the harvest options assigned to the main plot and genotypes to the sub plot.

The experiment

The study was conducted during the summer and winter seasons. Sowing dates were effected on 13 July 2012 and 15 October 2012, respectively. The plot consists of 4 ridges 6 m long spaced at 0.75 m. Sowing method, planting density and management practices were similar to those mentioned in the accompanying paper.

The data taken included: Forage yield (t/ha), grain yield in kg/ha (estimated from 3 replicates), stover yield, days to boot (taken in ratoon crop), days to heading, plant height (cm) and stem diameter (cm).

Statistical analysis

The data sets of each harvest option in each season was subjected to single ANOVA before performing the combined analysis which was carried out for characters that showed homogeneous error variance (Snedecor and Cochran, 1967). Analysis of variance of split plot in RCB design was performed as per Cochran and Cox (1957). The statistical packages GenStat (2011) was used to run the analysis.

Table 2. Mean squares of the main and interaction effects of harvest options and genotypes for grain yield in sorghum (Shambat Winter, 2012).

Source of variation	Df	Grain yield (kg/ha)	
		Summer season	Winter season
Harvest option (HOP)	1	27692448**	47314941**
Residual	2	201585	54690
Genotype (G)	6	1669009**	2832419**
G x HOP	6	678620**	925038**
Residual	30	133490	143138

**, Highly significant at 0.01 probability level.

Table 3. Performance of dual sorghum genotypes for HOPI* (Shambat, 2012).

Genotype	Green matter yield (t/ha)			Dry matter yield (t/ha)			Ratoon grain yield (kg/ha)	
	Winter	Summer	Combined	Winter	Summer	Combined	Winter	Summer
Abjaro	47.9	42.5	45.2	10.5	11.4	10.9	1504	890
Abnaffain	21.2	21.9	21.5	3.61	5.53	4.57	474	319
E-35-1	32.6	32.1	32.3	6.09	9.91	8.00	332	379
S.25Ab70	43.8	34.1	39.0	8.29	8.00	8.14	575	849
S.03Ab70	41.5	32.6	37.0	7.58	7.13	7.35	668	578
SG51	36.9	23.8	30.3	6.77	6.10	6.44	421	536
SG08	36.5	26.8	31.6	6.86	6.29	6.57	376	301
Mean	37.2	30.5	33.9	7.10	7.76	7.43	621	550
SE±	3.07	2.101	1.860	0.581	0.542	0.397	98.5	75.6
LSD (5%)	9.12	6.241	5.334	1.726	1.609	1.139	303.4	233.0
CV (%)	16.5	13.8	15.5	16.4	14.0	15.1	31.7	27.5

HOP1*= Forage crop harvested at heading time followed by grain crop harvested from ratoon.

RESULTS AND DISCUSSION

In each harvest option, highly significant differences were detected among genotypes for all traits studied in both seasons. The same is true for traits analyzed under combined analysis across seasons. Differences between harvest options and genotypes for grain yield were highly significant (Table 2). The interaction of genotypes with harvest options for gain yield was highly significant indicating that the genotypes performed differently in each harvest option with regard to grain yield. This may imply the need for evaluating dual sorghum cultivars across different harvest options.

Main and ratoon crop option (HOP1)

When harvesting the main crop for forage and grain from ratoon crop, Abjaro seemed to give the best forage yield and ratoon grain yield especially during winter season (Table 3). Its GMY and DMY averaged 47.9 and 10.9 t/ha, respectively. The Abu Sabein selection S.25Abu70 ranked second with respective yields of 43.8 t/ha and 8.29 t/ha. The winter ratoon grain yield of Abjaro was strikingly high (1504 kg/ha) exceeding that of S.03Abu70 (the 2nd best genotype) by > than twice and that of Abnaffain by > 3 folds. The Abu Sabein genotypes (S.03Abu70 in winter and S.25Abu70 in summer) ranked second to Abjaro in grain yield. In spite of that the choice of farmers may go for Abu Sabein since it was remarkably earlier than Abjaro especially in the summer season. This is especially true for S.25Abu70 in summer season which was 58 day earlier in heading time (Table 4) while keeping comparable ratoon grain yield to Abjaro (Table 3). The benefits gained from increased forage yield of Abjaro over that of Abu Sabein may not justify affording additional costs and implications imposed by delaying harvest for about nearly 2 months. On the other hand the Abu Sabein genotype S.25Abu70 may represent a good replacement for Abnaffain when used for producing forage and grain from main and ratoon crop, respectively. Abjaro was significantly the latest among the material tested taking 65.5 and 115 days to heading in winter and summer seasons, respectively. Abnaffain was the earliest in winter season with 43.5 days to heading (Table 4). All genotypes headed earlier in winter than summer.

Table 4. Performance of dual sorghum genotypes for some yield related traits in HOP1* (Shambat, 2012).

Genotype	Days to heading		Plant height (cm)		Stem diameter (cm)	
	Winter	Summer	Winter	Summer	Winter	Summer
Abjaro	65.5	115	289	217	1.38	2.18
Abnaffain	43.5	70.5	153	124	1.10	1.75
E-35-1	54.5	91.3	222	147	1.25	1.55
S.25Ab70	52.8	56.8	226	198	1.33	1.38
S.03Ab70	53.8	59.5	217	196	1.20	1.58
SG51	53.3	56.8	226	187	1.25	1.15
SG08	47.5	61.0	207	183	1.08	1.38
Mean	53.0	72.9	220	179	1.23	1.56
SE±	0.757	1.355	5.55	7.22	0.0391	0.1049
LSD (5%)	2.250	4.027	16.48	21.46	0.1161	0.3118
CV (%)	2.90	3.70	5.10	8.10	6.4	13.4

HOP1*= Forage crop harvested at heading time followed by grain crop harvested from ratoon.

Table 5. Performance of dual sorghum genotypes for two ratoon yield related traits in HOP1* (Shambat, 2012).

Genotype	Ratoon days to boot		Ratoon plant height (cm)	
	Winter	Summer	Winter	Summer
Abjaro	36.3	43.5	168	156
Abnaffain	22.3	23.5	132	98.3
E-35-1	27.5	23.0	130	98.0
S.25Ab70	29.5	34.0	137	143
S.03Ab70	25.5	23.8	137	134
SG51	32.8	26.8	162	142
SG08	25.5	28.8	160	135
Mean	28.5	29.0	147	129
SE±	2.008	2.71	4.74	9.23
LSD (5%)	5.967	8.06	14.60	28.44
CV (%)	14.10	18.70	6.50	14.30

HOP1*= Forage crop harvested at heading time followed by grain crop harvested from ratoon.

However, Abjaro and E-35-1 showed contrasting difference in heading time between the two seasons with respective ranges amounting to 50 and 37 days. Hence both cultivars could be regarded as photoperiod sensitive. Sorghum is a short day plant requiring short photoperiods to flower, with some variability among varieties (Clerget et al., 2004). Late tropical land races (like Abjaro) are known to be highly photoperiod-sensitive (Clerget et al., 2007). On the other hand, Abu Sabein genotypes could be considered as neutral or slightly photoperiod sensitive with seasonal difference in heading time of 4 to 6 days. These results may explain the farmers' practice of growing Abu Sabein during most of the year (Feb to Nov) while restricting Abjaro cultivation to winter sowings. Earliness is highly favored under limited moisture conditions. It could be noted that by growing Abu Sabein in summer instead of Abjaro, the farmers can spare 55 day (Table 4), enough to allow them maximizing the benefits gained from harvesting both grain and fodder. Since, in summer, the ratoon grain yield of Abu Sabein (S.25Abu70) is comparable to that of Abjaro (Table 3), growing of this cultivar in summer is suggested for harvesting fodder from the main crop and grain from the ratoon. In contrast, in the winter season Abjaro could be regarded as the right choice for a dual fodder/grain production since it gave ratoon grain yield of more than twice of that of the best Abu Sabein genotype (Table 3) while only being 13 day later in heading time (Table 4). The above suggestions will not be affected by the difference in ratoon days to boot as it almost followed the same trend of days to heading in the main crop (Table 5). This is in agreement with the finding of Gerik et

Table 6. Performance of dual sorghum genotypes for grain and stover yields in HOP2* (Shambat, 2012).

Genotype	Grain yield (kg/ha)		Stover yield (t/ha)	
	Winter	Summer	Winter	Summer
Abjaro	4139	3086	58.6	39.8
Abnaffain	1908	1362	36.6	22.5
E-35-1	2363	1641	50.6	28.2
S.25Ab70	3678	2825	51.7	31.3
S03Ab70	3670	3293	52.6	29.9
SG51	1680	1505	48.5	28.5
SG08	1798	1508	44.8	26.8
Mean	2748	2174	49.1	29.6
SE±	287.7	285.2	4.31	1.395
LSD (5%)	886.3	878.9	12.82	4.144
CV (%)	18.1	22.7	17.6	9.4

HOP2*= Grain crop harvested at seed maturity and the stover crop evaluated thereafter.

Table 7. Performance of dual sorghum genotypes some related traits in HOP2* (Shambat, 2012).

Genotype	Days to booting		Plant height (cm)		Stem diameter (cm)	
	Winter	Summer	Winter	Summer	Winter	Summer
Abjaro	58.5	105	288	226	1.53	2.05
Abnaffain	33.3	64.0	181	140	1.05	1.40
E-35-1	43.3	81.8	221	150	1.13	1.43
S.25Ab70	45.8	48.5	216	183	1.15	1.40
S03Ab70	46.8	50.8	228	190	1.13	1.28
SG51	41.0	44.3	240	194	1.03	1.08
SG08	37.8	48.0	211	179	1.03	1.08
Mean	43.8	63.2	226	180	1.14	1.39
SE±	0.891	0.690	9.31	6.87	0.0397	0.0831
LSD (5%)	2.649	2.050	27.65	20.42	0.1180	0.2469
CV (%)	4.10	2.20	8.20	7.60	6.90	12.00

HOP2*= Grain crop harvested at seed maturity and the stover crop evaluated thereafter.

al. (1990) that suggests similar phenology of planted and ratoon crops.

Ratooning is a cultural practice to stimulate regrowth of the basal or lower epigeal buds after removal of the photo-synthetically active material. A successful grain sorghum ratoon crop depends upon the production and development of healthy, grain-bearing tillers from these buds in the stubble of the preceding crop (Wilson, 2011). In the present study, tiller development has not been evaluated; however, the large stem diameter (Table 4) might be one of the reasons behind the high ratoon grain yield of Abjaro. Thicker stems contribute to increased content of soluble carbohydrates in the stubble which has been considered essential to the ratooned plant's survival and re-growth in the absence of roots and leaves (Enserink, 1995; Oizumi, 1977).

Main crop option (HOP2)

When harvesting grain and stover from the main crop, Abjaro also kept the top rank in both attributes in winter and summer seasons with respective grain yields amounting to 4139 and 3086 t/ha, whereas the respective stover yields were 58.6 and 39.8 t/ha (Table 6). However, Abjaro yields were not significantly different from that of Abu Sabin genotypes except for stover in the summer season. Considering the lateness of Abjaro (Table 7), farmers may favor growing Abu Sabin for grain/stover production in both seasons unless the stover value of the summer season is high enough to justify growing Abjaro, or if quality aspects of the stover were considered. In the Sudan, sorghum stover has the greater contribution in maintaining the national herd (Mohammed and Zakaria, 2014). High stover yielding cultivars are becoming increasingly valued over high grain but lower stover yielding ones. Similar trends were reported in the developing countries (Traxler and Byerlee, 1993) where farmers consistently select sorghum types that would compromise the desired fodder and grain attributes. Increased stover, however, must be digestible to contribute to improvement of livestock productivity (Kristjanson and Zerbini, 1999). In this study, the quality of stover was not investigated, however, in the companion paper the data presented for leaf to stem ration showed that Abjaro was leafier than Abu Sabein genotypes. Increased leaf to stem ratio indicates better digestibility and nutritional value of sorghum fodder (Mohammed and Zakaria, 2014). Improving stover digestibility is feasible without sacrificing grain yields as considerable variations in the quality value of sorghum stover exist (Blümmel and Reddy, 2006).

Conclusion

The study revealed that performance of dual sorghum cultivars differ across harvest options and seasons. To maximize grain and fodder yields from dual sorghum cultivars, different genotypes were suggested for different harvest options in different seasons. When harvesting the main crop for forage and grain from ratoon crop, the best choice is to grow the cultivar Abjaro during winter and S.25Abu70 during summer. When harvesting grain and stover from the main crop, Abjaro also kept the top rank in both attributes in winter and summer seasons however, considering the lateness of Abjaro, farmers may favor growing Abu Sabein unless the stover value of the summer season is high enough to justify growing Abjaro, or if quality aspects of the stover were considered. Future results should focus on developing dual sorghum cultivars with high quality stover with special emphasis on improved digestibility.

Conflict of Interest

The authors have not declared any conflict of interests.

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Performance of farmers' and improved varieties of barley for yield components and seed quality

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The objective of this study was to assess the performance of farmers' and improved varieties of barley for yield and yield related traits and seed quality attribute in North Shewa Zone of Oromiya Region, Ethiopian. Seven farmer's varieties (FVs) and three improved varieties (MVs) of barley were tested at three locations in Degem Wereda in randomized complete block design (RCBD) design with three replications during 2010 Meher (June-September) cropping season. Barley seed obtained from experimental plots was used to make seed quality analysis such as physical purity, germination, vigour and health as per ISTA procedures and methods (1996). Garbuu Ggurracha was superior in yield potential and seed quality traits for meher season. Damoy is suitable variety for belg season production due to its early maturity and low moisture requirement. Statistically, grain yield was significant ($p<0.01$) variation was observed among varieties tested for important quantitative traits across locations indicating the presence of variability among genotypes. The analytical purity of seed samples collected from field experiment was ≥ 98.17% which was greater than the national seed standard (85%). At harvest, barley seed exhibited dormancy and germinate poorly. Significant differences in seed germination were observed between the first (after one month) and the second (after four months) test which could be attributed to thick hull character which may warrant further investigation. Sixteen different fungi genera were identified from the seed samples among which eight are known to be seed transmitted and the rest causing seed deterioration. In general significant different was observed among varieties for different pathogen infection. This study may indicate greater yield response through direct selection in barley landraces. This may be the nature of FVs' with better adaptive traits to variable environmental factors which has paramount importance for the local farmers to reduce risk. Minimum improvement for adopting early maturing varieties in an area of short rainfall to attain food security is vital. Attention should be given for conservation and improvement of farmers' varieties.

Key words: Barley seed, germination, vigour, food barley.

INTRODUCTION

Farmers' varieties are important crop genetic resources and are valued by plant breeders and farmers because of diversity (heterogeneous population), rarity (embodying unique traits) and adaptability (exhibiting wide ecological and socio-cultural adaptation) (Brush and Meng, 1998; FAO, 1998; Smale, 2006). Farmers throughout the world continue to maintain and manage farmers' varieties within their production systems (Hawkes, 1971; Duvick, 1984;

Brush et al., 1995; Brush, 2004; Jarvis et al., 2008; FAO, 2010). Yet the value they contain for the farming communities that maintain them has not been fully capitalized on.

Not all landraces and improved varieties are equally valued by farmers for yield and yield related components and seed quality attributes. Some landraces are adapted to marginal ecosystems (Vandermeer, 1995; Bezancon et al., 2009; Barry et al., 2007; Rana et al., 2008) or have cultural, religious, or nutritional values (Rana et al., 2007; Sthapit et al., 2008; Johns and Sthapit, 2004). Some landraces maybe highly valued but their use is constrained by poor access to quality and quantity of seeds for planting (Tripp, 2001; Almekinders et al., 2006; Sperling, 2008; Hodgkin et al., 2007). Landrace populations may, themselves, not be uniform in their adaptive or quality traits, having significant variation both within and amount populations (Teshome et al., 2001; Harlan, 1975; Mariac et al., 2006; Barry et al., 2007).

One way of distinguishing farmer's varieties that provide high public value is to classify those in terms of their immediate and future plant breeding benefits (Smale et al., 2004). This required consultation with farmers and breeders but also other concerned including consumers, wholesalers and retailers (Sthapit et al., 2001; Sperling et al., 2001; Bellon et al., 2003; Witcombe et al., 2005).

The recent approach in participatory and decentralized plant breeding over the last decade has shown that improving varietal performance in low input systems can help improve local livelihoods (Ceccarelli et al., 2000; Smith et al., 2001; Almekinders et al., 2006; Zeven, 2000; Dawson et al., 2008). Varieties can be improved by selection of preferred traits from the heterogeneous populations, collected locally before any crop improvement programme is initiated. However, insufficient attention has been given to the potential use of the existing landrace variability in production systems to provide direct benefits to local communities (Sthapit and Rao, 2009).

Damoy is considered nutritious and is preferred and selected for medicinal value believed for healing broken bone and for women during childbirth. *Garbuu Adii* is preferred for porridge during *Meskel* festival and for *kincheatetee (facasa)* for the blessing of God for an Ethiopian new year. *Garbuu Gurracha* preferred for socio-cultural (for labor sharing) values and for its high yield. *Damoy* and *G/gurracha* selected for their early maturity and malt for local beverage.

Variability in grain quality of landrace is the main concern for traders and consumers in marketing it. Consumers are willing to pay a high price for its purchase, but the landrace has a problem with quality variation. Therefore, this study was to assess the one year data for performance between farmers' and improved varieties of barley for some yield and yield related traits and seed quality attributes.

MATERIALS AND METHODS

Description of the study sites

The experiment was conducted at Degem Wereda, North Shewa Zone of Oromiya (Figure 1) selected for the following reasons: (i) Barley was the dominant crop in the area; (ii) Some FV's were still being grown; (iii) Less government attention to conservation of FV's of barley, and (iv) There was no similar study that could be used as a baseline in the area. This assumption emanates from the fact that the prevailing networks in the farmers' seed system had been highly influenced by the formal seed system.

Field experiment

Experimental design and treatments

Three representative peasant associations (PAs), namely; *Anno Degem, Anno Qarree* and *Tumno Abdii* were selected for the field experiment. The experimental design used was randomized complete block design (RCBD) with three replications. Ten food barley varieties were included in the field experiment, that is, five FV's currently under production (*Damoy*, *G/adii*, *Tolasee*, *G/gurracha* and *Magee*), two lost FV's (*Hadho* and *Karfee)* and three improved varieties (HB42, HB1307 and *Shagee)* (Table 1). Seeds were planted at a seed rate of 30 g plot^{-1} in a plot size of 3 m^2 (six rows of 2.5 m long spaced 0.2 m apart between rows).

The experiment was planted on May 23 and 24 /2010. The first weeding was carried out thirty days after crop emergence and the second weeding was performed thirty days after the first weeding. Data were collected on 11 developmental and yield related traits (Table 2).

Seed quality analysis

Barley seed obtained from experimental plots was used to make seed quality analysis. The experiment was conducted in a Complete Randomized Design (CRD) with four replications as per ISTA methods (1996).

Determination of physical seed quality (Experiment-1)

Analytical purity test: From submitted sample of 120 g two replicates of 60 g was analyzed (ISTA, 1996). The samples were divided into three; (I) pure seed, (II) other crop seed, and (III), inert matter. The components were weighed on precision balance to the nearest two decimal places and the percentage of each component was determined (ISTA, 1996).

The percentage by weight of each component fraction was calculated by the following formula (ISTA, 1996):

$$\text{Component (\%)} = \frac{\text{Weight of each component fraction}}{\text{Total test sample weight}} \times 100$$

Thousand kernel weight (TKW): Eight replicates of 100 seeds

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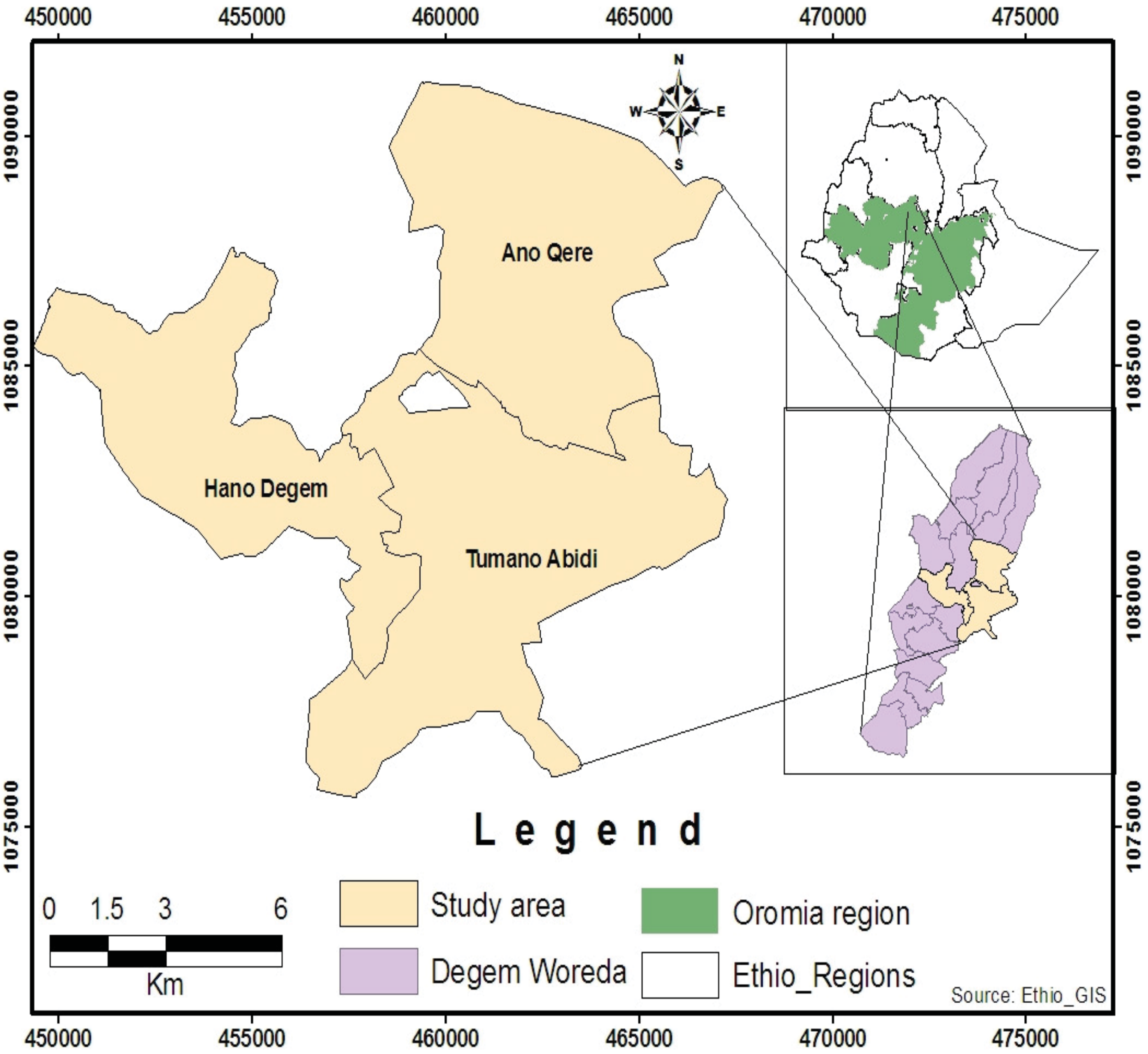

Figure 1. Map of Ethiopia, Oromiya and Degem Wereda showing the study area.

Table 1. List and description of barley varieties used for the field experiment.

S/N	Name	Pedigree	Year of release	Seed color	Row type
1	*Garbuu adii*	Farmers' variety	-	White	6R
2	HB-1307*	A cross made at Holetta from Awura gebs-1/IBON 93/91	2006	White	6R
3	*Garbuu hadho*	Farmers' variety	-	Purple	Irregular
4	HB-42*	A cross made at Holetta from IAR/H/81/Comp29/Comp 14/20/Cost	1985	White	6R
5	*Damoy*	Farmers' variety	-	White	6R
6	*Garbuu gurracha*	Farmers' variety		Black	6R
7	*Shagee* (Line 3333-20)*	Landrace selection from Arsi collection	1996	White	6R
8	*Tolasee*	Farmers' variety	-	White	6R
9	*Karfee*	Farmers' variety	-	Black	6R
10	*Magee*	Farmers' variety	-	Purple	6R

*Source: Fikadu (1987) and IAR (2006) Crop variety registration.

Table 2. Traits measured and derived on a plot basis for the field experiment.

No.	Traits	Abbreviation	Description
1	Days to flowering	DF	Recorded as number of days from sowing to the date on which 50% of the plants in four central rows of a plot have produced their first flower
2	Plant height	PH	Measured as a height in centimeter from the soil surface to the tip of the spike excluding the awns at maturity and expressed as an average of ten plants per plot
3	Days to maturity	DM	Recorded as number of days from sowing to the stage when 75% of the plants in four central rows of a plot have reached maturity
4	Grain filling period	GFP	Number of days between days to flowering and days to physiological maturity
5	Spikes length	SL	Spike length of main tiller measured in cm from base to tip excluding the awns and expressed as an average of ten plants in a plot
6	Kernel number per spike	KNPS	Determined by counting the number of kernel produced on the main tiller of each plant and expressed as an average of ten plants in a plot
7	Biomass production rate	BMPR	Computed by dividing the above ground biomass yield to number of days to physiological maturity and expressed as kg ha-^{1} day-^{1}
8	Biological yield	BY	Determined by weighing the total air dried above ground biomass harvested from the four central rows and expressed in kg ha $^{-1}$
9	Grain yield	GY	Grain yield in kilogram of the four central rows adjusted to 12% moisture content expressed in kg ha $^{-1}$
10	Harvest index	HI	Calculated as a ratio of dry weight of the grain to dry weight of the total above ground biomass yield and expressed as a percentage
11	Thousand kernel weight	TKW	Weight in gram of random sample of thousand seeds per plot

each were weighed from pure seed fraction (ISTA, 1996). The coefficient of variation was calculated to assess the acceptability of the test and the thousand kernel weight was calculated (Bishaw, 2004).

Determination of physiological seed quality (Experiment-2)

Several physiological tests such as standard germination, speed of germination, seedling shoot length, and seedling root length and seedling dry weight were measured to assess the vigour of barley seed from field experiment.

(a) Standard germination (SG) test: SG test was done for all seed samples obtained from all treatments. Four hundred (400) seeds of the pure seeds component were divided into four replicates of 100 seeds each in germination box size of 18, 9 and 13 cm (length, height and width, respectively), which were then sown in sterilized sand media. The planted seeds were incubated at a temperature of 20℃ for 7 days as specified by International Seed Testing Agency (ISTA, 1996). At the end of the incubation period the germination boxes were removed and the seedlings were evaluated. Germinated seedlings were divided into (I) normal seedlings, (II) abnormal seedlings, and (III) dead seeds to determine the percentage of different seedlings.

$$\text{Germination (\%)} = \frac{\text{Total number of normal seedlings}}{\text{Total number of seeds tested for germination}} \times 100$$

(b) Seed vigour test: Seed vigour is an important quality parameter which needs to be assessed to supplement germination and viability tests to gain insight into the performance of a seed lot in the field or in storage.

Seedling shoots and root length: The seedling shoot length and seedling root length were assessed after the final count in the standard germination test. Ten normal seedlings were randomly selected from each replicate after 7 days of seed sowing. The shoot length was measured from the point of attachment to the cotyledon to the tip of the seedling. Similarly, the root length was measured from the point of attachment to the cotyledon to the tip of the root. The averages shoot and root lengths were computed by dividing the total shoot or root lengths by the total number of normal seedlings measured (ISTA, 1996). Varieties producing the taller seedlings were considered more vigorous than the varieties producing shorter seedlings.

Seedling dry weight: Ten randomly selected seedlings from each replicate were cut from the cotyledons and placed in envelops to be dried in an oven at 80℃ for 24 h. The dried seedlings were weighed to the nearest milligram using sensitive balance and the average seedling dry weight was calculated. The seedling dry weight provides additional information for assessing seed vigour.

Vigour Index-I and Vigour Index-II: For each sample, two vigour indexes were calculated. Seedling vigour index-I was calculated by multiplying the normal germination percentage with the average sum of shoot and root length after seven days of germination and vigour index-II were calculated by multiplying the standard germination with mean seedling dry weight.

Vigor Index I=Standard germination (%) × Seedling length (cm)

Vigor Index II=Standard germination (%) × Seedling dry weight (mg)

Speed of germination: 100 seeds were replicated into four from each sample and kept at 20℃ for maximum of 7 days in an incubator. Each day, normal seedlings were removed. Then speed of germination (GS) was calculated as follows (Maguire, 1962):

$$\mathrm{GS} = \frac{\text{Number of normal seedlings}}{\text{Number of days to first count}} + \ldots + \frac{\text{Number of normal seedlings}}{\text{Number of days to final count}}$$

The varieties having greater germination index were considered more vigorous.

Table 3. Mean values of yield components of food barley varieties combined across locations at Degem Wereda 2010.

Varieties	DF	DM	GFP	BMPR	PH
Garbuu adii	107.4^{ab}	135.6^{ab}	28.1^{d}	57.7^{bcd}	105.8^{abcd}
HB 1307	101.2^{c}	135.4^{b}	34.2^{a}	79.6^{a}	99.2^{def}
Hadho	100.9^{c}	132.7^{c}	31.8^{ab}	50.3^{d}	97.3^{ef}
HB42	105.3^{b}	136.0^{ab}	30.7^{bcd}	50.5^{d}	108.4^{abc}
Damoy	91.1^{e}	115.0^{f}	23.9^{e}	49.5^{d}	103.6^{bcde}
G/gurracha	96.9^{d}	128.4^{e}	28.1^{d}	78.5^{a}	111.9^{a}
Shagee	101.2^{c}	135.0^{b}	33.8^{a}	51.1^{cd}	103.3^{cde}
Tolasee	108.1^{a}	136.0^{ab}	27.9^{d}	62.8^{b}	111.6^{a}
Karfee	99.7^{c}	130.3^{d}	30.7^{bcd}	37.3^{e}	94.9^{f}
Magee	108.6^{a}	137.1^{a}	28.6^{cd}	59.4^{bc}	111.4^{ab}
Mean	102.0	132.2	30.1	57.7	104.8
CV (%)	2.3	1.3	10.7	15.8	15.9

Means followed by a common letters with in a column are not significantly different from each other at P ≤ 0.05 according to Duncan multiple range test, DF=Days to flowering; DM=Days to maturity; GFP=Grain filling period; BMPR=Biomass production rate; PH=Plant height.

Seed health testing (Experiment-3)

The agar plate method: About 15 ml of sterilized medium was poured in each Petri dish (9 cm, Pyrex, USA) under aseptic conditions under micro flow. Four hundred seeds from each sample were surface sterilized in 1% NaOCl for ten minutes, rinsed with sterilized water, and then 20 seeds were plated in each Petri dish. The set was incubated at 22 ± 2℃ for 12 h of alternating cycles of day and night under fluorescent light (Anon, 1996). Colonies and fruiting bodies of the fungi were identified using stereo and compound microscopes with aids of appropriate reference materials.

Mycological evaluation: Mycoflora associated with barley seed were detected by standard methods (Anonymous, 1996). The presence and type of fungi were determined according to their development on the seed, which were incubated on Potato Dextrose Agar (PDA) medium. Seeds were examined by Binocular microscope, Compound microscope and CIMMYT Manual for Detection of Seed-borne Microorganisms and Descriptions (1998). Fungi appearing on Petri plates were directly identified up to the species level with the help of a compound microscope and relevant literature (Booth, 1971; Ellis, 1976; Sutton, 1980; Nelson et al., 1983; CIMMYT, 1998). Percent incidence of fungi was recorded. Data collected on incidence of fungi were analyzed statistically.

$$\text{Percent incidence} = \frac{\text{No. of infected seeds}}{\text{Total number of seeds examined}} \times 100$$

Data coding and entry

Semi structured and structured questions were properly coded and entered into the computer using Microsoft Excel Application Program. Quantitative data were organized to suit the different statistical packages used in the analysis. For better interpretation of results, some of the data sets were transformed into standard units. Qualitative data were organized in such a way that cumulative of the respondent's information was presented.

Data analysis

Data collected from the field and laboratory experiments were subjected to analysis of variance using software SAS version 9 and Genstat discovery edition. Treatment means were separated using Least Significance Difference (LSD) test and Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Performance of improved and farmers' varieties for yield and yield components

The performance of ten food barley varieties for various phenological and agronomic traits is presented subsequently.

Days to heading and maturity

Both days to heading and days to maturity differed significantly among varieties. Days to flowering ranged from 91 to 109 days with a mean value of 102 days. Days to maturity ranged from 115 to 137 days with a mean value of 132.15 days. *Damoy* was the earliest variety to heading (91 days) and maturity (115 days) while *Mage*e took longer days to heading (109) and maturity (137 days). *Hadho*, *G/gurracha* and *Karfee* were medium maturing varieties. Variety *Damoy* was the dominant variety grown during the *belg* season where rainfall variability is high. The variation for both phenological traits was high among the test varieties and this was more apparent on the FV's compared to improved varieties which all were late maturing (Table 3).

Grain filling period and plant height

Grain filling period ranged from 23.88 to 34.22 days with mean value of 30.11. The shortest grain filling period was observed on *Damoy* and the longest on *G/adii* (Table 3).

Table 4. Yield and yield related components.

Varieties	SL	NSPS	BY	GY	HI	TKW
G/ adii	6.7^{a}	47.9^{ab}	6190.6^{c}	2672.1^{cd}	0.44^{a}	44.5^{a}
HB-1307	6.1^{a}	40.8^{b}	8058.6^{a}	3446.5^{ab}	0.42^{a}	44.2^{a}
Hadho	6.6^{a}	42.9^{ab}	5068.8^{d}	2354.9^{cd}	0.44^{a}	42.7^{a}
HB-42	6.2^{a}	47.4^{ab}	5288.6^{d}	2187.5^{d}	0.40^{a}	45.0^{a}
Damoy	6.4^{a}	51.1^{a}	4504.6^{de}	2178.5^{d}	0.48^{a}	43.6^{a}
G/gurracha	6.3^{a}	50.1^{a}	7625.0^{ab}	3573.6^{a}	0.46^{a}	44.1^{a}
Shagee	6.4^{a}	45.1^{ab}	5155.9^{d}	2306.9^{cd}	0.44^{a}	42.4^{a}
Tolasee	6.7^{a}	51.3^{a}	6787.0^{bc}	2933.8^{bc}	0.43^{a}	44.9^{a}
Karfee	4.6^{b}	42.2^{ab}	3711.4^{e}	1489.2^{e}	0.39^{a}	44.4^{a}
Magee	5.8^{a}	51.1^{a}	6442.9^{c}	2892.7^{bc}	0.45^{a}	45.5^{a}
Mean	6.2	47.0	5883.3	2603.6	0.44	44.1
CV (%)	7.9	21.4	16.1	26.0	21.26	12.1
R^2	0.72	0.33	0.87	0.74	0.27	0.35

Means followed by a common letters with in a column are not significantly different from each other at $P < 0.05$ according to duncan multiple range test; SL=Spike length; NSPS=Number of spike per spikelet; GY, Grain yield (kg ha^{-1}); BY, Biomass yield (kg ha^{-1}); HI, Harvest index (%); TKW= Thousand kernel weight.

Varieties with the shortest grain-filling period had the advantage to escape terminal moisture stress and good character to cope up with the rainfall variability in the highlands of Degem.

Variation for plant height among the varieties ranged from 94.9 to 111.1cm with mean site value of 104.75. *Karfee* was the shortest variety (94.9 cm) whereas *G/gurracha and Magee (*111.5 cm) were the tallest varieties. Most of the FV's were tall with weak stem, which was the common character of the local FV's. The improved varieties were relatively short with strong stem. Fekadu (2010) also reported that modern varieties are shorter in plant height compared to the FV's.

In contrast to our findings, Martiniello et al. (1987) reported that modern genotypes showed trends towards earliness in both six and two row barley genotypes compared to landraces. It was reported that most modern barley varieties were relatively earlier than the landraces whereas maturity time was similar among all varieties (Wych and Rasmusson, 1983). Furthermore, similar observation was also reported in hard red winter wheat in USA (Cox et al., 1988), in spring wheat in Australia (Perry and D'Antuono, 1989), in wheat in UK (Austin, 1999) and in winter wheat genotypes in Great Plains (Donmez et al., 2001) that modern varieties reached flowering and maturity earlier than the older ones. Metzger et al. (1984) indicated that selection for grain filling duration was not promising to improve yield of barley in Minnesota, suggesting that grain-filling duration is not yield limiting factor in barley.

Spike length and number of spikletes per spike

The spike length ranged from 4.6 to 6.7 cm with mean value of 6.2 cm (Table 4). The total variation among the varieties was small and almost most of the varieties had spike length of 6.1 to 6.7 cm. Among the varieties, *Karfee* had the shortest spike length (4.6 cm) while *G/adii* and *Tolasee* were the longest (6.67 cm). The mean difference between the number of spikletes per spike varied from 40.8 for HB-1307 to 51.3 for *Tolasee* with the mean value of 47. The number of spiklets per spike for most of the varieties was in the range of 45 to 51 cm. Although, no significant difference was observed among varieties on number of spikelets per spike, kernel weight, spikelets per spike and spike length are observed as the main components of yield (Table 4). The morphology of spike is a major concern in crop improvement. Similarly, Bensemane (2011) reported that the yield components, spikes per square meter followed by kernels per spike exerted the greatest effect on grain yield. Similarly, Sinebo (2002) reported that barley spike is a source and sink of assimilates that ultimately determines grain yield.

Biomass yield, grain yield, thousand kernel weight and harvest index

Mean differences were observed among the barley varieties for biomass and grain yield, but not for thousand kernel weight and harvest index (Table 4). Biomass yield ranged from 3711.4 for *Karfee* to 8058.6 kg ha^{-1} for HB-1307 with mean value of 5883.3 kg ha^{-1} (Table 4).Varieties such as *Magee*, *Tolasee* and *G/adii* was on par in biomass yield. The variation for grain yield per hectare ranged from 1489.2 for *Karfee* to 3573.6 kg ha^{-1} for *G/gurracha* 2603.6 kg ha^{-1} (Table 4).

The site mean value of grain yield was 2554.6 kg ha^{-1} at *Anno Degem*, 2282.4 kg ha^{-1} at *Anno Qarree* and 2973.8 kg ha^{-1} at *Tummano Abdii*. Grain yield potential of *Anno Degem* was intermediate while that of *Tummano*

Table 5. Phenological/developmental traits of ten-food barley varieties at Degem Wereda in 2010.

Variety	Locations											
	Anno Degem				*Anno qarree*				*Tumano*			
	DF	PH	DM	GFP	DF	PH	DM	GFP	DF	PH	DM	GFP
G/adii	106.3^{a}	98.7^{abc}	135.3^{a}	29.0^{cd}	108.0^{a}	103.3^{abcd}	135.7^{a}	27.7^{cd}	108.0^{a}	115.3^{ab}	135.7^{a}	27.7^{cde}
HB-1307	100.0^{bc}	101.3^{abc}	135.7^{a}	35.7^{ab}	101.0^{b}	93.0^{cd}	135.3^{a}	34.3^{ab}	102.7^{b}	103.3^{bc}	135.3^{a}	32.7^{ab}
Hadho	101.0^{b}	101.7^{ab}	133.0^{ab}	32.0^{abc}	101.0^{b}	87.0^{d}	132.7^{b}	31.7^{abc}	100.7^{bc}	103.3^{bc}	132.3^{b}	31.7^{abc}
HB-42	100.0^{bc}	108.7^{a}	136.7^{a}	36.7^{a}	108.0^{a}	95.7^{abcd}	135.7^{a}	27.7^{cd}	108.0^{a}	121.0^{a}	135.7^{a}	27.7^{cde}
Damoy	87.0^{e}	96.0^{bc}	112.7^{d}	25.7^{d}	95.7^{b}	100.0^{abcd}	117.0^{d}	21.3^{d}	90.7^{d}	115.0^{ab}	115.3^{d}	24.7^{e}
G/gurracha	95.0^{d}	106.0^{ab}	128.3^{c}	33.3^{abc}	97.0^{b}	112.0^{a}	128.0^{c}	31.0^{abc}	98.7^{c}	117.7^{a}	129.0^{c}	30.3^{bcd}
Shagee	104.3^{a}	97.7^{bc}	133.7^{ab}	29.3^{cd}	99.7^{b}	103.7^{abcd}	136.3^{a}	36.7^{a}	99.7^{bc}	108.7^{abc}	135.0^{a}	35.3^{a}
Tolasee	105.0^{a}	106.7^{ab}	135.3^{a}	30.3^{bcd}	110.0^{a}	111.0^{ab}	136.7^{a}	26.3^{cd}	109.3^{a}	117.0^{a}	136.3^{a}	27.0^{de}
Karfee	98.0^{c}	90.7^{c}	130.7^{bc}	32.7^{abc}	100.0^{b}	93.3^{bcd}	130.0^{c}	30.0^{bc}	101.0^{bc}	100.7^{c}	130.3^{bc}	29.3^{bcd}
Magee	105.7^{a}	106.3^{ab}	137.3^{a}	31.7^{abc}	110.0^{a}	110.3^{abc}	137.0^{a}	27.0^{cd}	111.0^{a}	117.7^{a}	137.0^{a}	27.0^{de}
Mean	100.23	101.37	131.87	31.63	103.00	100.92	132.40	29.37	102.87	112.00	132.20	29.33
CV (%)	1.26	6.16	1.92	10.07	3.32	10.29	0.88	12.89	1.74	6.90	0.93	8.89
S.E	1.03	5.10	2.07	2.60	2.79	8.48	0.96	3.09	1.46	6.34	1.00	2.13

Means followed by a common letters with in a column are not significantly different from each other at $P < 0.05$ according to Duncan's Multiple Range Test. DF=Days to flowering, DM=Days to maturity; GFP=Grain filling period; PH= Plant height.

Abdii was relatively higher than both locations. The low yield obtained at *Anno Qarree* and high yield at *Tummano Abdi* could be attributed to low and high soil fertility respectively (Table 5).

Garbuu gurracha gave the highest grain yield followed by the recently released stiff straw variety HB-1307. Grain yield performance of HB-42 and *Shagee* varieties was lower compared to other varieties except *Damoy*, which was the least in grain yield (Table 4). Harvest index ranged from 39 to 48% ha^{-1} with mean value of 44%. Table 4 indicates that majority of the varieties had harvest index, between 40 and 48%.

No significant variation was observed among varieties for spike length, harvest index and thousand kernel weights. Number of spikelet per spike ranged from 42.2 to 51.1 with site mean value of 47.0 (Table 4).

Performance of improved and farmers' varieties of barley for yield and yield components at each location

At *Anno Degem*, the analysis of variance revealed highly significant differences ($P<0.001$ or $P<0.01$ or $P<0.05$) among the varieties for all the traits measured, except for TKW. Plant height was significantly different at $P<0.05$, while grain filling period was significantly different at $P<0.01$. Moreover, most yield and yield related traits showed highly significant at $P<0.0001$. However, number of spikelet per spike and thousand kernel weights were not significant.

The analysis of variance carried out at *Anno Qarree* on the eleven quantitative traits revealed highly significant differences among the varieties for most of the traits measured. Days to heading, grain filling period, biomass production rate, and biomass yield were significantly different at $P \leq 0.01$. Days to maturity and grain yield were highly significant different at $P<0.0001$. However, spike length, plant height number of spikelet per spike, harvest index and thousand kernel weights did not show any significant differences among the varieties.

At *Tumano,* the analysis of variance revealed significant differences among the varieties for most of the traits, except for spike length, number of spikelts per spike and thousand kernel weights. Plant height was significantly different at $P \leq 0.01$.

Table 6. Mean values for biomass production rate, spike length and number of spikelet per spike at the three sites.

Varieties	*Anno Degem*			*Anno qarree*			*Tumano*		
	BMPR	**SL**	**NSPS**	**BMPR**	**SL**	**NSPS**	**BMPR**	**SL**	**NSPS**
G/adii	74.8^{a}	7.3^{ab}	49.3^{a}	24.0^{d}	$5.^{a}$	44.0^{a}	74.3^{bc}	7.7^{a}	50.3^{a}
HB-1307	79.6^{a}	5.7^{cd}	42.7^{a}	76.8^{a}	5.7^{a}	38.0^{a}	82.5^{ab}	6.7^{ab}	41.7^{a}
Hadho	78.9^{a}	6.7^{bc}	46.3^{a}	28.4^{d}	6.0^{a}	38.3^{a}	43.4^{e}f	7.0^{a}	44.0^{a}
HB-42	62.4^{b}	5.3^{d}	54.0^{a}	32.1^{bcd}	6.7^{a}	45.7^{a}	57.1^{de}	7.0^{a}	43.3^{a}
Damoy	45.5^{c}	6.7^{bc}	53.3^{a}	54.0^{b}	6.0^{a}	48.0^{a}	49.0^{de}f	6.7^{ab}	52.0^{a}
G/gurracha	64.7^{b}	6.3^{bcd}	53.7^{a}	80.2^{a}	5.7^{a}	47.7^{a}	90.8^{a}	7.0^{a}	49.0^{a}
Shagee	38.7^{d}	7.0^{ab}	54.0^{a}	51.7^{b}	6.0^{a}	45.7^{a}	62.9^{cd}	6.3^{ab}	35.3^{a}
Tolasee	61.5^{b}	8.0^{a}	54.7^{a}	50.5^{bc}	5.0^{a}	49.3^{a}	76.4^{abc}	7.0^{a}	50.0^{a}
Karfee	43.9^{cd}	2.7^{e}	45.7^{a}	28.7^{cd}	5.0^{a}	46.0^{a}	39.2f	5.0^{b}	43.3^{a}
Magee	61.8^{b}	7.3^{ab}	55.0^{a}	38.7^{bcd}	5.0^{a}	38.0^{a}	77.7^{ab}	6.0^{ab}	52.3^{a}
Mean	61.19	6.3	50.9	61.19	5.6	44	65.31	6.63	46.1
CV (%)	6.27	11.3	17.47	6.2	21	17.1	12.89	15.2	27.6
S.E	3.14	0.4	7.26	10.42	1	6.43	6.89	0.82	10.4

Means followed by a common letters with in a column are not significantly different from each other at $P < 0.05$ according to Duncan's multiple range test; BMPR=Biomass production rate; SL=Spike length; NSPS=Number of spikelet per spike.

The other morphological and yield related components showed highly significant differences at $P<0.0001$.

Genotypic performance for phenological traits at each site

Mean phenotypic variation for phenological/ developmental/, of the 10 food barley varieties are shown in (Table 5). The amount of variation among the varieties for most of phenological traits was relatively high between the testing sites. At *Anno degem,* days to heading ranged from 87 to 106 days while at *Anno qarree* from 96 to 110 days and at *Tumano* it ranged from 91 to 111 days. The overall mean difference in DF among varieties were small (100, 103 and 103 days for *Anno degem, Anno qarree* and *Tumano*, respectively).

At *Anno degem,* plant height ranged from 90.7 to 108.7 cm with site mean of 101.4 cm while at, *Anno qarree* from 87 to 111 cm with site mean of 100.9 cm, and at *Tumano* from 100.7 to 121 cm with site mean value of 112 cm (Table 5). The variation in plant height across the three sites ranged from 100.9 to 112 cm, at *Anno qarree* and *Tumano*.

Mean days to grain filling period across the sites was 31.6 days at *Anno degem,* 29.4 days at *Anno qarree* and *Tumano*. The highest grain-filling period was observed by variety HB 42 (37 days) at *Anno degem* followed by variety *Shagee* (37 and 35 days) at *Anno qarree* and *Tumano,* respectively. Generally, FV's showed relatively short days to flowering and days to grain filling than the improved varieties (Table 5).

Agronomic / yield component traits / of food barley

Mean performance for agronomic/ yield component/ trait of 10 food barley varieties are shown in Table 6. The amount of variation among the varieties for most traits was relatively high among the testing sites. At *Anno Degem* biomass production rate (BMPR) ranged from 38.7 to 79.6 days while at, *Anno qarree* from 24.0 to 80.2 days and at *Tumano* from 39.2 to 90.8 days. There were no significant difference in overall mean among varieties in BMPR at *Anno degem* and *Anno qarree,* however, significant different was observed at *Tumano* site which was (65.3).

At *Anno degem,* spike length ranged from 2.7 to 8 cm with mean of 6.3 cm at *Anno qarree* from 5 to 6.7 cm with mean of 5.6 cm, at *Tumano* from 5 to 7.7 cm with site mean value of 6.6 cm (Table 6).

At *Anno degem,* number of spikelet per spike ranged from 42.7 to 55 with mean of 50.9 while at *Anno qarree* from 38 to 49 with mean of 44 and at *Tumano* from 35.3 to 52.3 with site mean of 46.1 (Table 6). The variation in number of spike per spikelet was relatively high across the three sites, it ranged from 44 to 50.9 at *Anno qarree*, and *Anno degem*.

Grain yield, biomass yield, thousand kernel weight and harvest index at each location

Mean values for grain yield, biomass yield, thousand kernel weigh and harvest index of each genotype and testing sites are shown in Table 7. At *Anno degem*, the grain yield ranged from 1722.2 kg ha^{-1} for variety *Shagee* to 3437.5 kg ha^{-1} for variety *G/adii* followed by 3395.8 kg ha^{-1} for variety *Hadho* while at, *Anno qarree* it ranged from 1037 kg ha^{-1} for *Karfee* to 3777.8 kg ha^{-1} for *G/gurracha* followed by 3596.3 kg ha^{-1} for HB1307. At *Tumano* grain yield varied from 1666.7 kg ha^{-1} for variety *Karfee* to 4244.4 kg ha^{-1} for variety *G/gurracha* followed

Table 7. Mean grain yield, biomass yield, harvest index and thousand kernel weight of food barley at each location.

Varieties	*Anno degem*				*Anno qarree*				*Tumano*			
	BY	**GY**	**HI**	**TKW**	**BY**	**GY**	**HI**	**TKW**	**BY**	**GY**	**HI**	**TKW**
G/adii	7958.3^{a}	3437.5^{a}	0.43^{ab}	42.4^{a}	2592.6^{d}	1203.7^{c}	0.46^{a}	42.9^{ab}	8020.8^{a}	3375.0^{c}	0.42^{d}	48.1^{a}
HB 1307	7958.3^{a}	2847.2^{a}	0.36^{c}	47.0^{a}	7759.3^{a}	3596.3^{ab}	0.46^{a}	44.7^{ab}	8458.3^{a}	3895.8^{abc}	0.46^{bc}	41.5^{ab}
Hadho	7968.1^{a}	3395.8^{a}	0.43^{ab}	43.0^{a}	2870.4^{cd}	2037.0^{abc}	0.54^{a}	47.5^{a}	4368.1^{c}	1631.9f	0.37^{e}	37.5^{b}
HB42	6236.1^{b}	2291.7^{c}	0.36^{c}	44.1^{a}	3463.0^{bcd}	2000.0^{abc}	0.48^{a}	45.2^{ab}	6166.7^{b}	2270.8^{de}	0.37^{e}	45.7^{ab}
Damoy	3958.3^{c}	1840.3^{d}	0.46^{a}	45.0^{a}	5111.1^{bc}	2514.8^{abc}	0.49^{a}	39.3^{b}	4444.4^{c}	2180.6^{e}f	0.49^{a}	46.7^{a}
G/guracha	6145.8^{b}	2698.6^{b}	0.44^{ab}	45.6^{a}	7777.8^{a}	3777.8^{a}	0.54^{a}	44.4^{ab}	8951.4^{a}	4244.4^{a}	0.47^{b}	42.4^{ab}
Shagee	4041.7^{c}	1722.2^{d}	0.42^{b}	42.4^{a}	5176.9^{b}	2400.0^{abc}	0.46^{a}	39.0^{b}	6250.0^{b}	2798.6^{d}	0.45^{c}	45.8^{a}
Tolasee	6458.3^{b}	3763.9^{b}	0.43^{ab}	46.8^{a}	5555.6^{ab}	2405.6^{abc}	0.43^{a}	44.6^{ab}	8347.0^{a}	3631.9^{bc}	0.44^{cd}	43.2^{ab}
Karfee	4305.6^{c}	1763.9^{d}	0.41^{b}	40.3^{a}	2870.4^{cd}	1037.0^{c}	0.35^{a}	47.9^{a}	3958.3^{c}	1666.7^{f}	0.42^{d}	43.2^{ab}
Magee	6527.8^{b}	2784.7^{b}	0.42^{b}	41.8^{a}	4259.3^{bcd}	1851.9^{bc}	0.45^{a}	48.2^{a}	8541.7^{a}	4041.7^{ab}	0.47^{ab}	48.4^{a}
Mean	6155.83	2554.58	0.41	43.85	4743.5	2282.41	0.47	44.3	6750.67	2973.74	0.44	44.24
CV (%)	6.193	6.822	4.658	14.99	28.22	48.66	34.5	10.06	13	11	3.3	10.9
S.E	311.269	142.292	0.016	5.37	1093.24	906.969	0.131	3.641	715.65	266.3	0.002	3.92

Means followed by a common letters with in a column are not significantly different from each other at $P \leq 0.05$ according to Duncan Multiple Range Test, GY, Grain yield (kg ha^{-1}), BY, Biomass yield (kg ha^{-1}), HI- Harvest index (%); TKW=Thousand kernel weight.

by 3895.8 kg ha^{-1} for variety HB1307. Location mean grain yield ranged from 2282.4 kg ha^{-1} at *Anno qarree* to 2554.6 kg ha^{-1} for *Anno degem* (Table 7). Variation for grain yield across the three sites was relatively high and ranged from 1037 kg ha^{-1} produced by *Karfee* at *Anno qarree* to 4244.4 kg ha^{-1} produced by *G/gurracha* at *Tumano.* Except HB 42, *Damoy* and *Karfee*, all varieties showed similar yield performance with HB-1307 (Table 7).

At *Anno qarree* mean grain yield ranged from 1037 kg ha^{-1} for variety *Karfee* to 3777.8 kg ha^{-1} for variety *G/gurracha*. Varieties *Hadhoo*, HB42, *Damoy*, *Shage* and *Tolasee* showed similar performance with an improved variety HB1307 and significantly higher than varieties *G/adii* and *Karfee* (Table 7). Moreover, the lowest and highest grain yield at Anno qarree was 1037 and 3777.8 kg ha^{-1} for varieties *Karfee* and *G/gurracha*, respectively. *G/gurracha* variety had significantly higher grain yield than the other varieties except at *Anno degem, G/adii* had significantly higher grain yield than the other local and improved varieties. This study showed that FV's of food barley had good yield performance than improved varieties on low input farmer's condition (Table 7). Similarly, Jalata (2011) reported that there was a differential yield performance among genotypes across testing environment mainly due to genotypic, genotypic and environmental interaction. Similarly, Sinebo (2002) reported that high straw yield was essential to high grain yield production.

Significant mean biomass yield differences among the varieties were observed at each site (Table 7). At *Anno degem*, mean biomass yield ranged from 3958 kg ha^{-1} for variety *Damoy* to 7968.1 kg ha^{-1} for variety *Hadho* followed by varieties *G/adii* and HB1307 (7958 kg ha^{-1}). Likewise, at *Anno qarree* mean biomass yield ranged from 2870 kg ha^{-1} for *Hadho* and *karfee* to 7777.8 kg ha^{-1} for *G/gurracha* followed by HB1307 (7759 kg ha^{-1}).

At *Tumano*, mean biomass yield ranged from 3958.3 kg ha^{-1} for *Karfee* to 8951.4 kg ha^{-1} for *G/gurracha* followed by variety HB1307 (8458 kg ha^{-1}). Location mean biomass yield for *Anno degem Anno, qarree* and *Tumano* were 6155.8, 4743.5 and 6750.7 kg ha^{-1}, respectively. Varietal difference for biomass yield was less marked at *Anno qarree* than the two sites, which might be due to better adaptation of all varieties to the growing conditions at Tumano, and *Anno degem.* Variety *G/gurracha* which gave the highest mean grain yield at *Anno qarree* and *Tumano* was also characterized by high biomass yield, 7777.8 and 8951 kg ha^{-1} at the two sites respectively. Moreover, the lowest mean biomass yield was obtained by varieties *Hadho* and *Karfee* (2870 kg ha^{-1}) at *Anno qarree* and the highest biomass yield was obtained by variety *G/gurracha* (8951.4 kg ha^{-1}) at *Tumano.* This result revealed that biomass yield was relatively related to grain yield for FV's except for HB-1307.

Similarly, Ortiz et al. (2002) reported that there was significant trend in increasing straw yield in Nordic spring barley germplasm whereas the biological yield of recent varieties and old varieties was almost the same. Fekadu (2010) also reported that the recent varieties (Dimtu and HB-1307) which gave high grain yield were also characterized by high biomass yield at all locations except HB-1307 at Holetta. Similarly, Sinebo (2002) reported that high biomass yield is essential to high grain yield production.

At *Anno degem*, the mean harvest index ranged from 0.36 for HB-42 and HB-1307 to 0.46 for *Damoy* while at *Anno qarree,* it was 0.35 for *Karfee* to 0.54 for *Hadho* and *G/gurracha* and that of *Tumano* was 0.37 for *Hadho* and HB-42 to 0.49 for *Damoy*. The highest and lowest varietal difference for harvest index was observed at *Anno qarree* than *Anno degem* and *Tumano*. The overall mean harvest index in this study varied from 0.35 for *karee* to 0.54 for *Shagee* and *G/gurracha* indicating FV's had shown significant variation for harvest index (Table 7).

There was no significant variation in thousand-kernel weight at *Anno degem*, however, at *Anno qarree* ranged from 39 to 48.2 gm with mean of 44.3 gm and at *Tumanno* ranged from 37.5 to 48.4 gm with mean of 44.24 gm. In this study, the effect of thousand-kernel weight is small for performance evaluation among the varieties tested. Similarly, Sinebo (2002) reported that the effect of kernel weight on grain yield was small.

Similarly, Hockett (2000) reported that mean values of the varieties were recorded within the range of barley yield potential performance study as described for yield potential of barley varies from state to state in America and ranged from 1451.0 to 5499.0 kg ha^{-1} and barley yield of ten top leading producing countries was within the range of 1730.0 to 5470.0 kg ha^{-1}.

Comparative yield potential of farmers' varieties and improved varieties over three sites

There were significant difference in performance of local against improved varieties in yield and yield related traits on low input and marginal environment. Accordingly, *G/gurracha* was the highest in grain yield followed by *Tolasee* and *Magee* among the FV's. Ceccarelli and Grando, 2001 cited in Brush (2000) reported that black-seeded FVs' was better adapted to dry areas and less vigorous in early growth, more cold resistant and more productive under stress than improved cultivars. However, HB-1307 gave high yield (3446.5 kg ha^{-1}) than other improved varieties and FV's except *G/gurrach* that gave 3573.6 kg ha^{-1}. High biological yield was obtained on HB-1307 (8058.6 kg ha^{-1}) and followed by FV's *G/gurrach, Tolasee, Magee* and *G/adii*. On the contrary, high TKW was observed by variety *Magee* followed by HB-1307. *Karfee* was the lowest in harvest index and *Damoy* was the highest in harvest index. In this study, *Karfee* was the lowest performing FV's. In contrast, HB-1307 gave relatively better yield and yield related traits over the other two improved varieties and the FV's except *G/gurrach*, which was superior in some traits (Table 8).

Correlation among the quantitative traits

The correlation coefficient among the quantitative traits was computed on the mean trait values of the two sites, that is, *Anno degem* and *Tumano* (Table 9*). Anno qarree* was excluded because of high CV value (>30%). Significant and strong positive correlation coefficients were found for DH with DM (0.88), BMPR with BY and GY (0.97 and 0.98, respectively) and BY with GY (0.97). Days to heading was positively correlated to grain filling period. On the other hand, days to grain filling period was negatively correlated to number of spikelet per spike at (r=-0.64) (Table 9). Similarly, (Ahmad, 2004; Tarekegn, 2009) reported that days to heading were positively and significantly correlated with days to maturity. Moreover, biomass yield showed significant correlation with grain yield. Sinebo (2002) reported that grain yield was correlated positively with mature heights, and grain-filling duration. On the contrary, grain yield was not correlated with kernel weight.

This finding suggests that characters showing positive correlation could effectively be utilized in improving FV's. The tendency of positive correlation among developmental traits, in spite of wide range of genetic diversity in FV's could effectively be utilized to improve barley FV's.

Seed quality analysis

Seed testing evaluates seed lot quality and is essential for both seed production and commercial seed transactions (AOSA, 1981). Seed testing is done to assess seed lot attributes to determine overall quality and value for production and storage. Seed testing standards provide set of procedures to conduct tests in a uniform manner to ensure comparable results that are within acceptable ranges (ISTA, 2005).

Analytical purity analysis

The analytical purity results of seed samples collected from field experiment were ≥ 98.17% which was greater

Table 8. Yield and yield related traits among local and improved varieties of barley in kg ha^{-1}at Degem in 2010.

Farmer varieties	**BY**	**GY**	**HI**	**TKW**
G/adii	6190.6	2672.1	0.44	45.5
Hadho	5068.8	2354.9	0.44	42.1
Damoy	4504.6	2178.5	0.48	30.7
G/gurracha	7625.0	3573.6	0.46	40.2
Tolasee	6787.0	2933.8	0.43	41.3
Karfee	3711.4	1489.2	0.39	34.8
Magee	6442.9	2892.7	0.45	46.8
Mean	5761.47	2584.97	0.44	40.20
Improved varieties				
HB-1307	8058.6	3446.5	0.42	46.2
HB-42	5288.6	2187.5	0.4	38.1
Shagee	5155.9	2306.9	0.44	39.5
Mean	6167.70	2646.97	0.42	41.27

Table 9. Estimates of Pearson correlation coefficient of combined location mean among the 10 traits.

	DF	**DM**	**GFP**	**BMPR**	**PH**	**SL**	**NSPS**	**TKW**	**BY**	**GY**	**HI**
DF	1	0.88**	0.23	0.06	0.37	0.08	-0.29	0.32	0.28	0.16	-0.4
DM		1	0.63*	0.19	0.16	0.01	-0.49	0.15	0.37	0.23	-0.54
GFP			1	0.09	-0.5	-0.2	-0.64*	-0.25	0.12	0.02	-0.57
BMPR				1	0.43	0.39	-0.28	-0.02	0.97***	0.98***	0.28
PH					1	0.36	0.2	0.18	0.5	0.53	0.37
SL						1	-0.09	-0.52	0.32	0.46	0.56
NSPS							1	0.42	-0.3	-0.3	0.03
TKW								1	0.05	-0.07	-0.54
BY									1	0.97***	0.19
GY										1	0.37
HI											1

*, **, *** r-values were significant at probability level of 0.05, 0.01 and 0.001 respectively, DF=Days to flowering; DM=Days to maturity, GFP=Grain filling period; BMPR= Biomass production rate; PH=Plant height; SL= Spick length; NSPS=Number of spikelet per spike; TKW=Thousand kernel weight; BY=Biomass yield; GY=Grain yield; HI= Harvest Index.

than 85% of the national standard for commercial seed in Ethiopia (ICARDA, FAO, AAR INENA and CIHEAM, 1999). Physical purity, however, ranged from 98.17 to 99.76% with an average of 99.38%. There was no difference in physical purity level between seed sources. However, varieties showed

Table 10. Physical purity of barley seed obtained from field experiment at Degem wereda 2010.

Variety	Composition by weight			
	ANPU	OCS	INM	TKW(g)
G/adii	99.76^{a}	0.14^{f}	0.00^{b}	45.7^{b}
HB 1307	99.69^{a}	0.17^{ef}	0.00^{b}	46.2^{ab}
Hadho	99.08^{b}	0.53^{c}	0.04^{a}	42.1^{c}
HB42	99.60^{ab}	0.24^{de}	0.00^{b}	38.1^{e}
Damoy	99.54^{ab}	0.25^{de}	0.04^{a}	30.7g
G/gurracha	99.59^{ab}	0.49^{c}	0.00^{b}	40.2^{d}
Shagee	99.55^{ab}	0.30^{d}	0.00^{b}	39.5^{d}
Tolasee	99.06^{b}	0.62^{b}	0.00^{b}	41.3^{c}
Karfee	98.17^{c}	1.12^{a}	0.00^{b}	34.8^{f}
Magee	99.74^{a}	0.27^{d}	0.00^{b}	46.8^{a}
Mean	99.38	0.41	0.01	40.58
CV (%)	0.24	9.14	45.15	2.68
R^2	0.87	0.99	0.97	0.95
Significance	0.0016	<.0001	<.0001	<.0001

Means followed by a common letters with in a column are not significantly different from each other at P< 0.05 according to Duncan's multiple range test; ANPU=%Analytical purity; OCS=Other crop seeds; INM=Inert matter; TKW=Thousand kernel weight (g).

significant difference for other crop seed, which ranged from 0.14 for *G/adii* to 1.12% for *Karfee* with mean of 0.41%. This variety contains more other crop seed than other varieties. Thousand seed weight also showed significant difference which ranged from 30.7 to 46.25 g with mean of 40.58 g. *Damoy* was the least in thousand seed weight followed by *Karfee,* which was 34.8 g. On the contrary, the highest seed weight was observed on *Magee* 46.8 gm followed by HB-1307 and *G/adii* (Table 10).

The presence of different "other seeds" species in the seed samples was identified. Major other crops seed observed were *Avena* spp., *Lolium*, *Triticum* and *Bromous* spp. *Avena* spp. and *Bromous* spp. were the major problematic weeds in Degem wereda. Significant (p<0.0001) mean differences were observed on other crop seeds between varieties. However, all local and improved varieties maintained the minimum purity standards. Moreover, all samples had less inert matter contamination than the standard (Table 10).

Thousand kernel weight

The overall average of thousand-kernel weight was 40.5 g ranging from 30.7 g for *Damoy* to 46.8 g *Magee*. Significant difference in seed weight was observed among different varieties at (p<0.0001) (Table 10). Seed sample of *Magee* were on average heavier than the grand mean and ranked first followed by HB-1307. This study revealed that except HB-1307, improved varieties had low 1000 kernel weight than the local ones. These results agreed with Sahilu (1999) and with Briggs (1978) in which they recorded that Ethiopian barleys were characterized by very high seed weights.

Physiological seed quality

Standard germination: Physiological seed quality analysis was conducted at different time. This was because of the appearance of seed dormancy on different varieties. The first laboratory analysis was conducted one month after harvest and the second was four months after harvest.

During the first germination test, there were high standard germination mean differences, which ranged from 5.25% for *Magee* to 98.25% for *Damoy*. Four varieties *Damoy*, HB-1307, *G/gurracha* and *Karfee* had germination percentage of 98.25, 97.75, 93.5 and 88.0%, respectively. Although these varieties were in the range of barley germination standards, the rest of the varieties were out of the standards due to seed dormancy (Table 11). Hence, further evaluation was conducted to capture this quality trait.

Accordingly, the second germination testing was made after four months of harvest. During the second germination test, mean differences for the trait ranged from 98.5% for *Tolese* and HB-42 to 99.75% *Shagee*. The result indicated that all varieties were above nationally recommended standard germination range after breaking dormancy following four months of storage.

Significant in seed germination differences were observed between the first and the second time of analysis (Table 11). This study revealed that seed dormancy was broken after-ripening (dry storage) for four

Table 11. Mean physiological quality (vigour) of barley seed from field experiments at Degem wereda 2010

Varieties	SG1 (%)	SG2 (%)	SPG	SL (cm)	RL(cm)	SDWT(g)	VIG1	VIG2	TKW
G/adii	13.25^{g}	99.25^{a}	19.76^{bc}	14.94^{b}	13.59^{a}	0.055^{ab}	2831.99^{bc}	5.23^{ab}	45.7^{b}
HB-1307	97.75^{ab}	99.00^{a}	18.47^{c}	16.56^{a}	11.67^{c}	0.032^{b}	2780.22^{bc}	3.23^{b}	46.2^{ab}
Hadho	83.50^{d}	99.25^{a}	18.48^{c}	16.69^{a}	13.25^{ab}	0.047^{ab}	2972.28^{a}	4.48^{ab}	42.1^{c}
HB-42	54.00^{e}	98.50^{a}	20.24^{b}	15.02^{b}	12.67^{b}	0.077^{a}	2729.25^{bc}	7.63^{a}	38.1^{e}
Damoy	98.25^{a}	98.75^{a}	22.46^{b}	16.19^{a}	12.90^{b}	0.025^{b}	2873.35^{ab}	2.47^{b}	30.7^{g}
G/gurrach	93.5^{b}	98.75^{a}	22.86^{a}	15.74^{ab}	10.22^{d}	0.055^{ab}	2564.94^{ef}	5.44^{ab}	40.2^{d}
Shagee	7.25h	99.75^{a}	19.60^{bc}	14.61^{b}	11.67^{c}	0.047^{ab}	2621.91^{de}	4.74^{ab}	39.5^{d}
Tolasee	41.75^{f}	98.50^{a}	19.29^{bc}	13.15^{c}	11.84^{c}	0.075^{a}	2462.35^{f}	7.39^{a}	41.3^{c}
Karfee	88.00^{c}	99.50^{a}	20.25^{b}	15.65^{ab}	12.99^{ab}	0.032^{b}	2849.5^{abc}	7.68^{a}	34.8^{f}
Magee	5.25h	99.00^{a}	20.25^{b}	13.31^{c}	11.84^{c}	0.075^{a}	2790.52^{ef}	3.23^{b}	46.8^{a}
Mean	58.25	99.02	20.16	15.19	12.25	0.052	2117	5.15	40.58
CV (%)	5.3	0.9	5.13	3.35	3.54	52.15	3.57	52.16	2.68
R^2	0.99	0.2	0.7	0.8	0.86	0.37	0.79	0.37	0.95
Signific^{a}nce	<0.001	0.58	<0.001	<0.001	<0.001	0.06	<0.001	0.07	0.001

Means followed by a common letters with in a column are not significantly different from each other at P <0.05 according to Duncan's multiple range test; SG1=Standard germination after one moth of harvest; SG2=Standard germination after four month of harvest; SPG=Speed of germination; SL(cm)=Shoot length; RL (cm)=Root length; SDWT (gm)=Shoot dry weight; VIG I=Vigor index I; VIG II= Vigor index II; TKW=Thousand kernel weight.

months although varieties had different period of seed dormancy (Figure 2).

Hull thickness has an effect on barley seed germination. Those varieties showed seed dormancy during germination test after one month of harvest have thick hull. At harvest, intact barley grains exhibited dormancy and germinate poorly. Bradrord et al. (2008) reported similar result that restriction to germination is attributable to the presence of the glumellae or hulls, as their removal or excision of the embryos greatly improves germination capacity. The restriction of germination by the hull has been attributed largely to its ability to reduce the availability of O_2 to the embryo (Lenoir et al., 1986). Bradford et al. (2008) reported that germination rates and percentages improved following after breaking dormancy for both seeds and embryos. This finding was supported by five months of after dormancy break allowed almost complete germination of seeds in 21% O_2, but germination remained highly sensitive to O_2 percentage as (Bradrord et al., 2008).

Speed of germination: Mean difference in speed of germination ranged from 18.47 for HB-1307 and *Hadho* to 22.86 for *G/gurracha*. The others were in par for this trait. Least mean shoot length was observed on *Magee* while, *Hadho* was the highest in shoot length. Likewise, *G/gurraha* was the shortest in root length but *G/adii* was the longest (Table 11). The speed of germination measures the rate at which the seeds were germinating and those seedlings with higher index or highest germination were expected to show rapid germination and seedling emergence and to escape adverse field conditions.

Seedling shoots and roots length: Mean difference in seedling shoots length ranged from 13.15 cm for *Tolasee* and 16.69 cm for *Hadhoo* with grand mean of 15.19 cm. Moreover, *Hadhoo*, HB-1307 and *Damoy* were in par for this trait. Likewise, mean difference in root length ranged from 10.22 cm for *G/gurracha* to 13.59 cm for *G/adii* with grand mean of 12.25 cm. *Hadhoo,* HB42 *Damoy* and *Karfee* were in par for the trait considered (Table 11). HB1307, *G/gurracha, Hadho, Damoy* and *Karfee* showed longer in their shoot length and *G/adii, Hadho* and *Karfee* showed longer in their root length. Significant variations were observed among varieties for seedling shoots and root length at (p<0.0001). Seedlings with well-developed shoot and root systems would withstand any adverse conditions and provide better seedling emergence and seedling establishment in the field.

Seed vigour test (Viguor Index I and Viguor Index II): Mean difference in vigour index I ranged 2462.35 for *Tolasee* to 2972.28 for *Hadhoo* with grand mean of 2117. *G/adii*, HB1307, HB 42 and *Karfee* were in par for this trait. *Hadho, Damoy* and *Kerfee* showed higher vigor index I while *Tolasee, Magee* and *G/gurracha* were lower in vigor index I (Table 11). Significant variations were observed among varieties for vigour index I at (p<0.0001). On the other hand, no significant difference observed among varieties for vigour index II at (p<0.05).

Varieties that had higher speed of germination were generally considered more vigorous. Moreover, vigorous varieties could be stored for longer periods without loss of germination. Vigor tests measure the potential for rapid, uniform emergence of seeds under a wide range of field conditions (Elias et al., 2010). Its results may be more

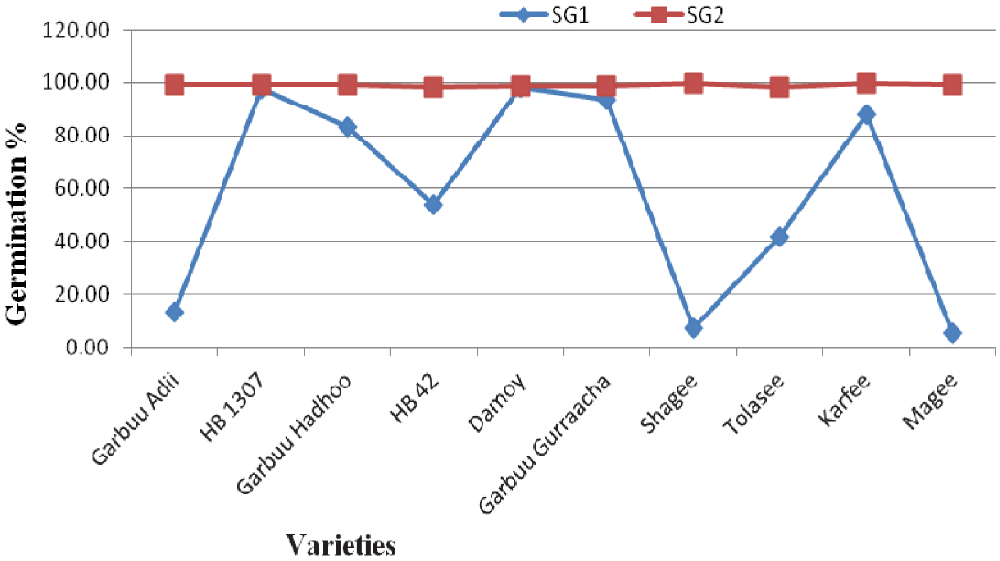

Figure 2. Standard germination after one and four months after harvest. SG1=Standard germination after one month of harvest; SG2=Standard germination after four month of harvest.

closely associated with field emergence than the standard germination test (Elias et al., 2006).

Mycological evaluation

The presence and type of fungi were determined according to their development on seed, which had been incubated on Potato Dextrose Agar (PDA) medium. Accordingly, sixteen different fungi genera were identified. Their importance, in relation to their occurrence were *Helmithosporium sativum, Helminthosporum teres, Fusarium graminarum, Fusarium oxysporum, Fusarium avenacerum, Cladosporium* spp., *Alternaria* spp., *Botryodiplodia* spp., *Phoma* sp., and *Stemphylium* sp.. In addition, storage fungi associated to barley seed were also identified, which include *Penicillium* spp., *Trichoderma* sp., *Aspergillus* spp. and *Chaetomium funicola* (Table 12).

The result indicated that high incidence of facultative fungal such as, *Fusarium avenacerum* and *Phoma* spp. and low incidence of field fungi like *Botryodiplodia, Aspergillus, and Trichoderma. Fusarium* spp were commonly occurring as seedborne fungi and responsible for causing seed decay and seedling mortality. Likewise, some diseases were also observed in large number on different varieties. This showed that there was differential occurrence of some fungi on varieties tested. The mean difference between varieties showed that *karfee* (3.52%) was highly infected followed by *Damoy* (2.44%) while *G/adii* (0.98%) was the least affected (Table 12). HB-1307, HB-42, *Damoy* and *G/gurracha* were more infected by *H. sativum,* while *Shagee, G/gurracha* and *Magee* were more infected by *F. oxysporum. Damoy, Hadhoo, Tolasee* and *Magee* were more infected by *F. avenacerum* (Table 12). In general significant different was observed between varieties for different seed-borne fungi. Similarly, Bekele et al. (2005) reported that most of the FV's were found susceptible to scald (*Rhynchosporium secalis* Oud.), net blotch (*Helminthosporium teres* Sacc.), spot blotch (*H. sativum* Pum.), leaf rust (*Puccinia hordei* Otth.) and lodging. Novak et al. (2001) also reported that difference in disease incidence were due to the ability of saprophytes to colonize, rapid germination of spores, quick hyphal invasion, high competitive nature, their ability to utilize a wide variety of substrates and their nutrient composition.

Among sixteen seed fungi observed, eight of them were known to be seed transmitted (Table 13). Seed transmitted pathogens are pathogen that can affect the yield in next production season and transmit pathogen to disease free environment. Therefore, to increase the planting values of the seed, treatment is important to produce healthy seed for the next planting season.

Significant different in seed infection was observed on varieties. High *H. sativum* was observed on *G/gurracha*, HB-1307, HB-42, and Damoy respectively.

H. teres was more observed on *Damoy* followed by HB-42. More *F. graminarum* seed infection was observed on *Shagee* followed by *Magee* and HB-1307and *F. oxysporum* was observed on *Sahgee*, *Magee* and *Tolesee*. *Fusarium avenacerum* was more observed on *Hadhoo*, HB- 42 and *Magee* (Table 13).

On the other hand, seven of the fungi were seed deteriorating pathogen (Table 14). These seed deteriorating fungi were affecting the planting value of the seed due to their deteriorating action. Seed infection was significant at ($p<0.001$) except for *Penicillium,* and

Table 12. Fungi detected on food barley seed collected from Degem wereda in 2010.

Fungi	Percentage of pathogen observed on different varieties										
	G/Adii	HB 1307	*Hadhoo*	HB 42	*Damoy*	*G/gurraacha*	*Shagee*	*Tolasee*	*Karfee*	*Magee*	Mean
HS	0.00	2.00	0.00	1.80	1.80	2.00	0.30	0.80	0.50	0.30	0.93
HT	0.30	0.00	0.30	0.80	1.00	0.00	0.00	0.30	0.00	0.00	0.25
FG	1.00	2.30	1.80	0.30	0.50	3.30	5.30	2.00	0.00	2.50	1.88
FO	0.30	0.50	2.00	1.00	0.80	0.80	1.00	0.50	0.30	1.80	0.88
FA	0.00	0.00	9.50	1.00	28.80	2.00	0.80	8.50	0.00	7.30	5.78
Fus	6.50	8.00	6.00	0.80	0.50	4.00	3.00	4.30	1.50	5.30	3.98
CL	0.50	0.30	1.00	0.30	0.80	1.30	0.00	0.50	0.00	1.30	0.58
AL	0.00	1.80	0.00	5.80	0.80	1.00	3.30	0.00	0.00	0.00	1.25
AS	0.50	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
CH	4.50	0.30	0.00	3.30	0.30	0.00	8.50	0.00	0.80	0.00	1.75
PE	1.50	8.30	3.50	4.00	1.80	6.50	0.00	3.00	0.30	7.00	3.58
TR	0.30	0.00	1.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.15
PH	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.50	0.00	20.70
BO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.03
RH	0.00	0.00	0.00	1.00	0.30	0.00	0.00	2.30	0.00	1.00	0.45
ST	0.30	1.00	0.30	1.00	1.80	0.30	0.50	0.30	1.50	0.00	0.68
Mean	0.98	1.52	1.61	1.30	2.44	1.31	1.41	1.39	3.52	1.66	2.68

HS=*Helmithosporium sativum*; HT=*Helminthosporum teres*; FG=*Fusarium graminarum*; FO=*Fusarium oxysporum*; FA=*Fusarium avenacerum*; *CL=Cladosporium*; *AL=Alternaria; BO=Botryodiplodia*; *PH=Phoma;* ST= *Stemphylium*; *PE=Penicillium*; *TR=Trichoderma*; *AS=Aspergillus*; CH=*Chaetomium*; Rh=*Rhinchosporium scalis*; Fus= *Fusarium* spp.

Alternaria.

Hence, appropriate seed handling should be made during pre-harvest and post-harvest operations to ensure quality seed system.

Heleminthosporium spp, *H. teres, Rhynchosporium, Ustilago nuda, U. hordi, H. graminea* are common barley seedborne disease in Ethiopia. Semeane et al. (1996) reported that net blotch, scald and leaf rust are the most three important barley diseases targeted for control. Of those, net blotch was an endemic disease in most highlands of the country where barley is important. Similarly, Hundie et al. (2001) also reported that on farm average yield loss of 28 to 29% was accounted for net blotch and leaf rust infection.

CONCLUSIONS AND RECOMMENDATION

The presence of significant ($p<0.01$) variation among FVs' and improved varieties for most characters implies that there is high variability among genotypes tested. This result showed that variability were existed among FVs' and improved varieties tested for important quantitative traits indicating high potential for effective barley enhancement and/or for further manipulation of the genetic resources through mass selection as FVs' are good sources of genes for many desirable traits. *Damoy* is the earliest in heading, maturity and grain filling period followed by *G/gurracha*. These traits are advantageous to escape terminal moisture stress and good character to cope up with the rainfall variability. *G/gurracha* gave highest grain yield (3573.6 kg ha^{-1}) which showed the possibility of improvement of FVs' through mass selection. In general, the study revealed that mass selection scheme would be more promising and encouraging for improving barley yield. This could be the nature of FVs' because of their better adaptive traits to variable environmental conditions which have important

Table 13. Mean difference seed transmitted pathogen observed on seed collected from field experiment at Degem 2010.

Varieties	HS(Ω)	HT(Ω)	FG(Ω)	FO(Ω)	FA(Ω)	PH(Ω)	RH(Ω)	F.sp(Ω)
G/adii	0.48^{b}	0.65^{bc}	1.00^{a}	1.0^{cdef}	0.66^{b}	1.42^{c}	0.66^{b}	0.48^{b}
HB1307	1.58^{a}	0.48^{c}	2.3^{bcd}	1.5^{abcd}	0.83^{ab}	2.68^{a}	0.48^{b}	0.48^{b}
Hadhoo	0.48^{b}	0.65^{bc}	1.8^{bcd}	1.4^{bcde}	1.56^{a}	1.99^{abc}	0.48^{b}	0.48^{b}
HB42	1.53^{a}	1.01^{ab}	0.25^{cd}	0.65^{ef}	1.13^{ab}	1.83^{bc}	0.48^{b}	0.48^{b}
Damoy	1.53^{a}	1.12^{a}	0.5^{cd}	0.83^{def}	0.95^{ab}	1.50^{c}	0.48^{b}	0.48^{b}
G/gurracha	1.62^{a}	0.48^{c}	3.25^{ab}	1.98^{ab}	0.95^{ab}	2.52^{ab}	0.48^{b}	0.48^{b}
Shagee	0.65^{b}	0.48^{c}	5.25^{a}	2.27^{a}	1.03^{ab}	0.48^{d}	0.48^{b}	0.48^{b}
Tolasee	0.95^{b}	0.65^{bc}	2.0^{bcd}	1.6^{abcd}	0.77^{b}	1.95^{abc}	0.48^{b}	0.48^{b}
Karfee	0.83^{b}	0.48^{c}	0.00^{d}	0.48^{f}	0.66^{b}	0.66^{d}	4.62^{a}	0.48^{b}
Magee	0.65^{b}	0.48^{c}	2.5^{bc}	1.76^{abc}	1.38^{ab}	2.67^{a}	0.48^{b}	0.66^{a}
Mean	1.03	0.65	1.87	1.35	0.99	1.76	0.91	0.49
CV%	33	41.7	85.86	40.59	54.56	28.64	16	22.55
Signficance	<0.0001	0.0105	0.0023	0.0007	0.3279	<0.0001	<0.0001	0.4612

(Ω)=Data was transformed by arc sine; HS=*Helmithosporium sativum*, HT=*Helminthosporum teres*; FG=*Fusarium graminarum*; FO=*Fusarium oxysporum*; FA=*Fusarium avenacerum*; *PH=Phoma*; *F.sp=Fusarium* sp.

Table 14. Mean difference seed deteriorating pathogen observed on seed collected from field experiment at Degem 2010.

Varieties	CH#	PE#	TR#	BO#	RH#	CL#	AL#
G/adii	0.48^{e}	0.77^{ab}	2.29^{a}	0.66^{b}	0.66^{b}	0.48^{d}	0.83^{ab}
HB1307	1.5^{bc}	0.48^{b}	0.65^{b}	0.48^{b}	0.48^{b}	0.48^{d}	0.66^{ab}
Hadhoo	0.48^{e}	0.83^{a}	0.48^{b}	1.13^{a}	0.48^{b}	2.99^{b}	1.13^{ab}
HB42	2.51^{a}	0.48^{b}	1.18^{b}	0.48^{b}	0.48^{b}	1.13^{b}	0.66^{ab}
Damoy	1.01^{d}	0.48^{b}	0.65^{b}	0.65^{b}	0.48^{b}	3.81^{a}	0.95^{ab}
G/gurracha	1.13^{cd}	0.48^{b}	0.48^{b}	0.48^{b}	0.48^{b}	1.33^{c}	1.14^{ab}
Shagee	1.92^{b}	0.48^{b}	2.87^{a}	0.48^{b}	0.48^{b}	0.95^{cd}	0.48^{b}
Tolasee	0.48e	0.48^{b}	0.48^{b}	0.48^{b}	0.48^{b}	2.84^{b}	0.77^{ab}
Karfee	0.48e	0.48^{b}	0.85^{b}	0.48^{b}	4.62^{a}	0.48^{d}	0.48^{b}
Magee	0.48e	0.48^{b}	0.48^{b}	0.48^{b}	0.48^{b}	2.72^{b}	1.24^{a}
Mean	1.04	0.54	1.04	0.58	0.75	1.72	0.83
CV%	28.15	41.47	56	39.97	26.64	29	56.67
Signficance	<0.0001	0.2013	<0.0001	0.005	<0.0001	<0.0001	0.2539

#=Data was transformed by arc-sine transformation, *CH=Chaetomium, PE=Penicillium, TR=Trichoderma BO=Botrytis , RH=Rinchosporium, CL=Cladosporium AL=Alternaria.*

implications for sustainable crop production. The maximum yield was obtained from *G/Gurracha*. This indicates that minimum improvement should be vital for barley yield and yield related traits improvement. *Damoy* has been selected as the sole variety for *belg* season production in the study area for its early in heading, maturity and grain-filling period and require low moisture. Improvement should be vital for adopting this variety in an area of short rainfall so as to attain food security. Varieties differ in dormancy duration. Hence, dormancy behavior of the genotypes needs to be studied. Seed is the basic input of crop production. Therefore, seed treatment and quarantine measure should have to be undertaken prior to seed delivery for the end-users to improve field planting value of the seed lots. Attention should be given to exploit variability of FVs' for for varietal improvement and enhancement to attain food security. In general, Ethiopian barley FVs' is contributing as major sources of variability for selection and enhancement which has many advantages than improved varieties. Therefore, the available variability is useful to design better selection strategies in FVs'.

Conflict of Interest

The authors have not declared any conflict of interest.

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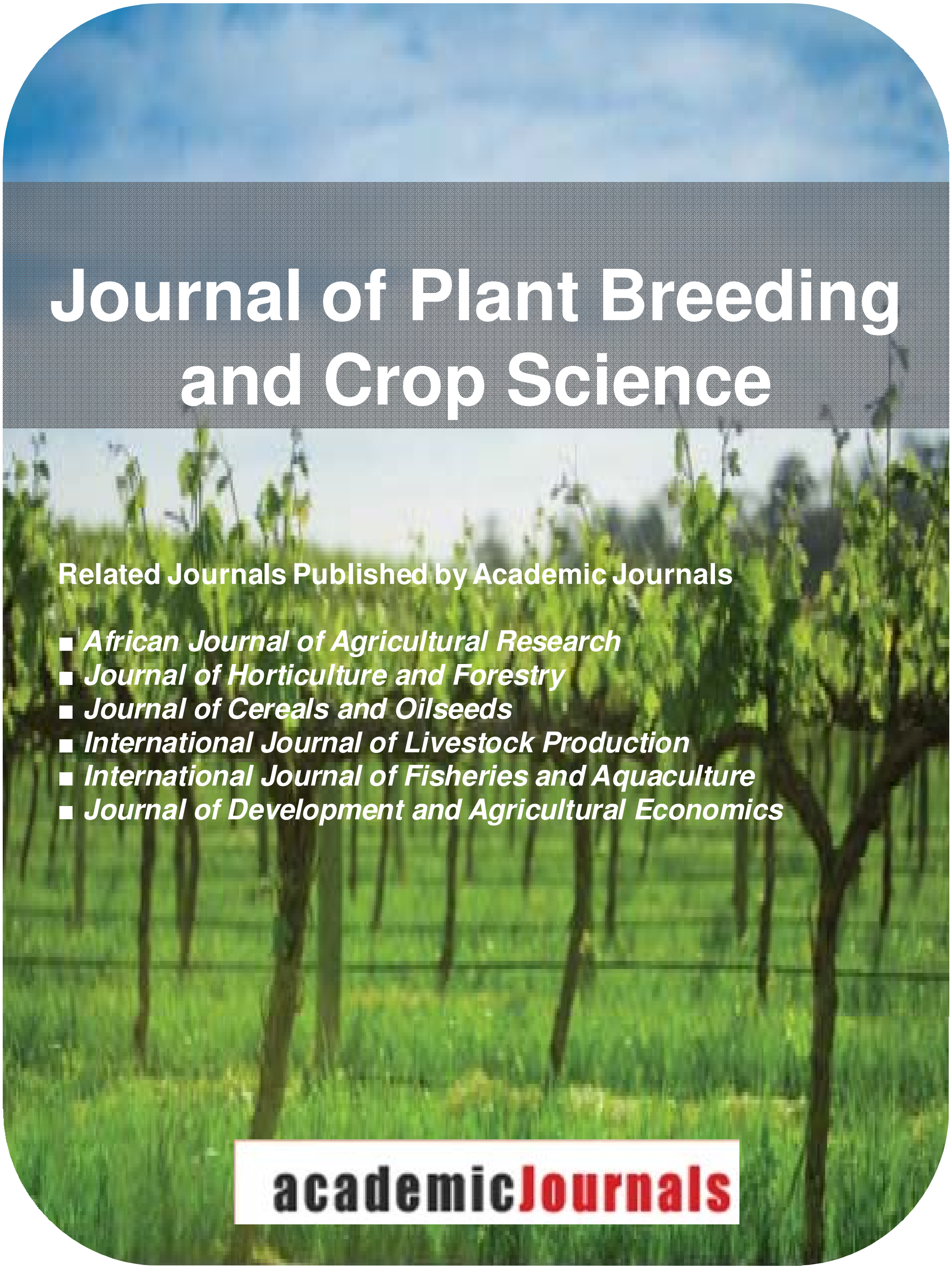

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