Phenotypic Variation of Ethiopian Hexaploid Wheat Accessions

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Abstract: Variable climatic factors, i.e. rainfall, relative humidity and temperatures across regions and altitudes resulted in a high genetic diversity in wheat species. The objective of the study was to evaluate the variation in morphological traits of hexaploid wheat accessions across different regions and altitudes using frequency and Shannon-Weaver diversity index. Polymorphism was observed in all traits with the exception of glume hairiness. More than 85% of the collections contained medium to large and plump seed types. Over all accessions diversity indices ranged from 0.03 for glume hairiness to 0.85 for beak length. Average regional diversity indices for all traits ranged from 0.47 for Group II (accessions from Gojam and Gonder) to 0.57 for Group III (accessions from Shewa). Traits diversity in altitude ranged from 0.44 for altitudes > 2800 masl to 0.63 for altitudes ≤ 2200 masl. Within regions and within altitudes diversity accounted for 89% and 93% of the total variation, respectively. Hence, emphasis should be given to have more samples within one and the same region and range of altitudes to capture more genetic diversity and use it as breeding material for variety improvement programmes.

Keywords: Ethiopia; Phenotypic Diversity; *Triticum aestivum*

1. Introduction

In Ethiopia wheat (*Triticum sp.*) is the fourth most important cereal food crop next to tef (*Eragrostis tef* (Zucc.) Trotter), maize (*Zea mays* L.), and Sorghum (*Sorghum bicolour* (L.) Moench). National total production and productivity of wheat during 2011 were 2.86 million metric tons and 1.83 t ha^{-1}, respectively (CSA, 2011). Compared to world's productivity of 3.0 t ha^{-1}, it is about 39 % less (OECD-FAO, 2011). The lower productivity is due to the prevalence of different abiotic and biotic stresses, e.g. low moisture stress (Girma *et al*., 2001), frost and low soil fertility, low yielding varieties, and head, leaf and stem diseases (Geleta and Grausgruber, 2009). Especially the new stem rust (*Puccinia graminis* f. sp. *tritici*) race TTKS (*Ug99)* threatens wheat production of east Africa (Singh *et al*., 2006). About 90% of the world's wheat production is coming from hexaploid wheat (*Triticum aestivum* L.) (Feuillet *et al*., 2007). Ethiopian wheats constitute both tetraploid (*Triticum turgidum* L.) and hexaploid (*T. aestivum* L.). The majority of the farmers grow landraces which are mixtures of different agrotypes and sometimes even species (Worede and Hailu, 1993). Landraces are phenotypic and genotypic not uniform and, therefore, widely adapted to varying climatic conditions and often resistant or tolerant to pests and diseases. Assessing the variation present in collections conserved at IBC/E is an important prerequisite for crop improvement. Ethiopian wheats are known as sources of important traits such as high protein content, drought and disease resistance and early maturity (Perrino and Porceddu, 1990; Annicchiarico *et al*., 1995; Worede, 1997).

Differences in regions and altitudes affect crop diversity. Many reports are available in regard to phenotypic diversity studies of tetraploid wheat landraces from Ethiopia in relation to differences caused by regions and altitudes (Bechere *et al*., 1996; Belay *et al*., 1997; Eticha *et al*., 2005; Teklu and Hammer, 2008; Geleta and Grausgruber, 2009). Diversity studies are also available for barley (*Hordeum vulgare* L.) (Engels, 1994; Demissie and Bjørnstad, 1996; Asfaw, 2000), sorghum (*Sorghum bicolor* (L.) Moench) (Ayana and Bekele, 1998; Ayana and Bekele, 2000) and tef (*Eragrostis tef* (Zucc.) Trotter) (Assefa *et al*., 2002). However, only few works have been carried out with hexaploid wheat collections (Bekele, 1984; Negassa, 1986). Assessing phenotypic diversity of landraces across regions and altitudes are important since landraces are usually adapted to different conditions and exhibit tolerance to different diseases. Landraces can be directly used for variety trials or can be used as breeding sources for crossing with 'exotic' high yielding and resistant varieties to the new virulent wheat stem rust (*Puccinia graminis* f. sp. *tritici*) race TTKS (*Ug99)*, a dangerous fungal disease prevalent in east Africa including Uganda, Kenya and Ethiopia (Wanyera and Macharia, 2009). The prevalence of any pathogen in crop plants depends on suitable environmental conditions such as temperature, rainfall and relative humidity (Backhouse and Burgess, 2002). Therefore, assessing the variation of wheat accessions between and within regions and altitudes of collection sites with varying climatic conditions like in Ethiopia is of paramount importance. The objective of the study was to assess the variation in morphological traits within and between regions, and within and between altitudes of origin of hexaploid wheat collections.

2. Materials and Methods

2.1. Plant Materials

Fifty-three accessions of hexaploid wheat (*T. aestivum* L.) were obtained from Institute Biodiversity

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Conservation/Ethiopia (IBC/E), Addis Ababa, in 2007. The accessions were collected from different parts of Ethiopia and Eritrea (Table 1). The samples were grown at BOKU–University of Natural Resources and Applied Life Sciences, Vienna, in 2008. Each sample was grown in two rows of 1 m length and with 20 cm spacing between rows. NPK fertilizers containing some other macronutrients were applied half at planting and heading. The nutrients were applied at the rate of 60 kg N, 24 kg P, 24 kg K, 9 kg Mg and 12 kg S per hectare in the form of Linzer Ware Complex (20/8/8 + 3 MgO + 4 S). Weed control was carried out manually.

Table 1. Accession code, region of collection and altitude of investigated wheat germplasm.

Accession ID	Origin	Altitude (m.a.s.l.) [a]	Accession ID	Origin	Altitude (m)
5011	Bale	3100	203902	Kefa	2533
5335	Shewa	2270	204704	Eritrea	2400
5396	Gonder	2145	204707	Eritrea	2400
5418	Gonder	2720	208877	Sidamo	2020
5435	Shewa	2510	208878	Sidamo	2370
5670	Shewa	2300	216473	Gonder	2370
5694	Shewa	2810	225845	Gamu Gofa	2100
5721	Shewa	2420	230247	Eritrea	2200
6883	Bale	2460	230252	Eritrea	2000
6956	Gojam	2750	231630	Eritrea	2400
6991	Arsi	2800	236173	Sidamo	2050
6999	Arsi	2585	241960	Gojam	2160
7010	Arsi	2635	241961	Gojam	2550
7049	Arsi	2650	241963	Gonder	2420
7116	Shewa	2700	241966	Gonder	2530
7145	Shewa	2720	241969	Gonder	2410
7226	Shewa	2000	241971	Gonder	2610
7227	Shewa	2000	241974	Gonder	2755
7231	Welega	2140	241978	Gonder	3145
7248	Gojam	2400	241980	Gonder	3080
7253	Gojam	2290	241984	Gonder	3055
7257	Gojam	2390	241986	Welo	2845
7263	Gonder	2320	241987	Welo	2845
7309	Shewa	2030	241991	Welo	1990
7407	Gonder	2500	241993	Tigray	2950
7451	Gonder	2330	241995	Tigray	2445
7453	Gonder	2330			

[a]*m.a.s.l. –meters above sea level*

2.2. Statistical Analysis

Wheat accessions were grouped into five different regions and four altitudes. Group I contained 10 accessions from Eritrea, Tigray and Welo, Group II 21 accessions from Gonder and Gojam, Group III 10 accessions from Shewa, Group IV 6 accessions from Arsi and Bale, and Group V 6 accessions from Kefa, Welega, Sidamo and Gamu Gofa. Similarly, the accessions were grouped according to the elevation of their collection site into four altitudes, i.e. ≤ 2200, ≤ 2500, ≤ 2800 and > 2800 masl, with 12, 19, 14 and 8 accessions, respectively. The investigated morphological traits were beak shape (1- sloping, 3- slightly sloping, 5- straight, 7- elevated, and 9- strongly elevated with second part present); beak length (3- short, 5- medium and 7- long); glume color (1- white, 2- red/brown and 3- purple/black); awn color (1- white, 2- red/brown and 3- purple/black); glume hairiness (0- absent and 1- present); seed color (1- white, 2- red/brown and 3- purple/black); seed size (3- small, 5- medium, 7- large and 9- very large); vitreousness (3- vitreous, 5- partly vitreous and 7- non-vitreous); seed shape (3- ovoid, 5- semi-elongated, and 7-elongated); seed plumpness (3- plump, 5- partly plump, and 7- shriveled) (CPVO, 2008).Vitreous grains have a compact, translucent endosperm whereas mealy grains have a white, opaque endosperm (Donner and Osman, 2006). A total of 1855 plants (35 plants per accession) were analysed.

Phenotypic frequency and Shannon-Weaver diversity index were used to evaluate variation within all accessions, between and within regions of origin and altitudes. The Shannon-Weaver diversity index was calculated as described by Hutchenson (1970) and used by Ayana and Bekele (1998), i.e.

$$H' = -\sum_{i=1}^{n} \pi \log_e^{\pi}$$

where π is the proportion of accessions in the i^{th} class of an n-class character and n is the number of phenotypic classes for a character. Each value of H' was divided by its maximum value, $log_e n$ and normalized in order to keep the values between 0 and 1. Partitioning of phenotypic diversity estimates into within and between regions and altitudes were made following the methods given by Wachira *et al.* (1995) and used by Ayana and Bekele (1998).

3. Results

3.1. Regional Distribution of Characters

The distribution of morphological traits within regions and elevations is presented in Table 2. Beak shape showed polymorphic distribution both within regions and within all accessions. Slopping and slightly slopping beak shapes were more frequent and accounted about 75%. This trait is non-randomly distributed within accessions. The slopping type was frequent (66%) in accessions from Gonder and Gojam (Group II). Similarly, beak length showed non-random distribution within accessions and short and medium beak length accounted about 90%, indicating a strong selection pressure for the reduction of beak length. This trait also showed differentiation between regions. The short beak type was frequent in Northern region, i.e. accessions from Group II (76%) and Group I (48%), while the medium beak type was frequent in Southern region, i.e. accessions from Group V (67%). The white and red colour for glumes and awns accounted about 98% in the total accessions showing purple colour in hexaploid wheat from Ethiopia is rare. No regional differentiation was observed due to the differences in glume and awn colours. White colour is predominant (≥72%) in glume and awn colour. Almost all accessions had non-hairy glumes with the exception of one accession from Group III.

The proportion of white seed types was high within all accessions (90%) but red seed types were frequent in southern regions of Ethiopia (Group V). At least one accession for purple seed types was present in all regions except in Group IV. Purple seed colour for hexaploid wheat was not reported in Ethiopia. Regarding the present finding, there are two speculations. First, there might be possibility of gene/s introgressed from tetraploid to hexaploid since there are practices of growing species mixtures on the same farm in Ethiopia (Eticha *et al.*, 2005). Second, the purpled colour wheat accessions might not be actually hexaploid but tetraploid. To prove or disprove each of the above speculations, further analysis by cytological means is paramount important. The proportion of medium (41%) and large (51%) seeds were frequent within all accessions. Group II and III contained all ranges of phenotypes for this trait indicating higher diversity. The presence of a high proportion of large size in all regions indicates a high selection pressure since the start of agriculture for large seed sizes by the farmers. The majority of accessions were partly vitreous to vitreous types (88%). The proportion slightly varied between regions and it ranges from 82% (Group I and V) to 100% (Group IV). The proportion of ovoid and semi-elongated seed types accounted about 90% within all accessions and its proportion varied with regions, e.g. Group II and Group V had a higher proportion for ovoid seeds, 63 and 43 %, respectively. All phenotypic classes for this trait were displayed in all regions showing a high diversity. About 85% of all accessions had plump seeds.

Table 2. Frequency distribution of different morphological traits within regions and altitude ranges.

	Beak shape					Beak length			Glume colour			Awn color		
Region	1	3	5	7	9	1	3	5	1	2	3	1	2	3
Group I	54	36	4	6	0	48	38	14	82	16	2	76	20	4
Group II	66	3	20	4	7	76	22	2	68	32	0	67	32	1
Group III	40	22	32	4	2	34	48	18	76	22	2	86	11	3
Group IV	47	33	3	0	17	33	40	27	62	37	1	62	37	1
Group V	40	43	0	7	10	30	67	3	83	16	1	83	16	1
Altitude (masl)														
≤ 2200	42	18	20	15	5	47	35	18	82	16	2	81	16	3
≤ 2500	55	13	19	2	11	48	45	7	70	29	1	68	31	1
≤ 2800	51	29	16	0	4	49	37	14	60	39	1	68	31	1
> 2800	67	30	0	3	0	75	25	0	98	0	2	97	0	3
All	54	21	15	4	6	53	37	10	72	27	1	74	24	2

Table 2. Continued.

	Glume hairiness		Seed colour			Seed size				Vitrousness		
Region	0	1	1	2	3	3	5	7	9	3	5	7
Group I	100	0	94	4	2	0	40	55	5	73	9	18
Group II	100	0	92	7	1	11	54	33	2	91	2	7
Group III	99	1	96	1	3	2	37	53	8	65	19	16
Group IV	100	0	83	17	0	0	17	83	0	95	5	0
Group V	100	0	75	23	2	0	35	65	0	60	22	18
Altitude (masl)												
≤ 2200	99	1	86	13	1	2	53	41	4	68	15	17
≤ 2500	100	0	93	6	1	6	42	52	0	84	8	8
≤ 2800	100	0	91	7	2	0	25	66	9	88	7	5
> 2800	100	0	90	8	2	13	50	37	0	71	6	23
All	100	0	90	8	2	4	41	51	4	79	9	12

Table 2. Continued.

	Seed shape			Seed plumpness		
Region	3	5	7	3	5	7
Group I	10	69	21	89	10	1
Group II	63	35	2	93	6	1
Group III	2	88	10	66	24	10
Group IV	2	77	22	77	23	0
Group V	43	55	2	93	7	0
Altitude (masl)						
≤ 2200	26	65	9	64	28	8
≤ 2500	24	76	0	96	4	0
≤ 2800	34	49	17	82	16	2
> 2800	50	33	17	96	4	0
All	31	59	10	85	12	3

3.2. Distribution of Characters across Altitudes

All beak shape types were distributed in all altitudes but the pattern was not consistent with elevation (Table 2). Sloping, slightly sloping and straight beaks were frequent in decreasing order of importance. The proportion of short beak length was slightly increasing with elevation while it was not consistent for medium and large beak lengths. Short beaks were more frequent (45-75%). The proportion of white glumes and awns was decreasing with altitudes up to 2800 masl and increased at > 2800 masl, while it was vice versa for red glumes and awns. Purple glumes and awns were rare at all altitudes. The proportion of non-hairy glumes was 100% in all altitudes with the exception of ≤ 2200 masl. The proportion of red seeds was higher (13%) in accessions from ≤ 2200 masl compared to the other altitudes. Purple seeds were generally rare. The frequency of medium seed size was decreasing with increasing elevation up to 2800 m but it was higher above 2800 m. Small and very large seeds were less frequent. The proportion of vitreous seeds was increasing with altitudes up to 2800 masl and declined above 2800 masl. The proportion of ovoid types of seed shape was slightly increasing with elevation. Elongated seeds were more frequent (17%) at > 2500 masl. The distribution of plump seeds was not consistent within altitudes but in all classes plump types were more frequent.

3.3. Estimates of Diversity

Estimates of diversity for morphological traits are presented in Table 3. Diversity indices within all accessions ranged from 0.03 for glume hairiness to 0.85 for beak length. Most traits had medium (0.50 – 0.59) to higher (≥ 0.60) diversity values while traits including glume hairiness, seed colour and seed plumpness had lower (≤ 0.45) diversity values. Pooled over traits, within region mean diversity ranged from 0.47 for Group II to 0.57 for Group III. Diversity within region varied with traits. Beak shape, beak length, glume and awn colour, seed size and seed shape had medium to high diversity indices in all regions while glume hairiness and seed colour had consistently low diversity values. Seed vitreousness and plumpness had variable diversity indices in different regions. High values of 0.81 for Group III, 0.69 for Group I and 0.86 for Group V were observed for vitreousness, whereas high diversity of 0.77 for seed plumpness was observed only for Group III. Similarly, within altitudes diversity indices ranged from 0.44 to 0.63. Higher diversity was observed for ≤2200 m (0.63), followed by ≤2800 m (0.57) while it was lower for >2800 m (0.44). The pattern of diversity for individual traits varied within altitudes. For instance, it was decreasing for beak shape and beak length as elevation increases while it was increasing for glume colour up to 2800 m and it was lower above 2800 m. Diversity values for glume hairiness and seed colour was minimum within altitudes. Seed size and vitreousness showed a decreasing trend with increasing altitude up to 2800 m. Seed shape did not show any trend but had high diversity indices at all altitudes.

3.4. Inter and Intra Regions/Altitudes Diversity

Partitioning of estimates of diversity between and within regions of collection and altitudes is presented in Table 4. Variation in morphological traits was due to within regions of origin (89%). Individual traits like beak length, glume and awn colour, seed colour, seed vitreousness and plumpness had higher variation within region than between regions of collection. Similarly, for all traits within altitudes variation was 93% of the total variation. Most traits were more variable within altitude than between altitudes.

4. Discussion

Frequency distributions of morphological traits within and between regions of collection sites revealed polymorphism within all regions for beak shape. In regard to beak length short beaks were frequent in accessions from Group II (Gonder and Gojam) (76%) while long beaks were more frequent in accessions from Group III (Shewa) and IV (Arsi and Bale). Purple glumes and awns were generally rare and white glumes were more frequent than red ones. Glume hairiness was monomorphic in all regions except one accession from Group III (Shewa). This is in agreement with previous reports (Negassa, 1986; Eticha *et al.*, 2005; Geleta and Grausgruber, 2009). Purple seeds were rare in all regions.

Table 3. Shannon-Weaver index for different morphological traits across regions and altitude ranges.

Region	Beak shape	Beak length	Glume color	Awn color	Glume hairiness	Seed color	Seed size	Vitreousness	Seed shape	Seed plumpness	Mean±SE
Group I	0.62	0.91	0.49	0.59	0.00	0.24	0.61	0.69	0.74	0.35	0.52±0.08
Group II	0.63	0.56	0.61	0.60	0.03	0.27	0.73	0.30	0.67	0.27	0.47±0.07
Group III	0.79	0.94	0.57	0.44	0.09	0.17	0.71	0.81	0.38	0.77	0.57±0.09
Group IV	0.70	0.99	0.64	0.64	0.00	0.41	0.32	0.18	0.55	0.49	0.49±0.08
Group V	0.71	0.68	0.46	0.46	0.00	0.57	0.47	0.86	0.69	0.22	0.51±0.08
Altitude (masl)											
≤ 2200	0.89	0.94	0.49	0.52	0.07	0.40	0.65	0.77	0.77	0.77	0.63±0.08
≤ 2500	0.77	0.81	0.59	0.62	0.03	0.25	0.63	0.50	0.50	0.14	0.48±0.08
≤ 2800	0.70	0.91	0.66	0.62	0.00	0.33	0.60	0.41	0.93	0.49	0.57±0.09
> 2800	0.45	0.51	0.35	0.29	0.00	0.35	0.70	0.68	0.93	0.15	0.44±0.08
All	0.78	0.85	0.58	0.58	0.03	0.33	0.69	0.59	0.82	0.45	0.57±0.08

Table 4. Shannon-Weaver index *H′* for different morphological traits partitioned into within and between regions, and within and between altitudes ranges.

Trait	$^{b}H'$	Region			Altitude		
		H'_{cr}	H'_{cr}/H'	$(H'-H'_{cr})/H'$	H'_{ca}	H'_{ca}/H'	$(H'-H_{ca})/H'$
Beak shape	0.78	0.69	0.88	0.12	0.70	0.90	0.10
Beak length	0.85	0.82	0.96	0.04	0.79	0.93	0.07
Glume colour	0.58	0.55	0.95	0.05	0.52	0.90	0.10
Awn colour	0.58	0.55	0.95	0.05	0.51	0.88	0.12
Glume hairiness	0.03	0.02	0.67	0.33	0.03	1.00	0.00
Seed colour	0.33	0.33	1.00	0.00	0.33	1.00	0.00
Seed size	0.69	0.57	0.83	0.17	0.65	0.94	0.06
Vitrousness	0.59	0.57	0.97	0.03	0.59	1.00	0.00
Seed shape	0.82	0.61	0.74	0.26	0.78	0.95	0.05
Seed plumpness	0.45	0.42	0.93	0.07	0.39	0.87	0.13
Mean	0.57	0.51	0.89	0.11	0.53	0.93	0.07

[b]H′ = Shannon-Weaver diversity index for each character calculated from entire data set; H'_{cr} *and* H'_{ca} *= Average diversity index for five regions and four altitudes, respectively;* H'_{cr}/H' *and* H'_{ca}/H' *= Proportion of diversity within regions and altitudes, respectively;* $(H'-H'_{cr})/H'$ *and* $(H'-H_{ca})/H'$ *= Proportion of diversity between regions and altitudes, respectively, in relation to total variation.*

In addition to white and red grains, purple and blue grains occur in wheats. Purple grains are due to anthocyanins in the pericarp while blue grains are due to anthocyanins in the aleurone layer (Zeven, 1991; Knievel *et al.*, 2009). Zeven (1991) reported the presence of purple grains in Ethiopian tetraploid wheats and in a Chinese bread wheat accession. Blue grains are not naturally existing in hexaploid wheats prior to artificial introgression of genes from diploid wheat and *Agropyron* species. The composition and stability of anthocyanins in purple and blue grained wheats has been described by Abdel and Hucl (2003). Purple pericarp and blue aleurone layer have been suggested as phenotypic markers (Zeven, 1991; Zheng *et al.*, 2006a; b) in plant breeding and cytological analysis of wheat. Generally, the presence of purple grain colour in hexaploid wheat is rare and the present few Ethiopian accessions with purple grains may be due to the introgression of genes from tetraploid into common wheat. In Ethiopia wheat landraces are often species mixtures (Worede, 1997; Eticha *et al.*, 2006). The present purple grained accessions still need further cytological analysis to confirm the ploidy level. Börner *et al.* (2005) indicated that the predominance of white-grained wheats in certain countries like India, Pakistan or Libya may also be because of the habit and preferences for end-use product.

Medium to large seeds were dominant within all regions indicating a strong selection pressure towards large seed size by Ethiopian farmers and modern breeders. Seed size and weight are important yield components especially in case that the number of seeds per unit area is limited. Large seed size is often associated with increased seedling vigour and hardiness, improved stand establishment and higher productivity (Grieve and Francois, 1992). Guillen-Portal *et al.* (2006) found that wheat plants derived from large seeds had negative effects on wild oat via a reduction in panicles per area unit and seed weight. Accessions with large seeds and other desirable agronomic traits like disease and lodging resistances are appreciated in variety improvement programmes. In the present study many morphological traits showed polymorphism in all regions but seed colour, vitreousness, shape and plumpness showed region specific frequencies. Similar studies in Ethiopian barley by Demissie and Bjørnstad (1996) showed a high polymorphism for rachilla hair and aleurone colour. The same authors found regional differences for phenotypic traits and regions like Tigray, Gonder, Arsi and Welega contained the vast diversity. Asfaw (1989) found in Ethiopian barley associations between morphology and hordeins, morphology and altitude, and hordeins and altitude. The magnitude of association was higher between morphology and hordeins than between hordeins and altitude. Assefa *et al.* (2002) reported variation for most phenotypic traits of teff in regard to regions and altitudes.

Glume and awn colour were polymorphic within altitudes except for red glume and awned accessions from > 2800 masl. The patterns were not clear but the frequency of red glumes and awns are slightly increasing with elevation up to ≤ 2800 masl. The proportion of large seeds increased with elevation up to 2800m and decreased above 2800 masl indicating that seed size might indicate the adaptation of the cultivar (Tesemma and Belay, 1991). The proportion of vitreous seeds was increasing with elevation until 2800 m and started to decline above 2800 m. Vitreous seeds (hard endosperm) might be frequent at higher elevations. As described by Dziki and Laskowski (2005) vitreousness is well correlated with higher flour yield. Hence, vitreous seeds are of higher quality than non-vitreous (soft) grain types. The present results showed that in Ethiopia the best seed quality for hexaploid wheat can be obtained when grown <2800 m. Altitude influences wheat production in Ethiopia by affecting the amount of rainfall, temperature and prevalence of pests and diseases. It also influences caryopsis structure and pigmentation of glumes and awns (Nastasi, 1964; Gebre-Mariam, 1991). The same authors indicated that Ethiopian grown wheat at altitudes of 2200-2700 m has vitreous kernel and deeper pigmentation of spikes while wheat grown at <2200 m exhibits yellow berry kernels and absence of pigmentation. The proportion of semi-elongated seed types was frequent in all altitudes. The distribution of plump seeds was not consistent within altitudes but in all cases plump types were more frequent.

Shannon Weaver diversity index (H') within all accessions ranged from 0.03 for glume hairiness to 0.85 for beak length. Glume hairiness and seed colour displayed low diversity while other traits displayed medium to high diversity. The present study agrees with a previous report by Negassa (1986). Averaged over all morphological traits within region diversity indices showed slight differences and ranged from 0.47 for Group II (Gonder and Gojam) to 0.57 for Group III (Shewa). This indicates that all regions are rich in genetic diversity for the considered traits. Group III had a higher diversity than all others. Within regions diversity for individual traits was variable. Beak shape, beak length, glume and awn colour, seed size and seed shape had medium to high diversity indices in all regions while glume hairiness and seed colour had lower diversity indices. For Ethiopian barley regional differences for phenotypic diversity were reported by Demissie and Bjørnstad (1996). The same authors stated that Tigray/Gonder in the North, Welega in the West and Arsi in Central and East Ethiopia were richer in diversity than other regions. In our study Shewa is richer in diversity than others followed by Tigray/Welo/Eritrea. However, the diversity status in all regions is similar indicating that all regions have rich sources of germplasm. Barley is known to have a higher diversity compared to tetraploid wheat (Vavilov, 1926; Demissie and Bjørnstad, 1996); Even though hexaploid wheat is a recent introduction it has a broader environmental adaptation than durum wheat in Ethiopia (Tesemma, 1986; Tesfaye *et al.*, 1991).

Averaged over all traits, mean diversity across altitudes were decreasing with increasing altitudes. Mean diversity indices were highest (0.63) for ≤ 2200 masl and lowest (0.44) for > 2800 masl. This indicates that in Ethiopia hexaploid wheats are best adapted to altitudes ≤ 2800 masl. At very high altitudes cool climate and long growing seasons limit genetic diversity. The pattern of diversity for individual traits was variable within altitudes. The agro-climatic zones of

Ethiopia are subdivided into cold highlands (> 3000 masl and > 2200 mm rainfall), cool humid highlands (2500-3000 masl and 2200 mm rainfall), temperate, cool sub-humid highlands (1500-2500 masl and 800-1200 mm rainfall), warm semi-arid lowlands (< 1500 masl and 200-800 mm rainfall) and hot and hyper-arid (< 200 mm rainfall) (PECAD, 2003). In each zone the crop types grown are relatively different. At >3000 masl only barley is dominantly grown, whereas at 2500-3000 m both barley and wheat are grown. Therefore, there are slightly differences in ecological niche for both crops to compare diversity.

Various studies on the influence of region and altitude on phenotypic traits in different food crops from Ethiopia are available. Engels (1994) reported that for barley almost all studied traits were influenced by differences in altitudes within region and maximum diversity was obtained between 2400 and 2800 m a.s.l. The difference to hexaploid wheat is due to a wider environmental adaptation of barley in regard to altitudes. Barley is adapted to conditions from 1400 to 4000 m a.s.l., however, greatest diversity is found between 2000 to 3400 m (Demissie and Bjørnstad, 1996; Asfaw, 2000). Assefa *et al.* (2002) reported that in teff overall mean diversity indices were decreasing with increasing altitude from 1800 to 2400 m. This indicates that hexaploid wheat and teff compete for production area in similar agroecological zones, while barley is adapted to more extreme elevations.

Partitioning of the diversity estimates into between and within regions of collection sites and altitudes revealed that more variation was due to within regions than between regions. Similarly, variation within altitude was higher than between altitudes. Other researchers (Ayana and Bekele, 1998; Geleta and Labuschagne, 2005) reported higher proportions of variation due to within regions of origin and altitudes in Ethiopian sorghum germplasm. On the other hand several papers on tetraploid wheat from Ethiopia (Negassa, 1986; Bechere *et al.*, 1996; Eticha *et al.*, 2005; Eticha *et al.*, 2006; Teklu and Hammer, 2008; Geleta and Grausgruber, 2009) reported higher variation within than between regions and altitudes.

5. Conclusion

In the present study, all morphological traits showed polymorphism except glume hairiness. Seed colour, vitreousness, shape and plumpness showed region specific frequencies. Altitude affected seed size and vitreousness. The frequency of seed size and vitreous increased with altitude up to 2800 m a.s.l. indicating that productivity increased in hexaploid wheat with altitude. Except for glume hairiness and seed colour, all traits showed medium to high diversity values for the accessions analysed. The narrow mean ranges between regions and altitudes showed that all regions and altitudes were similar rich in diversity. Generally, the remarkable phenotypic variations that have been detected in the accessions within regions and altitudes give possible information for using the germplasm resources for future breeding programs.

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7. References

Abdel, E.S.M. and Hucl, P. 2003. Composition and stability of anthocyanins in blue-grained wheat. *Journal of Agriculture and Food Chemistry* 51: 2174-2180.

Annicchiarico, P., Pecetti, L., and Damania, A.B. 1995. Relationship between phenotypic variation and climatic factors at collecting sites in durum wheat landraces. *Hereditas* 122: 163-167.

Asfaw, Z. 1989. Relationships between spike morphology, hordeins and altitude within Ethiopian barley, *Hordeum vulagare* L. (Poaceae). *Hereditas* 110: 203-209.

Asfaw, Z. 2000. The barleys of Ethiopia. pp. 77-108, *In*: S.B. Brush (ed.). Genes in the field: On-farm Conservation of Crop Diversity. Lewis Publishers, Boca Raton.

Assefa, K., Merker, A., and Tefera, H. 2002. Qualitative traits variation in tef (*Eragrostis tef* (Zucc.) Trotter) germplasm from Western and Southern Ethiopia. *Euphytica* 127: 399-410.

Ayana, A. and Bekele, E. 1998. Geographical patterns of morphological variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Ethiopia and Eritrea: qualitative characters. *Hereditas* 129: 195-205.

Ayana, A. and Bekele, E. 2000. Geographical patterns of morphological variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Ethiopia and Eritrea: quantitative characters. *Euphytica* 115: 91-104.

Backhouse, D. and Burgess, L.W. 2002. Climatic analysis of the distribution of *Fusarium graminearum*, *F. pseudograminearum* and *F. culmorum* on cereals in Australia. *Australian Plant Pathology* 31: 321-327.

Bechere, E., Belay, G., Mitiku, D. and Merker, A. 1996. Phenotypic diversity of tetraploid wheat landraces from northern and north-central regions of Ethiopia. *Hereditas* 124: 165-172.

Bekele, E. 1984. Analysis of regional patterns of phenotypic diversity in the Ethiopian tetraploid and hexaploid wheats. *Hereditas* 100: 131-154.

Belay, G., Bechere, E., Mitiku, D., Merker, A. and Tsegaye, S. 1997. Patterns of morphological diversity in tetraploid wheat (*Triticum turgidum* L.) landraces from Ethiopia. *Acta Agric Scand Sect B Plant Soil Sci* 47: 221-228.

Börner, A., Schäfer, M., Schmidt, A., Grau, M. and Vorwald, J. 2005. Associations between geographical origin and morphological characters in bread wheat (*Triticum aestivum* L.). *Plant Genet Resour* 3: 360-372.

CSA (Central Statistical Agency). 2011. Agricultural Sample Survey. Report on area and Production of Major Crops: Private Peasant Holdings, Meh

Season. Vol. I. Statistical Bulletin, Addis Ababa, Ethiopia.

CPVO (Community Plant Variety Office). 2008. Protocol for Distinctness, Uniformity and Stability Tests. *Triticum aestivum* L. Wheat. CPVO-TP/003/4, Community Plant Variety Office, Angers.

Demissie, A. and Bjørnstad, Å. 1996. Phenotypic diversity of Ethiopian barleys in relation to geographical regions, altitudinal range, and agro-ecological zones: as an aid to germplasm collection and conservation strategy. *Hereditas* 124: 17-29.

Donner, D. and Osman, A. 2006. Handbook: Cereal Variety Testing for Organic and Low Input Agriculture. Chair Hanne Ostergard, (Riso National Laboratory, Denmark). 26 pp.

Dziki, D. and Laskowski, J. 2005. Wheat quality physical properties and milling process. *Acta Agrophysica* 6: 59-71.

Engels, J. M.M. 1994. Genetic diversity of Ethiopian barley in relation to altitude. *Genet Resour Crop Evol* 41: 67-73.

Eticha, F. Bekele, E., Belay, G. and Börner, A. 2005. Phenotypic diversity in tetraploid wheats collected from Bale and Welo regions of Ethiopia. *Plant Genet Resour* 3: 35-43.

Eticha, F., Belay, G. and Bekele, E. 2006. Species diversity in wheat landrace accessions from two regions of Ethiopia. *Genet Resour Crop Evol* 53: 387-393.

Feuillet, C., Langridge, P. and Waugh, R. 2007. Cereal breeding takes a walk on the wild side. *Trend Genet* 24: 24-32.

Gebre-Mariam, H. 1991. Wheat production and research in Ethiopia, pp. 1-16, *In*: H. Gebre-Mariam, D. G. Tanner and M. Huluka, (eds.) Wheat research in Ethiopia: A historical perspectives.. IAR/CIMMYT, Addis Ababa, Ethiopia.

Geleta, N. and Grausgruber, H. 2009. Phenotypic diversity of tetraploid Ethiopian wheat landraces. p 72, In: Meglic, U., and Bastar, M. T. (eds.). 19th EUCARPIA Conference, Genetic Resources Section, May 26-29, Ljubljana, Slovenia, Book of Abstracts. Agricultural Institute of Slovenia, Ljubljana.

Geleta, N. and Labuschagne, M.T. 2005. Qualitative traits variation in sorghum (*Sorghum bicolour* (L.) moench) germplasm from eastern highlands of Ethiopia. *Biodiv Conserv* 14: 3055-3064.

Girma, B., Gelalcha, S. and Alemayehu, Z. 2001. Drought tolerance of some bread wheat in Ethiopia. *Afr. Crop Sci.* J. 9: 385-392.

Grieve, C.M. and Francois, L.E. 1992. The importance of initial seed size in wheat plant response to salinity. *Plant Soil* 147: 197-205.

Guillen-Portal, F.R., Stougaard, R.N., Xue, Q. and Eskridge, K.M. 2006. Compensatory mechanisms associated with the effect of spring wheat seed size on wild oat competition. *Crop Sci.* 46: 935-945.

Hutchenson, K. 1970. A test for comparing diversities based on the Shannon formula. *J. Theor. Biol.* 29: 151-154.

Knievel, D.C, Abdel-Aal, E.S. M., Rabalski, I., Nakamura, T. and Hucl, P. 2009. Grain colour development and inheritance of high anthocyanin blue aleurone and purple pericarp in spring wheat (*Triticum aestivum* L.). *J. Cereal Sci.* 50: 113-120.

Nastasi, V. 1964. Wheat Production in Ethiopia. Information Bulletin on The Near East Wheat and Barley Improvement and Production Project 1: 13-24.

Negassa, M. 1986. Estimates of phenotypic diversity and breeding potential of Ethiopian wheats. *Hereditas* 104: 41-48.

OECD-FAO (Organization for Economic Co-operation and Development – Food and Agricultural Organization). 2011. Agricultural Outlook, 2011-2020. OECD-FAO 2011. (http://www.agri-outlook.org/dataoecd/2/38/48184282) (Accessed on March 19, 2011).

PECAD. 2003 Agroclimatic zones of Ethiopia. Production Estimates and Crop Assessment Division, Foreign Agricultural Service (FAS), US Dept Agric (USDA). [Available online: http://www.fas.usda.gov/pecad2/highlights/2002 / 10/ethiopia/baseline/Eth_Agroeco_Zones.htm; verified 8 September 2009].

Perrino, P. and Porceddu, E. 1990. Wheat genetic resources in Ethiopia and the Mediterranean region. pp. 161-178, *In*: Srivastava, J. P., and Damania, A. B. (eds.) Wheat Genetic Resources: Meeting Diverse Needs, John Wiley and Sons, Chichester.

Singh, R.P., Hodson, D.P, Jin, Y., Huerta-Espino, J., Kinyua, M. G., Wanyera, R., Njau, P. and Ward, R. W. 2006. Current status, likely migration and strategies to mitigate the threat to wheat production from race *Ug99* (TTKS) of stem rust pathogen: CAB Rev Perspect Agric Vet Sci Nutr Nat Resour 1, No. 54.

Teklu, Y. and Hammer, K. 2008. Diversity of Ethiopian tetraploid wheat germplasm: breeding opportunities for improving grain yield potential and quality traits. *Plant Genet Resour* 7: 1-8.

Tesemma, T. (1986) Improvement of indigenous durum wheat landraces in Ethiopia. pp 232-238, In: Proc Int Symp PGRC/E.

Tesemma, T. and Belay, G. 1991. Aspects of Ethiopian tetraploid wheats with emphasis on durum wheat genetics and breeding research. pp 47-71, *In*: Gebre-Mariam, H., Tanner, D.J., and Huluka, M. (eds.) Wheat research in Ethiopia: a historical perspective,. IAR/CIMMYT, Addis Ababa, Ethiopia.

Tesfaye, T., Getachew, B. and Worede, M. 1991. Morphological diversity in tetraploid wheat landrace populations from the central highlands of Ethiopia. *Hereditas* 114: 171-176.

Vavilov, N.I. 1926. Studies on the origin of cultivated crop plants. *Bull Appl Bot Genet Plant Breed* 16: 1-248.

Wachira, F. N., Waugh, R., Hackett, C. A. and Powell, W. 1995. Detection of genetic diversity in tea (*Camellia sinensis*) using RAPD markers. *Genome* 38: 201-210.

Wanyera, R. and Macharia, J.K. 2009. Foliar Fungicides to control wheat stem rust, race TTKS (Ug99), in Kenya. *Plant Disease*. 93:929-932.

Worede, H. 1997. Ethiopian *in situ* conservation. pp 290-301, *In*: N. Maxted, B. V. Ford-Lloyd and J. G. Hawkes (eds.) Plant genetic conservation: the *in situ* approach. Chapman and Hall, London..

Worede, M. and Hailu, M. 1993. Linking genetic resources conservation to farmers in Ethiopia. pp. 78-84, In: D. de Boef, (ed.) Cultivating Knowledge: Genetic Diversity, Farmer Experimentation and Crop Research. Intermediate Technology Publications, London.

Zeven, A.C. 1991. Wheats with purple and blue grains: a review. *Euphytica* 56: 243-258.

Zheng, Q., Li, B., Mu, S., Zhou, H. and Li, Z. 2006a. Physical mapping of the blue-grained gene(s) from *Thinopyrum ponticum* by GISH and FISH in a set of translocation lines with different lines with different seed colours in wheat. *Genome* 49: 1109-1114.

Zheng, Q., Li, B., Zhang, X., Mu, S., Zhou, H., and Li, Z. 2006b. Molecular cytogenetic characterizations of wheat-*Thinopyrum ponticum* translocations bearing blue-grained gene(s) induced by *r*-ray. *Euphytica* 152: 51-60.