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Correlation and path analysis of yield, yield contributing and malt quality traits of Ethiopian sorghum (*Sorghum bicolor* (L.) Moench) genotypes

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Sorghum is a drought tolerant C_4 tropical crop with wide diversity grown for food, feed and beverages. There is a growing demand for food and malt type sorghum varieties due to the low supply of mat barley, and climate resilient and gluten free nature of the crop. This study was initiated to estimate the associations among traits and the relative importance of traits in influencing grain yield and malting quality of sorghum genotypes. The experiment was conducted at Fachagama in Mhoni ARC, Northern Ethiopia in 2016/2017 using α- lattice design in two replications using supplementary irrigation. Data were collected on agronomic traits, and a selection of 300 g pure seeds were malted (18 hr steeping, 72 hr in 28°C germinated and 24 hr in 50°C dried) for malt quality analysis. Positive and significant correlations with grain yield of TKW (0.766, 0.715), KL (0.671, 0.644), KW (0.524, 0.491) HLW (0.532, 0.504, FHWE (0.257, 0.241) and DP (0.275, 0.271) at both phenotypic and genotypic level was found respectively. TKW exerted high positive genotypic (0.334) and phenotypic (0.287) direct effect and even higher indirect effect on grain yield, which indicated that attention should be given to TKW primarily for direct and indirect selection for yield improvement. Thousand kernel weight and fine grind hot water extract showed a significant positive correlation with diastatic power at genotypic level and increment in these traits results in advancement of diastatic power.

Key words: Diastatic power, direct effect, indirect effect, genotypic and phenotypic association.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is classified under the grass family of Poaceae, genus Sorghum Moench (Poehlman and Sleper, 1995). It originated in Africa, more precisely in Ethiopia, between 5000 and

7000 years ago Vavilov, (1951) and/or centre diversity Harlan, (1992). The crop has spread to other parts of Africa, India, and Southeast Asia, Australia and the United States (Mesfin and Tileye, 2013).

Sorghum is a drought tolerant C_4 tropical crop with wide diversity. It is the fifth most important cereal crop in the world with grain production grown in arid and semi-arid parts of the world (FAO, 2016). It contributes to the protein and energy requirements for millions of people mainly living in Sub-Saharan Africa and Asia (Orr et al., 2016). Sorghum is one of the major staple food crops on which the lives of millions of Ethiopians depend. The majority of grain production goes towards the preparation of diverse food recipes, like porridge,"injera", "Kitta", "Nifro", infant food and syrup (Asfaw, 2007). A small fraction of the grain it is malted for local beverages, such as "Arake", "Tella", and "Borde" (Abegaz et al., 2002).

Barley is the grain of choice for malting in modern brewing (Taylor and Dewar, 2000). Next to barley, of which sorghum malt found the most appropriate alternative for brewing (Agu et al., 2013) and further the brewing qualities are advanced due to gluten-free nature of sorghum protein to substitute the gluten rich cereals in the diet of people suffering from celiac disease (Anheuser, 2010).

Malting is the controlled germination of cereals in moist air, under controlled conditions for mobilizing the endogenous hydrolytic enzymes, especially α-amylase and β-amylase enzymes of the grain. The malting process modifies the grain structure, so that it will be readily solublized during the brewing process to produce fermentable wort (Taylor and Belton, 2002).

In any crop improvement program, the primary (or most essential) characteristic that the breeder looks into is the existence of genetic variability for the characters of interest (Jahufer and Gawler, 2000). Breeders are also interested in the relationship and interdependence that may exist between or among characters for direct and indirect selection (Muhammad et al., 2003).

Grain yield and its quality are the principal characters of a cereal crop (Bello and Olaoye, 2009). They are complex quantitative characters, which are influenced by a number of yield and malt quality contributing factors. Hence, the selection for desirable genotypes should not only be based on yield alone, but also other yield and malt quality components. Direct selection for yield is often misleading in sorghum because yield is polygenically controlled.

For effective utilization of the genetic stock in crop improvement, information of mutual association between yield, malt quality and yield components is necessary. It is therefore, necessary to correlate various characteristics with yield, malt quality and among themselves. The correlation between yield, malt quality and yield components usually show a complex chain of interacting relationship. Path coefficient analysis partitions the components of correlation into direct and indirect effects and highlights the relationship in a more meaningful way (Muhammad et al., 2003). However, no character association studies have been conducted at national level as wel as especially for yield and malt quality.

Although both correlation and path analysis have been extensively studied for agronomic traits in sorghum, such information is unavailable for malting quality traits in Ethiopia. Therefore, such association is essential among traits for further sorghum yield and malt quality improvement, particularly in the region and generally in the country for sorghum malt varieties development. Therefore, the current study was carried out to estimate; the magnitude of genotypic and phenotypic correlation between grain yield, malt quality and yield contributing characters and direct and indirect effects of yield related and malt quality traits for malting (diastatic power) and yield.

MATERIALS AND METHODS

Description of the experimental area

The experiment was carried out at Mehoni Agricultural Research center (MhARC) Fchagama test s tation site in Raya Azebo Woreda using supplementary irrigation in the 2016/2017 cropping season. Fachagama is located at 668 km from the capital Addis Ababa and about 120 km south of Mekelle, capital city of Tigray regional state. Geographically the experimental site is located at 12.70 °N latitude and 39.70 °E longitude with an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 539 mm with an average minimum and maximum temperature of 12.8 and 23.2°C, respectively. The soil textural class of the experimental site was clay with pH of 6.89 (Gebremeskel et al., 2017).

Treatments and experimental design

The study genotypes (Table 1) including the two checks (Redswazi and Macia) were kindly availed by the national Sorghum Research Program of Melkasa Agricultural Research Center (MARC). The genotypes are selected based on their dominancy in production and historical usage for local beverage preparation and for some are recently released food varieties to evaluate whether they can be used for both food and malting.

The treatments (genotypes) were grown in (7, 8) α- lattice in two replications, 2 m path width between replications and 0.5 m path between plots found within incomplete blocks. The gross size of experimental plot was 1.5 m x 3 m (4.5 m^2) accommodating two

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Table 1. List of fifty- six Sorghum genotypes including two checks used in the study.

S/N	Genotype	Seed color	Seed Source	G.N.	Genotype	Seed color	Seed source
1	Abamelko	Brown	JARC	29	Degalit Yellow	Yellow	SARC
2	AL-70	White	MARC	30	Demhay	Chalky	TARI
3	Baji	Red	MARC	31	Dima	Red	MARC
4	Birimash	Red	MARC	32	Jamiyu	Red	MARC
5	Osmel	Red	MhARC	33	Jeru	Yellow	MARC
6	Chiro	Red	MARC	34	Jigurti	Red	MARC
7	Dagim	Red	MARC	35	Kodem	Yellow	MARC
8	E36-1	White	MARC	36	Lalo	Brown	TARI
9	Emahoy	Brown	PARC	37	Masugi Red	Red	MARC
10	Merawi	Chalky	MhARC	38	Masugi Yellow	yellow	MARC
11	AbaAre-1	White	MARC	39	Tetron White	Chalky	MARC
12	America-1	Red	MARC	40	Tewzale	Red	TARI
13	Baduqane	Yellow	MARC	41	Tseada Achire	White	TARI
14	Berjokecoll#1	Red	MARC	42	Tseada chimure	White	MARC
15	DagalitYellow-1	Yellow	MARC	43	Wediarse	Chalky	TARI
16	Gorade-2	White	MARC	44	Wegere	Yellow	MARC
17	Hodem-1-3	Yellow	MARC	45	Wetetbegunchie	Red	MARC
18	JimmaLocal-2	Brown	MARC	46	Wode aker	Chalky	MARC
19	Marye#2	Yellow	MARC	47	Yeju	White	SARC
20	Meminay-4	White	MARC	48	ZeriAdis	Yellow	TARI
21	Welenchity Col # 3	Redish	MARC	49	Goronjo	White	MARC
22	Wollo Col#050	Red	MARC	50	Gedo	White	SARC
23	Gano	Yellow	MhARC	51	Melkam	White	MARC
24	Bobe red	Red	MARC	52	Misikir	White	SARC
25	Bobe white	White	MARC	53	Dekeba	White	MARC
26	Dabar	White	MARC	54	Seredo	Buff	MARC
27	Dagnaw	Yellow	TARI	55	Macia (check)	White	MARC
28	Degalit	Yellow	JARC	56	Redswazi (check)	Buff	MARC

Key: TARI = Tigray Agricultural Research Institute, MARC = Melkassa Agricultural Research center, MhARC = Mehoni Agricultural Research center, SARC = Sirinka Agricultural Research center, JARC = Jimma Agricultural Research center and PARC = Pawe Agricultural Research center and G.N= Genotype number.

rows with spacing of 75 cm between rows and 20 cm between plants. The two outer most rows at both ends of first and the last blocks were treated as borders leaving two middle rows of each of the genotypes for sampling.

The experimental field was prepared by using farm tractor plough according to semi conventional farming practice.

It was sown July 11, 2016 at a spacing of 75 x 20 cm.

The full dose of DAP (diaminophosfate) (46% P_2O_5, 18% N) fertilizer at the rate of (100 $kgha^{-1}$) were drilled at planting. Nitrogen fertilizer in the form of urea (46% N at a rate of 100 $kgha^{-1}$) were applied half at sowing by mixing with DAP and the remaining half of urea was top-dressed at knee height. The seeds were sown by hand in the rows as uniformly as possible and covered with soil manually and thinning of seedlings was done two weeks after emergence.

Data collection and measurements

Agronomic traita

Agronomic data were collected from two rows in each plot on the following parameter; days to flowering (DF), days to maturity (DM), plant height (PH cm), number of productive tillers per plant (NPT), thousand kernel weight (TKW g) and grain yield (GY kg). The moisture level for TKW and GY was adjusted to 12.5% according to (Biru, 1979).

$$Adjusted\ seed\ weight = \text{Intial seed weight}\left(\frac{100-\text{OMC}}{100-\text{DMC}}\right)$$

where, OMC means Original moisture content and DMC means Desired moisture content.

Sorghum grain quality parameters

Hectoliter weight (HLW kg/hL):

Calculated using the instrument which uses hectoliter weight, electronic balance and moisture tester simultaneously according to the American Association of Cereal Chemists (AACC) (2000) method 55 - 10 and obtained values were adjusted to moisture content of 12.5% by the following equation;

$$\text{HLW (12.5\% M basis)} = \text{HLW}\frac{100 - \text{\% moisture measured in the grain}}{100 - 12.5}$$

where, HLW is Hectoliter weight.

Kernel size (KS):

The kernel width (KW), kernel length (KL) and kernel thickness (KT) of ten kernels of each variety of each plot were measured and average value were taken using a digital caliper ($\pm$0.01 mm) according to the modified method of (Schuler et al., 1994).

Germination energy (GE %):

This was done in the Haramaya university food science laboratory. It was done by placing 100 representative grains on damp filter paper with 4 ml water in closed petridshs. The seeds germinated at a temperature of 25°C and 100% relative humidity and counting germinated seeds after 24, 48 and 72 hrs. Germinated seeds were counted and expressed in percentage (Taylor and Taylor, 2008).

Endosperm texture (ET):

The relative proportion of vitreous (corneous) to floury endosperm were determined by cutting 5 kernels in halves longitudinally and evaluated using a rating scale of 1 (corneous), 2 (intermediate to corneous), 3 (intermediate), 4 (intermediate to flowery) and 5 (floury) as described by (Rooney and Millner, 1982).

Grain crude protein content (CP %):

The total protein content was measured by using Near Infrared Reflectance Spectrometry (NIRS), Model EU Perten Machine-IM9500 at Melkassa Agricultural research center food science laboratory. Then the result is converted to dry basis using the formula:

$$\text{Protein (dry basis)} = \frac{\text{(as is)}100}{100 - \text{m}}$$

where, as is = the protein taken from the reading and M is % of moisture content of the grain.

Sorghum malt preparation and Sorghum malt quality traits

The malting process was done in the Haramaya university food science laboratory.

Steeping:

Sorghum grain samples of 300 g of each plot were cleaned by a hand picking to remove any defectives and washed three times to remove dirty, dusty and other foreign matters. The samples of the cleaned grains were placed in 300 x 300 mm nylon bags and steeped for 6 hr in steeping vessels (1 kg) containing 0.1% NaOH solution (Taylor and Taylor, 2008). At the end of 6 hr, the vessel was drained off and then refilled with fresh water at 25°C and the water was drained of every 3 hrs after 1 hr of air rest for total of 18 hrs (Dewar et al., 1997a).

Germination:

The steeped samples of each genotype were allowed to germinate in a germination vessel at optimal temperature (28 °C) for 72 hr germination time and keeping the relative humidity high (95%). Distilled water (20 ml) was sprayed using hand sprayer twice daily to avoid the decrease of relative humidity. The grain was turned to avoid meshing roots and shoots. The germinated samples of the test genotypes were transferred to a temperature controlled drying oven for kilning (Dewar et al., 1997b).

Drying or Kilning: The germinated samples were dried in a temperature controlled drying oven at 50 °C for 24 hrs according to Dewar et al. (1997a).

Malt quality traits

Malting weight loss (MWL %):

The total malting weight loss was determined by weighing the grains before and after malting by using the following equation (Dewar et al., 1997b).

$$\text{Malting weight loss} = \frac{\text{Initial dry weight of grains} - \text{dry weight of malt}}{\text{Initial dry weight of grains}} \times 100$$

Malt moisture content (MMC %):

The Moisture content of the malt was estimated by gravimetric method of the European brewing convention (EBC) (1997). Malt flour of 5 g was dried in an air forced dry oven for 3 hrs at 103°C. The mass loss on dry mass was determined as % moisture by using the equation:

$$\%\mathbf{MC}\ (\mathbf{Moisture\ content}) = \frac{(W2-W3)}{(W2-W1)} * 100$$

Where, MC is Moisture content of the malt, W_1 is Weight of container, W_2 is Weight of container and the sample before drying and W_3 is Weight of the container and the sample after 3hr drying.

Diastatic power of malt (DP) (°WK):

The diastatic power of the malt was determined using EBC Method 4.12, 1997 in the Asela malt factory.

Fine grind hot water extract (FHWE %):

It was done in Asela malt factory using the method of American Society of Brewing Chemists (ASBC) (2008).

Data analyses

Correlation analysis

The phenotypic and genotypic correlation between yield components and malting traits of two variables were estimated as described by Singh and Chaudhary in 1985.

$$\text{Phenotypic } r = \frac{\sigma_{p12}}{\sqrt{(\sigma^2{}_{p1})\,(\sigma^2{}_{p2})}}$$

$$\text{Genotypic } r = \frac{\sigma_{g12}}{\sqrt{(\sigma^2{}_{g1})\,(\sigma^2{}_{g2})}}$$

where, σ_{p12} is the phenotypic covariance between the two traits, $\sigma^2{}_{p1}$ is the phenotypic variance of the first trait and $\sigma^2{}_{p2}$ is phenotypic variance of the second trait, $\sigma^2{}_{g12}$ is the genotypic covariance between the two traits, $\sigma^2{}_{g1}$ is the genotypic variance of the first trait and $\sigma^2{}_{g2}$ is the genotypic variance of the second traits.

The covariance was computed from the analysis of covariance.

where, r is number of replications:

$$\text{Cov g12} = \frac{MSPg - MSPe}{r}$$

Cov p12 = Cov(g12**)** **+** Cov(e12)

where, Cov (g12) is genotypic covariance between traits 1 and y2, Cov p12 is phenotypic covariance between character 1 and 2, Cov (e12) is environmental covariance between character 1 and 2, MSPg is mean sum of cross products of genotype of 1 and 2, MSPe is mean sum of cross products of error of 1 and 2, and r = number of replications.

The phenotypic correlation coefficients were tested for traits significance with 'r' table for sample correlation coefficients at n-2 degree of freedom, as suggested by Gomez and Gomez (1984) or Singh and Chaudhary (1985).

$$t = r_{pxy}\sqrt{\frac{g-2}{(1-rp^2{}_{xy}y)}}$$

t value was tested against the tabulated t-value for (g-2) degree of freedom. Where g is the number of genotypes studied. The genotypic correlation coefficients were tested for their significance using the formula adopted by Robertson (1959).

$$t = \frac{r_{gxy}}{SE_{gxy}}$$

$$SE_{gxy} = \sqrt{\frac{(1-r^2)^2}{2h^2{}_x h^2{}_y}}$$

$SErg_{xy}$ is Standard error of genotypic correlation coefficient between character X and Y.

The 't' value, calculated using the above formula, were compared with 't' tabulated at (g-2) degree of freedom at 1 and 5% levels of significance; where r_{gxy} is the genotypic correlation between x and y traits; g = number of genotypes, $h^2{}_x$ and $h^2{}_y$ are heritability for traits x and y, respectively.

Path coefficient analysis

Based on genotypic correlation, path coefficient which refers to the direct and indirect effects of the yield attributing traits on grain yield (dependent character) and diastatic power contributing traits were calculated using the method described by Dewey and Lu (1959):

rij = Pij + Σrik pkj

where, rij is mutual association between the independent character (i) and dependent character (j) as measured by the genotypic (phenotypic) correlation coefficients, Pij is direct effects of the independent character (i) on the dependent variable (j) as measured by the genotypic (phenotypic) path coefficients, and Σrikpkj is summation of components of indirect effects of a given independent character (i) on a given dependent character (j) via all other independent characters (k).

The residual effect, which determines how best the causal factors account for the variability of the dependent factor yield and diastatic power, was computed using the formula:

$1 = p^2R + \Sigma$ p ij rij

where, p^2R= is the residual effect and p ij rij = the product of direct effect of any variable and its correlation coefficient with dependent trait.

Table 2. Estimates of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients for 14 traits.

Traits	DF	PH	NPT	GY	TKW	HLW	KL	Kw	KT	GE	CP	MWL	FHWE	MMC	DP
DF	1	0.679**	-0.234	0.173	0.284*	-0.395**	0.099	0.223	0.479**	-0.362**	-0.218	-0.019	0.378**	-0.093	-0.071
PH	0.624**	1	-0.06	0.453**	0.406**	-0.12	0.379**	0.23	0.338*	-0.217	-0.08	0.184	0.303*	-0.257	0.153
NPT	-0.234-	-0.045	1	0.166	-0.109	0.046	0.071	-0.118	0.011	-0.181	0.047	-0.054	-0.079	-0.099	0.096
GY	0.17	0.428**	0.16	1	0.766**	0.532**	0.671**	0.524**	0.445**	0.216	-0.099	0.182	0.257*	-0.344**	0.275*
TKW	0.270**	0.367**	-0.104	0.715**	1	0.502**	0.596**	0.61**	0.513**	0.223	-0.081	0.329*	0.369**	-0.334*	0.363**
HLW	-0.379**	-0.11	0.041	0.504**	0.467**	1	0.364**	0.326*	0.032	0.327*	-0.036	0.321*	0.04	-0.163	0.108
KL	0.094	0.347**	0.073	0.644**	0.581**	0.339**	1	0.603**	0.454**	0.308*	0.101	0.221	0.134	-0.241	0.177
Kw	0.208*	0.216*	-0.107	0.491**	0.588**	0.30**	0.584**	1	0.684**	0.256	0.055	0.242	0.288*	-0.308*	0.138
KT	0.470**	0.328**	0.012	0.425**	0.493**	0.021	0.451**	0.651**	1	0.055	-0.081	0.058	0.378**	-0.228	0.028
GE	-0.349**	-0.195*	-0.177	0.207*	0.221*	0.301**	0.300**	0.237*	0.057	1	0.201	0.176	-0.074	-0.088	0.151
CP	-0.194*	-0.045	0.05	-0.084	-0.06	-0.059	0.13	0.088	-0.016	0.177	1	-0.003	-0.275*	-0.064	-0.026
MWL	-0.024	0.183	-0.049	0.175	0.301**	0.287**	0.210*	0.221*	0.058	0.181	0.001	1	0.113	-0.15	0.454**
FHWE	0.363**	0.303**	-0.073	0.241*	0.348**	0.043	0.14	0.286**	0.377**	-0.068	-0.183	0.12	1	-0.176	0.276*
MMC	-0.093	-0.241*	-0.095	-0.329**	-0.322**	-0.162	-0.225*	-0.294**	-0.217*	-0.083	-0.044	-0.134	-0.168	1	-0.093
DP	-0.071	0.196*	0.096	0.271**	0.349**	0.101	0.179	0.138	0.032	0.082	-0.003	0.442**	0.275**	-0.09	1

* and ** are significant at P≤0.05 and P≦0.01.

The residual effect (p^2R) was estimated using the formula:

$$\sqrt{1-R^2}$$

where, $R^2 = \Sigma pij\ rij$

$$p^2R = \sqrt{1-\sum pij\, rij}$$

RESULTS AND DISCUSSIONS

Correlation of grain yield with agronomic and malt quality traits

Estimates of phenotypic (r_p) and genotypic (r_g) correlation coefficients between each pair of the traits are presented in Table 2. Grain yield (kg ha^{-1}) showed positive and highly significant (P $\leq$0.01) genotypic correlation with plant height (r_g=0.453), thousand kernel weight (r_g=0.766), hectoliter weight (r_g=0.532), kernel length (r_g=0.671), kernel width (r_g=0.524) and kernel thickness (r_g=0.445) at (P $\leq$0.05), for fine grind hot water extract (r_g=0.257) diastatic power (r_g=0.275) (Table 2), which indicates that improving these chaaracters may result in the improvement of yield due to high positive correlation. Selecting sorghum genotypes with late maturing and higher plant height might lead to larger grain size, seed weight, increased grain yield and fermentable extract. The findings of the present study are in agreement with the results obtained for plant height and days to flowering by Kalpande et al. (2014) and plant height and thousand kernel weights by (Ezeaku and Mohammed, 2006). Therefore, any improvement of these traits would result in a substantial increment on grain yield.

Grain yield (kg ha^{-1}) showed positive and highly significant (P $\leq$0.01) phenotypic correlation with plant height (r_p=0.428) thousand kernel weight (r_p=0.715), hectoliter weight (r_p=0.504), kernel length (r_p=0.644), kernel width (r_p=0.491) kernel thickness (r_p=0.425) and diastatic power (r_p=0.271) and positive significant (P $\leq$0.05) correlation with germination energy (r_p=0.207). This assures that as vigorousity increases high dry matter acumulation and possibility of grain yield improvement by phenotypic selection of these traits. Khandelwal et al. (2015) reported similar result for thousand kernel weights but negative significant correlation for plant height.

Grain yield had significant negative correlation with malt moisture content (r_g=-0.344) and

(r_p=-0.329) at genotypic and phenotypic level, respectively. This is in accordance with Laidig et al. (2017) for thusand seed weight, grain size, malt extract and protein content and in contrary for hectoliter weight and malting weight loss. Similar results were also found by Alhassan et al. (2008) for germination energy and malting weight loss. The traits such as plant height, thousand kernel weight, hectoliter weight, kernel length, kernel width and kernel thickness showed positive and highly significant correlation (P≤0.01) at both genotypic and phenotypic levels, while DP showed significant correlation (P≤0.05) at phenotypic level with grain yield. This indicated that selection for PH, TKW, HLW, KL, KW, KT, FHWE and DP would improve grain yield.

Grain yield had shown highly significant negative genotypic and phenotypic correlation with malt moisture content and non significant negative correlation at both genotypic and phenotypic level for protein content. This could be due to nutrient and others competition between the traits that arise from their inherent nature of the linkage or pleiotropy. The negative correlation impedes the improvement of grain yield.

Phenotypic correlation among agronomic and malt quality traits

This study indicated that days to flowering showed positive and significant correlation at (P≤0.01) with plant height (r_p=0.624) and kernel thickness (r_p=0.47), whereas at (P≤0.05) with kernel width (r_p=0.208) (Table 2) which sugests that selection for those traits improves grain yield simultaneously. Alam et al. (2014) reported positive and non significant phenotypic association to plant height and days to flowering. Days to flowering revealed highly significant negative correlation with hectoliter weight (r_p= -0.379) and germination energy (r_p = -0.349). Alhassan et al. (2008) found negative correlation of days to flowering with α- and β- amylase enzymes, whereas, positive correlation to germination energy and malting weight loss.

Plant height showed significant (P≤0.01) positive correlation with kernel length (r_p = 0.347), kernel thickness (r_p=0.328), hot water extract (r_p=0.303) and diastatic power whereas, negatively and significantly correlated with germination energy (r_p=- 0.195). Plant height showed significant positive association to germination energy and negative to association to α- and β- amylase enzymes were reported by Alhassan et al. (2008). The negative correlation between those traits makes it impossible to achieve the simultaneous improvement of those traits along with each other. Kernel length showed positive significant (P≤0.01) association with kernel thickness (r_p=0.451) and germination energy (r_p=0.3).

Thousand kernel weight revealed significant positive association (P≤0.01) for days to flowering (r_p=0.27), plant height (r_p=0.367), grain yield (r_p=0.715), hectoliter weight (0.467), kernel length (r_p=0.581), kernel width (r_p=0.491) and kernel thickness (r_p=0.493) and at (P≤0.05) for germination energy (r_p=0.221). This indicates that simultaneously improvement of these traits. Amsalu and Endashaw (2012), found similar result with plant height and thousand kernel weight with days to flowering. The positive correlation of thousand kernel weight with germination energy, malting weight loss and diastatic power is similar with the finding of Beta et al. (1995). Positive correlation of thousand kernel weight with grain size and test weight were reported by Adetunji (2011). Hectoliter weight showed highly significant positive association (P≤0.01) with kernel length (r_p=0.339), kernel width (r_p=0.300) and malting weight loss (r_p=0.287) while negative association with plant height.

Protein content revealed negative significant correlation (P≤0.05) to days to flowering and also non significant negative correlation to plant height, grain yield, thousand kernel weight, hectoliter weight, kernel thickness, fine grind hot water extract and malt moisture content. This negative correlation between two desirable traits may impede to achieve the simultaneous improvement of those traits along with each other. Similar results were reported by Kassahun et al. (2011) for days to flowering, maturity, plant height, thousand kernel weight and grain yield. Alhassan et al. (2008) also reported similar finding for germination energy, malting weight loss and malt moisture content.

Fine grind hot water extract showed positive association (P≤0.01) for days to flowering, (0.363), plant height, (0.303), kernel width (0.286) and kernel thickness (0.377) also positive association for hectoliter weight, kernel length and malting weight loss. However, negative association to germination energy. Non significant positive association of fine grind hot water extract with medium size seed, hectoliter weight and thousand kernel weights was found by Adetunji (2011). Malt moisture content showed significant negative association at (P≤0.01) with grain yield (r_p=-0.329) and plant height (rp=-0.322) and kernel width (r_p=-0.294), at (P≤0.05) to plant height (r_p=-0.241), kernel thickness (rp=-0.217) and kernel length (rp=-0.225). This is in harmony with Beta et al. (1995) and Alhassan and Adedayo (2011).

A positive significant correlation was shown for diastatic power at (P <0.01) with thousand kernel weight (rp = 0.246) and at (P <0.05) for grain yield (rp = 0.21) however, non significant negative correlation with days to flowering, protein content. According to Alhassan et al. (2008) Alfa- and β-amylase were positively correlated with thousand kernel weight, and negatively to days to flowering. Generally, positive phenotypic correlation of any pairs of traits of the present sorghum population indicated the possibility of correlated response to selection. In contrary to this, the negative correlation prevents the simultaneous improvement of those traits along with each other.

Genotypic correlation among the component traits

Days to flowering showed positive and highly significant correlation with kernel thickness (r_g=0.479) and plant height (r_g=0.679), while non significant positive correlation with kernel length (Table 2). In contrary, it shown highly significant negative association with hectoliter weight (rg=-0.395) and germination energy (rg=-0.362). Alhassan and Adedayo (2011), reported significant positive association of germination energy with days to flowering which is contrary to the current finding.

Plant height showed significant positive association (P≤0.01) with kernel length, (r_g=0.379), (P≤0.05) kernel thickness (r_g=0.338) whereas, negative association with germination energy. The positive correlation of GY, DF and PH suggests selecting sorghum genotypes with higher plant height might lead to reduced earliness and increased grain yield. This in agreement with Amsalu and Endashaw (2012) and in contrary to Alam et al. (2014) reported positive and non significant genotypic association to plant height and days to anthesis.

Thousand kernel weight showed positive significant correlation at (P≤0.01) with hectoliter weight (rg=0.502). Kernel length (rg=0.596), Kernel width (rg=0.603), kernel thickness (r_g=0.513) and at (P≤0.05) with MWL (r_g=0.3290). This probably indicated that longer phenological period of tall genotypes could result in large assimilate accumulation with the maximum contribution to thousand kernel weight and grain yield. This is partially agreed with the result of Amsalu and Endashaw (2012) for plant height and days to flowering. Non significant positive correlation of thousand kernel weight with test weight (Kg/hl) and positive significant for large side size and significant negative with small seed size association with grain size was found by Chiremba et al. (2011).

Protein content showed significant negative correlation with fine grind hot water extract (r_g=-0.275) and non significant negative correlation with days to flowering, plant height, grain yield, thousand kernel weight, hectoliter weight, kernel thickness, malt weight loss and diastatic power. For both genotypic and phenotypic associations this is in agreement with Adetunji (2011) for hectoliter weight, thousand kernel weight, seed size and fine grind hot water extract, and Alhassan et al. (2011) for plant height, days to flowering, malting weight loss and germination energy. The negative correlation of the desirable trait protein content to those traits may impede or makes it impossible to achieve the simultaneous improvement of those traits along with each other.

Fine grind hot water extract revealed positive correlation at (P≤0.01) with days to flowering (r_g=0.378), thousand kernel weight (r_g=0.369), and kernel thickness (r_g=0.378) at (P≤0.05) with plant height (r_g=0.303), kernel width (r_g=0.288) and grain yield (r_g=0.257) suggesting that longer phenological period of genotypes could result in large seed size with the maximum contribution to thousand kernel weight, grain yield and fermentable extract. Similarly, Adetunji (2011) reported positive correlation of total fermentable sugars to TKW and HLW.

Diastatic power revealed positive significant (P≤0.01) correlation with malt weight loss (r_g= 0.454) and thousand kernel weight (r_g=0.363); and at (P≤0.05) fine grind hot water extract (rg=0.276) and grain yield (rg=0.275). The significant positive correlation is in conformity with Edney et al. (2007). This indicates metabolic reaction created due to high disatatic power and germination energy resulted in respiration loss, rapid germination in short period of time and malting loss. The negative genetic correlation for some of the malting and agronomic traits indicated that improvement of malting quality traits will require more than just selection. According to Alhassan et al. (2008) α- and β-amylase were positively correlated with thousand kernel weight, and negatively to days to flowering were reported. Malt moisture content correlated negatively for all of the traits at both genotypic and phenotypic level. This is in accordance with Alhassan et al. (2008).

Generally, genotypic correlation coefficients were relatively higher in magnitude than that of phenotypic correlation coefficients, which indicated the presence of inherent association among various traits that could be mainly due to the presence of linkage and of the pleiotropic effects of different genes. However, in some cases the phenotypic correlation values were higher than the genotypic correlation values suggesting the importance of environmental effects. This finding is in agreement with previous findings of Khandelwal et al, (2015) in sorghum. The positive association between all possible pair of traits suggested that the possibility of correlated response to selection so that with the improvement of one trait, there will be an improvement in the other positively correlated trait. This is because a positive genetic correlation between two desirable traits makes the job of plant breeder easy for improving both traits simultaneously. Unlike positive correlation, negative correlation between two desirable traits may impede to achieve the simultaneous improvement of those traits along with each other.

Phenotypic direct and indirect effects of various traits on grain yield

Partitioning of phenotypic correlations into direct and indirect effects on grain yield (Table 2) revealed that the trait hectoliter weight showed the highest positive direct effect with value (0.307) on grain yield followed by thousand kernel weight (0.287), kernel length (0.258), plant height (0.227) while, diastatic power showed

Table 3. Estimates of direct (bold diagonal) and indirect effect (off diagonal) at phenotypic level of nine traits on grain yield.

Traits	PH	TKW	HLW	KL	KW	KT	FHWE	MMC	DP	r_p
PH	0.227	0.106	-0.034	0.090	-0.016	0.040	-0.008	0.016	0.009	0.428**
TKW	0.083	0.287	0.143	0.150	-0.042	0.060	-0.009	0.022	0.017	0.715**
HLW	-0.025	0.134	0.307	0.088	-0.022	0.002	-0.001	0.011	0.005	0.504**
KL	0.079	0.167	0.104	0.258	-0.042	0.055	-0.004	0.015	0.007	0.644**
KW	0.049	0.169	0.092	0.151	-0.072	0.079	-0.007	0.020	0.007	0.491**
KT	0.074	0.142	0.006	0.117	-0.047	0.121	-0.010	0.015	0.006	0.425**
FHWE	0.069	0.100	0.013	0.036	-0.020	0.046	-0.025	0.011	0.013	0.241*
MMC	-0.055	-0.092	-0.050	-0.058	0.021	-0.026	0.004	-0.068	-0.004	-0.329**
DP	0.044	0.100	0.034	0.039	-0.010	0.014	-0.007	0.006	0.048	0.271**

Residual = 0.24, r_{p} = phenotypic correlation with grain yield.

negligible positive direct effect on grain yield. However, kernel width (-0.072), malt moisture content (-0.068) and fine grind hot water extract (-0.025) had negative phenotypic direct effect on grain yield. So, the improvement of grain yield is as the expense of KW, MMC and FHE directly. Similar result was reported by Chittapur and Biradar (2015) for direct positive correlation of plant height, thusand kernel weight and seed size with grain yield.

Thousand kernel weights, both the direct and indirect positive effects largely via hectoliter weight and kernel length outweighed for the positive correlation with grain yield (r_p = 0.715**). So, both direct positive and indirect positive effects were the causes of the significant correlation. Therefore, such considerable indirect effects should be considered for selection. Considerable direct effect and positive significant correlation of thousand kernel weight with grain yield was reported by Khandelwal et al.(2015).

Plant height had positive direct effect and the phenotypic correlation with grain yield was significant positive. Its indirect effect via thousand kernel weight and other traits were mostly positive therefore, the positive correlation coefficient with grain yield was due to its direct and indirect effect. This is agreed with the finding of Kassahun et al. (2011).

Kernel length was another trait which had positive direct effect which is small as compared to its correlation coefficient. But it also contributed considerable positive indirect effect to grain yield via thousand kernel weight and hectoliter weight. Therefore, high positive correlation of kernel length with grain yield was due to both its positive direct effect and indirect effect via thousand kernel weight and hectoliter weight. The high positive correlation of KW with GY was mainly due to the indirect effects of Kernel length and thousand kernel length, so, KL and TKW should considered for grain yield improvement.

Diastatic power and kernel thickness showed positive direct effect (Table 3). The indirect effect of diastatic power via other characters was positive and negligible except TKW; therefore, its significant positive correlation coefficient with grain yield was mainly due to the indirect effect of thousand kernel weight.

Fine grind hot water extract, kernel width and Malt moisture content exerted directly negative effect on and negative correlation to grain yield. The positive association of FHWE with grain yield is mainly due to indirect effect of TKW. However, the negative association malt moisture with grain yield is due to both negative direct and indirectly effects of most of the traits. Negative direct effect of FHWE to grain yield was reported in barley by Pržulj et al. (2013).

The traits that exerted positive direct effect (thousand kernel weight, hectoliter weight, plant height and kernel length, kernel thickness, and diastatic) and their positive significant correlation coefficient with grain yield were known to affect grain yield in the favorable direction and needs much attention during the process of selection. Moreover the small indirect effects of TKW (0.169), HLW (0.143), PH (0.083) and KL (0.151) through other traits should be simultaneously considered. The phenotypic residual value (0.24) indicated that the traits which were included in the phenotypic path analysis explained 75.66% of the variation in grain yield.

Genotypic direct and indirect effects of various traits on grain yield

Estimates of genotypic direct and indirect effects of the selected traits on grain yield are presented in (Table 4). Genotypic path analysis showed that thousand kernel weight (0.334), exerted the highest positive direct effect to grain yield followed by hectoliter weight (0.309), kernel length (0.256) plant height (0.219). Diastatic power and

Table 4. Estimates of direct (bold diagonal) and indirect effect (off diagonal) at genotypic level of nine traits on grain yield**.**

Traits	PH	TKW	HLW	KL	KW	KT	FHWE	MMC	DP	r_g
PH	0.219	0.136	-0.037	0.097	-0.020	0.042	-0.006	0.017	0.007	0.453*
TKW	0.089	0.334	0.155	0.152	-0.054	0.063	-0.008	0.021	0.012	0.766**
HLW	-0.026	0.167	0.309	0.093	-0.029	0.004	-0.001	0.010	0.004	0.532**
KL	0.083	0.199	0.113	0.256	-0.054	0.056	-0.003	0.015	0.005	0.671**
KW	0.051	0.204	0.101	0.154	-0.089	0.085	-0.006	0.020	0.005	0.524**
KT	0.074	0.171	0.010	0.116	-0.061	0.123	-0.008	0.015	0.004	0.445**
FHWE	0.066	0.123	0.012	0.034	-0.026	0.047	0.021	0.011	0.009	0.257*
MMC	-0.056	-0.112	-0.050	-0.061	0.027	-0.028	0.004	-0.064	-0.003	-0.344*
DP	0.044	0.121	0.036	0.038	-0.012	0.014	-0.006	0.006	0.034	0.275*

Residual = 0.17, rg = genotypic correlation with grain yield.

fine grind hot water extract exerted negligible positive direct effect to grain yield. Similar result was reported by Chittapur and Biradar (2015) for direct positive correlation of plant height and thousand kernel weight.

Thousand kernel weight and Hectoliter weight which had significant high positive correlation (0.766**) and (0.532**), respectively with grain yield exerted positive direct effect (0.334) and (0.309). This indicated that the correlations of these traits with grain yield were found to be partly due to their direct effects. Therefore, simultaneous selection through these traits will be effective for grain yield improvement. Considerable direct effect and positive significant correlation of thousand kernel weight with grain yield was reported by (Khandelwal et al., 2015; Silva et al., 2017).

Plant height had positive direct effect and the genotypic correlation with grain yield was significant and positive. Its indirect effect via thousand kernel weight was positive therefore, the positive correlation coefficient with grain yield was mainly due to its direct and indirect effect. The direct positive effect of plant height to grain yield is in accordance with Kalpande et al. (2014) and Silva et al. (2017)

Kernel length revealed small positive direct effect to grain yield and also showed positive indirect effect through thousand kernel weight and hectoliter weight to grain yield. The causes of the positive association of kernel length with yield were mainly due to its positive direct effect and indirect effects through thousand kernel weight and hectoliter weight. Kernel width exerted direct negative effect on grain yield. The positive correlation with GY was due to the counter balance of the positive indirect effects of TKW, HLW and KL. So, the TKW, HLW and KL should be considered for the increment of grain yield.

Fine grind hot water extract has negligible positive direct effect and positive genotypic correlation with grain yield. This indicated that the positive correlation was mainly through in direct effect of thousand kernel weight. Diastatic power showed negligible positive direct effect to grain yield. The positive significant correlation of diastatic power with grain yield is due to the positive direct effect and positive indirect effects of thousand kernel weight.

Malt moisture content exerted directly negative effect on and negative correlation to grain yield. The negative association with grain yield is mainly due to the equivalent indirect effect of thousand kernel weight. The negative direct effect and correlation of MMC to grain yield was favorable, as malt moisture does not need to increase.

Generally, the positive significant correlation and positive direct effect of PH, TKW, HLW, KL, KT and FHWE, synchronization with considerable indirect effects of thousand kernel weight (0.204), hectoliter weight (0.155) plant height (0.084) and kernel length (0.154) will be most effective in improving grain yield of these genotypes. For all the traits taken to path analysis the direct effects are not equivalent to their correlation coefficients, so this allows for simultaneous selection at phenotypic level. The genotypic residual value (0.17) indicated that the traits used in the genotypic path analysis explained 82.06 % of the variation for grain yield.

Genotypic direct and indirect effects of various traits on diastatic power

Estimates of genotypic direct and indirect effects of the selected traits on diastatic power are presented in (Table 5). Genotypic path analysis showed that malt weight loss (r_g=0.382) had the greatest unfavorable positive direct effect. So, selection could be effective for genotypes having high diastatic power with low to medium malt weight loss. The positive direct effect of malting weight loss on diastatic power is indicative of the respiratory loss during seedling growth. The current study is in conformity

Table 5. Estimates of direct (bold diagonal) and indirect effect (off diagonal) at genotypic level of four traits on diastatic power.

Traits	GY	TKW	MWL	FHWE	r_g
GY	0.068	0.093	0.070	0.044	0.275*
TKW	0.052	0.122	0.126	0.063	0.363**
MWL	0.012	0.040	0.382	0.019	0.454**
FHWE	0.018	0.045	0.043	0.171	0.277*

Residual factor = 0.66

with Wenzel and Pretorius (1995) in sorghum. Alhassan et al. (2008) reported direct effect of (0.16) MWL to alpha amylase.

Thousand kernel weight (r_g=0.122), FHWE (r_g=0.171) exerted considerable direct effect and positive correlation to DP and showing the direct effects were higher than indirect effects. The considerable direct effect and positive correlation of FHWE to DP and the DP value of the genotypes above specification (28 SDU/g) indicates the availability of enough diastase enzymes to digest the starch to get fermentable sugars. This is in agreement with Kumar et al. (2014) for both timely and late sown barley and in contrary to Bichoński and Śmiałowski (2004) in Bbarley of DP and FHWE. Kumar et al. (2014) also reported that TKW (0.222) direct effect to malt extract in late sown barley. Grain yield exerted negligible positive direct effect to DP and its significant correlation with DP was due its both direct effect and indirect positive effects of TKW, MWL and FHWE. Therefore, Selection through direct positive effect of TKW, FHWE and low to medium malt weight loss content (higher dry malt mass) genotypes will be effective in improving sorghum diastatic power.

Path coefficient analysis in this study did not account for all variation in diastatic activity as indicated by the magnitude of the residual effects (0.66) of the nine agronomic and malting quality traits which pointed out that there are other traits in addition to the four traits to be included in the path analysis that contribute to diastatic activity. This is agreed with the high residual effect (0.97) for sorghum diastatic power as reported by Wenzel and Pretorius (1995), (0.4) for sorghum α-amylase activity (Alhassan et al., 2008) and for finger millet agronomic traits to grain yield (0.89) (Abuali et al., 2012).

SUMMARY AND CONCLUSIONS

Grain yield (kg ha^{-1}) was found to be positively and significantly correlated with PH, TKW, HLW, KL, KW, KT, FHWE and DP both at phenotypic and genotypic level and significant positive correlation with GE at phenotypic level. So, the significant genotypic correlations of PH, TKW, HLW, KL, KT and higher r_g than r_p can be concluded that the association was inherent and selection would be effective to improve GY of the genotypes.

Focus on the direct and indirect favorable effect and significant positive correlation of TKW, HLW, KL, KT, and PH at both Phenotypic and genotypic level needs much attention and implies that selection on these traits would have a tremendous value for yield improvement of these sorghum genotypes. The considerable direct effect of TKW (0.122), FHWE (0.171) and their positive correlation with DP at genotypic level and increment in these traits would results in advancement of DP. However, unfavorable positive direct effect and significant correlation of MWL with DP genotypic level impedes DP improvement.

So, in order to bring an effective improvement of grain yield and malt quality traits, more attention should be given for traits such as PH, TKW, kernel size which showed high positive phenotypic and genotypic correlation coefficients with a considerable direct and indirect effect on grain yield and the positive correlation of the most limiting malt quality traits of DP and FHWE with grain yield of sorghum genotypes in the present study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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