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BIOLOGICAL POTENTIAL OF WINTER CEREALS IN THE NORTHERN TRANS-URALS, RUSSIA

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SUMMARY

Winter cereals (wheat, triticale, and rye) are the most cultivated crops in Russia, and their yield and quality results from the combination of environment and farm management. Generally, winter cereals have a much higher yield than spring cereals due to the ability to use winter moisture for growth. The latest study aimed to conduct a comparative assessment of the winter wheat, triticale, and rye according to the variability of quantitative traits under the environmental conditions of Northern Trans-Urals, Russia, during 2019–2020 and 2020–2021. Results revealed that the genotypes of winter triticale (× *Triticosecale* Wittmack) and winter rye (*Secale cereale* L.*)* showed improved harvests compared with winter wheat even under unfavorable environmental conditions of the Northern Trans-Urals, Russia. The chlorophyll content in the plant leaves was used as a tool for screening the genotypes of different winter cereals. Plant screening with the SPAD 502 Plus optical chlorophyll counter made it possible to determine the responses of genotypes to the heat and water stress conditions. For chlorophyll content in the flag leaf cells, intra- and inter-specific differences were observed. The fields of winter crops harvested in summer (late July to early August) can serve for growing multifunctional crops like ground cover, fodder, and green manure crops.

Keywords: Winter wheat, triticale, rye, diverse environments, chlorophyll, SPAD 502 device, cultivars testing

Key findings: Winter cereals (wheat, triticale, and rye) showed a high potential for winter hardiness, resistance to lack of moisture, and against high air temperatures, giving high grain yield. Thus, the study suggests them as promising under the environmental conditions of the Northern Trans-Urals, Russia. Further, in evaluating plant morphological traits, the chlorophyll content in leaves at using a portable meter SPAD 502 provides a useful criterion for screening the genotypes. The fields of winter crops harvested in summer can serve for growing multipurpose crops.

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INTRODUCTION

Growing winter crops (wheat, triticale, and rye) can provide various advantages over growing spring crops (wheat, barley, and oat). These crops are preferred due to earlier ripening (late July – early August), as well as, due to their efficient use of moisture from deeper layers (>50–60 cm), and the ability to accumulate moisture in the root zone till end of the tillering phase, from precipitation in the autumn-winter and early spring periods. However, the utilization of winter crops is limited due to a lack of scientifically-based data for the selection of good species and cultivars (Bome and Bome, 2005). In Siberia, Russian agriculture began about 427 years ago in the Northeastern regions of the Sverdlovsk region and the Northwestern regions of the Tyumen region (Ivanenko, 1990; Ivanenko, 2013). The first scientific publication on the cultivation of winter rye came out at the end of the 18th century (Shukshin, 1794), and on winter wheat at the beginning of the 20th century (Chernogolovin, 1939; Strakhov, 1939). According to Rosstat, in recent years (2017–2021), the total area of winter cereals crops amounted to 8,300–10,900 ha in the Tyumen region, Russia.

The limited spreading of winter crops in the regions is characterized by unfavorable soil and climatic conditions associated with several limiting factors, i.e., severe winter conditions, possible return of cold weather in spring, and early spring droughts (Nikolaev, 1994; Karpova, 2005; Vikulova, 2006; Darzi-Ramandi *et al*., 2016; Dwivedi *et al*., 2018). Therefore, the need to develop a technology for winter crops (Ivanenko and Ivanenko, 2012) and cultivars plays a crucial role in over-wintering and increasing productivity (Ismagilov *et al*., 2005; Shaimerdenova *et al*., 2022; Sial *et al*., 2022; Zulkiffal *et al*., 2022). Currently, among the promising crops, triticale is considered, which is an amphiploid cereal obtained from crossing wheat (*Triticum* spp.) and rye (*Secale cereale* L.), and can have different levels of ploidy (tetraploid (2n = 14 = AARR) (McGoverin, 2011) to octoploid (2n = 56 = AABBDDRR) (Oettler *et al.*, 2005).

Improved triticale cultivars have more grains than wheat (Mergoum and Macpherson, 2004) and are comparable to rye (Kavanagh and Hall, 2015). Earlier studies showed that triticale provides higher yields even in unfavorable environmental conditions (Blum, 2014), which has a competitive advantage over wheat, and other fodder and cover crops. Nikolaev and Yusova (2021) reported the ability of winter triticale to give higher grain productivity in the conditions of Western Siberia. In the Tyumen region, winter rye, wheat, and triticale are evaluated on the experimental fields of the State cultivars' plots to select those adapted to difficult soil and climatic conditions. Among the important tasks is the rational use of the soil after the harvest of winter crops, which occurs much earlier than the spring crops harvest. Growing ground cover plants after the main harvest are now becoming common practice in many countries. Continuous canopy management can help improve soil health and prevent soil erosion.

The effectiveness of cover crops depends on the individual species, their mixture, soil type, and climate (Thorup-Kristensen *et. al.*, 2003). For example, legume cover crops are widely used because of their short growing season and also enrich the soil with biologically fixed nitrogen (N) for subsequent crops (Wortman *et. al*., 2012; Wittwer *et. al.*, 2017). The application of cover plants to the soil as green manure also improves organic matter and improves fertility (Doran and Smith, 1987; Drinkwater *et al*., 1998). Cover crop management helps adapt to climate change and enhances soil water management during periods of waterlogging and drought (Kaye and Quemada, 2017). The latest research work aims to conduct a comprehensive assessment of the genotypes of winter triticale, rye, and wheat according to the variability of quantitative traits under the conditions of the Northern Trans-Urals, Russia.

MATERIALS AND METHODS

Meteorological conditions

The vegetation periods of the study location differed significantly in terms of heat and moisture supply. The period from May to August in 2021 was characterized by an increased temperature compared to the long-term average of 1.0°C–5.6°C against the background of a significant lack of precipitation (10%–57% relative to the norm), which is considered arid. In 2020, plants experienced a significant lack of moisture only in July (21% of the norm; May, June, and August had 91%–123% of the norm). Meanwhile, the average daily air temperature was 21.5°C (2.7°C above the norm).

During the sowing of winter crops in August 2019 until plant growth in September and October, the weather conditions remained favorable. During the germination of seeds and the formation of seedlings, the air temperature was close to the average long-term value, and the rate of precipitation to the norm was 119%:83%. In the winter months, air temperatures exceeded the average long-term data by 4.0°C in December 2019, and 5.2°C and 7.3°C in January and February 2020, respectively. The heaviest volume of precipitation (183% of the norm) was recorded in February. In the spring period (March, April) the volume of precipitation was close to the norm (102%–118%), and the air temperature was 5.9°C–3.1°C higher.

Notably, in the third day of August 2020, the sowing of winter crops was carried out at an abnormally high air temperature (2.2°C–8.2°C above the long-term average) and a lack of moisture (5.1 mm). The growth and development of the plants in September took place under conditions with significant fluctuations in air temperatures (from 9.3°C to 24.2°C); October and November were characterized by a lack of precipitation (67% and 65% of the norm, respectively). In winter, the structural and functional states of plants were determined by insufficient snow cover in December and January (the amount of precipitation was 49% and 91% of the norm, respectively), lower air temperatures compared with the long-term average in January (-3.9°C) and February (-4.4°C). A nonsignificant amount of precipitation (49% of the norm) against the background of relatively high temperatures (+2.2°C) led to rapid snow melting. Thus, over-wintering of winter crops, re-growth in spring, and the passage of phenological phases in summer were accompanied by the influence of meteorological factors contrasting over the years (Figure 1).

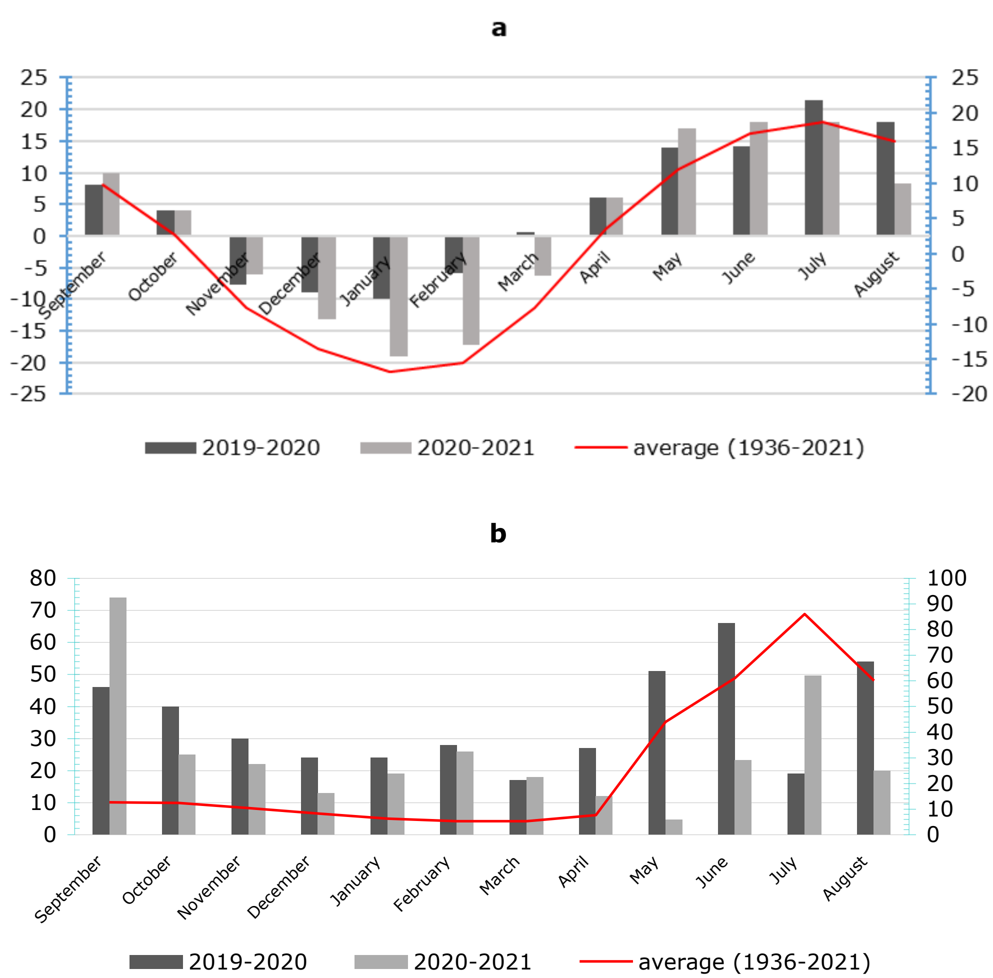

Figure 1. a) Average daily air temperature in °C, b) The amount of precipitation in mm, during 2019–20 and 2020–21 (Source: Meteorological Station, Tyumen, Russia).

Figure 2. General view of the winter crops: a) Shoots-tillering in September 2020, b) Ingredient ripening (wax ripeness) in July 2021.

Data on average daily air temperature and precipitation were obtained from the reference and information portal "Weather and Climate, 2021" (http://www.pogodaiklimat.ru). The average annual values of the average daily air temperature and precipitation for 1936–2021 were taken as the norm.

Place of study

The study was conducted at the Department of Botany, Biotechnology and Landscape Architecture, Institute of Biology, Tyumen State University, Russia. The field research work took place in 2019–2022 at the experimental site of the Biological Station of the Tyumen State University "Lake Kuchak" (Russia, Tyumen region, Nizhnetavdinsky District, 57.35° N 66.06° E). The soil of the site was cultivated, sod-podzolic sandy loam, with humus content (3.67%), and acidity in salt extract (6.6), which was close to neutral (Figure 2).

Plant material

The study used plant materials comprised of four cultivars of winter rye (‘Chusovaya,’ ‘Alisa,’ ‘Parom,’ ‘Yantarnaya’), nine samples of winter wheat from the world collection of All-Russian Institute of Plant Industry ("VIR") (k-60753, k-64170, k-64496, k-64504, k-63003, k-64507, k-64198, k-64499, k-64172), two selected samples of winter wheat from competitive cultivar testing (CCT-35/17, CCT-38/17), triticale cultivar ‘Istoksky,’ and two breeding samples of triticale (CCT-17/17, CCT-16/17). The seeds were obtained from the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (“VIR”), Federal State Budgetary Scientific Institution "Omsk Scientific Agrarian Center", Ural Research Institute of Agriculture - a branch of the Federal State Budget Scientific Institution URFANITs Ural Branch of the Russian Academy of Sciences, Russia (Table 1). These specimens were selected based on preliminary assessment in collection nurseries.

Table 1. Plant material used in the study.

Culture	Code	Genotype	Origins	Obtained from
Wheat	G1	Kazanskaya 234	Russia	VIR
	G2	CDC Osprey	Canada	VIR
	G3	Dar Luganshchiny	Ukraine	VIR
	G4	Pysanka	Ukraine	VIR
	G5	Soldier	Great Britain	VIR
	G6	Edwin	USA	VIR
	G7	Mera	Russia	VIR
	G8	Dosvyd	Ukraine	VIR
	G9	Clemson	USA	VIR
	G10	KSI 35/17	Russia	OARC
	G11	KSI 38/17	Russia	OARC
Rye	G12	Chusovaya	Russia	URIARAS
	G13	Alisa	Russia	URIARAS
	G14	Parom	Russia	URIARAS
	G15	Yantarnaya	Russia	URIARAS
Triticale	G16	Istoksky	Russia	URIARAS
	G17	KSI 17/17	Russia	OARC
	G18	KSI 16/17	Russia	OARC

Research methodology

Seeds of wheat (*Triticum aestivum* L.), triticale (× *Triticosecale* Wittmack), and rye (*Secale cereale* L.) were sown on the third day of August at the rate of 650 pcs/m^2. The accounting plot area measured 3 m^2 and the experiment was repeated three times. The row spacing measured 15 cm, with the seeding depth at 5-6 cm. During the growing season, the height of plants, the length and width of the flag leaf, the content of chlorophyll in the leaves, and the grain yield were recorded.

Plant height was measured from the soil surface to the tip of the ear. The assessment of plant resistance to lodging was carried out visually throughout the growing season (Int. Classifier, 1984) on a nine-point scale (in points), i.e., 1 point = very low; 3 points = low; 5 points = average; 7 points = high; and 9 points = very high. The flag leaf area was calculated according to Miralles and Slafer (1991) using the following formula.

$$\text{Flag leaf area} = L \times W \times bi$$

where:
L = length of the leaf blade, W = maximum width, and b_i = 0.835.

The chlorophyll content in flag leaf cells was determined using a SPAD 502 optical counter (Minolta Camera Co. Ltd., Tokyo, Japan). Based on the instrument, the data was taken by measuring the spectral absorption in two spectral ranges corresponding to the absorption of chlorophyll, and calculating the numerical value of the SPAD, which is proportional to the content of chlorophyll in the leaves. The SPAD measurement was calculated based on the leaf absorbance of chlorophyll at 650 nm (maximum absorption of chlorophyll and absorbance at 940 nm), taking into account the leaf thickness. For each sample, the chlorophyll content got measured in the flag leaves of 10 plants. The middle part of the leaf sheet was placed on the bottom of the device and clamped for a few seconds until a numerical value appeared. The device automatically remembers all readings and calculates the average value of the relative chlorophyll content. The SPAD 502 is a portable chlorophyll meter used in Plant Physiology, Agriculture, and Forestry (Gáborčik, 2003; Pinkard *et al*., 2006; Marenco *et al*., 2009). The device allows to quickly assess the total chlorophyll content in leaves without removing plants from the phytocenoses, which is especially important for multiple measurements in one leaf (Hawkins *et al*., 2009; Coste *et al*., 2010).

Harvesting of winter crops was done during the phase of full grain ripeness by hand and by pulling out plants with roots. The assessment of plant resistance to lodging was carried out visually on a nine-point scale (Int. Classifier, 1984). The mass of 1000 grains was determined from two samples of 500 grains (GOST-12042-80). After harvesting on 01 August 2021, the spring crops were sown without additional tillage: oats samples (k-15190, k-15203, k-15255, k-15346, k-15377, and k-15375) from the collection of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources; rape cultivars (Flagman, Sirius, Favorit, and Antares), sarepta mustard (Luxe), colza (Lisichanka), vetch (Harmony), and peas (Tyumenets). The chosen plants met the requirements for ground cover crops in terms of morpho-biological features and properties, as well as, the duration of plant vegetation. The plot area measured 3 m^2 with 3-fold repetitions. After the onset of frost on 03 October 2021, plant height was determined by measuring the plants at five points, the chlorophyll content in leaves using a SPAD 502 device, and the biomass by weighing on Seca 374 (+) scales (Germany).

Statistical analysis

All recorded data for various parameters were presented as mean values (n = 10) in standard error (Sx), and coefficient of variation (CV). Statistical analyses were done by correlation analysis and performed with Excel and Statistica (v. 7.0) packages.

RESULTS AND DISCUSSION

In the first stage of the study of winter crops, materials were analyzed on the zoning of cultivars in the Tyumen region early in the study years. During the growing seasons of 2018–2020, the seven cultivars of winter wheat, six cultivars of winter rye, and three cultivars of winter triticale got studied at four State cultivar testing plots (SCTP) of the Tyumen region (Yalutorovsky, Omutinsky, Ishimsky, and Nizhnetavdinsky). On average, over three years, the yield of winter crops fluctuated within the following limits (t/ha), i.e., wheat (1.0–3.6), rye (3.8–5.9), and triticale (3.3–6.1) (Varietal Zoning, 2020). Winter wheat cultivars were characterized by low resistance to adverse environmental factors. For three years, the study noted the death of all assessed cultivars from freezing in the Omutinsky SCTP, and in 2020 in the Yalutorovsky SCTP.

In the dry year of 2021, winter wheat was tested at three SCTPs (Yalutorovsky, Ishimsky, and Nizhnetavdinsky), along with four new cultivars. The meteorological conditions for the autumn development and over-wintering were favorable for plants in the SCTPs of the Northern forest-steppe and subtaiga. With high winter hardiness (5 points), the grain yield varied by cultivars from 1.2 to 4.1 t/ha (Ishimsky SCTP) and from 2.4 to 3.2 t/ha (Nizhnetavdinsky SCTP) with an average yield of 2.9 and 3.0 t/ha, respectively. In the experimental plots of the Yalutorovsky SCTP, researchers again registered an almost complete death of plants (winter hardiness = 1 point) (Varietal Zoning, 2021). Analysis of cultivars showed that one of the reasons for the insufficient distribution of winter crops in the agroecological zones of the Tyumen region is a limited set of cultivars included in the ecological test. Relatedly, the study noted to solve such problem, an extensive study of the production process of winter crops needs implementation, taking into account climate change.

One of the definitive factors in crop yield was resistance to lodging of plants, largely determined by the structure and properties of shoots (Berry *et al*., 2004; Wang *et al*., 2018) and the root system (Pinthus, 1973). In wheat, the shorter stalks contribute to higher yields due to good lodging resistance (Chairi *et al*., 2019). The inclusion of semi-dwarf cultivars in wheat and rice breeding programs in Asia in the 1960s and 1970s served an important factor in ushering in the Green Revolution (Hedden, 2003). Lodging of plants is caused by various factors, i.e., heavy rains with strong winds, especially during grain filling, the density of plants per unit area, and high doses of chemical fertilizers (Liu *et al*., 2019; Young and Ribal, 2019). In selecting cultivars for specific conditions, plant height is one of the vital morphological features that determine resistance to lodging. In addition to genetic effects, the formation of crop shoots is also influenced by environmental conditions.

Comparative analysis of the winter crops revealed that the differences were based on the characteristics observed during the study period. A decrease in plant height was common for winter crops (wheat, triticale) due to water and temperature stress during the vegetative period of 2021, while the effect was most pronounced in triticale samples (44.9% of plant height decreased compared in 2020). The trait was more stable in the triticale cultivar Istoksky (100.3±1.95 cm in 2020 and 107.1±1.52 cm in 2021) (Table 2). The studied genotypes were characterized by a high incidence of lodging (rye - 7 points, wheat and triticale - 9 points). All the plant parts were capable of photosynthesis and participating in the accumulation of organic matter (Kovtun *et al*., 1990; Shevelukha, 1992; Zykin *et al*., 2000), however, the flag leaf gave the highest photosynthetic activity, which provided by a large number of chloroplasts per unit of assimilating surface (Kumakov, 1980).

The length and width of the flag leaves were significantly higher in the studied genotypes in more favorable conditions during 2020. Under conditions of water and heat

Table 2. Comparative assessment of winter crops by breeding and valuable traits (Average for 2020–2021).

Genotypes	Plant height (cm)*				Flag leaf area (cm^2)				1000-grain weight (g)				Yield (g/m^2)			
	2020	2021	$\bar{x}$	CV,%	2020	2021	$\bar{x}$	CV,%	2020	2021	$\bar{x}$	CV,%	2020	2021	$\bar{x}$	CV,%
Winter wheat																
G1	82.0	65.0	73.5	16.35	14.1	10.8	12.5	18.74	25.9	35.9	30.9	22.88	226.3	219.2	222.8	2.25
G2	85.9	73.4	79.7	11.09	16.2	12.5	14.4	18.23	29.1	40.2	34.7	22.65	229.7	124.1	176.9	42.21
G3	79.2	80.7	80.0	1.32	15.7	12.8	14.3	14.39	26.1	21.3	23.7	14.32	251.2	121.4	186.3	49.26
G4	80.3	82.3	81.3	1.73	18.3	13.3	15.8	22.37	27.6	21.1	24.4	18.87	237.9	178.1	208.0	20.32
G5	86.6	51.7	69.2	35.68	14.2	13.4	13.8	4.09	26.7	20.3	23.5	19.25	234.3	120.0	177.2	45.62
G6	77.4	56.8	67.1	21.71	16.0	13.6	14.8	11.46	28.5	21.8	25.2	18.83	198.8	108.0	153.4	41.85
G7	81.8	35.6	58.7	55.65	17.8	11.7	14.8	29.24	28.0	38.8	33.4	22.86	224.9	143.5	184.2	31.25
G8	90.3	37.4	63.9	58.58	16.2	9.5	12.9	36.86	30.1	23.2	26.7	18.30	207.3	124.0	165.7	35.56
G9	79.3	80.4	79.9	0.97	20.4	14.1	17.3	25.82	31.2	23.1	27.2	21.09	189.5	134.0	161.8	24.26
G10	80.5	42.3	61.4	43.99	21.5	14.2	17.9	28.91	36.3	26.3	31.3	22.59	435.5	251.9	343.7	37.77
G11	83.1	63.3	73.2	19.12	20.8	16.5	18.7	16.30	35.2	36.8	36.0	3.14	429.8	355.6	392.7	13.36
Average	82.4	60.8	71.6	24.20	17.4	12.9	15.2	20.58	29.5	28.1	28.8	18.62	260.5	170.9	215.7	31.25
Rye																
G12	91.4	94.5	93.0	2.35	16.1	11.8	13.9	21.79	36.4	26.9	31.7	21.22	436.1	409.9	423.0	4.38
G13	92.7	114.4	103.6	14.80	17.8	11.9	14.9	28.09	32.9	31.1	32.0	3.97	420.0	439.5	429.8	3.21
G14	95.7	111.8	103.8	10.97	18.6	10.7	14.7	38.13	33.8	26.3	30.1	17.64	421.3	303.8	362.6	22.92
G15	99.1	107.7	103.4	5.88	17.5	9.8	13.7	39.88	35.7	35.5	35.6	0.39	429.4	325.6	377.5	19.44
Average	94.7	107.1	100.9	8.50	17.5	11.1	14.3	31.97	34.7	30.0	32.4	10.81	426.7	369.7	398.2	12.49
Triticale																
G16	189.3	81.1	135.2	56.58	19.2	9.6	14.4	47.14	34.6	34.4	34.5	0.41	412.3	364.5	388.4	8.70
G17	190.9	76.4	133.7	60.57	21.3	11.9	16.6	40.04	34.9	33.8	34.4	2.26	427.9	335.1	381.5	17.20
G18	100.3	107.1	103.7	4.63	21.1	12.1	16.6	38.33	39.2	39.2	39.2	0.00	387.1	217.6	302.4	39.64
Average	160.2	88.2	124.2	40.59	21.5	11.2	15.9	41.84	36.2	35.8	36.0	0.89	409.1	305.7	357.4	21.85

Note: *Plant height measured of plants (n = 10).

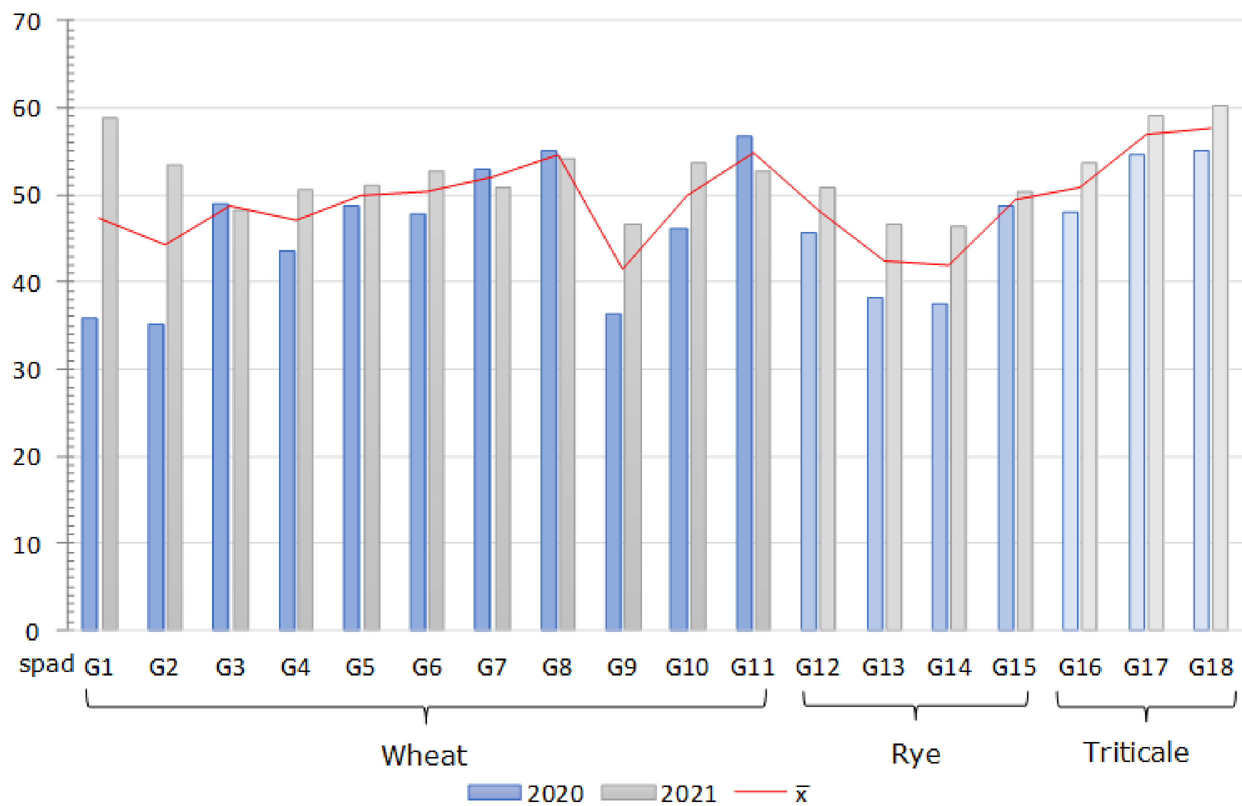

Figure 3. Chlorophyll content in the studied genotypes (SPAD units).
Note: The content of chlorophyll was determined in the flag leaves during the heading phase of plants using the SPAD 502 instrument (n = 10).

stress, the linear dimensions of the leaves decreased. In both years of the study, breeding numbers KSI 35/17 and KSI 35/18 displayed distinction among winter wheat accessions. No significant differences between the cultivars of winter rye in the linear dimensions of the flag leaves were observed. Triticale leaves compared with wheat and rye were the largest in 2020 (length = 19.2±0.45–24.1±1.18 cm; width = 1.2±0.02–1.4±0.03 cm), and under the unfavorable factors in 2021, short (9.6±0.78–12.1±0.72 cm), but relatively wide leaves (1.1±0.01-1.2±0.03 cm) were formed. Triticale accessions had an advantage in the flag leaf area when compared to wheat and rye (Table 2).

The reaction of plants to changing environmental conditions is manifested in the optimization of photosynthetic processes. Chlorophyll synthesis in different plant species is closely related to soil nutrients (Fredeen *et al.*, 1990), air temperature (Nagata *et al.*, 2005), and precipitation and water content in soil and leaves (Zhou, 2003). Therefore, the chlorophyll index serves as a good criterion for assessing the state of phytocenoses and predicting changes in their functioning. To date, no thorough studies exist on how the chlorophyll content in leaf cells varies between species and cultivars depending on the impact of abiotic and biotic stress factors in agrocenoses. In the latest results, during dry conditions of 2021, the accumulation of chlorophyll occurred more intensively in the cells of flag leaves of the winter crops (wheat, rye, triticale). As it reached the heading phase, the pigment content was significantly higher compared in 2020. Figure 3 shows the trait advantage observed in samples of triticale.

Comparative evaluation of the SPAD 502 readings on winter wheat revealed a significant increase in chlorophyll in 2021 in two breeding lines (KSI 35/17, and KSI 38/17) and in the collected samples from Canada (k-64170 CDC Osprey), Ukraine (k-64496 Dar Luganshchiny; k-64504 Pysanka; k-64499 David), and Russia (k-64198, Mera). The chlorophyll content in the leaves of cultivars Kazanskaya 234 (k-60753, Tatarstan), Soldier (k-63003 England), and Edwin (k-64507 USA) was relatively stable during growing seasons of 2020 (49.1±1.12–55.2 ±1.15 SPAD units) and 2021 (48.5±1.70–54.2±1.13 SPAD units). Only a single winter wheat cultivar Clemson from the USA (k-64172) experienced a decline in chlorophyll content in 2021. All the selected lines of winter rye under conditions of water and temperature stress were characterized by a more active accumulation of chlorophyll. Similarly, in 2021 the most pronounced process was in the winter rye cultivar, Alisa, and the breeding line triticale, CCP 16/17, by 30.0% and 11.4%, respectively.

Comparative evaluation of winter crops by yield during two vegetative periods revealed the advantages of rye and triticale samples. In 2021 conditions, there was a general observation for all winter crops, which manifested a decrease in yield (Table 2). The response to water and stress conditions was well manifested in the crops exhibiting degraded grain productivity in 2021 compared in 2020, which was highest in winter wheat (21.3%) compared with winter rye (15.4%) and winter triticale (13.4%). There were no significant differences in the years for the grain size of wheat and triticale. The negative impact of weather conditions in 2021 was displayed in 1000-grain weight of rye, however, the triticale grains were heavier (Table 2).

The correlation analysis of the studied traits helped reveal their significance in the shaping process (Table 3). Productivity of winter crops during the growing seasons of 2020–2021 largely depended on the plant height and 1000-grain weight. The grain size was verified by the development of the flag leaf area and the chlorophyll content. In the formation of the leaf area, a greater role belongs to the length than the width. A significant variation in winter crops under the influence of environmental factors was noted in the flag leaf length.

After the harvest of winter crops (early and mid-August), the soil remains free from plants and thus, was more vulnerable to erosion and deflationary processes. On the experimental plot where the plants got harvested manually with the removal of the root system, a chance of deterioration in agro-physical properties may occur. It is important to choose a crop that relatively forms phytomass and a well-developed root system fast, and is resistant to autumn temperatures and energy frosts. The latest study measured negative air temperature values for five days in September, with the value of -2.4°C on 24 September 2021. A month later, as the temperature again dropped to -2.4°C (02 October 2021), the biomass and additional features accounted for half of the rest of the plants. At harvest time, the typical species and flavors were significantly higher in height (Table 3, Figure 4). However, the Sarepta mustard (*Brassica juncea*) and rapeseed (*Brassica campestris*) plants served as the maximum indicators for this characteristic.

The likelihood of obtaining potential properties of cover crops involves the change in chlorophylls of the leaves. Two weeks before the second measurement of chlorophyll, air temperature for eight days ranged at 0.1°C–5.8°C below normal and an increase in temperature for five days (1.4°C–4.7°C above the norm). Despite night frosts (up to -8.3°C on 11 October 2021), the plants continued to grow. The chlorophyll content in the cells of the leaves, on average for the samples, seemed not to increase in rapeseed and oats, but it accumulated in mustard, colza, peas, and vetch (Table 4).

Likewise, the reaction of cultivars and collected samples to changing environmental factors was unclear. The content of chlorophyll at the second measurement in three accessions of oats showed significant increase, i.e., Alaman (k-15346, Kazakhstan, var. *mutica*), 97106126 (k-15203, Bulgaria, var. *byzantine*), and AC Juniper (k-15255, Canada, var. *byzantine*). In four samples from Germany, i.e., Canton (k-151909, var. *aurea*), KWS Kontender (k-15376, var. *krausei*), Canyon (k-15375, var. *aurea*), and Scorpion (r-15377, var. *aurea*), such indicator appeared significantly lower, which means the cessation of pigment accumulation in oat leaves by 17 October 2021. Rapeseed cultivars Favorit and Antores responded to changing environmental conditions by the activation of chlorophyll accumulation processes (content: 51.6±0.32; 49.0±0.98 SPAD units - first count, and 54.3±0.80; 56.6±0.83 SPAD units - the second count, respectively). However, the cultivars Flagman and Sirius displayed no significant differences during the dates of measurements.

The studied crops are classified as cover crops, to protect the soil from adverse environmental factors. These crops can serve as fall feed supplements for animals and as green manure ploughed back into the soil to replenish nutrients. The biomass of the studied species varied over a relatively wide range, from 0.80 kg/m^2 (pea) to 3.67 kg/m^2 (rapeseed) (Table 3). Cover crops can be incorporated into the soil in the fall to promote organic nitrogen mineralization (Dabney *et al*.,

Table 3. Correlation matrix of valuable traits of winter cereals (Average for 2020–2021).

Traits	PH	LF	WF	AF	SPAD	WG
LF	0.062					
WF	0.489*	0.620*				
AF	0.022	0.981*	0.584*			
SPAD	0.072	0.265	0.379	0.187		
WG	0.457	0.344	0.384	0.274	0.334	
YE	0.648*	0.247	0.282	0.249	0.077	0.605*

Note: *significant at P<0.05. PH - plant height; LF - length of flag leaf; WF - width of flag leaf; AF - flag leaf area; SPAD - content of chlorophyll; WG - 1000-grain weight; YE – yield.

Figure 4. Ground cover crops. a) Growth and development of the plants in August 2021, b) Comparison of plant species by phytomass, mustard in the foreground, end of September 2021, c) Part of the plants left to observe the snow cover (December 2021–March 2022) and soil moisture in the spring - 2022.

Table 4. Plant height and dynamics of chlorophyll accumulation in the leaves of some species grown after harvesting winter crops.

Cultures	Plant height (cm)	Chlorophyll content in leaves (SPAD units)		Plant biomass, (kg/m^2)
		1 count	2 count	
Rape	43.6±0.97	51.1±0.67	52.9±1.49	3.8±0.78
Mustard	84.7±0.73	37.4±0.75	47.0±1.22*	3.2±0.81
Sure pitsa	96.6±1.81	38.5±1.05	47.5±1.12*	2.3±0.50
Oats	49.6±1.01	55.1±1.05	57.9±1.30	2.7±0.68
Peas	30.6±0.74	37.8±0.87	42.4±1.26*	0.8±0.09
Vika	26.9±1.33	10.0±1.04	32.7±1.92*	1.5±0.12

Note: 1st count – 03.10.2021, 2nd count – 17.10.2021

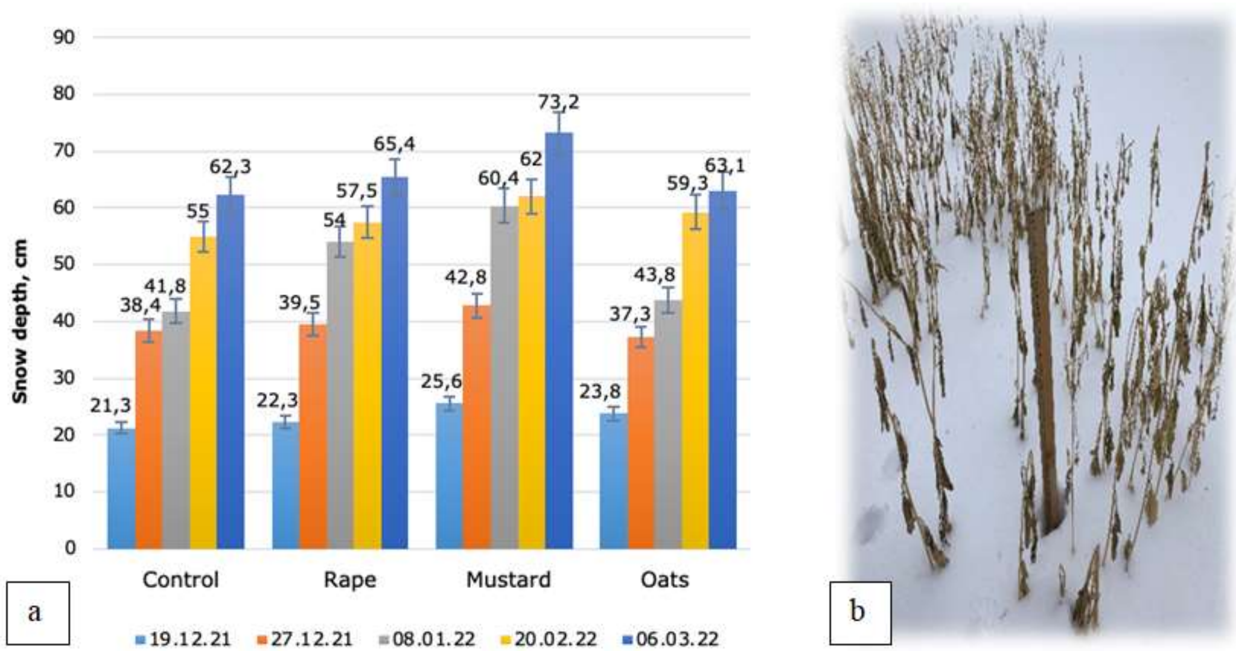

Figure 5. a) Dynamics of snow accumulation in areas with cover crops in 2021–2022, b) Measurement of snow cover in the area with mustard.

2011). These cover crops are left on the soil surface through the fall and winter until the planting of the main crop in no-till in the spring to control weeds and nitrogen application (Halde *et al*., 2014).

During the experiments, some part of the cover crops was left without ploughing into the soil (Figure 4). Observations of the dynamics of snow accumulation on plots with different crops and controls made it possible to reveal significant differences (Figure 5). By 06 March 2022, the height of the snow cover reached its maximum values on the plots with mustard and on average from repetitions of the experiment were 73.2± 2.42 cm and 73.2±2.42 cm, which was 10.9 cm more than in the control. Fields of winter wheat, rye, and triticale, harvested in summer (late July and early August) can be used for growing crops for various purposes. Drought, during the studied growing seasons of 2020 and 2021, suggests that further climate change may lead to an increase in the intensity of heat and water stress. Therefore, one of the crucial tasks is to search for methods of storing and conserving moisture in the soil.

In the spring (01 May 2022) experiment, the location was determined with ground cover crops (GOST 28268-89). According to the IMetos IMT300 meteorological station installed at the experimental site, soil moisture at a depth of 20 cm on that day was 43.2%. Determination of the structure under cover crops at the same depth as the thermostatic-weighted method revealed differences between the variants. The accumulation and preservation of moisture were more effective under the cover of summer rape (50.1%), mustard (47.4%), and oats (45.5%), compared with the control (42.8%). Relatively, probable indicators on plots with rapeseed (41.1%) were due to a possible increase in biomass and high moisture consumption in the summer-autumn period. Vetch and peas were inferior to other plant species in terms of biomass and snow accumulation. The efficiency of using plants may also increase when grown in various mixtures.

Under special circumstances, plants get exposed to many adverse environmental stress conditions. The state of chlorophyll in the leaves of acute inflammation denotes a high rate of photosynthesis under stress conditions. In this connection, one of the priority tasks is to develop methods for monitoring and quantitative determination of chlorophyll in plants. As part of the study, understanding whether chlorophyll in leaves can be used as criteria for screening genotypes is vital for predicting yields and developing a methodological assessment of agricultural plant biomass. Still, limited research on the relationship between photosynthetic capacity and chlorophyll content exists (Houborg *et al*., 2013). The latest findings suggested that SPAD readings can be efficient for the estimation of relative chlorophyll content.

The limited selection of species and cultivars for cultivation in the autumn period needs consideration given the temperature regime, but climate changes associated with warming can significantly increase diversity and the ability to manage it. Cover crops can reduce the amplitude of ambient temperature fluctuations through well-developed plant biomass (Dabney *et al*., 2001), which provides soil organic matter, weed suppression, and improves soil moisture retention. In a changing climate, multi-species mixtures that differ in their environmental sustainability could be more stable than monocultures (Tribouillois *et al*., 2015).

CONCLUSIONS

Winter triticale and winter rye have high adaptive and productive properties under the conditions of the Northern Trans-Urals. For winter wheat, additional research needs focus to search and create genotypes resistant to environmental stressors. The main features in the formation of winter crop yields include plant height (r = 0.648) and 1000-grain weight (r = 0.605). According to the study, mustard, sure pitsa, and oats proved as the most promising ground cover crops under the environmental conditions of the Northern Trans-Urals, Russia.

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