

Patterns of Variation for Phenotypic Traits in Tetraploid Wheat (*Triticum turgidum* L.) Populations of Ethiopia

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Abstract

The objective of the study was to investigate patterns of variation in qualitative phenotypic traits in fifty tetraploid wheat *T. turgidum* L., populations of Ethiopia. The populations were obtained from gene bank of Ethiopia and grouped into six regions and five altitudinal classes of collection sites. Data for ten qualitative traits with two or more phenotypic classes were taken. A total of 1500 plants (30 plants per population) were sampled to record phenotypic data. Phenotypic frequency distribution and Shannon-Weaver's diversity index were statistically calculated. The results showed that the frequency of phenotypic traits: short beak types, white glume colour, white awn colour, non-hairy glumes, white seed colour, large seed size and plump seed types accessions were 66%, 68%, 58%, 88%, 65%, 85% and 88% respectively in the populations. Mean diversity index (H') within accession ranged from 0.05 to 0.61, and the total mean diversity index ranged from 0.53 for glumes hairiness to 0.96 for beak shape. Mean regional H' ranged from 0.58 for Gonder and Gojam (G-II) to 0.76 for Eritrea, Tigray and Welo (G-I). Similarly, mean H' for altitudinal classes ranged from 0.62 for ≤ 2200 m a.s.l. to 0.79 for 2201-2500m a.s.l. Within region and altitudinal class phenotypic diversity values contributed 86% and 89% respectively, to the total variations. The importance of traits variations in relation to crop improvement and plant genetic resources conservation were discussed.

Keywords

Ethiopia, Phenotypic Diversity, Populations, Qualitative Traits, *Triticum turgidum*

Received: March 2, 2015 / Accepted: March 23, 2015 / Published online: March 30, 2015

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1. Introduction

Tetraploid wheats (*T. turgidum* L., BBAA, $4x=2n=28$) are grown traditionally by peasant farmers in Ethiopia under rain fed conditions at altitudes of 1800-2800m.a.s.l. and some times above 3000 m (Tesemma & Belay, 1991; Zaharieva *et al.*, 2010). In Ethiopia the traditional farming system practiced by farmers gave an opportunity for the continued existence of landraces and intra- hybridizations between different species. Isolation from other wheat germplasm, primitive farming systems, heterogeneous environments, and natural cross-fertilization due to field mixtures contributed to the occurrence of a great diversity in the Ethiopian tetraploid

wheats (Tesemma & Belay, 1991). Ethiopian farmers have been instrumental in creating, maintaining and promoting crop genetic diversity through a series of other long standing activities (e.g. intercropping and cropping with varietal mixtures and growing diversity of local varieties of crops) (Bekele, 1984; Worede & Mekbib, 1993; Eticha *et al.*, 2006; Geleta *et al.*, 2009). Such cropping systems (Bekele, 1984; Tesemma, 1991) might have advantage for yield stability and adding values to the nutritional diets and to reduce the risk of loss due to the outbreak of new pests and diseases or due to unusual environmental conditions.

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The indigenous landraces of the various crop plant species, their wild relatives and the wild and weedy species that form the bases of Ethiopia's plant genetic resources are all highly prized for their potential value as sources of important variations for crop improvement programmes (e.g. disease and pest resistance, drought tolerance, high protein content, low stature, and early heading) (Annicchiarico *et al.*, 1995; Worede, 1997; Geleta and Grausgruber, 2013a, c). Jain *et al.* (1975) acknowledged the high overall diversity of the Ethiopian durum wheat followed by Portuguese among the world's collections for traits they considered; and noted that the centre of diversity seems to be Ethiopia, the Mediterranean region and India.

Germplasm exploration and collections in countries like Ethiopia that are believed to be unique in wheat genetic diversity needs strategy that could be obtained by studying the patterns of population structure across different regions and altitudinal classes. This has been done for sorghum (Ayana & Bekele, 1998) and for hexaploid wheat (Geleta and Grausgruber, 2011) in Ethiopia. Such study can be done by systematic sampling across regions and altitudinal ranges and analysing for important traits that are less influenced by the environment. Though diversity studies have been done in tetraploid wheat by different researchers (Negassa, 1986a; Bechere *et al.*, 1996; Teklu & Hammer, 2008) none of the researchers used the same wheat germplasm and the same phenotype. For instance, Teklu & Hammer (2008) used quantitative morphological traits as a measure of diversity in tetraploid wheat landraces of Ethiopia. The present study is solely based on qualitative morphological traits with two or more phenotypic classes that are less prone to change in environmental conditions and do not depend on test locations

and years.

The analysis of phenotypic variations for simple traits is a useful tool in crop improvement work to identify parental stocks which could be used in crossing programs to transfer valuable traits. Thus results of such a study could be utilized by breeders in the national and regional wheat improvement programs. It also provides useful information for the germplasm collectors to determine their sampling strategies across regions and altitudes. Therefore the objectives of the study were to investigate the patterns of phenotypic qualitative traits variations in tetraploid wheat populations of Ethiopia.

2. Materials and Methods

Plant materials: The study was conducted using fifty tetraploid wheat *T. turgidum* L., landrace populations obtained from the Institute of Biodiversity Conservation of Ethiopia (IBC/E) in 2007. All the landrace populations were originally collected from Eritrea (2 accessions) and the following regions of Ethiopia: Shewa (16 accessions), Arsi (3 accessions), Kefa (2 accessions), Bale (2 accessions), Gojam (2 accessions), Welo (6 accessions), Gamu Gofa (2 accessions), Hararge (2 accessions), Sidamo (1 accession), Gonder (1 accession), Tigray (3 accessions), and 8 populations with unidentified region and altitude (Table 1). All the samples were grown at BOKU-University of Natural Resources and Applied Life Sciences, Vienna, Austria, in spring 2008. Each sample was grown in two rows of 1 m length keeping the distance between rows and plots to be 20 cm. Recommended dose of chemical fertilizers such as NPK were applied at sowing/at booting stage. Weeds were controlled in the plots as well between plots by manual cultivation.

Table 1. Accession number, region and altitude of investigated Ethiopian tetraploid wheat germplasm

Accession code	Region ^a of collection site	Altitude (m)	Accession code	Region of collection site	Altitude (m)
5155	Shewa	2667	241959	Gojam	2125
5180	Shewa	2300	241982_1	Gonder	3080
5325	Kefa	2667	241988	Welo	2845
5613	Shewa	2400	241989	Welo	2845
5738	Shewa	2420	241990	Welo	2445
5768	Shewa	2300	241994	Tigray	2965
5888	Shewa	2920	241996	Tigray	2445
5982	Shewa	2930	241997_1	Tigray	2445
6078	Arsi	2740	241999	Shewa	3030
6861	Bale	2500	5101	Hararge	N/A
6915	Gojam	2030	5326	Kefa	N/A
7073	Arsi	2480	5585	Shewa	2650
7199	Shewa	2500	5861	N/A	N/A
7472	Welo	2920	5880	N/A	N/A
8317	Gamu Gofa	2680	6125	Shewa	2720
204700_1	Eritrea	2280	6137	Shewa	2670
204708	Eritrea	2400	6370	N/A	N/A
6102	Shewa	2430	6761	N/A	N/A
6325_1	N/A	N/A	6872	Bale	2480
209774	N/A	N/A	7028	Arsi	2880

Accession code	Region ^a of collection site	Altitude (m)	Accession code	Region of collection site	Altitude (m)
214370	Shewa	1975	7135	Shewa	2820
226232	Hararge	N/A	7479	Welo	2840
226469_1	N/A	N/A	8085	N/A	N/A
7485	Welo	2830	8314	Gamu Goffa	N/A
237869_1	Sidamo	2050	226637	N/A	N/A

^aN/A- Not available.

Data recording: At harvesting time data were recorded for phenotypic characters: beak shape, beak length, glumes colour, awn colour, glumes hairiness, seed colour, seed size, seed shape, vitreousness, and seed plumpness (Table 2). Thirty individual plants per population making a total of 1500 single plants were used for recording phenotypic data.

Table 2. Scores of used traits and their description (CPVO 2003)

Character	Score	Description
Beak shape	1	Sloping
	3	Slightly sloping
	5	Straight
	7	Elevated
Beak length	9	Strongly elevated with second part present
	3	Short
	5	Medium
Glumes colour	7	Long
	1	White
	2	Red/brown
Awn colour	3	Purple/black
	1	White
	2	Red/brown
Glumes hairiness	3	Purple/black
	0	Absent
Seed colour	1	Present
	1	White
	2	Red/brown
	3	Purple/black
Seed size	3	Small
	5	Medium
	7	Large
	9	Very large
Vitreousness	3	Vitreous
	5	Partly vitreous
	7	Non-vitreous
Seed shape	3	Ovoid
	5	Semi-elongated
	7	Elongated
Seed plumpness	3	Plump
	5	Partly plump
	7	Shrivelled

Data analysis: For the analysis of regional patterns of phenotypic traits variations, accessions were systematically grouped into five different regions of origin according to their similarity or proximity of geographical regions. Accordingly, G-I (accessions from Eritrea, Tigray and Welo); G-II (accessions from Gonder and Gojam); G-III (accessions from Shewa); G-IV (accessions from Bale, Arsi and

Hararge); G-V (accessions from Kefa, Sidamo, and Gamu Gofa); and G-VI (accessions with no region code) were grouped together. The accessions were also grouped into four different altitudinal ranges from which they were originally collected and accessions with no altitude code were grouped together forming fifth group. The altitudinal classes were: ≤ 2200 , ≤ 2500 , ≤ 2800 and > 2800 m a.s.l. 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.

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

Where p_i 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 zero and one. The partitioning of the phenotypic diversity estimate into within and between regions and altitudinal classes were made following the methods given by Wachira *et al.* (1995) and used by Ayana & Bekele (1998). All categorical data were analysed using SAS Vers. 9.1 software.

3. Results

Regional distribution of characters: The frequency distributions of traits within region are presented in Table 3. Beak shape and beak length were polymorphic in their distributions within all regions. The short and medium beak types were more frequent than the long beak type in all regions. Glumes and awn colours were also polymorphic in distribution, though the white glumes and awn were predominant. Purple colour was also frequent in accessions from G-I and G-II while the red/brown colour was more frequent in the accessions from G-V and G-IV. This indicates that either there might be strong colour preferences among the regions or genes controlling the colour of glumes and awns are linked to adaptation of cultivar/variety to specific ecological zones and/or both situations could happen. Glume hairiness was generally monomorphic in distribution and

88 % are non-hairy types in entire populations. The hairy glumes types originate from G-V. Non-hairy glumes might have been selected during domestication and subsequent cultivation by the farmers since hairy glumes types might be less preferred (the reason might be due to some other advantages which might need further investigation).

White seed types were more frequent in all regions compared to the red/brown coloured types. Purple colour was most frequent in accessions from G-I, G-IV, and G-V while it was less frequent in G-III. Farmers' preferences towards grain colour might differ from region to region based on the socio-cultural status. Further, both colour groups differ in end-use purposes in Ethiopia (Geleta *et al.*, 2009). Large and very large seed types were frequent (85%) in entire populations. This might be due to high selection pressure since the start of

agriculture for large seed types by the farmers. Seed vitreousness was also polymorphic in distribution within all regions and this might be due to the low selection pressure for specific types. Both vitreous and non-vitreous seed types were frequent. The vitreous and non-vitreous types were also used for different end-uses. For instance, the vitreous seed types are used for dishes like *Kinche* (crushed grain consumed after boiling) while the non-vitreous seeds are used for bread and other locally prepared food and beverage types in Ethiopia (Geleta *et al.*, 2009; Geleta and Grausgruber, 2013b). The semi-elongated and elongated shape types were frequent in all regions. This is generally true for the *T. turgidum* L. types. The plump seed types were more frequent (88 %) in entire populations.

Table 3. Frequency distribution of different morphological traits within regions and elevations of origin

Region	Beak shape				Beak length			Glume colour			Awn colour			Glume hairiness		Seed colour			
	1	3	5	7	9	1	3	5	1	2	3	1	2	3	0	1	1	2	3
G - I	38	37	7	7	11	47	27	26	59	15	26	40	16	44	95	5	53	7	40
G - II	53	20	27	0	0	60	33	7	63	12	25	53	5	42	100	0	100	0	0
G - III	40	15	25	5	15	75	22	3	84	10	6	75	19	6	88	12	64	9	27
G - IV	7	30	17	23	23	53	47	0	76	24	0	61	26	13	100	0	64	0	36
G - V	40	12	0	16	32	84	16	0	38	49	13	37	49	14	46	54	42	0	58
G - VI	20	10	17	20	33	80	20	0	65	33	2	63	32	5	89	11	81	11	8
Altitude																			
≤2200 m	33	27	27	0	13	40	53	7	68	17	15	63	12	25	84	16	100	0	0
≤2500 m	48	9	19	15	9	51	34	15	66	20	13	52	25	23	96	4	65	10	25
≤2800 m	27	24	22	9	18	82	18	0	56	36	8	48	44	8	68	32	58	0	42
>2800 m	31	40	5	7	17	67	23	10	78	6	16	60	9	31	94	6	38	6	56
Unknown	17	9	14	17	43	83	17	0	71	27	2	70	26	4	91	9	85	9	6
All	33	22	15	11	19	66	26	8	68	21	11	58	24	18	88	12	65	6	29

Table 3. Continued

Region	Seed size				Vitreousness			Seed shape			Seed plumpness		
	3	5	7	9	3	5	7	3	5	7	3	5	7
G - I	0	18	46	36	66	20	14	4	33	63	43	47	10
G - II	0	17	37	46	20	13	67	17	50	33	80	17	3
G - III	1	20	40	39	41	20	39	0	33	67	36	52	12
G - IV	0	16	21	63	33	1	66	0	23	77	40	57	3
G - V	0	0	80	20	30	4	66	0	20	80	26	58	16
G - VI	0	10	71	19	42	13	45	0	44	56	10	69	21
Altitude													
≤2200 m	0	0	65	35	5	5	90	0	50	50	55	30	15
≤2500 m	1	33	34	32	53	19	28	3	41	56	56	32	12
≤2800 m	0	1	68	31	30	6	64	0	23	77	14	70	16
>2800 m	0	6	34	60	54	21	25	4	14	82	40	57	3
Unknown	0	17	58	25	42	11	47	0	46	54	12	71	17
All	0	15	48	37	43	14	43	2	33	65	35	53	12

Table 4. Shannon-Weaver diversity index for different morphological traits in the entire set of accessions

Accession	Beak shape	Beak length	Glume colour	Awn colour	Glume hairiness	Seed colour	Seed size	Vitreousness	Seed shape	Seed plumpness	Mean±SE
5101	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.05±0.05
5155	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.56	0.00	0.00	0.12±0.08
5180	0.66	0.00	0.59	0.59	0.29	0.00	0.00	0.56	0.00	0.00	0.27±0.09
5325	0.83	0.46	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.19±0.10
5326	0.31	0.00	0.51	0.51	0.00	0.00	0.00	0.56	0.00	0.00	0.19±0.08
5585	0.42	0.61	0.18	0.18	0.00	0.00	0.00	0.46	0.00	0.30	0.22±0.07
5613	0.31	0.00	0.00	0.00	0.00	0.30	0.58	0.46	0.00	0.30	0.20±0.07
5738	0.42	0.00	0.30	0.30	0.00	0.30	0.00	0.30	0.00	0.30	0.19±0.05
5768	0.00	0.00	0.47	0.72	0.00	0.56	0.23	0.61	0.00	0.63	0.32±0.10
5861	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.56	0.09±0.06
5880	0.42	0.00	0.86	0.86	0.00	0.61	0.00	0.00	0.00	0.00	0.28±0.12
5888	0.00	0.00	0.00	0.63	1.00	0.63	0.36	0.63	0.00	0.00	0.33±0.12
5982	0.66	0.92	0.38	0.38	0.00	0.61	0.00	0.56	0.00	0.00	0.35±0.11
6078	0.66	0.00	0.56	0.56	0.00	0.46	0.23	0.63	0.30	0.86	0.43±0.09
6102	-	-	0.00	0.30	0.47	0.00	0.00	0.46	0.00	0.86	0.26±0.11
6125	0.31	0.00	0.36	0.36	0.00	0.30	0.36	0.46	0.00	0.30	0.25±0.06
6137	0.66	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.63	0.18±0.09
6325_1	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.07±0.07
6370	0.31	0.00	0.00	0.46	0.88	0.00	0.00	0.00	0.00	0.00	0.17±0.09
6761	0.42	0.46	0.38	0.38	0.00	0.00	0.00	0.00	0.00	0.46	0.21±0.07
6861	0.42	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.63	0.15±0.08
6872	0.42	0.46	0.59	0.72	0.00	0.56	0.49	0.61	0.63	0.00	0.45±0.08
7028	0.31	0.00	0.00	0.00	0.00	0.30	0.00	0.86	0.00	0.00	0.15±0.09
7073	0.59	0.61	0.51	0.68	0.00	0.63	0.00	0.00	0.00	0.56	0.36±0.10
7135	0.66	0.00	0.18	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.10±0.07
7199	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.63	0.00	0.63	0.16±0.08
7472	0.66	0.00	0.77	0.77	0.00	0.30	0.00	0.61	0.00	0.00	0.31±0.11
7479	0.42	0.00	0.51	0.63	0.29	0.46	0.00	0.94	0.00	0.96	0.42±0.11
7485	0.31	0.46	0.63	0.63	0.00	-	-	-	-	-	0.41±0.12
8085	0.00	0.00	0.30	0.30	0.00	0.00	0.00	0.56	0.00	0.00	0.12±0.06
8314	0.00	0.00	0.61	0.63	0.00	0.00	0.00	0.63	0.00	0.63	0.25±0.10
8317	0.42	0.00	0.18	0.00	0.47	0.30	0.00	0.00	0.00	0.30	0.17±0.06
204700_1	0.42	0.61	0.56	0.68	0.88	0.00	0.00	0.00	0.30	0.56	0.40±0.10
204708	0.00	0.61	0.63	0.63	0.00	0.56	0.00	0.00	0.56	0.63	0.36±0.10
209774	-	-	0.00	0.00	0.00	0.56	0.44	0.00	0.00	0.00	0.13±0.08
214370	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.08±0.08
226232	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.08±0.08
226469_1	-	-	0.18	0.18	0.00	0.00	0.49	0.61	0.00	0.61	0.26±0.10
226637	0.00	0.00	0.56	0.72	0.88	0.00	0.00	0.00	0.00	0.56	0.27±0.11
237869_1	0.66	0.61	0.63	0.63	0.72	0.00	0.00	0.86	0.00	0.56	0.47±0.10
241959	0.31	0.46	0.86	0.36	0.00	0.00	0.00	0.00	0.00	0.30	0.23±0.09
241982_1	0.00	0.00	-	-	-	0.00	0.50	0.61	0.63	0.86	0.37±0.14
241988	0.42	0.00	0.38	0.84	0.00	0.00	0.49	0.61	0.00	0.00	0.27±0.10
241989	0.42	0.00	0.67	0.38	0.47	0.30	0.00	0.56	0.00	0.00	0.28±0.08
241990	0.83	0.46	0.95	0.92	0.29	0.00	0.50	0.56	0.61	0.99	0.61±0.10
241994	0.66	0.61	0.18	0.18	0.00	0.63	0.00	0.46	0.00	0.56	0.33±0.09
241996	0.00	0.46	0.91	0.94	0.00	0.00	0.44	0.61	0.00	0.46	0.38±0.12
241997_1	0.31	0.46	0.98	0.97	0.00	0.00	0.44	0.56	0.56	0.56	0.48±0.11
241999	0.31	0.00	0.63	0.38	0.00	0.00	0.00	0.46	0.00	0.46	0.22±0.08
Total	0.96	0.75	0.75	0.88	0.53	0.74	0.74	0.91	0.66	0.87	0.78±0.04

Distribution of characters within altitudinal classes: The frequency distribution of phenotypic traits within the altitudinal classes are presented in Table 3. Beak shape and beak length were polymorphic in distributions within all altitudinal classes. Beak shape showed no trend across the altitudinal gradients. The frequency of short beak types was increasing with elevation up to 2800m while it was vice versa for the medium types. Glume and awn colours showed no clear pattern between the altitudinal classes. Non-hairy glume types were frequent within all altitudinal range though hairy

types were also present in all cases. White and purple/black seed types were present in all altitudinal classes except purple/black in altitudinal class $\leq 2200\text{m}$. The frequency of purple/black colour increased with elevations. Large and very large seed types were frequent in all altitudinal classes while the medium seed type was frequent in altitudinal range 2201-2500m. There was no trend observed with the distribution of this trait in relation to elevations. Extremely high number of non-vitreous seed types was present for accessions originated in the altitudinal class $\leq 2200\text{m}$. This might be the soft types

(non-vitreous) seed types cannot withstand cold temperature at higher altitudes (drought stress tolerant). Interestingly, the frequency of elongated seed types were slightly increased as the elevation increases while it was vice-versa for the semi-elongated types. This might be due to the long duration of maturity time at very cooler environment than at warmer air favouring the full development of the seed shape.

Estimates of diversity within populations: Estimate of phenotypic diversity values within populations are presented in Table 4. The landraces have tremendous diversity for phenotypic traits at individual population level. Averaged over 10 phenotypic traits, diversity values ranged from 0.05 for Acc. no. 5101 to 0.61 for Acc. no. 241990. Thirty percent of the total populations had mean diversity values greater than 0.30. Estimate of diversity values varied with traits within single population (e.g. 0.00 for seed colour and 0.99 for seed plumpness in Acc. no. 241990). On individual population basis, higher diversity values for most traits can be of interest to use in the breeding program. The pooled mean estimates of H' over all accessions ranged from 0.53 to 0.96 with mean of 0.78. From all traits, beak shape (0.96) had the highest diversity value followed by seed vitreousness (0.91) and awn colour (0.88). Glumes hairiness had the lowest diversity value (0.53).

Estimates of diversity within regions and altitudes: Estimates of the diversity index for regions and altitudinal classes are presented in Table 5. Pooled over all traits within regions H' value ranged from 0.58 for G-II to 0.76 for G-I. Individual trait showed different level of diversity across different regions. Glume hairiness ($H'=0.00$) had the lowest value for accessions from G-II and G-IV and the highest value (0.99) for accessions from G-V. Seed colour ($H'=0.00$) had lowest value for accessions from G-II and the highest value (0.88) for populations from G-I. Pooled over all the traits within altitudinal classes the value of H' ranged from 0.62 for ≤ 2200 to 0.79 for ≤ 2500 m a.s.l. All traits differed in diversity values across all altitudinal classes. Tetraploid wheats are

usually grown and adapted in the range of altitudes between 1800m to 2800m and some times up to 3000m in Ethiopia (Tesemma & Belay, 1991). The low differences for H' values between altitudinal gradients indicated that tetraploid wheats are suitably grown in all ranges of altitudinal classes in Ethiopia. But there were variations with specific traits across altitudinal classes. For instance, seed colour had the lowest ($H'=0.00$) value at ≤ 2200 m while maximum at >2800 m. 100% white seeds were found at ≤ 2200 m. In general, it is hard to compare diversity values for traits having different phenotypic classes. In most cases phenotypic traits with less or equal to three classes have higher diversity value than those with more than three phenotypic classes. This problem was clearly stated by Ayana & Bekele (1998).

Inter and intra region(s) and altitudinal classes diversity: The partitioning of H' into within and between regions and altitudinal classes were done to study the sources of variation in entire populations. The results are presented in Table 6. Pooled over all traits, within region diversity was 86 % of the total variation while between regions was only 14%. This indicates that there are sufficient variations within the regions as compared to between regions for the traits considered. Similarly, pooled over characters, within altitudinal class variation accounted about 89 % of the total variation while it was only 11 % for between altitudinal ranges. This also indicates that within the altitudinal classes there are more variations than between altitudinal classes for all the traits. On individual trait basis, beak length, glumes hairiness, seed colour and vitreousness had more contribution to between regional variations than other traits. Similarly, seed colour, vitreousness and seed size had more contribution to between altitudinal variations than other traits. For breeding programs more samples shall be taken within same regions/altitudes of the gene bank collections to capture more variations for phenotypic traits thereby to maintain sufficient genes or alleles controlling noble traits such as earliness, biotic and abiotic stresses resistances and quality traits.

Table 5. Shannon-Weaver index for different morphological traits across regions and altitudes of origin

Region	Beak shape	Beak length	Glume colour	Awn colour	Glume hairiness	Seed colour	Seed size	Vitreousness	Seed shape	Seed plumpness	Mean±SE
G - I	0.84	0.96	0.86	0.93	0.27	0.80	0.75	0.63	0.72	0.86	0.76±0.06
G - II	0.63	0.77	0.81	0.77	0.00	0.00	0.74	0.62	0.92	0.54	0.58±0.10
G - III	0.89	0.59	0.49	0.63	0.52	0.78	0.80	0.96	0.58	0.88	0.71±0.05
G - IV	0.94	0.63	0.50	0.84	0.00	0.59	0.66	0.64	0.49	0.72	0.60±0.08
G - V	0.79	0.40	0.89	0.90	0.99	0.62	0.36	0.70	0.46	0.87	0.70±0.07
G - VI	0.96	0.46	0.66	0.73	0.50	0.56	0.57	0.90	0.63	0.75	0.67±0.05
Altitude											
≤ 2200	0.83	0.80	0.77	0.81	0.63	0.00	0.47	0.36	0.63	0.89	0.62±0.09
≤ 2500	0.87	0.91	0.79	0.93	0.26	0.78	0.83	0.91	0.72	0.85	0.79±0.06
≤ 2800	0.97	0.43	0.82	0.84	0.91	0.62	0.49	0.73	0.49	0.75	0.71±0.06
>2800	0.84	0.76	0.60	0.80	0.32	0.79	0.61	0.91	0.52	0.71	0.69±0.06
Unknown	0.90	0.42	0.61	0.67	0.44	0.49	0.69	0.87	0.63	0.73	0.65±0.05
All	0.96	0.75	0.75	0.88	0.53	0.74	0.74	0.91	0.66	0.87	0.78±0.04

Table 6. Shannon-Weaver index H' for different morphological traits partitioned into within and between regions, and within and between altitudes of origin

Trait	H'	Region			Altitude		
		H'_{cr}	H'_{cr}/H'	$(H'-H'_{cr})/H'$	H'_{ca}	H'_{ca}/H'	$(H'-H'_{ca})/H'$
Beak shape	0.96	0.84	0.88	0.13	0.88	0.92	0.08
Beak length	0.75	0.64	0.85	0.15	0.66	0.88	0.12
Glume colour	0.75	0.70	0.93	0.07	0.72	0.96	0.04
Awn colour	0.88	0.80	0.91	0.09	0.81	0.92	0.08
Glume hairiness	0.53	0.38	0.72	0.28	0.51	0.96	0.04
Seed colour	0.74	0.56	0.76	0.24	0.54	0.73	0.27
Seed size	0.74	0.65	0.88	0.12	0.62	0.84	0.16
Vitreousness	0.91	0.74	0.81	0.19	0.76	0.84	0.16
Seed shape	0.66	0.63	0.95	0.05	0.60	0.91	0.09
Seed plumpness	0.87	0.77	0.89	0.11	0.79	0.91	0.09
Mean	0.78	0.67	0.86	0.14	0.69	0.89	0.11

H' = Shannon-Weaver diversity index for each character calculated from entire data set; H'_{cr} and H'_{ca} = Average diversity index for six regions and five 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

4. Discussion

Except glume hairiness all the studied traits were polymorphic in their distributions within all regions. Bechere *et al.* (1996) reported polymorphic distributions of most traits except for dense spike, long beak and glumes hairiness in populations from north and north-central Ethiopia. Non-hairy glume types were frequent (88%) as compared to the hairy glumes (12%) in studied populations. Other researchers (Negassa 1986b; Tesfaye *et al.*, 1991; Geleta and Grausgruber, 2011) reported lowest diversity value for glume hairiness in Ethiopian tetraploid and hexaploid wheats. Selection for the non-hairy types might have been done by the farmers since the start of cultivation. It might happen also that the hairy glume type genes could be linked to other undesirable traits that could be of no interest to farmers. However, this speculation should be verified in the future. There was also slight difference in distribution of this trait between regions. For instance, the hairy glumes types were from accessions originated from G-V. These accessions are coming from wetter areas or south and south western parts of Ethiopia. The present investigation agrees with the previous report by Negassa (1986b) that the occurrence of hairy glumes in Ethiopian wheat accessions are rare and hairy glumes wheats were from Gamu Gofa region. The hairy glumes might increase the photosynthetic efficiency of the plant and also it might help the spike to protect from pests/diseases development. In addition, hairy glumes types might limit the production of insect pests in wetter and warmer areas due to the desiccation of eggs or larvae and subsequent death.

Glume pubescence is used as morphological marker in wheat breeding and one dominant gene (H_g) controls the trait; and it is located on chromosome 1A. Though hairy glume types

of wheat occur in all wheat species, the frequency differs among the species; it is higher in *T. boeoticum* and emmer wheats than in durum and common wheats and/or it is frequent in primitive wheat types than the modern wheats (Tsunewaki, 1966; Buerstmayr *et al.*, 2011).

The distributions of glume and awn colours varied between regions. Purple colour was frequent in accessions from G-I and G-II (northern Ethiopia and Eritrea) while the red/brown colours were frequent in the accessions from G-V and G-IV (southern, south eastern and western Ethiopia). Interestingly, purple glumes and awn types are more adapted to the northern parts as compared to the southern parts and it was vice-versa for the red/brown glumes and awns. The central parts, Shewa is the transition between the northern and southern parts and both colour groups were found. The white seed colour types were frequent in all regions while the red/brown colour were less frequent and the purple colour was most frequent in accessions from G-I, G-IV, and G-V while it is totally absent in G-II and less frequent in G-III (central Ethiopia). The distributions of white and purple seed types indicated that both seed colours are important and independently selected for different uses by the farmers. The preferences to colour types might differ from region to region based on the socio-cultural and beliefs of the farming communities. Further, both colour groups differ in end-use purposes in Ethiopia (Tsegaye *et al.*, 1994; Geleta *et al.*, 2009; Geleta and Grausgruber, 2013b). There was no clear difference between the regions for seed sizes. The large and very large seed sizes were frequent. This might be due to the selection pressure since the start of agriculture for large seed size by the farmers. Seed vitreousness was also polymorphic distribution within all regions and this might be also important due to the vitreous and non-vitreous types are used for different end-use purposes. For instance, the vitreous seed

types are used for traditional dishes like *Kinche* while the non-vitreous seeds are used for bread and other locally prepared food and beverage types (Geleta *et al.*, 2009; Geleta and Grausgruber, 2013b). With regard to seed shape, the semi-elongated and elongated types were frequent in all regions. This is generally true for the *T. turgidum* L. types. The plump and semi shrivelled seed types were frequent in all regions.

According to Ohsawa and Ide (2008), genetic diversity within populations can vary along altitudinal gradients as a result of several factors. The present study showed that beak shape is polymorphic in distribution across all altitudinal classes except the elevated type at ≤ 2200 m. The distribution of this trait across all altitudinal classes did not show any trend. The short and medium types of beak were frequent across all altitudinal classes. Similarly, the white glumes and awns were frequent and did not show any trend. With regard to the distribution of glumes hairiness, the hairy types were found in the range ≤ 2200 and 2501 - 2800m a.s.l. The white and purple/black seed types are found in all altitudinal classes except only white ones were present in altitudinal class ≤ 2200 m a.s.l. The frequency of purple/black colour increased with elevations. This might be related to adaptation of crops to the different temperature gradient. As the elevation increases, the air temperatures become cooler and in extreme elevations, (e.g. > 2800 m) there is frost problem. This might happen that the purple seed types are more adapted to the cooler and frost conditions in extreme elevations like 3000m. Belay *et al.* (1995) stated that purple seed colour types of tetraploid wheat landraces from Ethiopia were superior to the white and red groups having earlier maturity, shorter height, high fertility and tillering capacity and harvest index signifying better adaptation to various stresses including water logging condition. Our finding agrees with the report by Kebebew *et al.* (2001) that white glumes colour was predominant at lower altitude (< 2300 m a.s.l.), brown glumes were frequent at higher altitude (> 2300 m a.s.l.) and the frequency of purple seed colour increases with elevations. Both large and very large seed size classes were frequent in all altitudinal classes as compared to the small and medium seed size except the medium seed size in altitudinal range 2201-2500m a.s.l. There was no any trend observed across altitudinal gradient for this trait. Vitreous and non-vitreous seed types were more frequent than the partially vitreous ones. Extremely less number of vitreous seed types was found at altitudinal gradient ≤ 2200 m a.s.l. This might be because vitreous seed types are adapted to the cooler temperature conditions. With regard to seed shape, the semi elongated and elongated seed types were frequent in distribution as compared to ovoid types at all altitudinal gradients. Interestingly, the frequency of elongated seed

types slightly increased as the elevation increases while it was vice-versa for the semi-elongated types. This might be due to the long duration of maturity time at very cool environment that favours the more development of the seed shape.

It was shown that the germplasms have tremendous diversity for phenotypic traits at individual population level. Pecceci & Damania (1996) reported higher variations due to differences in agrotypes within landraces followed by variations among landraces within and between provinces respectively. On trait basis beak shape had the highest estimate of diversity ($H' = 0.96$) followed by awn colour (0.88) and seed plumpness (0.87) but the lowest was for glumes hairiness ($H' = 0.53$). Similar results were reported by Geleta and Grausgruber (2011) for hexaploid wheat accessions from Ethiopia. Bechere *et al.* (1996) reported highest diversity indices for seed colour, seed shape and glume pubescence.

On regional basis, estimates of phenotypic diversity (H') was highest for populations from G-I followed by G-II. This indicated that there are differences between different regions with regard to diversity. On altitudinal basis, the highest mean estimate of diversity value was for 2201-2500 followed by 2501-2800 and for > 2800 m a.s.l. The altitudinal range, ≤ 2200 m had lowest mean estimate of diversity value. Bechere *et al.* (1996) reported also highest diversity index for Tigray region (northern Ethiopia) and the altitude range between 2401 and 2600m a.s.l. This indicates that not only the regional differences in diversity but also altitudinal gradients play a role in displaying significant variations among the phenotypic classes. Due attention should be given to the different regions and altitudes when gene bank collections are used for breeding programs.

It was observed that 86 % of the total variation among the populations was due to within regions as compared to 14% between regions. This indicates that there are more variations among the populations within the region as compared to between regions for the traits considered. Similarly, 89 % of the total variation among the populations were due to variations within altitude as compared to 11 % due variations between altitudes. This also indicates that variations within the altitude are more than between altitude in the populations. The present findings agree with (Bekele, 1984; Bechere *et al.*, 1996) that most of the variations in the populations are within the regions and altitudinal classes. Geleta and Labuschagne (2005) reported higher variations for within localities as compared to between localities for sorghum landraces evaluated from eastern Hararge, Ethiopia. Ayana and Bekele (1998) reported large portion of the total variation within region of origin and within adaptation zones for sorghum germplasm from Ethiopia and Eritrea. On trait basis, beak length, glumes hairiness, seed colour, and seed

virtuousness displayed better variations in the populations due to between regions. Similarly, Seed colour, virtuousness, and seed size displayed better variations in the populations due to between altitudes.

5. Conclusion

In the present study higher phenotypic variations were observed in all traits considered. However, the extents of variation varied with traits, populations, regions and altitudinal classes. The frequency of short beak types, white glume colour, white awn colour, non-hairy glumes, white seed colour, large seed size and plump seed types were greater than 50%, in the populations. Within population diversity was immense for most of the traits and 30% of the population had diversity value greater than 0.30; and the total mean diversity index ranged from 0.53 for glumes hairiness to 0.96 for beak shape for the entire populations. Regional phenotypic diversity values varied from 0.58 for Gonder and Gojam (G-II) to 0.76 for Eritrea, Tigray and Welo (G-I). Similarly, mean H' for altitudinal classes varied from 0.62 for ≤ 2200 m a.s.l. to 0.79 for 2201-2500m a.s.l. Within region and altitudinal class phenotypic diversity values contributed 86% and 89% respectively, to the total variations. Generally, the study showed that the populations had immense phenotypic diversity even within population that could be exploited for the wheat breeding programs for different objectives.

Acknowledgment

The author thanks Dr. Tesfaye Awas, Mrs. Feven Werkiye, Mr. Tamene Yohanes, and Mr. Belachew Wassihun for their kind support and cooperation providing the germplasm, Institute of Biodiversity Conservation of Ethiopia.

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