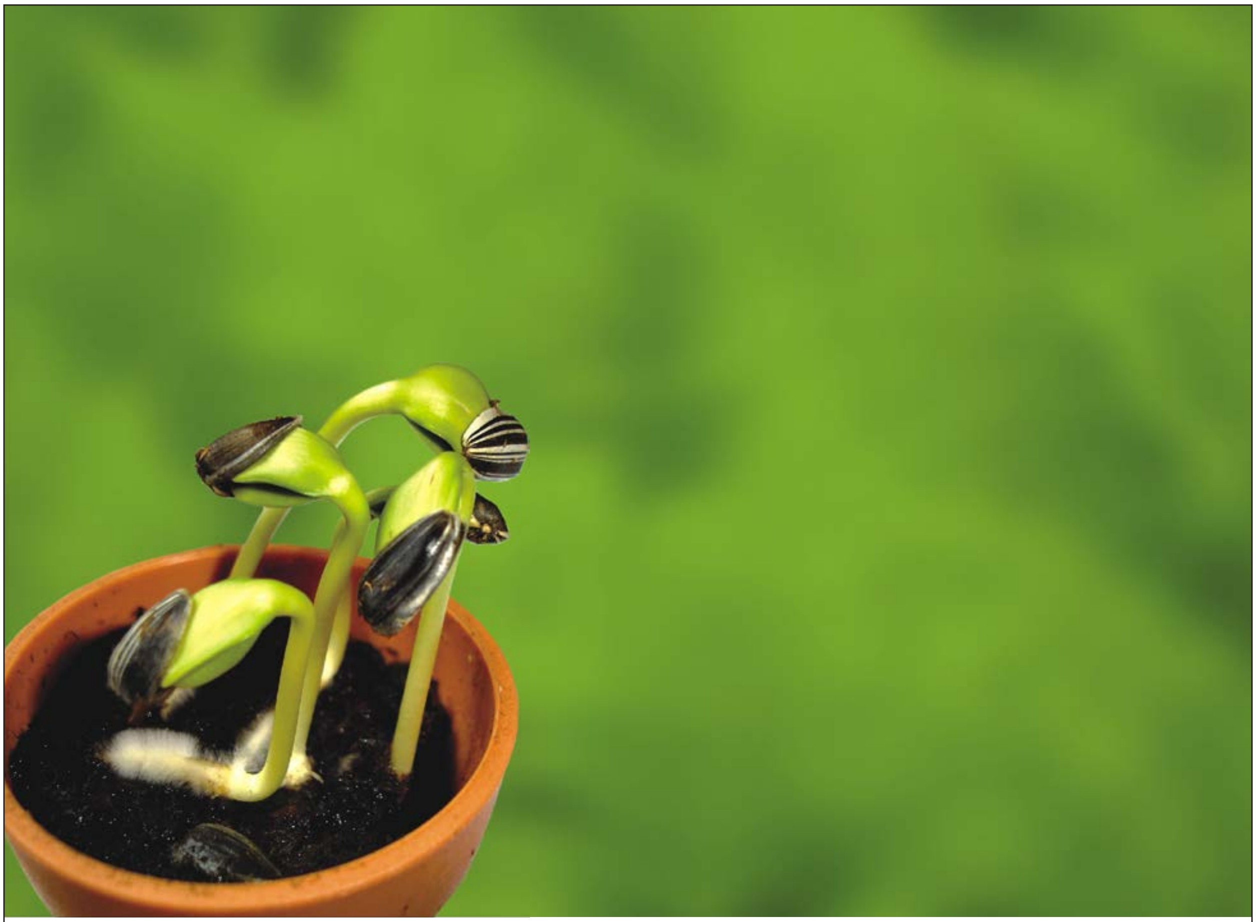

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Variation and Associations of Quality Parameters in Ethiopian Durum Wheat (*Triticum turgidum* L. var. *durum*) Genotypes

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ABSTRACT

Knowledge on variability and quality of durum wheat genotypes for pasta making as well as associations among quality parameters is important to design a suitable plant breeding program. Sixteen durum wheat genotypes were tested at Sinana and Adaba, Southeastern Ethiopia during 2009 bona season. The experiment was laid out in a randomized complete block design with three replications. Thirteen quality parameters were included in the study. Pooled analysis of variance revealed significant differences among genotypes for all quality parameters studied indicating the presence of variability. Genotypic correlation coefficient depicted important quality parameters are positively correlated with grain protein content, suggesting a common genetic basis among these traits and indicating the possibility of simultaneous improvement. Yellow pigment content showed the highest heritability value of 84.3% and gluten index had the lowest value of 3.8%. Dry gluten content (0.65**) and thousand kernel weight (0.26*) had the highest positive direct effect on grain protein content and significant positive genotypic correlation with grain protein content. Hence these traits are important as selection criteria for improvement of grain protein content in durum wheat. Protein content of the genotypes ranged from 10.7% (CDSS94) to 13.2% (Leliso). The study also showed variations in gluten strength as measured by alveograph strength W ranging from 64.3×10^{-4} J (Gerardo) to 187.6×10^{-4} J (Hitosa). Considering the performance of genotypes across most quality parameters, all the studied genotypes except Gerardo, Oda and Cocorit-71 were superior and could also serve as donor sources in durum wheat breeding programs for good pasta making quality.

Key words: Alveograph strength, correlation coefficient, gluten strength, *Triticum turgidum* L. var. *durum*, protein content

INTRODUCTION

Tetraploid (2n = 4x = 28) wheats have been under cultivation in Ethiopia since ancient times. Among the tetraploids, durum wheat (*Triticum turgidum* L. var. *durum*) is the predominant species (Tesfaye, 1991). Various researchers (Simane *et al.*, 1993; Messele, 2001) reported the uniqueness of the Ethiopian tetraploid wheat germplasm for different useful traits. In Ethiopia, durum wheat is traditionally planted on heavy black clay soils (vertisols) of the highlands between 1800 and 2800 masl (Tesemma and Belay, 1991). It is produced exclusively by peasant farmers under rainfed conditions with little or no fertilizer or weeding (Tesemma, 1991). Bozzini (1988) reported that durum wheat is best adapted to regions having a relatively dry climate, with hot days and cool nights during the growing season, typical of Mediterranean and temperate climates. Arsi and Bale highlands of Southeastern Ethiopian are some of the regions which are highly suitable for durum wheat production (Gebre-Mariam, 1991).

Quality is an important aspect of durum wheat. High-quality pasta begins with good quality wheat (Mariani *et al*., 1995). Durum wheat is the best wheat for superior pasta products due to its kernel hardness, vitreous endosperm and golden amber color which also vary among durum wheat genotypes (Motalebi *et al*., 2007). Cooked pasta made from durum wheat semolina retains good firmness and elasticity and is resistant to surface disintegration and stickiness (Bechere *et al*., 2002; Motalebi *et al*., 2007). Pasta is delicious and healthy food as a ready source of protein and complex carbohydrates. Modern food science has revealed that pasta is rich in minerals such as iron, phosphorus and essential B Vitamins (Thiamine, Niacin and Riboflavin) (Petrova, 2007). Now it is also fortified with folic acid which is important for the early development of infants in the womb (Petrova, 2007). The basic quality criteria valid today include a high yield of highly refined semolina; high protein and yellow pigment content, strong gluten and good pasta cooking quality (Mariani *et al*., 1995; Dexter and Marchylo, 2000). Protein content and type in the grain of durum wheat is important for human nutrition and end use processing quality. In addition, high protein determines premium prices for wheat in many regions of the world, making high grain protein content a primary target for durum wheat and hard common wheat breeding programs (Olmos *et al*., 2003).

In Ethiopia, research on durum wheat improvement since its beginning until recently has focused mainly on improving grain yield and disease resistance as reported by Tarekegn *et al*. (1995), Letta *et al*. (2008) and Abebe *et al*. (2008). With the expansion of agro industries, good processing quality durum wheat grain has become increasingly important for variety release (MARD, 2004). Currently, there are large markets for durum wheat for domestic consumption and for export to other countries where there is a greater demand for food due to increasing populations and improving standard of living. On the other hand, limited work has been done on determining quality requirements of Ethiopian durum wheat genotypes used for pasta and other products (Letta *et al*., 2008; Abebe *et al*., 2008).

Plant geneticists and breeders have made significant efforts in the past to improve the quality of seed proteins (Yadav and Singh, 2011). Quality improvement in wheat is possible through evaluation and selection, whenever wide variation exists in breeding material (Peterson *et al*., 1998). Response to selection for quality depends on the heritability, genetic advance of quality traits and correlated response with other characteristics (Fisher *et al*., 1989). The genetic progress achievable through breeding is largely dependent on the identification of genotypes with better quality attributes and of critical traits on which selection can be based (Ammar *et al*., 2000).

Correlation coefficient is helpful in determining main traits influencing grain protein content and grain yield for indirect selection criteria. However, it provides incomplete information regarding relative importance of direct and indirect effects on individual factors involved (Zecevic *et al*., 2004). On the other hand, path coefficient analysis revealed a complex pattern of relationships among traits and divides the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959). Path coefficient analysis was used for identification of complex relationships among agronomic traits in durum wheat (Garcia del Moral *et al*., 2005; Sadeghzadeh and Alizadeh, 2005; Yagdi, 2009), spring wheat (Li *et al*., 2006) and bread wheat (Khan *et al*., 2003, 2005; Kotal *et al*., 2010; Tripathi *et al*., 2011). However, limited information exists on interrelationships among quality traits in Ethiopian durum wheat.

In the present study, durum wheat genotypes were evaluated for quality parameters related to pasta making. Moreover, traits associations were analyzed and the direct and indirect contribution of traits to the association was examined by applying path analysis.

MATERIALS AND METHODS

Plant materials and experimental design: Sixteen durum wheat genotypes were included in the study (Table 1). Thirteen genotypes were released varieties by the wheat breeding program at Sinana and Debre Zeit Agricultural Research Centers and three are Sinana Agricultural Research Center advanced durum wheat breeding lines. They were selected based on their agronomic performances and suitability to the growing conditions. The variety Cocorit-71 was used as a check. The traits studied were thousand kernel weight, test weight, kernel vitreousity, grain hardness, protein content, wet gluten content, dry gluten content, gluten index, yellow pigment content, SDS-sedimentation volume and alveograph parameters. The genotypes were grown under rainfed during 2009 main (*bona*) crop growing season for one year with uniform conditions at Sinana and Adaba, Southeastern Ethiopia. Sinana is found at 7°N latitude and 40°E longitude and 2400 masl, 867.7 mm mean annual rainfall, with the average annual temperatures of 20.5°C for the maximum and 10.1°C for the minimum during the crop growing season) (SARC, 2009). The area has bimodal rainfall pattern with two growing seasons; *bona* (Meher) extending from August to December and *ganna* (Belg) from March to July. Mean seasonal rainfall generally ranges from 354-716 mm for *bona* and 346-1030 mm for *ganna*. The soil is clay in textural type with slightly acidic pH (Yadessa *et al*., 2008).

Adaba has an elevation of 2365 masl. The area has monomodal rainfall pattern with the growing season extending from June to November. The mean annual rainfall ranges from 600 mm to 750 mm and it has mean monthly temperature varying from 4.5-9.6°C for the minimum and 22.6-26.4°C for maximum temperatures (BADE, 2009). The soil type is chromic and pelvic vertisols and dystric and humic cambisols. Chromic and pelvic vertisols are predominantly found in flat areas while dystric and humic cambisols mainly occur in steep sloping areas at high altitude where rainfall is high (Dejene and Hassena, 1994).

Table 1: Description of durum wheat genotypes studied

Genotypes	Pedigrees and/selection history	Year of release
Bakkalcha	98-OFN-Gedilfa/Guerou/ 15patho	2005
Cocorit-71	-	1976
Denbi	AJAIA/BAUSHEN... CSS98IY00025-0MXI-3QK-4DZR	2009
Ejersa	LABUD/NIGRIS-3//Gan-CD98206	2005
Gerardo	VZ466/61-130xLdsxGII's'CM9605	1976
Hitosa	CHEN/ALTAR 84...CDS-97-B00265... IQX... 6DZR	2009
Ilani	Ilumilo/Rahum/A4#72/3/Gerardo	2004
Leliso	Cit-71/3/Gerardo//61-130/G//"S"/4/Boohai//Hora//Gerardo/3/ Boohai	2002
Obsa	ALTAR84//ALTAR84/SERI/3/6* ALTAR84	2006
Oda	DZ046881/imlo//cit71/3/RCHI/LD357//imlo/4/Yemen/cit'5'/Plc's'/3/Taganroy	2004
Tate	DACK/KIWI/OSTE/3/CHEN 84//4/MEXI/5/5...	2009
Ude	CHEN/ALTAR84//JO69	2002
Yerer	CHEN/TEZ/GVIL//C11	2002
CDSS94	CANGRUS/POHO-1//SUGU-14CDSS94Y00597T-A-1M-0Y-0B-1Y-0B	Advanced line
CD86772	Cocorit-71/DUKEM/DON87 CD86772-DZ491	Advanced line
CD1B2620	KUCK CD1B2620-G-8M-030Y-030M-2Y-0-2Y-0B	Advanced line

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot was 2.5 m long and 2.4 m wide, with twelve rows 20 cm apart, giving a gross plot area of 6 m^2 and net plot area of 5 m^2. Adjacent blocks were 1 m apart. Sowing was done by hand drilling and covered lightly with soil. The seed and fertilizer rate was 150 kg ha^{-1} and 41/46 N/P_2O_5 kg ha^{-1}, respectively (MARD, 2004). All other agronomic practices were done as recommended for wheat production in the area (Geleto *et al*., 2008).

Quality analysis: Random homogenous sample of each harvested genotypes was used for laboratory analysis. Test weight and thousand kernel weights were measured on dockage free basis as described (AACC, 2000) Method 55-10 and 55-31, respectively. Kernel vitreousity was estimated by using transmitted light according to ICC standard number 129 (ICC, 2000).

Grain hardness was analyzed by particle size index method as described in the AACC method 55-31. The wheat grain samples were milled with a CD1 mill (CHOPIN, 2001) fitted with 1 mm sieve after well blended and cleaned grain samples were conditioned to 12% moisture content. Higher values indicate softer kernel texture. Grain nitrogen content on 12.5% mb (moisture basis) was determined by micro-kjeldahl (method 46-11). Urea was used as a control in the analysis; Values are multiplied by 5.75 for grain protein content determination. The wet gluten content was determined by hand washing method (AACC Method 38-10-01) using 10 g of flour mixed with 5 mL of 2% sodium chloride solution for the washing and dry gluten content was estimated after drying total wet gluten piece at 100°C for 24 hours in air draught oven to get the dry mass according to AACC Method 38-10. Approved AACC Method 38-12 was followed for the determination of Gluten Index (GI) of whole meal samples.

Yellow pigment content (14%, mb) was determined after extraction of the pigment from 3 g flour in 15 mL water saturated n-butanol (WSB) (1:5 v/v). The resultant solution were then filtered through Whatman No.1 filter paper and the extract was analyzed on a UV-visible spectrophotometer at 435.8 nm (Spectronic Genesis 20, USA) against WSB as a blank (AACC, 2000 Method 14-50). Absorbance (1.6632) of 1 mg pigment in 1 cm cuvet dissolved in 100 mL WSB was used in the conversion (Johnson *et al*., 1980; Santra *et al*., 2003). Then the pigment mass was calculated by the following equation:

$$\text{Yellow pigment (ppm)} = \frac{\text{Sample absorbance} \times 0.15}{1.6632 \times \text{Sample weight (g)}} \times 1{,}000$$

The SDS Sedimentation volume was determined by measuring the SDS sedimentation volume increase for a batch of eight samples by hand mixing procedure using 3% SDS-lactic acid as a reagent as described in the AACC Method No.56-70. The sedimentation volume was recorded to the nearest 0.5 mL after 20 min at room temperature. Results were expressed in height (mL) of the interface line between solid (ground sample) and liquid (solution) into a measuring cylinder.

Alveograph parameters were analyzed on an alveograph (Chopin MA 82, Villeneuve-la-Garenne, France) according to Approved Method 54-30A. At least 5 replicates per sample were obtained. The resulting alveogram were used to determine, elasticity (P, mm) an indicator of dough resistance to pressure, extensibility (L, mm) at the point of bubble rupture and gluten strength parameter (W, 10^{-4}J) required to inflate the dough bubble until it ruptures. The elasticity/ extensibility ratio (P/L), an indicator of the rheological balance of the dough was also computed.

Statistical analysis: The SAS GLM procedure (SAS, Institute, 2002) was employed for the analysis of variance. Fisher's Least Significant Difference (LSD) test at 5% level of significance was used for mean comparisons, whenever F- tests were significant. Combined analysis of variance was carried out after verifying the homogeneity of error variance using Bartlett's χ^2 test following fixed effect model (Gomez and Gomez, 1984). Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) were calculated following the method of Burton (1952). Broad-sense heritability (h^2) was calculated as the ratio of the genotypic variance to the phenotypic variance according to Singh and Ceccarelli (1996). Genetic advance as percentage of the mean was also estimated following the procedure of Singh and Chaudhary (2004).

Genetic correlations among traits were done at 1 and 5% probability levels using variances and covariances according to Singh and Chaudhary (2004). Path analysis was carried out using GENRES3 for windows version 7.01, Pascal Intl Software Solutions (GENRES3, 1994) to study the direct and indirect contributions of the traits to the associations according to Dewey and Lu (1959), Li (1975) and Williams *et al.* (1990). Traits that were significantly correlated with grain protein content were entered as a predictor variable in the path analysis that estimated their direct and indirect effects on grain protein content which is the response variable.

The contribution of the remaining unknown factor was measured as the residual factor and was calculated as:

$$\text{Residual effect} = \sqrt{1 - R^2}, \text{ where } R^2 = \sum p_{ij} r_{ij}$$

Where:

r_{ij} = Mutual association between the independent variable 'i' and the dependent variable 'j' as measured by correlation coefficient

p_{ij} = Components of direct effects of the independent variable 'i' on dependent variable 'j' as measured by the path coefficients

RESULTS AND DISCUSSION

The pooled analysis of variance revealed highly significant difference ($p<0.01$) among genotypes for all quality parameters studied (Table 2). The significant difference among genotypes for the parameters implies the presence of variation among genotypes which is central to the study of both quantitative and qualitative traits. These give an opportunity to plant breeders for improvement of these characters through breeding. It also showed highly significant ($p<0.01$) effects of locations for test weight, vitreousity, grain hardness, wet gluten content, yellow pigment content and alveograph strength and significant ($p<0.05$) effect on SDS sedimentation volume. However, it depicted non significant effects of location on thousand kernel weight, grain protein content, dry gluten content, alveograph elasticity and elasticity/extensibility ratio. Similarly, it revealed highly significant ($p<0.01$) G×L interaction for all traits combined except wet and dry gluten contents. Genotype×location interactions is important in evaluating genotype adaptation, selecting parents and developing genotypes with improved end-product quality (Ames *et al.*, 1999). The existence of genotype× location interaction indicates that selection should be carried out in a range of environments and it is essential to breed different genotypes for specific environment (Falconer and Mackay, 1996). Based on the results obtained in this study, it is recommended to

Table 2: Estimates of statistical and genetical parameters of 13 quality traits in sixteen durum wheat genotypes from combined analysis of variance

Parameters	TKW	TW	V	GH	GPC	WGC	DGC	GI	SDS	YPC	W	P	P/L
MSg	118.88**	10.46**	292.79**	13.17**	2.66**	39.98**	5.1942**	147.60**	92.44**	6.39**	5192.80**	19.98**	1.51**
MS_l	4.17^{ns}	28.17**	1917.09**	249.29**	1.71^{ns}	1207.71**	13.58^{ns}	1794.01**	1934.11*	18.46**	61357.59**	43.85^{ns}	3.76^{ns}
$MS_{g\times l}$	8.35**	0.55**	123.52**	10.08**	0.87**	4.10^{ns}	1.0158^{ns}	135.97**	53.56**	0.38**	1197.98**	8.26**	1.74**
PCV	11.02	1.73	9.64	17.27	7.19	12.23	13.94	9.49	16.22	20.04	28.98	29.22	43.58
GCV	10.06	1.56	6.11	5.31	4.57	8.73	8.70	1.86	6.27	18.40	19.49	15.63	8.92
$h^2_{(B)}$	83.34	81.51	40.11	9.46	40.36	51.01	38.99	3.84	14.93	84.32	45.23	28.62	4.19
GA (%mean)	18.93	2.91	7.97	3.37	5.98	12.85	11.19	0.75	4.99	34.81	27.00	17.23	3.76

**, *: Significant at 0.01 and 0.05 probability levels respectively, ns: non significant, MSg: Mean squares due to genotypes, MSl: Mean squares due to locations, MS_{gxl}: Mean squares due to genotype × location interaction, PCV: Phenotypic coefficient of variability, GCV: Genotypic coefficients of variability, h2 (B): Broad sense heritability (%), GA: Genetic advance, TKW: Thousand kernel weight (g), TW: Test weight ($kghl^{-1}$), V: Vitreousity (%), GH: grain hardness (%), GPC: Grain protein content (%), WGC: Wet gluten content (%) ,DGC: Dry gluten content (%), GI: Gluten index (%), SDS: Sedimentation volume (mL), YPC: Yellow pigment content (ppm), W: Alveograph dough strength (x10-4J), P: Elasticity (mmH_2O), P/L: elasticity/ extensibility ratio

develop durum wheat varieties for different environment with respect to important quality traits which is generally considered as major target in durum wheat breeding program.

Variations, heritability and genetic advance: Phenotypic and genotypic coefficients variations, broad sense heritability and genetic advance as percent of mean of the studied durum wheat genotypes for different quality parameters are presented in Table 2. Accordingly, thousand kernel weight, yellow pigment content, alveograph dough strength and alveograph elasticity showed higher PCV (phenotypic coefficients variations) and GCV (genotypic coefficients variations) values (>10%), indicating less environmental influence on the expression of these traits and greater scope for improvement through breeding. On the other hand, test weight, grain protein content, dry gluten content and elasticity/ extensibility P/L ratio revealed lower GCV values (<5%). The magnitude of phenotypic coefficients of variation was greater than that of genotypic coefficients of variations for all the traits studied. Similar results were observed by Kotal *et al.* (2010).

Heritability is a measure of the genetic contribution to phenotypic variability. It is a measure of the degree to which observed phenotypic differences for a trait are genetic, remainder being due to environment. The most important function of the heritability in the genetic study of metric and qualitative traits is its predictive role, expressing the reliability of the phenotypic value as a guide to the breeding value (Nyquist and Baker, 1991; Rehman and Alam, 1994). Broad sense heritability of the studied genotypes ranged from 3.8 to 84.3% for gluten index and yellow pigment content, respectively. Consequently, yellow pigment content, thousand kernel weight and test weight showed the highest heritability values. High heritability coupled with high expected genetic advance as percent of mean (assuming selection intensity of 5%) was observed for yellow pigment content and thousand kernel weight and the intermediate to high heritability for wet gluten content, dry gluten content and alveograph strength W. This suggests high breeding value and more additive genetic effects and selection can be effective for these traits in this population. These are in agreement with the study of Bushuk (1998) who reported that most quality traits in wheat has high heritability values and indicated the potential of improving wheat for end product use quality through conventional plant breeding. Similarly, Lukow and McVetty (1991) and Peterson *et al.* (1998) reported that several characters contributing to good quality have high heritability values.

Genotype performance for quality parameters: Mean performance values of the studied genotypes for different quality parameters are given in Table 3. The studied genotypes showed thousand kernel weights variation ranging from 35.4 to 48.6 g and test weight from 79.5 to 83.8 kg hl^{-1}. This range was consistent with the results of Bechere *et al.* (2000) and Gashawbeza *et al.* (2003) from 33-50 g for thousand kernel weight and 76-86 kg hl^{-1} for test weight on Ethiopian released durum wheat varieties. Accordingly, Denbi, Hitosa, CDSS94 and Ejersa showed the highest values, whereas; Ilani, Cocorit-71 and Gerardo had significantly lower test weight values ($p<0.05$) than other genotypes. The acceptable thousand kernel weight for durum wheat is 30-35 g db (dry basis) (Petrova, 2007) and that of test weight is 81 kg hl^{-1} (Sissions, 2004; Petrova, 2007; Abebe *et al.*, 2008).

Vitreousity of the studied genotypes exhibited wider ranges from 71.2 to 95.8%. Higher endosperm vitreousity in durum wheat grain is indicative of an increase in the production of semolina than flour (Bushuk, 1998; Xie *et al.*, 2004). Twelve out of 16 genotypes showed vitreousity of over 80% which most milling industries demand and pays premium price for the farmers (Sissions, 2004; Petrova, 2007). Leliso (13.2%) had the highest protein content followed by Yerer (13.0%), Ejersa (12.8%), Oda (12.4%) and Bakkalcha (12.2%) (Table 3). High grain protein content is one of the most important factors determining pasta and bread making quality and is also important to human nutrition. Adequate quantity and quality of wheat protein is necessary if the final products are to have good tolerance to overcooking, low cooking loss, desirable organoleptic features and acceptable nutritional value. Galterio *et al.* (1993) and Mariani *et al.* (1995) have

Table 3: Mean values of sixteen durum wheat genotypes for different quality parameters

SN	Genotypes	TKW‡	TW‡	V‡	GH‡	GPC‡	WGC‡	DGC‡	GI‡	SDS‡	YPC‡	W‡	P‡	P/L‡
1	Bakkalcha	47.2^{b}	82.7^{cd}	90.83^{de}	13.32^{def}	12.23^{cd}	27.35^{cdef}	9.52^{cde}	76.8^{def}	44.8^{ab}	5.3^{ef}	126.2^{defg}	9.5^{bcdef}	2.5^{bc}
2	Cocorit-71	41.0^{e}	79.9^{g}	71.17^{j}	15.77^{ab}	11.75^{defg}	29.72^{bc}	9.90^{bcd}	72.0^{hi}	40.4^{bcd}	3.0^{h}	117.3^{efg}	7.8^{efg}	1.7^{ed}
3	Denbi	37.2^{g}	83.8^{a}	91.50^{cd}	12.22^{fgh}	11.63^{efg}	25.18^{f}	8.53^{e}	76.5^{def}	42.2^{bc}	6.0^{c}	173.7^{ab}	11.4^{ab}	2.9^{ab}
4	Ejersa	43.1^{d}	83.1^{bc}	95.83^{a}	12.18^{fgh}	12.80^{ab}	31.33^{ab}	10.88^{ab}	77.3^{cde}	41.2^{bcd}	5.6^{de}	151.9^{bcd}	9.7^{bcde}	2.3^{bcd}
5	Gerardo	46.3^{b}	80.1^{g}	86.10^{f}	12.85^{efg}	12.07^{cde}	28.20^{cde}	9.35^{cde}	75.0^{ef}	36.6^{de}	4.4^{g}	64.3^{h}	5.1^{h}	1.5^{e}
6	Hitosa	38.1^{g}	83.8^{a}	92.83^{bc}	11.52^{gh}	11.30^{g}	25.00^{f}	8.57^{e}	81.3^{b}	47.6^{a}	6.5^{b}	187.6^{a}	13.1^{a}	3.5^{a}
7	Ilani	48.6^{a}	79.5^{g}	87.50^{f}	13.68^{cdef}	11.98^{cdef}	26.97^{cdef}	9.37^{cde}	74.7^{fg}	44.9^{ab}	5.3^{f}	156.5^{bc}	9.1^{cdefg}	1.9^{cde}
8	Leliso	46.9^{b}	82.7^{cd}	78.17^{i}	14.97^{abcd}	13.22^{a}	31.57^{ab}	10.85^{ab}	72.2^{gh}	33.4^{e}	4.4^{g}	108.2^{fg}	7.2^{g}	1.7^{de}
9	Obsa	37.0^{g}	82.4^{def}	78.83^{hi}	15.22^{abc}	11.27^{g}	25.25^{ef}	9.18^{de}	79.5^{bc}	40.5^{bcd}	6.6^{ab}	128.9^{cdef}	9.0^{cdefg}	2.3^{bc}
10	Oda	48.8^{a}	82.6^{cde}	91.83^{cd}	12.83^{efg}	12.35^{bc}	29.77^{bc}	10.20^{abcd}	66.0^{k}	37.4^{cde}	5.7^{cd}	98.9^{g}	7.5^{fg}	2.2^{cde}
11	Tate	39.7^{f}	82.5^{cdef}	89.83^{e}	13.08^{efg}	11.93^{cdef}	26.93^{cdef}	9.28^{cde}	84.7^{a}	43.9^{ab}	5.2^{f}	123.6^{defg}	8.3^{defg}	2.0^{cde}
12	Ude	46.7^{b}	82.6^{cde}	93.83^{b}	12.87^{efg}	11.87^{cdef}	28.32^{cd}	9.43^{cde}	70.0^{hij}	36.4^{de}	5.5^{def}	146.0^{bcde}	10.4^{bc}	2.4^{bc}
13	Yerer	44.6^{c}	81.9^{f}	93.67^{b}	11.07^{h}	13.00^{a}	33.50^{a}	11.27^{a}	78.0^{cd}	37.1^{cde}	4.5^{g}	146.6^{bcd}	10.1^{bcd}	2.2^{cde}
14	CDSS94	41.6^{e}	83.5^{ab}	83.17^{g}	16.07^{a}	10.65^{h}	25.75^{def}	8.33^{e}	68.7^{j}	42.8^{ab}	5.5^{def}	126.0^{defg}	$8.1d^{efg}$	1.9^{cde}
15	CD86772	35.4^{h}	82.0^{ef}	79.83^{h}	14.52^{abcde}	11.77^{defg}	27.67^{cdef}	10.47^{abc}	76.3^{def}	43.5^{ab}	6.8^{ab}	139.2^{cde}	8.7^{cdefg}	2.4^{bc}
16	CD1B2620	40.4^{ef}	82.9^{cd}	86.83^{f}	14.07^{bcde}	11.48^{fg}	25.42^{def}	8.35^{e}	69.5^{ij}	37.3^{cde}	6.9^{a}	123.3^{defg}	8.1^{defg}	1.9^{cde}
Mean		42.7	82.2	86.99	13.51	11.96	28.00	9.59	74.9	40.6	5.4	132.4	8.9	2.2
SE		0.48	0.21	0.49	0.62	0.18	1.05	0.44	0.91	1.83	0.12	10.22	0.71	0.24
LSD (5%)		1.35	0.6	1.40	1.76	0.51	2.96	1.24	2.58	5.17	0.35	28.91	2.02	0.67
CV (%)		2.75	0.64	1.39	11.28	3.71	9.15	11.18	2.98	11.02	5.54	18.91	19.53	26.4

TKW: Thousand kernel weight (g), TW: Test weight(kghl-1), V:Vitreousity (%), GH: Grain hardness (%),GPC: Grain protein content (%), WGC: Wet gluten content (%), DGC: Dry gluten content (%), GI: Gluten index (%), SDS: Sedimentation volume (mL), YPC: Yellow pigment content (ppm), W: Alveograph dough strength ($\times 10^{-4}$J), P: Elasticity (mmH2O), P/L: Elasticity/ extensibility ratio, ‡Means within each column followed by the same letter are not significantly different from each other at ($p<0.05$)

indicated that durum wheats with 13% protein could provide excellent products whereas wheats with protein contents below 11% give products of inferior quality. However, the large differences in the rheological and cooking properties of gluten existing among genotypes of similar protein content have posed the problem on durum wheat gluten quality.

The genotypes under this study can be classified in to two groups based on their performance with respect to grain hardness classification according to Hruskova and Svec (2009). Consequently, genotypes Yerer and Hitosa were in the very hard to hard range in grain hardness based on the particle size index, whereas, the remaining genotypes were in the hard class. Endosperm hardness can affect the amount of starch damaged during the milling process and subsequently the water requirements of the resulting flour. Grain hardness is a strong predictor of dough handling and loaf texture characteristics. It varies significantly between wheat classes and even between genotypes within a class (Hruskova and Svec, 2009).

Wet gluten content of the studied genotypes ranged from 25.0 to 33.5%. Yerer gave the highest wet gluten content followed by Leliso, Ejersa, Oda and Cocorit-71. Genotypes with higher wet gluten content had also higher dry gluten content. This is due to very high and positive correlation between these traits in the study. Dry gluten content of the studied genotypes ranged from 8.3% (CDSS94) to 11.3% (Yerer). This was within the range reported by Bechere *et al.* (2000) from 4.2 to 11.7%. Accordingly, Yerer, Ejersa and Leliso had higher dry gluten content. Dry gluten is an important trait for pasta quality i.e., genotypes having high protein content and gluten content are preferred for selection during quality breeding (Troccoli *et al.*, 2000).

Yellow pigment content ranged from 3.0 ppm (Cocorit-71) to 6.9 ppm (CD1B2620). CD1B2620, CD86772, Obsa and Hitosa had significantly ($p<0.05$) higher yellow pigment content than other genotypes, whereas, Cocorit-71 showed significantly the lowest values (Table 3). According to Landi (1995), genotypes under this study were classified in to two groups based on their yellow pigment content values, with values ranging from 3.0 to 5.0 ppm (parts per million) as a medium quality and values over 5.0 ppm as a high quality groups. Accordingly, genotypes like Cocorit-71, Gerardo, Leliso and Yerer are in the medium quality class and the remaining genotypes are in the high quality class. Grain yellow pigment concentration is a desirable end-use quality trait in durum wheat, where a bright yellow color is a standard quality pre-requisite for semolina and pasta products. High yellow pigment concentration, which confers intense bright yellow color durum wheat based products, is highly appreciated on the market (Santra *et al.*, 2003; Maccaferri *et al.*, 2009) for its consumer appeal and for the health benefits associated with carotenoids such as antioxidant activity and prevention of mascular degeneration (Abdel-Aal *et al.*, 2007). Generally, almost all genotypes under this study had yellow pigment content within the acceptable range for good pasta making quality.

Gluten index measures of gluten strength (quality) of the studied genotypes were within the acceptable range, i.e., higher than 60%. Maximum gluten index was observed for genotypes Tate (84.7%) followed by Hitosa (81.3%) and Obsa (79.5%). Oda (66.0%) showed relatively the lowest gluten index value as compared to other genotypes. The gluten index method provides information on both quantity and quality of wet gluten. Gluten index value is a criterion defining whether the gluten quality is weak, medium or strong. It is also a standard quality descriptor of high or low molecular weight glutenin subunit (Collar *et al.*, 2007).

SDS-sedimentation volume is a measure of gluten strength of wheat genotypes in breeding programs (Kovacs *et al.*, 1997). It is an important quality trait because of its predictive role in pasta making quality in durum wheat and positive correlations with other quality parameters of wheat (Brites and Carrillo, 2001). Hitosa, Ilani, Bakkalcha and CD86772 had highest SDS sedimentation volume than other genotypes, whereas; Leliso recorded the lowest sedimentation volume. Petrova (2007) reported on Bulgarian durum wheat varieties that sedimentation volumes of 25 to 35 mL indicate moderate gluten-strength varieties and volumes greater than 35 mL indicate strong-gluten varieties. According to the author, all the genotypes under this study were within moderate to strong gluten range based on SDS-sedimentation volume.

Alveograph measures of gluten strength parameters indicated a wide range of dough strength among the durum wheat genotypes. Gluten strength differences among genotypes were clearly distinguishable by W, P and P/L measurements. The Chopin alveograph analysis indicated that Hitosa (187.6×10^{-4} J) and Denbi (173.7×10^{-4}J) followed by Ilani (156.5×10^{-4}J) and Ejersa (151×10^{-4}J) performed well for alveograph dough strength (W). Gerardo, Oda and Leliso showed lower alveograph strength (W). Study by Cubadda *et al.* (1992) for alveograph W showed a range of values from 48 to 120×10^{-4} J. Therefore, in this study all genotypes are within and some are even higher than the range reported by the author.

Hitosa, Denbi and Ude, exhibited the highest alveograph elasticity (P). The alveograph elasticity/extensibility ratio (P/L) value showed very different gluten elasticity increasing from 1.7 to 3.5. Accordingly, Hitosa, Denbi, Bakkalcha and Ude showed the highest elasticity and lower extensibility. The greater dough resistance and lower extensibility may be associated with the increase in gluten protein quality. Alveograph parameters are the measures of dough viscoelastic properties and thereby gluten strength (quality). Du Cros (1987) found out that viscoelasticity of cooked pasta correlates strongly with protein content and type. The strong gluten quality of the genotypes may be due to the presence of HMW-GS and LMW-2/γ-45 gliadin. Ruiz and Carrillo (1995) found out that there is a general agreement that the presence of LMW-2/γ-gliadin45 allelic pattern and 6+8/7+8 HMWGS, in durum wheat, are correlated with strong gluten genotypes and good pasta-making quality, whereas that of LMW-1 and γ-gliadin 42 implicated to give poor pasta quality. This is very important for breeding of durum wheat and predicting the quality of flour and dough.

Correlation and path coefficient analysis: Genetic relationship of traits may result from pleotropic effects of a gene, linkage of two genes, linkage disequilibrium and epistatic effects of different genes or due to the environmental influences (Falconer and Mackay, 1996). The genotypic correlation coefficients showed significant association among some traits (Table 4). Thousand kernel weight (r_g = 0.55*), wet gluten content (r_g = 0.86**) and dry gluten content (r_g = 0.85**) revealed significant positive association with grain protein content. SDS sedimentation volume (r_g = -0.49*) showed negative and significant correlation with protein content. Vitreousity was negatively and strongly related to grain hardness. This implies harder genotypes were more vitreous as higher values of grain hardness based on particle size index indicates softness of the kernels. Therefore, the direction of the correlation will be reversed. Similarly, vitreousity showed positive and significant correlation with alveograph elasticity (r_g = 0.49*) and elasticity/extensibility ratio (r_g = 0.49*).

Test weight revealed significant positive association with yellow pigment content (r_g = 0.59*), alveograph elasticity (r_g = 0.52*) and elasticity/extensibility ratio (r_g = 0.62**). This is partially in accordance with the investigations of Rharrabti *et al.* (2000).

Table 4: Estimates of genotypic correlation coefficients among 13 quality parameters in durum wheat genotypes

Parameters	TKW	TW	V	GH	GPC	WGC	DGC	GI	SDS	YPC	W	P	P/L
TKW	1.0	-0.36	0.26	-0.15	0.55*	0.50*	0.33	-0.46	-0.42	-0.48	-0.40	-0.34	-0.42
TW		1.0	0.41	-0.21	-0.18	-0.26	-0.25	0.07	0.13	0.59*	0.42	0.52*	0.62**
V			1.0	-0.86**	0.22	0.06	-0.01	0.18	0.13	0.30	0.38	0.49*	0.49*
GH				1.0	-0.40	-0.22	-0.18	-0.38	-0.08	-0.12	-0.38	-0.49*	-0.52*
GPC					1.0	0.86**	0.85**	0.04	-0.49*	-0.43	-0.19	-0.17	-0.24
WGC						1.0	0.92**	-0.14	-0.55*	-0.61**	-0.25	-0.24	-0.38
DGC							1.0	0.03	-0.40	-0.40	-0.17	-0.18	-0.25
GI								1.0	0.53*	0.12	0.38	0.39	0.40
SDS									1.0	0.34	0.58*	0.53*	0.57*
YPC										1.0	0.41	0.41	0.56*
W											1.0	0.95**	0.79**
P												1.0	0.91**
P/L													1.0

, *: Significant at 0.05 and 0.01 probability levels, respectively, TKW: Thousand kernel weight (g), TW: Test weight (kg hl^{-1}), V: Vitreousity (%), GH: Grain hardness (%), GPC: Grain protein content (%), WGC: Wet gluten content (%), DGC: Dry gluten content (%), GI: Gluten index (%), SDS: Sedimentation volume (mL), YPC: Yellow pigment content (ppm), W: Alveograph dough strength ($\times 10^{-4}$J), P: Elasticity (mmH_2O), P/L: Elasticity/extensibility ratio

Positive and highly significant correlation was observed between wet gluten content and dry gluten content (r_g = 0.92**). This was in agreement with the works of Pena and Pfeiffer (2005) who observed a very high and positive correlation between dry and wet gluten contents. It implies that gluten hydration capacity is at large a measure of gluten quantity rather than of gluten quality. It also showed positive and significant relationship with thousand kernel weight (r_g = 0.50*). However, it revealed negative and medium to strong associations with SDS sedimentation volume (r_g = -0.55*) and yellow pigment content (r_g = -0.61**). The SDS sedimentation volume showed positive and significant correlation of moderate magnitude with gluten index (r_g = 0.53*), alveograph strength W (r_g = 0.58*), alveograph elasticity (r_g = 0.53*) and alveograph elasticity/ extensibility ratio (r_g = 0.57*). This partially agrees with studies carried out by Ammar *et al*. (2000) and Brites and Carrillo (2001) who reported medium to high relationships among SDS-sedimentation, gluten index, alveograph parameters of strength and extensibility. Other researcher (Pena, 2000) found out a weak to moderate association for sedimentation volume with alveograph dough strength (W) and alveograph elasticity/ extensibility ratio (P/L). Alveograph elasticity/extensibility ratio (P/L) was strongly correlated with alveograph elasticity P (r_g = 0.91**) and alveograph dough strength W (r_g = 0.79**). This was in agreement with those of Nelson *et al*. (2006).

Genotypic path coefficient analysis for traits that had significant correlation with grain protein content revealed that dry gluten content (0.65**) had the highest positive and significant direct effect on grain protein content followed by thousand kernel weight (0.26*), whereas, SDS sedimentation volume had negative direct effects (Table 5). Therefore, this study revealed that dry gluten content and thousand kernel weights are important as selection criteria for improvement of grain protein content in durum wheat. The high residual effect (0.44) indicated considerable amount of variability in grain protein content has not been accounted for by the independent characters included in this analysis (Singh and Chaudhary, 1999).

Table 5: Estimates of genotypic path coefficient of direct (bold diagonal) and indirect effects of 4 quality parameters on grain protein content for durum wheat genotypes

Parameters	TKW	WGC	DGC	SDS	r_g
TKW	**0.26**	0.05	0.21	0.03	0.55*
WGC	0.13	**0.09**	0.60	0.04	0.86**
DGC	0.09	0.09	**0.65**	0.02	0.85**
SDS	-0.11	-0.05	-0.26	**-0.07**	-0.49*

Residual effect = 0.44, TKW: Thousand kernel weight (g), WGC: Wet gluten content (%), DGC: Dry gluten content (%), SDS: Sedimentation volume (mL), *, **: Significant at 0.05 and 0.01 probability levels, respectively, r_g: Genotypic correlation coefficient of traits with grain protein content

CONCLUSIONS

The present study depicted the presence substantial variations among durum wheat genotypes for all quality parameters tested which gives an opportunity to plant breeders for the improvement these traits. Genetic correlation coefficient analysis indicated that important quality parameters are positively correlated with grain protein content. This suggests a common genetic basis among these traits. Hence, simultaneous improvement of these traits would be possible. Path coefficient analysis revealed that dry gluten content and thousand kernel weight showed the highest positive direct effect and significant positive correlation with grain protein content. Hence, these traits are important as suitable selection criteria for improvement of protein content in durum wheat. All the studied genotypes except Gerardo, Oda and Cocorit-71 were superior across most quality traits and could also serve as good donor sources in durum wheat breeding programs.

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