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Research Article

IDENTIFICATION OF SUPERIOR WINTER WHEAT VARIETIES FOR GRAIN YIELD AND DISEASE RESISTANCE IN GEORGIA

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ABSTRACT. Wheat has historically been a staple food crop in Georgia. Wheat sown area and yield over the past 5 years averages 46.5 thousand hectares and 2.1 t/ha, respectively. Unfortunately, the competitiveness of wheat has reduced in Georgia which can be explained, among other reasons, by growing low-yielding and poorly-adapted varieties. Strengthening the grain production in the country through growing improved varieties is one of the internal priorities for the Georgian agricultural sector. The study objective was to evaluate the relative performance of nine breeding lines and one local variety at four locations in Georgia for two years to understand the main factors contributing to genotype x environment interaction as well as to identify superior disease resistant and high-yielding genotypes for potential use as variety candidates. The combined analysis of variance for grain yield and 1000-kernel weight showed that the effects of genotypes, locations and years and all interactions were highly significant for grain yield, TKW and other agronomic traits. According to the experiment data, four genotypes HBK0935W, KUV/LJILN, F885K1.1 and AMSEL/TUI showed especially high yield, 1000 kernel weight and agronomic traits. The highest yielding genotype AMSEL/TUI with moderate resistance to diseases, high agronomic traits and quality could be recommended for growing in all wheat producing areas tested in this study.

Keywords: *Wheat trials, grain yield, agronomic traits, quality.*

INTRODUCTION

Wheat is one of the most important crops to humankind as it is the main source of food around the world and livelihood for many people in developing countries. Today the issue to provide bread to the population of the world, especially in developing countries, is highly important. The situation is complicated because that the growth in demand for bread is ahead of the level of its production. To meet the demand of the world's growing population for the required amount of wheat, the yields must increase at least 1.0% per year to 2030 [1]. The most effective way to meet the population's need is to breed and release the high yielding wheat varieties.

Wheat (*Triticum aestivum* L.) has historically been a staple food crop in Georgia. Winter wheat was cultivated in eight geographic zones of the country. If in the 1970-80s of the 20th century the wheat producing area was about 300 thousand hectares [2], then over the past ten years it has decreased significantly. According to Geostat data [3], wheat sown area and yield over the past 5 years averages 46.5 thousand hectares and 2.1 t/ha, respectively. These figures are much lower than those in the neighboring countries. Unfortunately, the competitiveness of wheat has reduced in Georgia as the prices for imported grain are often less than the cost of the locally produced wheat grain. However, wheat is a very important crop for the East Georgia drylands, where it has no alternatives in crop rotations.

Georgia's population needs 800 thousand tons of wheat annually for food consumption alone. Unfortunately, wheat produced in Georgia meets only 10-15% of local demand. The low competitiveness of wheat in the region can be explained, among other reasons, by growing low-yielding and poorly-adapted varieties and lack of quality seed [4]. After the collapse of the Soviet Union efforts to breed and introduce better adapted varieties in Georgia declined. Therefore, strengthening the grain production in the country through raising the competitiveness of wheat production, which can be promoted through growing improved varieties, is one of the internal priorities for the Georgian agricultural sector [5]. To improve the productivity of winter wheat, the International Maize and Wheat Improvement Center (CIMMYT) in the frame of the International Winter Wheat Improvement Program (IWWIP) distributes different International Nurseries globally to over 100 cooperators in 50 countries (including Georgia). National partners (local breeders) in collaboration with IWWIP have the possibility to study yield levels of elite lines developed by program across the diverse environments in order to properly utilize them in national programs and develop future varieties [6].

Since 2000, Georgian wheat breeders and phytopathologists have been involved in the international winter wheat breeding material improvement network, which provided the national breeding program with numerous nurseries comprising high yielding advanced breeding lines. As a result of the regional testing of these nurseries seven genotypes as varieties with broad adaptation to a range location have been released in Georgia [7].

The study objective was to evaluate relative performance of nine breeding lines and one local variety at four locations in Georgia during two years to understand the main factors contributing to genotype x environment interaction as well as to identify superior disease resistant and high-yielding genotypes for potential use as variety candidates.

MATERIALS AND METHODS

Wheat germplasm

The wheat trial included one local improved wheat cultivar Lomtagora 126 (local check) and nine advanced wheat breeding lines (genotypes) selected from different International Nurseries (IN) of CIMMYT-ICARDA (Table 1). The detailed information on the experimental genotypes is available at www.iwwip.org/Nursery.

Table 1. *Pedigree and origin of the wheat germplasm used in the study*

#	Genotype name	Origin nursery
9	Lomtagora 126 (Local check)	
1	HBK0935W-24/KS84W063-9-34-3-2//KARL 92/4/SH	17th IWWYT-IR-9807
2	BURBOT-6/CARDINAL	18thFAWWON-SA-33
3	SG-RU 24/BILINMIYEN96.55	20th IWWYT-IR-13
4	KUV/LJILN//ORACLE/PEHLIVAN	20th IWWYT-IR-17
5	F885K1.1/SXL/3/OMBUL/A1AMO//MV11/4/BONITO-	20th IWWYT-IR-22
6	T03/17	4thWWSRRN -8
7	PYN/PARUS/3/VPM/MOS83-11-4-8//PEW/4/BLUEG	4thWWSRRN -13
8	DULGER-1/VORONA/BAU	4thWWSRRN -20
10	AMSEL/TUI//BLUEGIL//SHARK/F410w2.1	CWA-WFYT-44

Experimental locations and climate conditions

The wheat trials were established at the research stations of Agriculture Research Center in four locations of Georgia: Dedoplistskaro, village Shavchrelebi (Kakheti zone), Mtskheta, village Tsilkani (Shida Kartli zone), Akhalkalaki, village Vachiani (Javakheti zone) and Borjomi, village Tsagveri (Meskheti zone). These sites widely differ by geographic position, altitude, temperatures, precipitation and soil types (Table 2, 3; Fig.1). The wheat yield trials were conducted in the 2019-2020 and 2020-2021 growing seasons (October-August).

Table 2. *General description of the locations used in the study*

Geographic zone	Location, district	Latitude	Longitude	Above sea level, m	Type of soils
Kakheti	Dedoplistskhar, Shavchrelebi	41.40247N	046.23380E	608	Cinnamonic calcareous
Shida Kartli	Mtskheta, Tsilkani	41.93961N	044.69039E	520	Cinnamonic
Javakheti	Akhalkalaki, Vachiani	41.36599N	043.43324E	1742	Mountain-meadow chernozemic
Meskheti	Borojomi, Tsagveri	41.94380N	043.50707E	1082	Brown soil

Mtskheta is located in Shida Kartli plain which is characterized by moderately humid subtropical climate with mild cold winters and hot summers. The average two-year air temperature and precipitation were 12.7 °C and 11.3 mm per month of growing season, respectively.

Fig.1. *The map of Georgia with the location of experimental plots*

Dedoplistskharo municipality is located in the Shiraki plain. It has a dry subtropical climate with long dry hot summers and relatively cold winters. The average air temperature and precipitation were 11.3 °C and 11.5 mm. January is the coldest month of the year with an average temperature of 0.6 °C. In the hot month of July, an average temperature was 25.8 °C. The rain falls mainly in summer. Akhalkalaki is located on the Javakheti plateau characterized by a mountain steppe climate with short summer, dry and cold winters and strong winds. The average temperature and precipitation for the two cropping seasons were 7.4 °C and 14.3 mm, respectively. The Akhalkalaki area is especially at a high risk of hail. In Borjomi a climate is mid-mountainous, cold and temperate; winters are moderately mild, rather snowy, and summers - moderately warm and dry. The temperature here averaged 7.1 °C. The warmest month was July (20.2 °C), and the coldest – January (−2.5 °C). The climate data and general description of experimental locations were obtained from the Department of Environment and Climate Changes of Georgia [8].

Table 3. *Monthly precipitation and mean air temperature for growing season at experimental sites in 2020 and 2021.*

Location	Temperature, °C, 2019-2020											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	Mean
Akhalk	12.1	4.3	-1.3	1.2	1.8	2.8	11.2	15.0	19.4	22.3	21.8	8.8±2.5
Borjom	12.1	2.5	1.3	-1.7	-0.6	7.3	7.6	13.5	19.0	22.3	-	8.4±2.6
Dedop	13.7	5.0	3.9	0.6	3.4	7.6	8.6	15.8	24.2	25.8	-	10.9±2.7
Mtskhet.	17.2	7.6	6.3	3.8	5.0	10.4	11.3	17.9	24.3	26.9	-	11.5±2.5
	Precipitation, mm											**Mean**
Akhalk	6.0	10.3	6.0	18.0	13.7	25.3	12.7	8.7	19.3	19.5	29.7	15.4±2.3
Borjom	12.0	12.7	10.3	6.7	8.0	23.3	12.7	13.3	20.0	8.7	-	12.8±1.6
Dedop	0.0	10.3	0.0	5.3	3.7	16.0	12.3	27.7	4.3	16.0	-	9.6±2.1
Mtskhet	1.7	6.7	0.3	0.7	0.0	15.6	10.0	26.3	18.3	9.3	-	8.9±2.3
	Temperature, C°, 2020-2021											
	X	**XI**	**XII**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**Mean**
Akhalk	9.6	0.5	-0.4	-4.9	-3.7	3.6	4.1	10.4	15.3	18.1	15.3	6.2±2.4
Borjom	9.8	2.7	-2.1	-3.2	-2.8	-1.7	8.5	11.7	15.5	18.1	-	5.7±2.9
Dedop	14.2	7.3	1.3	2.5	3.6	3.8	13.9	17.2	22.7	24.2	-	11.1±2.8
Mtskhet	15.9	9.3	3.7	3.7	5.8	6.4	14.9	16.0	24.6	25.9	-	12.6±2.5
	Precipitation. Mm											**Mean**
Akhalk.	0.0	4.0	4.7	3.7	6.3	8.3	18.7	34.7	24.0	25.7	14.7	13.2±2.8
Borjom	6.3	1.7	2.3	0.7	11.3	8.0	12.3	43.3	20.7	13.3	-	11.9±2.8
Dedop	13.0	13.0	7.7	8.0	10.0	16.3	4.7	32.3	13.3	14.7	-	13.3±2.3
Mtskhet	5.0	15.3	12.0	2.0	11.7	16.0	23.3	17.0	11.7	22.0	-	13.6±2.1

Field trials

All trials included ten genotypes listed in Table 1. The trials were arranged in randomized complete block design in four replications. The plot area was equal to 10 m^2 (10 mx1 m) in all trials. Each variety was sown in 10 rows spaced 20 cm apart. The distance between plots (replications) was 2.0 m [9, 10]. The planting rate was equal to 200-250 kg/ha depending on the experimental site. The trial was hand-planted to reduce experimental error. The experiment fields were managed based on practices recommended for the areas, where trials were planted. Fields have been disk ploughed twice and then harrowed prior to planting. Phosphorus mineral fertilizer was applied at planting, while ammonium nitrate was applied at a rate of 90 kg/ha in early spring to promote tillering. Weeds were controlled both manually and using herbicide application of 2.4 D amine at the booting stage (in early April-May). The preceding crop in Mtskheta trials was soybean, in Akhalkalaki and Borjomi trials – potato and in Dedoplistskharo – corn. Only Mtskheta location was irrigated.

Field data collection

Measurement of disease incidence and severity in wheat varieties at four trial sites under natural conditions during each of the two growing seasons was conducted according to methods described by Roelfs et al. [11]. Evaluation of plant resistance to stripe rust (*Puccinia f.sp.striiformis*), stem rust (*Puccinia f.sp.graminis*), leaf rust (*Puccinia f.sp.triticina*), Septoria glum blotch (*Stagonospora nodorum*) and Tan spot (*Pyrenophora tritici-repentis*) was commonly done in the field. Two types of scoring were combined: a) the host response to infection in the field was scored using 'R' (resistance) or 'MR' (moderate resistance); "MS' to indicate moderate susceptible, and "S' to indicate full susceptibility, b) the disease severity. Wheat disease severity was recorded twice during the flowering late milk ripening stages during experimentation time using the scales specified for rusts [12] and spot diseases [13, 14]. For phenology records the Zadoks scale [15] for a description of the wheat growth stages were used.

Days to heading were recorded from January 1 when spikes of 50% of the plants on the plots emerged. The plant height was measured from ground level to the tip of the spike. In the late autumn, the autumn growth rate was assessed using a 1-5 scale. Resistance to lodging was assessed during the flowering-late dough stages.

For determining other agronomic traits: spike length, productive spikelet per spike, grains per spike and thousand kernel weight (TKW), 10 productive tillers from each plot replication were cut randomly at ground level prior to harvesting as a sample, placed in paper bags, and then were hand-threshed carefully after air drying. 1000 kernels were sampled randomly from the total grains harvested from each experimental plot and were weighted [16]. For measuring the grain yield, the wheat spikes were harvested from each 10 m^2 plot and threshed by a wintersteiger AG and laboratory thresher LD 350. After that, grain yield was weighed.

To determine the relationship between digital parameter green areas (m^2) and yield the digital photos were taken using a Canon EOS camera around midday from 80–100 cm above the canopy parallel to the soil. Digital photos were taken using automatic mode without flash. The measurements were taken on sunny, dry days for the trials established in Mtskheta in 2021 only starting at tillering every 7-10 days. Digital images were processed using BreedPix [17]. Several parameters were obtained for each image but based on the conclusions of Casadesus et al. [18] we used the parameter of green area per plot for analysis.

The protein content, wet gluten content and gluten deformation index were estimated in all genotypes harvested in Mtskheta location by standard methods approved in Georgia: GOST-protocols #10846-91; #13586-2014. These protocols are built on the Kjeldahl (1883) method acceptable internationally [19]. The essence of the method for determination of protein consists in mineralization of organic substance with sulfuric acid in the presence of a catalyst with the formation of ammonium sulfate, destruction of ammonium sulfate with alkali with the extraction of ammonia, the distillation of ammonia with water steam into the solution of sulfuric or boric acid with further titration. Wet gluten was washed from whole-grain wheat flour by an automatic gluten washing apparatus, centrifuged under standardized conditions, sieved and weighed.

Statistical analysis

Statistical analysis consisted of ANOVA, t-criteria for comparing means, calculation of coefficients of correlations, and regression analysis using JMP statistical software. Yields and thousand kernel weight data from the multi-locational study were analyzed using ANOVA (R studio). Firstly, two-year data sets per each location were analyzed separately. GGE biplot analyses were conducted to determine grain yield stability and superior genotypes. The concept of biplot is a scatter plot that graphically displays both the entries (e.g., cultivars) and the testers (e.g., environments) of two-way data and allows visualization of the interrelationship among the genotypes, environments and the interaction between entries and testers. GGE biplot analysis was analyzed using GenStat for simultaneous selection of genotypes based on stability and mean yield. determining the best genotype in each environment

RESULTS AND DISCUSSION

Grain yield and agronomic traits

The combined analysis of variance for grain yield and 1000-kernel weight showed that the effects of genotypes, locations and years and all interactions were highly significant for both grain yield and TKW (Table 4). This indicates that the cultivars and breeding lines tested change their ranks for both traits depending on the location and year of the experiment.

***Table 4**. Analysis of variance for grain yield and TKW for winter wheat trail tested at four locations in Georgia in 2020 and 2021.*

Trait	Probability of F values for the main factors and interactions:						
	Genotypes	Locations	Years	Genotypes x locations	Genotypes x years	Locations x years	Genotypes x years x locations
Yield	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001
TKW	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

According to wheat trial data for two years and four locations (Table 5), the overall mean yield of all genotypes differed significantly and varied from 4.86 to 6.32t/ha which may be caused by variations in climatic conditions across these locations as experimental locations differ greatly from each other by geographic site, air temperature, rainfall, and also, field management practice. The level of average yield was highest in Mtskheta station (6.22-8.39 t/ha) followed by Akhalkalaki (5.03-7.39 t/ha) locations due to the existence of an irrigation system in the area and sowing after legumes, which increases soil fertility. In Mtskheta and Akhalkalaki the most fertile brown and maintain-meadow chernozemic soils are distributed, respectively. However, the average yield in the 2020 and 2021 cropping seasons was different. In 2021 the yield was significantly less (5.39 t/ha) than in 2021 (6.68 t/ha). The reduction of grain yield in the Akhalkalaki location in the 2020-2021 growing season of wheat was caused by hail before harvesting [8]. The genotypes SG-RU 24 and TO3/17 were especially damaged and the average yield of these genotypes in the growing season of 2020-2021 was 3.9 t/ha and 4.4 t/ha, respectively, while in 2019-2020 their yield was 7.45 t/ha and 6.8 t/ha. The lowest average yield (2.23-5.35 t/ha) was recorded in Borjomi which might be explained by the poor fertility of brown forest soils, especially, by low nitrogen and phosphorus content. In addition, early spring frosts occurred during the second year of this study and increased the risk of plant damage [20]. Organic and mineral fertilizers were needed to improve the soil, but due to the pandemic, field visits were very limited and trial plots in Borjomi were not fertilized in a timely manner. The 2019-2020 cropping season of wheat in Dedoplistskharo was characterized by unfavorable climatic conditions, which were manifested in the autumn-winter and late spring drought which caused delayed emergence of autumn seedlings, formation of unfilled grain and consequently low yields. The main problems thwarting agricultural development in Dedoplistskaro are lack of irrigation water and long droughts. Unfortunately, in the Shiraki plain drought conditions due to the shortage of predecessors, wheat is sown in the same plot for several years in a row, which contributes to the degradation of soil structure and soil fertility [21].

As shown in Table 5, in general, the overall average grain yield of the tested genotypes in the trials could be considered high (4.86-6.32 t/ha) compared to the average wheat yield (2.1 t/ha) in Georgia. The overall average yield of several wheat genotypes HBK0935W, KUV/LJILN, F885K1.1 and AMSEL/TUI varied from 5.68 to 6.32 t/ha was higher than the yield of local check variety Lomtagora 126 (5.56 t/h) and is closest to the yield of Ukrainian cultivars commercial varieties Sonichko (6.03 t/ha) and Poliska 90 (5.4 t/ha) [22]. The yield of the remaining five genotypes (BURBOT-6, SG-RU-24, T03/17, PYN/PARUS, and DULGER-1) was inferior to the local check. Three genotypes HBK0935W, KUV/LJILN and F885K1.1 were especially distinguished in Akhalkalaki and Mtskheta locations where their 2-years average yield was between 7.03 -8.39 t/ha.

As mentioned above, over the past 5 years, seven promised lines: Lomtagora 123, Lomtagora 126, Lomtagora 143, Lomtagora 109, Lomtagora 149, Sauli 9 and Agruni 1 have been selected from international nurseries and registered as a new variety in Georgia [7]. One of them Lomtagora 126 together with several Russian and Austrian wheat varieties after the state testing were included in the national catalog of plant genetic resources. The remaining varieties are currently being under state-grade testing. According to the data of the National catalog [23] the average grain yield of the commercial varieties Amicus, Lupus, Bagira, Grom, released in 2019, is lower (4.2 t/ha) compared to the high-yielding genotypes revealed in this study.

Table 5. *Mean yield of experimental genotypes in four locations for 2020-2021 cropping years*

Genotype	**Yield (t/ha)**					
	Akhalkal	**Borjomi**	**Dedopl**	**Mtkheta**	**Overall mean yield**	**Rank**
Lom-126 (Check)	5.56	4.59	4.85	7.28	5.56	5
HBK0935W	7.39	2.23	4.48	8.03	5.68	4
BURBOT-6	5.64	2.50	4.82	6.69	4.91	9
SG-RU 24	5.68	3.47	4.09	6.22	4.86	10
KUV/LJILN	7.09	3.86	5.70	7.61	6.06	3
F885K1.1	6.72	4.15	5.43	8.39	6.17	2
T03/17	5.64	4.31	4.80	7.05	5.43	6
PYN/PARUS	5.03	3.30	5.35	6.75	5.11	8
DULGER-1	5.65	3.75	4.94	6.29	5.16	7
AMSEL/TUI	5.96	5.35	5.74	8.22	6.32	1
Mean	6.04	3.75	5.00	7.25		

TKW is very important traits directly related to the grain yield and milling quality of the grain. According to the data given in Table 6 the average TKW of all genotypes for two years and four locations varied between 35.1-48.4 g. The high TKW (41.6-47.0 g) was observed in Akhalkalaki and Mtskheta locations. Although that the mean yield in Borjomi was low, the mean TKW for 2 years was high (43.7 g). The lowest TKW (33.5 g) was indicated in Dedoplistkharo. It is known that moisture deficiency in the formation of wheat grains at the stages of flowering-milk ripeness negatively affects the value of TKW [24]. Accordingly, the lowest TKW reported in Dedoplistkharo was caused by drought i. e. lack of sufficient precipitation while in Borjomi the climate was more favorable during the formation of grains for almost all tested genotypes. The genotype AMSEL/TUI was characterized with the highest weight of 1000 grains (average TKW - 48.4 g). Also, genotype AMSEL/TUI has shown high TKW from 43.4 g to 52.8 g in all locations.

The average height of plants, the spike length, spikelets per spike and grains per spike of all genotypes was very different for the locations and two years (Table 7). Mean values of plant height, spike length, spikelets per spike and grains per spike varied from 58.5 to 86.9 cm, from 8.40 to 14.1 cm, from 16.8 to 18.5 and from 37.3 to 51.4, respectively. The number of spikelets per spike and grains per spike increased slightly in Mtskheta and Dedoplistkharo in 2021 and in Akhalkalaki and Borjomi in 2020 which is associated with increases in yield in these locations. On the other hand, the spike length decreased in all locations in the second year. The average height of plants, the spike length, spikelets per spike and grains per spike of all genotypes was very different for the locations and two years (Table 7). Mean values of plant height, spike length, spikelets per spike and grains per spike varied from 58.5 to 86.9 cm, from 8.40 to 14.1 cm, from 16.8 to 18.5 and from 37.3 to 51.4, respectively. The number of spikelets per spike and grains per spike increased slightly in Mtskheta and Dedoplistkharo in 2021 and in Akhalkalaki and Borjomi in 2020 which is associated with increases in yield in these locations. On the other hand, the spike length decreased in all locations in the second year. The genotypes BURBOT-6 and PYN/PARUS expressed the highest average value of grains per spike (55.6 and 54.0) and spike length (10.1cm) while its average yield was lower in comparison with other tested genotypes. The genotype F885K1.1 had a small size of the spike (8.4 cm) and a low value of grains per spike (37.5), however, its average yield and TKW were high (6.14 t/ha and 43.4 g). It is assumed that the final yield level is dependent on grain filling, as it affects the kernel weight [25]. Nevertheless, the obtained results showed that the correlation between yield and yield components is not observed that is in agreement with conclusions of other authors who reported that the significant differences between the wheat cultivars according to the agronomic traits, dependent on germplasm genetics and environmental factors [26]. In accordance with Zhang et.al. [27] the higher the temperature during the spikelet formation phase, which is from flag leaf initiation to terminal spikelet initiation, the higher the number of spikelets per spike in the standard group. Like this, in our study, the average number of spikelets per spike (18.5) was higher in locations with high air temperature Mtskheta and Dedoplistskharo, than in other experimental locations. Mwadzingeni et al. [28] concludes that high temperatures reduce grain yield and yield components. The number of grains per spike is the most reduced component under heat stress but the genotypes with drought tolerance maintained high values for yield components.

Table 6. *Mean TKW of experimental genotypes in four locations for 2020-2021 cropping years*

Genotype	**Thousand Kernel Weight (g)**					
	Akhalkal	**Borjomi**	**Dedopl**	**Mtkheta**	**Overall mean TKW**	**Rank**
Lom-126(LC)	44.9	48.3	37.0	44.7	42.1	5
HBK0935W	48.1	47.5	34.3	46.3	43.7	2
BURBOT-6	39.0	36.6	27.3	40.2	35.1	10
SG-RU 24	42.6	39.7	28.9	41.1	36.9	9
KUV/LJILN	50.0	46.6	32.9	48.1	43.3	3
F885K1.1	49.1	48.5	36.6	42.5	43.2	4
T03/17	47.8	43.3	32.3	38.6	39.8	6
PYN/PARUS	41.1	41.5	29.9	40.3	37.9	7
DULGER-1	40.5	41.2	31.9	38.6	37.2	8
AMSEL/TUI	51.8	43.5	43.4	52.8	48.4	1
Mean	45.5	43.7	33.5	43.3		

Almost all genotypes were resistant to lodging, except of genotype T03/17. The average height of plants ranged between 80.3-86.9 cm in Dedoplitskharo and Mtskheta and from 58.5 cm to 77.3 cm - in Akhalkalaki and Borjomi. The genotypes with the highest mean yield had different plant heights from 71.5 to 84.2 cm. It appears that plant height did not effect on the yield because the highest yielding genotype AMSEL/TUI and lowest yielding genotype SG-RU 24 had nearly the same plant height: 73.1 cm and 72.9 cm, respectively, similar to the local check. The genotypes with the height of 82.3-84.4 cm also showed the high yield (Table 8). This finding is in agreement with the findings of Lima et al. [29], Yadai et al..[30]

Table 7. *Agronomic performance of winter wheat trials grown at four sites in Georgia in 2020 and 2021.*

Trait	**Year**	**Location**				
		Akhalk	**Borjomi**	**Dedopl**	**Mtskheta**	**LSD 0.05**
Yield. t/ha	2020	6.68	4.73	4.61	7.01	0.66
	2021	5.39	2.77	5.46	7.49	0.58
TKW, g	2020	47.0	41.1	28.4	41.6	4.1
	2021	43.9	40.9	38.4	44.8	3.8
Plant height, Cm	2020	58.5	77.3	80.3	86.9	4.3
	2021	64.6	74.5	84.6	83.1	3.9
Spike length, cm	2020	14.1	9.0	9.8	9.4	0.5
	2021	9.1	8.4	10.1	10.8	0.6
Spikelets per spike	2020	18.0	17.2	17.5	18.4	1.1
	2021	16.8	16.9	18.5	18.5	1.2
Grains per spike	2020	51.4	42.3	47.1	46.1	3.4
	2021	37.3	45.1	47. 6	46.6	3.2

The inconsistent results were obtained by different researchers studying the relationship between wheat grain yield and grain components. The part of scientists considers that there is a relationship between the yield components and grain yield. Gulmezoglu et al. [31] and Shamsi et al. [32] indicated that grain yield of wheat depended on plant height, length of spike and 1000 grain weight. According to the Mohamad et al. [33]), a high yielding genotype in moisture limited conditions was related with low plant height. Also, Rahman et al. [34] reported that the most consistent correlation of grain yield was observed for PH and TGW.

Depending on the site environment, the difference between the heading dates varied from 130- to 177 days, thus reflecting the large genotypic variability for heading dates in this germplasm. In the autumn-sown experiment located in Akhalkalaki the days to headings varied in the range of 172-177 while it was lower in the other locations ranging from 130 to 140. The earliest maturing genotype was AMSEL/TUI and the latest maturing was KUV/LJILN. Both early-maturing and late-maturing genotypes obtained the high yield. Compared to local check, the highest yielding genotype AMSEL/TUI did not differ significantly for plant height and days to heading. Days to heading showed a moderate but negative correlation with grain yield in all the seasons [34]. In accordance with the results of Liatukas et al. [35] medium late cultivars outyielded the early maturing cultivars. As reported by Gummadov et al. [36], the relationship between in days to heading and grain yield was not important, and it depends on both germplasm and environmental conditions.

As shown in table 8 four genotypes AMSEL/TUI, F885K1.1, KUV/LJILN and HBK0935W with the highest yield and the best agronomical traits are promising. However, high-yielding genotypes might not always be stable in different environment [37].

Table 8. *Agronomic performance of the germplasm across four sites in Georgia, 2020-2021*

# #	Genotype	Plant heigh, cm	Grain per spike	TKW	YIELD
		for 4 sites, 2020-2021			
9	L-126 (LC)	76.4	39.3	42.1	5.56
10	AMSEL/TUI	73.1	45.0	48.4	6.32
5	F885K1.1	82.3	37.5	43.2	6.17
4	KUV/LJILN	71.5	47.9	43.3	6.06
1	HBK0935W	84.2	44.3	43.7	5.68
6	T03/17	82.4	39.8	39.8	5.43
8	DULGER-1	74.6	44.8	37.2	5.16
7	PYN/PARUS	70.0	54.0	37.9	5.11
2	BURBOT-6	74.9	55.6	35.1	4.91
3	SG-RU 24	72.9	46.1	36.9	4.86
	LSD	4.9	3.1	3.7	1.35

GGE biplot analyses were conducted to determine grain yield stability and superior genotypes. As shown in Figure 2 the genotypes closer to the center of the concentric rings and located at the vertex of a segment are considered superior across the environments based on the mean performance and stability. The three most superior genotypes based on their GGE rank for grain yield were F885K1.1, AMSEL/TUI, and KUV/LJILN.

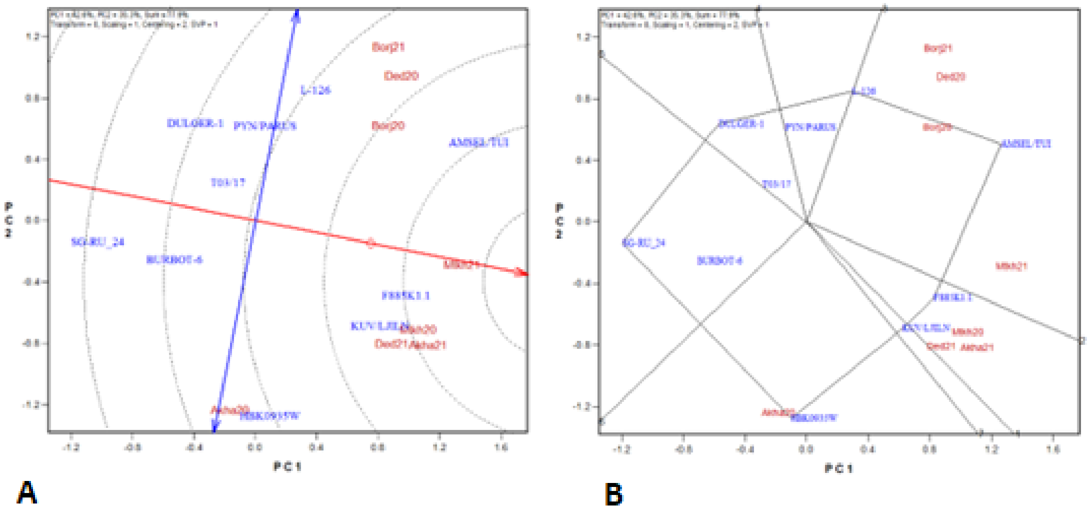

Fig. 2. *GGE biplot for grain yield showing genotypic superiority and stability of the 10 wheat genotypes evaluated in four environments in two growing seasons*

As shown in figure 3, the three most superior genotypes closer to the center of the concentric rings and located at the vertex of in a segment based on their GGE rank for TKW were AMSEL/TUI, HBK0935W and KUV/LJILN.

The genotype AMSEL/TUI was superior for all environments based on its high mean value and stability for TKW.

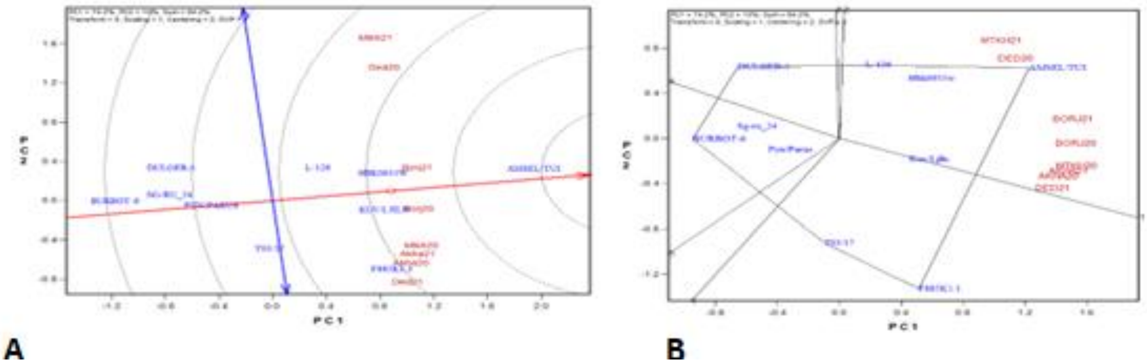

Fig. 3. *GGE biplot showing which genotype superior for TKW in specific environments in a study of 10 genotypes in two growing seasons*

Disease incidence and severity

All three rusts were observed on wheat trials in all locations over 2 years except Dedoplistskharo where no rust diseases were found in 2020. The experiment locations differed by the dates of the first appearance of rusts. The earliest place for three rusts was Dedoplistskharo, followed by Mtskheta and Borjomi in 7-10 days intervals. The first symptoms of the diseases showed up on nearly all tested genotypes in mid-May in Dedoplistskharo, in early June in Mtskheta and Borjomi. The rust diseases were detected in Akhalkalaki at the end of June. The trial results revealed that the incidence and severity of rusts in 2021 were higher as compared to the crop growing year of 2020. This severity may be attributed to the relatively dry weather that prevailed in 2021. More rainfalls in Akhalkalaki and Borjomi favored the severity of leaf rust and stem rusts in almost all genotypes.

Table 9. *The severity of wheat rusts on 10 genotypes in high-yielding locations (Akhalkalaki, Mtskheta*

Genotype	Leaf rust		Stem rust		Stripe rust	
	Akhalk 2021	Mtskheta 2021	Akhalk 2021	Mtskheta 2020	Akhalk 2020	Mtskheta 2021
L-126 (LC)	1MS	30MS	30 MS	1MS	10MR-MS	MR
AMSEL/TUI	1MS	10MS	20 MR	0	5MR	0
F885K1.1	30MS	40MS	5 MS	0	30MR	0
KUV/LJILN	0	0	0	0	0	0
HBK0935W	10MS	5MRMS	5 MS	0	0	5MR
T03/17	1MS	5MR-MS	5 MS	5MS	15MS	1MR
DULGER-1	10MS	5MS	40 MS	10MS	0	0
PYN/PARUS	0	5MS	5 MS	5MS	80MR	0
BURBOT-6	10MS	50MS	40 MS	5MS	0	5MS
SG-RU 24	30MS	60MS	10 MS	1MS	0	1MR

The reaction of the tested genotypes to rusts did not differ significantly by location. The stripe rust, leaf rust and stem rust were recorded on the majority of genotypes except KUV/LJILN. No stripe rust was found on genotype AMSEL/TUI. The incidence of leaf rust was higher than stripe rust and stem rust. The high severity (40-60%) of leaf rust was scored on moderately susceptible genotypes: BURBOT-6, F885K1.1 and SG-RU24 in Mtskheta in 2021. For stem rust, moderate susceptibility to stem rust was observed on seven genotypes with a severity of 5-40% while genotype AMSEL/TUI demonstrated 20MR reaction. The Severity of stem rust was higher in Akhalkalaki than in other locations. High incidence stripe rust was recorded on genotype PYN/PARUS with severity 80MR in Akhalkalaki. Most genotypes were resistant or moderately resistant to stripe rust (Table 9). Generally, the incidence and severity of rusts were low in the two wheat growing seasons. Since 2010 serious outbreaks of rusts have not been recorded in Georgia. The high severity of rusts was observed in the separate wheat fields with susceptible varieties [38, 39, 40]. The blotch diseases (Septoria glum blotch, Tan spot) occurred in all locations with different intensities. They were found on all genotypes with 10-40% severity. The blotches were more abundant in Mtskheta than in other locations. The obtained results suggest that the diseases did not affect significantly on grain yield because the majority of tested genotypes were characterized by moderate resistance. The genetics of resistance of these genotypes has not been studied yet, but it seems that they were demonstrated adult plant resistance. The research to determine the genetics of resistance and resistance genes of the superior genotypes should be continued in the future. The blotch diseases (Septoria glum blotch, Tan spot) occurred in all locations with different intensities. They were found on all genotypes with 10-40% severity. The blotches were more abundant in Mtskheta than in other locations. The results suggest that the diseases did not affect significantly on grain yield.

Grain quality

Gluten is an important component of wheat because the nutritional, technological and commodity value of wheat grains depends on the content of gluten. The quantity and quality of gluten provide strength and texture to baked wheat products. The higher the gluten content the better will be the quality of wheat flour for bread [41]. According to the quality analysis of ten tested genotypes the wet gluten, protein contents and gluten deformation index of wheat genotypes flour ranged between 6.0 and 22.7 %, 8.46-11.2% and 74-103, respectively (Table 10). The highest content of the wet gluten was recorded for genotype AMSEL/TUI/(22.7%) but the highest content of protein (11.2%) was found in the genotypes HBK0935W and F885K1.1/. These genotypes had superior quality values than local check Lomtagora 126. The quality of the high-yielding genotype KUV/LJILN was very low (6.0-9.2%) compared to the remaining genotypes. It is stated that the amount of wet gluten is higher than 35% in wheat with high gluten value, between 28-35 (% w/w) in good wheat, between 20-27 (% w/w) in medium wheat, and less than 20 (% w/w) in wheat with low degree gluten [42]. Accordingly, high-yielding genotypes with 20.2-22.7% wet gluten content can be considered as medium wheat cultivars.

As mentioned above, following the trials data five genotypes HBK0935W, KUV/LJILN, PYN/PARUS, F885K1.1 and AMSEL/TUI showed especially high yield, 1000 kernel weight and good agronomic traits. However, the analysis revealed that among the highest yielding genotypes only one genotype AMSEL/TUI was the most stable across years and diverse sites in Georgia. Accordingly, the highest yielding genotype AMSEL/TUI with the moderate resistance to diseases, relatively high agronomical traits and grain quality could be recommended for growing in Shida Kartli and Javakheti zones. The remaining high-yielding genotypes which showed very high yield (about 7-8 t/ha) in separate years and locations were selected for future research to determine the potential yield under the appropriate best cultural practices in the main wheat production areas.

Table 10. *Grain quality of ten tested genotypes*

Genotype	**Protein, %**	**Wet gluten, %**	**Gluten deformation index**
Lomtagora 126 (Local check)	8.6± 0.44	18.3± 0.21	91
HBK0935W-	11.2± 0.3	20.2 ±0.15	83
BURBOT-6/	9.7± 0.2	19.2 ±0.25	74
SG-RU 24/	9.6±0.32	8.3 ±0.25	100
KUV/LJILN//	9.2± 0.26	6.0 ± 0.2	103
F885K1.1/	11.1 ±0.21	21.4± 0.95	86
T03/17	8.5 ±0.15	19.4± 0.35	93
PYN/PARUS/	10.3± 0.25	20.5± 0.2	85
DULGER-1/	10.4± 0.1	18.3± 0,2	97
AMSEL/TUI/	10.4± 0.11	22.7±0.25	80

Over the last 20 years, numerous breeding nurseries comprising high-yielding advanced breeding lines were introduced from CIMMYT and ICARDA and evaluated under diverse world environments [43, 44, 45, 46, 47, 48] including Georgia [49]. As a result of this collaboration several new varieties: Mtskheta 1), Sauli 9, Agruni 1, Lomtagora 109, Lomtagora 107, Lomtagora 155, Lomtagora 149, Lomtagora 143 Lomtagora 123 and Lomtagora 126 were selected from international nurseries and already released in Georgia. The data on the genotypes tested in this study is very limited. However, some nurseries (4thWWSRRN, CWA-WFYT) were earlier evaluated in Ukraine [50] and Uzbekistan [51] and similar results were obtained. Several genotypes of these nurseries were selected as resistant to stripe rust [52] and stem rust [53] based on results of previous PhD research in the frame of collaboration with CIMMYT.

Association of digital parameters with grain yield

According to Casadesus et al. [18], a number of parameters can be derived from a plot digital photo: area, intensity, saturation, a, b and u from Lab color space, green area and greener green area. The digital photo was taken six times during the crop season in irrigated location, Mtskheta in 2021. Each digital photo parameter was correlated with the grain yield at each observation date. The value of correlation between digital photo parameters and grain yield varied depending on the crop stage. It is demonstrated by the graph in Figure 4.

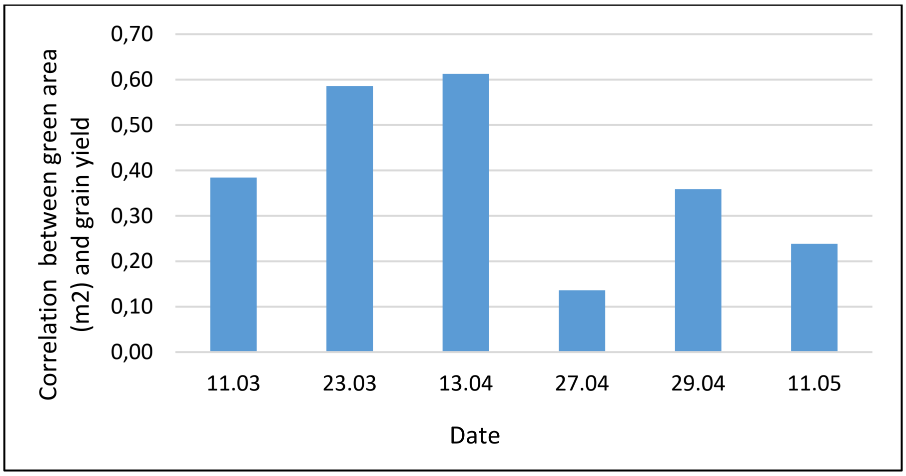

Fig. 4. *Values of the correlation coefficient between the digital parameter green area (m^2) and grain yield took at six dates in Mtshkheta in 2020.*

The Relationship between the parameter of green area and grain yield was positive and had value close to 0.4 at the early tillerng stage on March 11 and then increased to 0.6 during observations on March 23 and April 13 but decreased again in later April and early May. We selected data from April 13 to demonstrate a correlation between the green area from a digital photo and grain yield (Figure 5). Clearly, two highest yielding genotypes had the highest value of the green area. The correlations between grain yield and both the NDVI and the GGA is observed by other researchers too [29, 34]

Overall, using a digital photo for the evaluation of grain yield can be useful but requires identification of the optimal stage of crop to evaluate digital parameters. The data from the current experiment was limited to one year only and requires additional experiments. Our data were in agreement with results obtained by Morgounov et al. [17].

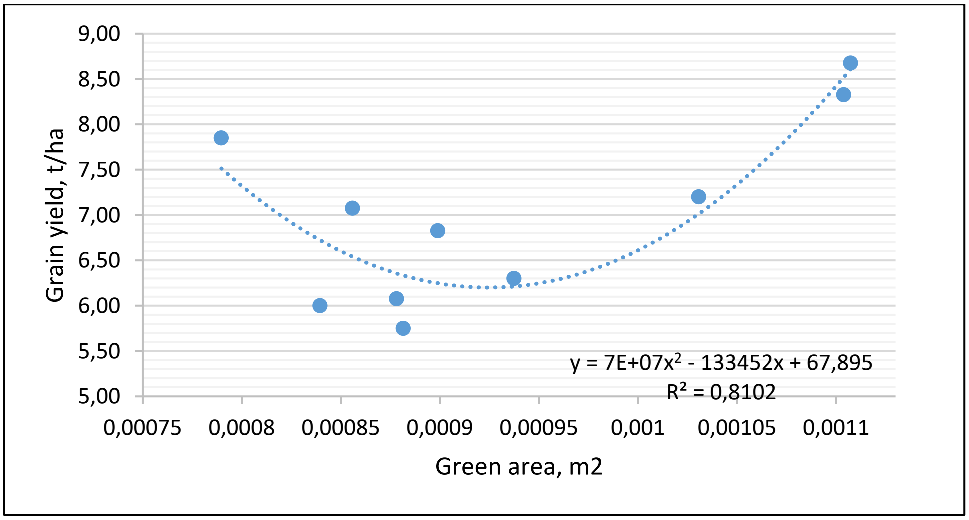

Fig.5. *Relationship between the digital parameter green area (m^2) taken on 13.04.2020 and grain yield in Mtshkheta.*

CONCLUSION

The combined analysis of variance showed that the effects of genotypes, locations and years and all interactions were highly significant for grain yield, TKW and other agronomic traits.

On the basis of the experimental data obtained from this research, it was identified that superior high-yielding genotypes (HBK0935W, KUV/LJILN, F885K1.1 and AMSEL/TUI) for future researches.

The highest yielding genotype AMSEL/TUI with the moderate resistance to diseases high agronomic traits and quality was selected to submit to "Sakpatenti" of Georgia for registration as a new variety named "Khvamli". It could be recommended for growing in all locations tested in this study.

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Conflict of Interest. The authors declared that there is no conflict of interest.

Authorship Contributions. Concept: S.Z.V., Design: S.Z.V., M.A., Data Collection or Processing: S.Z.V., C.G., S.T., N.K., D.R., G.L.A., S.K.T., Analysis or Interpretation: S.Z.V., C.G., S.T., N.K., D.R., G.L.A., S.K.T., T.D., M.A., Literature Search: S.Z.V., M.A., Writing: S.Z.V., M.A.

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