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SHORT RESEARCH ARTICLE

Determination of physico-chemical grain quality characters, their associations and genetic diversity in bread wheat (*Triticum aestivum* L.) varieties under lowland at Arba Minch, Southern Ethiopia

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Abstract

A set of 27 bread wheat varieties from Ethiopia was assessed for physico-chemical quality characteristics of grain under lowland. Varieties differed significantly for all the studied quality traits. Grain weight, diameter and hardness of the grain were positively associated with starch content and grain yield but negatively associated with protein content. D^2 and principal component analysis grouped 27 genotypes in to four diverse genotypic clusters accounting for 89.17% of the total variation. The PC1 accounted for 46.41% of the variation with major contribution by total wet gluten, dry gluten, kernel diameter and red kernel, while PC2 accounted for 25.06% of the variation with major contribution by gluten index, kernel weight, water bound wet gluten, Zeleny index and grain yield. Based on the genetic diversity for physico- chemical characters and correlations, the appropriate varieties can be used for different food products and utilized as parents in breeding programme for improving quality.

Keywords: Associations, bread wheat, genetic diversity, kernel physical and chemical characters, lowland

Wheat (*Triticum aestivum* L.) is the third important food crop of Ethiopia grown in 1.69 mha producing 46.42 mt with the productivity of 2.73t/ha during 2017-18. It is not sufficient to meet the countries' demand. Consequently, Ethiopia is importing one million tons wheat annually since 2008 (Gebre et al. 2017) but recently increased to 1.7 million tonnes of wheat imported in the country (EIAR 2020). Wheat is consumed in different form of end products in the country for which the quality wheat is required. The physical (kernel hardness, weight, diameter and moisture) and chemical (protein, starch, Zeleny index and wet and dry gluten content, water bound wet gluten and gluten index) are important grain (kernel) quality characters for preparation of different food products (Boz et al. 2011). Physical traits are used for classifying varieties for hardness and softness, and the colour differences for food products and the marketability (Ponce-García 2017) while chemical traits are important for baking, swelling or expansion of dough, loaf volume and the viscosity in flour slurry (Başlar and Ertugay 2011). Several wheat varieties have been developed for cultivation in low land areas in Ethiopia from germplasm received from ICARDA and CIMMYT (Gebre et al. 2017). However, the information on the quality characteristics of these varieties is lacking. Knowledge of grain quality is important for selection of suitable varieties for preparation of different food products. The present study was therefore aimed to assess the physico-chemical characters, characters interrelationship and the genetic diversity using 27 varieties

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to identify their suitability for different food products, marketability, and future use.

A set of 27 bread wheat varieties (Table 1) were grown in a replicated field experiment under irrigated lowland conditions at Amibara Farm, Arba Minch (6⁰3'37 N, 37⁰33' E and 1202 m above mean sea level) during March-June 2020. The grains of the varieties were used for determining physico-chemical characteristics at the Food Science and Nutrition Laboratory, Agricultural Research Centre of the Ethiopian Institute of Agriculture Research (EIAR) at Kulumsa during May-June, 2021. Kernel weight (KW), hardness (KH), diameter (KD) and moisture (KM) were determined using single kernel characterization system (SKCS 4100) of Perten Instruments (AACC 2000; Osborn and Anderson 2003). KW was determined by load cell in mg, KH by pressure force (%), KM (%) and the KD (mm) by electrical current. The kernel colour (KC) was measured as per Commission Internationale de l'Eclairage (CIE) standards for L*(whiteness – black), a*(redness - greenness) and b*(yellowness - blueness) in per cent (Oliver et al. 1992) using dual-beam non-contact reflectance spectrophotometer of Hunter Lab, Aeros (USA) as per AACC (2000).

Assessment of quality characters

The chemical characters, grain protein (GP), moisture, starch content (SC), Zeleny index (ZI) were determined by near infrared spectroscopy through FOSS Infratec 1241 grain analyser as per method No. 39-11 of AACC (2000). Gluten protein was determined using Perten Glutomatic instrument following standard method 38-12 of AACC

Table 1. Mean performance of 27 varieties for Physical Grain characters and grain yield

Varieties	KW (mg)	KH (%)	KM (%)	KD (mm)	CL*	Ca*	Cb*	Grain yield (g)/ 5.4 m²plot
Amibara-1	29.2ghi	81.15bc	10.84abcdef	2.61defg	50.44abcdef	8.17efg	24.9def	1240.33f
Amibara-2	28.29hij	78.08bcd	11.17abc	2.65de	51.43abcde	8.66bcdef	26.37abcd	1460.77c
Fentale-1	29.27efgh	82.83b	11.35a	2.60defg	50.22abcdef	8.25efg	24.79defg	1657.72b
Fentale2	30.43defg	80.57bcd	10.51defghi	2.63def	51abcdef	8.42defg	25.53bcde	1334.49de
Ga'ambo	34.4ab	75.98cde	10.94abcde	2.84ab	51.2abcde	8.78abcdef	26.08abcd	1326.38e
Lucy	33.74bc	81.34bc	11.22ab	2.83ab	45.3ij	8.2efg	21.97gh	2073.22a
Werer-2	26.34klm	80.97bc	11.33ab	2.50ghij	50.65abcdef	8.25efg	25.41cde	1230.82f
Alidoro	31.33def	66.49gh	11.10abcd	2.67cde	46.65ghi	7.8fg	21.53h	1459.01c
Biqa	27.06jkl	79.24bcd	10.57cdefgh	2.53fghij	50.78abcdef	9.08abcde	27.19abcd	1069.59g
Daka	32.24bc	69.65g	10.55cdefgh	2.78bc	50.76abcdef	8.57bcdef	25.75bcde	1353.6de
Dashen	29.5fghi	88.46a	10.41efghi	2.69cd	47.4fghi	9.54abc	26.35abcd	1135.81g
Dereselign	26.22klm	65.90gh	9.80jkl	2.42jk	51.44abcde	8.87abcdef	25.37cde	1125.68g
Enkoy	25.96klmn	41.87j	9.96hijkl	2.43ijk	42.7j	9.25abcde	21.69h	616.86n
ET-13A2	27.57ijkl	56.56i	9.07m	2.46hijk	49.32cdefgh	9.39abcd	25.42cde	353.63o
Hawi	27.22jkl	70.45fg	10.03hijk	2.66de	52.46abcd	9.1abcde	28.35ab	957.3hi
Hidase	31.64de	61.65hi	10.69bcdefg	2.57efg	50.4abcdef	8.29efg	25.23cde	1138.98g
Hoggana	27.6ijk	82.93b	10.39efghijk	2.51ghij	48.48efghi	7.83fg	22.94efgh	428.58o
Honqolo	26.98jkl	78.81bcd	9.97hijkl	2.51ghij	49.11defgh	8.44defg	25.27cde	969.05h
Kakaba	26.36jkl	77.90bcd	9.76kl	2.57efgh	49.38cdefgh	9.65ab	26.44abcd	707.48m
Kingbird	24.41mn	70.80efg	10.57cdefgh	2.44ijk	52.6abc	9.01abcde	27.72abc	877.78ij
Kubsa	26.77jkl	67.88g	9.87ijkl	2.52fghij	53.4ab	8.93abcde	28.76a	815.03jk
KBG-01	22.31o	82.06b	9.35lm	2.28l	49.88cdefg	9.85a	26.5abcd	543.38n
Millenium	27.64ijkl	39.55j	9.98hijkl	2.54fghi	46.34hi	8.54cdefg	22.28fgh	792.46kl
Ogolcho	36.21a	75.91cdef	10.44efghij	2.89a	51.86abcd	8.65bcdef	24.83def	1413.03cd
Pavone-76	25.81lmn	90.67a	10.19fghijk	2.45ijk	50.13bcdef	8.64bcdef	25.47cde	939.02hi
Shorima	27.63ijklm	78.05bcd	10.81abcdef	2.54fghi	53.28ab	8.71bcdef	24.75defg	720.71lm
Wane	24.25no	75.14def	10.14ghijk	2.37kl	53.55a	7.52g	21.24h	782.43klm
G .Mean	28.42	73.36	10.41	2.57	50.04	8.6	25.11	1056.41
SE(±)	0.67	1.88	0.22	0.03	1.15	0.37	0.97	29.04

Values in a column with same letter in superscript are not significantly different at 5% probability level

(2000). The residue retained after washing was the wet gluten (Anonymous 2004). It was removed from the washing chamber and centrifuged at 6000 rpm for 1-minute stopping, automatically. The wet gluten passed through the sieve was weighed. The weight percentage of wet gluten remaining on the sieve to the total weight of wet gluten was defined as the gluten index. The residue retained inside the screen was weighed and dried in Glutrok 2020 heater at 15°C for 4.0 minutes to measure dry gluten. The difference between weight of total wet gluten and total dry gluten was the water bound wet gluten. Gluten constituents of grain were expressed in weight per cent on 14% moisture basis. Data were subjected to analysis of variance for the characters following SAS–Version 9.00 (2004). Phenotypic and genotypic correlations among the characters were processed by Windostat Version 9.2 from Indostat services. Multivariate genetic diversity analyses were performed as per method of Mahalanobis (1936) and elaborated by Rao (1952).

The analysis of results showed that wheat varieties differed significantly ($p < 0.01$) for all the characters under study suggesting sufficient genetic variability. Mean values of the physical kernel characters for 27 varieties are presented in Table 1. The values for KW ranged widely and variety Ogolocho (36.21mg) followed by Ga'ambo (34.4 mg) formed the first non- significant group High KW is an important trait associated with higher flour recovery. Thus, these varieties appeared better for higher flour recovery. Ten varieties had KW around general mean (28.42 mg). Differences among varieties for KW have been reported earlier by several researchers (Kasahun 2018; Khan et al. 2020) and the present results agree with their findings. KH is an important parameter to differentiate hard and soft wheat to decide end use product quality (Pomernaz and Williams 1990). The KH ranged from 39.55 to 90.67 with a general mean 73.36. Significantly superior KH was recorded in Pavone-76 (90.67) and Dashen (88.46). The KH values in next non-significant seven varieties ranged from 79.24 to 82.93. Hard kernels had better filled endosperm without spaces among its constituents, starch granules and storage proteins (Kasahun 2018) and required more force to crush, having high water absorption capacity suitable for bread and *chapati*. Varieties, Alidoro, Dereselign, Honqolo, ET-13A2, Enkoy and Millenium with lower KH values can be grouped into soft wheat, which fracture easily producing finer textured flours with less damage to starch granules and hence were suitable for cookies, cakes, pastries, and some types of noodles (Morris and Rose 1996; Anonymous 2004).

The KM is affected by genotypic differences for days to maturity, drying and storage and the method of moisture determination (Bean et al. 2006; Khan et al. 2020). The highest value was recorded in Fentale-1 (11.35%) followed by Werer-2 (11.33%), Lucy and Amibara-2 (11.17%) while lowest in ET-13A2 (9.07%). The KD was highest in Ogolcho (2.89 mm) and lowest in KBG-01 (2.28 mm). Other varieties with higher KD were Amibara-2, Ga'ambo, Lucy, Daka, Dashen and Alidoro. Kasahun (2018) found that these varieties produced plump grains with better filled endosperm, the major source of starch and protein with potential for good flour recovery from bold and plump kernel is a desired trait that fetches high price in the market. The KH, KM and KD together had effect on the milling properties such as tempering, roll gap settings, and flour starch damage content (Anonymous 2004).

Wheat kernel colour generally results from the bran portion which makes up 14% of grain weight (Anonymous 2004). The higher kernel whiteness (L*) was recorded in nine varieties, (Wane, Kubsa, Shorima, Kingbird, Hawi, Dereselign, Amibara-2, Ga'ambo and Ogolcho) which will yield white flour which is suitable for baking white bread, *chapati, naan* and other food products. Colour character b* denoting kernel yellowness was found in Kubsa, Hawi, Kingbird, Biqa, Dashen, Kakaba, Amibara-2, Ga'ambo and KBG-01, which are suitable for preparation of pasta and noodles preferred in Asian market (Kasahun 2018). The genetic differences among varieties with respect to colour were reported earlier by other researchers also (Bean et al. 2006; Onipe et al. 2015). The mean values for GP, GM, SC and ZI of varieties are presented in Supplementary Table S1. Kasahun (2018) and Gebre et al. (2017) have earlier studied all the above-mentioned traits and reported results akin to the findings of present study. Highest GP and ZI were recorded in variety, Enkoy followed by Kakaba, Dereselign, KBG-01, Wane, ET-13 A2, Alidoro, Biqa, Amibara-1, Fentale-1, Daka and Millenium, whereas low GP and ZI were in Ga'ambo, Ogolcho and Lucy. Varieties with high GP and ZI were suitable for bread and other food products at household and the food industry (Kumar et al. 2018). A few varieties also differed significantly for gluten protein constituents, such as, WG, DG, water bound wet gluten (WBWG) and GI (Supplementary Table S1). Gluten, the water insoluble protein component confers elasticity, adhesiveness and extensibility to dough making it suitable for preparation of bread and other products.WG, DG and WBWG were significantly higher in Enkoy and Dereselign while remaining varieties were at par with general mean value. Varieties, Honqolo, KBG-01, Hoggana, Kingbird, Biqa, Pavone-76, Wane, Daka, Millenium, Kakaba, Shorima and Alidoro exhibited more GI values indicating better gluten strength. GI was affected by the stickiness in water bounded flour caused by the starch and the protein.

Correlations and principal component analysis

Genotypic and phenotypic correlations among physico-chemical kernel characters and grain yield are presented in Supplementary Table S2. KW, KH, KM and KD showed highly significant negative correlations (phenotypic) with GP suggesting that more values for these traits were associated with lower protein content (Khattak et al. 2005). Significant positive correlations of KW, KH, KM and KD with SC and GY showed that the higher the values of the physical kernel characters, the higher the SC and GY. Starch, being the major component (83%) of wheat grain (Anonymous, 2004), positive association of it with GY is very logical. Thus, these physical kernel characters may be used as selection parameter for improving GY and SC in wheat. GP had significant negative correlation with starch content. Similar relationship was reported by Ma et al. (2021). Grain colour characters CL* for whiteness and Cb* for yellowness had highly significant positive correlation with SC which indicated that the grain colour can also be used as selection parameter for starch content. Starch in grain was reported to cause chalkiness/whiteness to wheat/flour colour (Anonymous 2004). GP had highly significant positive correlations with gluten-based characteristics, viz., Zeleny index, WG, DW and WBWG. This showed that the higher the GP, the higher the gluten protein and gluten constituents for the baking and cooking quality of bread wheat (Khattak et al. 2005).

Multivariate analysis grouped 27 genotypes into 4 clusters. The cluster I included 12 genotypes (44.4%) followed by cluster II with 9 genotypes (33.3%), cluster III consisted of 5 genotypes and cluster IV represented only one genotype (Supplementary Table S3). Maximum diversity was contributed by gluten index (62.96%) followed by grain yield (26.78%), WBWG (2.85%), Zeleny index (2.56%) and starch (1.71%), while other characters contributed in a lesser magnitude. Wide variation in cluster means (Supplementary Table S4) was observed for grain yield/plot (5.4 m^2) from cluster IV (792.48g) to cluster II (1199.26 g), and KH from cluster IV (39.26%) to cluster I (77.05%). KW was highest in cluster III (31.02 mg) and lowest in cluster I (26.84 mg). Highest value for KD was found in cluster III (10.63 mm) and lowest in cluster I (10.23 mm). Cluster II had exhibited maximum values (51.03%) and cluster IV minimum (46.25%) for CL* trait for kernel whiteness. Ca*for kernel redness and Cb*for kernel yellowness recorded maximum values in cluster I (8.95% and 26.40%) and minimum in cluster III (8.35%) and cluster IV (22.28%), respectively. PC varied from 12.66% in clusters I to 13.00% in cluster II. DG ranged from 16.75% in cluster I to 20.55% in cluster IV. Cluster II showed maximum value for ZI (52.78%) and TWG (54.41%), while cluster III (48.61%) and cluster I (47.20%) had the minimum value for these traits. Cluster II showed maximum value (35.37%) for WBWG and minimum for GI (67.08%). On the contrary, cluster IV showed the reverse trend and exhibited minimum value for WBWG (67.08) and maximum value for GI (76.84). These results suggested that selection of parental line for breeding should be based on individual trait or a combination of traits as well as inter cluster differences to get the high level of genetic variability for the further improvement (Singh and Panwar 2005).

The result of PCA analysis, which is complementary to D^2 statistic, formed four principal components (PCs). The eigen values of PC1, PC2, PC3 and PC4 were 7.43, 4.01, 1.70 and 1.13, respectively. PC1 accounted for 46.41% of the total phenotypic variation with major contribution with positive factor by TWG (0.343), DG (0.313), KD (0.309) and KM (0.305) and negative factor by Ca* for KH(-0.339). The PC 2 was responsible for 25.06% of the total variation with major contribution with positive factor by GI (0.391) and KW (0.327) and negative factor by WBWG (-0.457), ZI (-0.359) and GY (-0.344). The principal components, PC 3 and PC 4 accounted for 10.62% and 7.08% of the total phenotypic variation, respectively. PC 3 was mainly contributed with positive factor by Cb* for kernel yellowness (0.573), CL* for kernel whiteness (0.395), PC (0.364) and KW (0.349). PC4 was mainly caused with positive factor by KM (0.593), grain yield (0.251) and kernel weight (0.212) with negative factor by PC (-0.530) and CL* for kernel whiteness (-0.218). These results suggested that KD, KW, kernel colours, PC, gluten constituents and ZI were important wheat quality characters and hence should be given more weightage for making selection for wheat quality. The varieties with higher values of the quality traits identified through the present study may be suitable for using flour for food products and can also be used in breeding as parents for combining grain protein with yield.

Authors' contribution

Conceptualization of research (AQK, BL, AG); Designing of the experiments (AQK, BL, AG); Contribution of experimental materials (AQK, BL, AG); Execution of field/lab experiments and data collection (AQK, BL, AG, CK); Analysis of data and interpretation of results (AQK, BL, AG, CK), Preparation of the manuscript (AQK, BL, AG, CK).

Supplementary materials

Supplementary Tables S1 to S4 having analysed data are provided.

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Supplementary Table S1. Mean performance of 27 varieties for chemical grain characters

Varieties	GP (%)	GM (%)	SC(%)	ZI	TWG	DG	WBWG	GI
Amibara-1	13.3defgh	12.9a	64.95defgh	53.8bcdef	50.65bcdef	17.5defg	33.15bcde	57.21gh
Amibara-2	11.95ijkl	12.95a	66.55abc	46.05hij	47.6cdef	16.8defg	30.8bcde	65.48cdefgh
Fentale-1	13.25defgh	11.75ab	64.5fghi	52.4cdefgh	51.95bcdef	18.45cdefg	33.5bcde	59.51fgh
Fentale2	12.6ghijk	11.25bcd	66.3abcd	51.2defgh	55.45bcde	19.7cde	35.75bcd	57.18gh
Ga'ambo	11.55klm	11.4bcd	65.8abcdefg	44.15ij	51.95bcdef	15.15fg	36.8bc	56.07gh
Lucy	10.5m	11.55bcd	64.45fghi	35.3k	44.45def	15.1fg	29.35cde	65.34cdefgh
Werer-2	12.15hijkl	11.6bc	67.3a	48.45efghi	45.4def	15.65efg	29.75cde	65.8cdefgh
Alidoro	13.95bcdef	11.4bcd	62.8jkl	54.8abcde	49.85bcdef	18.3cdefg	31.55bcde	74.69abcde
Biqa	13.40cdefg	11bcd	64.3ghij	54.7abcde	45.6def	16.55defg	29.05cde	79.35abc
Daka	12.95efghij	11.1bcd	64.85fgh	51.5defgh	44.7def	16.95defg	27.75cde	77.63abcd
Dashen	11.7kl	11bcd	65.45bcdefg	47.3fghij	45.75def	16.15efg	29.6cde	73.4bcdef
Dereselign	14.7ab	10.7bcd	62.35klm	58.85abc	74.95a	25.2ab	49.75a	60.97efgh
Enkoy	15.85a	10.95bcd	60.15n	60.6a	76.5a	27.1a	49.75a	57.56gh
ET-13A2	14.1bcde	10.3d	63.5hijk	57abcd	60.6b	20.6cd	40b	52.97h
Hawi	12.2hijkl	11.05bcd	65.55bcdefg	48.15fghij	49bcdef	17.55defg	31.45bcde	70.16cdefg
Hidase	12.9fghij	11.1bcd	65.2bcdefg	52.85bcdefg	52.95bcdef	18.95cdef	34bcde	72.54bcdef
Hoggana	13.1defghi	10.bcd	63.1ijkl	50.5defghi	43.1f	15.6fg	27.5cde	85.85ab
Honqolo	12.25ghijkl	10.8bcd	65.95abcdefg	47.75fghij	41.25f	15.15fg	26.1e	88.89a
Kakaba	14.8ab	10.7bcd	61.85lm	58.45abc	58.85bc	21.9bc	36.95bc	76.41abcd
Kingbird	12.3ghijk	11.1bcd	65.05cdefg	49.05efghi	42.9f	14.8g	28.1cde	85.54ab
Kubsa	11.85jkl	10.85bcd	66.1abcde	46.65ghij	47.35cdef	16.55defg	30.8bcde	64.72defgh
KBG-01	14.5bc	10.4cd	62.5klm	59.35ab	47.2cdef	17.2defg	30cde	86.30ab
Millenium	13gfhij	11.1bcd	61.2mn	50.35efghi	49bcdef	20.55cd	28.45cde	76.84abcd
Ogolcho	11.25lm	11.1bcd	66.4abcd	41.85j	42.15f	15.45fg	26.7de	69.18defgh
Pavone-76	11.95ijkl	11.05bcd	66.65ab	48.55efghi	43.55ef	15.65efg	27.9cde	78.52abcd
Shorima	12.9fghij	11.45bcd	65.4bcdefg	53.35bcdef	42.35f	15.45fg	26.9de	75.46abcd
Wane	14.25bcd	10.7bcd	61.85lm	57abcd	56.1bcd	20.5cd	35.6bcde	77.86abcd
Mean	12.93	11.18	64.44	51.1	52.45	17.94	32.48	70.79
SE(±)	0.41	0.43	0.53	2.24	4.21	1.4	3.19	4.95

Values in a column with same letter in superscript are not significantly different at 5% probability level

Supplementary Table S2. Phenotypic (upper diagonal) and genotypic (lower diagonal) correlation coefficients between grain quality and grain yield in 27 bread wheat varieties

	KW	KH	KM	KD	CL*	Ca*	Cb*	PC	SC	ZI	TWG	DG	WBWG	GI	GY
KW	-	0.0494	0.4833 ***	0.9494 ***	-0.0977	-0.2653	-0.1644	-0.4802 ***	0.3322 *	-0.5246 ***	-0.1662	-0.2544	-0.1123	-0.3216 *	0.6653 ***
KH	0.064	-	0.3226 *	0.1384	0.3359 *	-0.1088	0.2485	-0.4039 **	0.5465 ***	-0.2980 *	-0.4701 ***	-0.5630 ***	-0.3943 **	0.1941	0.3040 *
KM	0.5403	0.3883	-	0.5078 ***	0.0028	-0.4109 **	-0.1244	-0.4179 **	0.4086 **	-0.4150 **	-0.3305 *	-0.4063 **	-0.2721 *	-0.1447	0.7076 ***
KD	0.9703	0.1254	0.6214	-	-0.0493	-0.2044	-0.0564	-0.5663 ***	0.4063 **	-0.6039 ***	-0.2475	-0.3256 *	-0.1933	-0.2389	0.6999 ***
CL*	-0.133	0.4201	0.0554	-0.0875	-	-0.1925	0.3691 **	-0.2304	0.4892 ***	-0.0644	-0.2381	-0.3154 *	-0.1849	0.0904	-0.0536
Ca*	-0.3881	0.0912	-0.8726	-0.2471	0.2238	-	0.6432 ***	0.1918	-0.1469	0.2241	0.1796	0.17	0.1726	-0.0503	-0.3232 *
Cb*	-0.1675	0.3653	-0.2424	0.0007	0.9391	0.4819	-	-0.2553	0.4663 ***	-0.117	-0.1845	-0.2584	-0.1365	-0.0196	-0.0875
PC	-0.5611	-0.4635	-0.5452	-0.6581	-0.2365	0.2195	-0.3023	-	-0.7954 ***	0.9566 ***	0.6656 ***	0.7578 ***	0.5775 ***	-0.0171	-0.5090 ***
SC	0.3496	0.5962	0.4946	0.4268	0.5464	-0.052	0.655	-0.8012	-	-0.6542 ***	-0.5386 ***	-0.6725 ***	-0.4383 ***	-0.0914	0.4021 **
ZI	-0.6557	-0.3582	-0.5658	-0.7416	-0.024	0.2636	-0.0958	0.961	-0.6419	-	0.5913 ***	0.6710 ***	0.5141 ***	0.0157	-0.5538 ***
TWG	-0.2329	-0.6229	-0.413	-0.3584	-0.3383	0.2573	-0.3145	0.7916	-0.7053	0.6544	-	0.9103 ***	0.9103 ***	-0.5492 ***	-0.1856
DG	-0.291	-0.7271	-0.4749	-0.4034	-0.3965	0.2023	-0.4295	0.8536	-0.8083	0.7295	0.9965	-	0.8075 ***	-0.3588 **	-0.2599
WBWG	-0.2013	-0.5655	-0.3788	-0.3333	-0.3063	0.286	-0.2521	0.7562	-0.8083	0.6124	0.999	0.9917	-	-0.6068	-0.1373
GI	-0.424	0.2478	-0.1646	-0.3437	0.0488	0.0577	-0.102	-0.0186	-0.0816	0.0584	-0.5416	-0.4046	-0.6132	-	-0.2770 *
GY	0.7014	0.3057	0.8311	0.7323	-0.0533	-0.5125	-0.1105	-0.5718	0.4375	-0.6422	-0.2333	-0.3135	-0.1899	-0.3511	-

K W =Kernel weight, KH = Kernel hardness, K M = Kernel moisture, K D =Kernel diameter, CL* = Kernel colour whiteness, Ca* = Kernel colour redness, Cb *= Kernel colour yellowness,Zeleny I =Zelenyindex,
TWG = Total wet gluten, DG= Dry gluten, WBWG = Water bound wet gluten, GI= Gluten index, GY= Grain yield

Supplementary Table S3. Clustering of wheat genotypes based D2 values using physico-chemical kernel quality characters and grain yield

Cluster	Genotypes	Genotypes
I	12	Kingbird, Kubsa, Shorima, Hawi, ET-13 A2, Dashen, KBG-01, Biqa, Werer-2, Honqolo, Fentale-2, Pavone-76
II	9	Dereselign, Wane, Ga'ambo, Fenale-1, Daka, Kakaba, Amibara-1, Amibara-2 Hidase,
III	5	Hoggana, Ogolcho, Alidoro, Lucy, Enkoy
IV	1	Millenium

Supplementary Table S4. Character means of the wheat genotypes grouped in different clusters.

Character	Cluster I	Cluster II	Cluster III	Cluster IV
KW(mg)	26.84	29.17	31.02	27.64
KD(%)	77.05	74.25	69.71	39.56
KM (%)	10.23	10.58	10.63	9.99
KD (mm)	2.51	2.62	2.67	2.54
CL*- whiteness(%)	50.87	51.03	47.02	46.25
Ca*-redness(%)	8.95	8.53	8.35	8.54
Cb*-yellowness(%)	26.40	25.13	22.60	22.28
GP (%)	12.66	13.29	12.93	13.00
GM (%)	10.99	11.48	11.16	11.10
SC (%)	65.34	64.21	63.38	61.20
ZI (%)	50.96	52.78	48.61	50.35
WG(%)	47.20	54.41	51.28	49.00
DG (%)	16.75	19.04	18.31	20.55
WBWG (%)	30.45	35.37	32.97	28.45
GI (%)	73.19	67.08	70.52	76.84
GY(g)/5.4 m^2plot	912.22	1199.26	1198.14	792.46