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Main Trends in the Production of Spring Wheat and Spring Barley in the Extreme Conditions of the Forest-Steppe of Western Siberia

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Abstract

The article contains the results of studying the main trends of the production process of spring wheat and spring barley in Western Siberia. Field experiments were performed on leached medium humic medium thick black soils of the Northern forest-steppe of the Novosibirsk region. During the studies, the influence of weather conditions and cultivation technology on the leaf area, the total yield, ear productivity elements and grain quality of soft spring wheat varieties Novosibirskaya 31 (mid-early) and Novosibirskaya 18 (mid-ripening), and spring barley varieties Biom (mid-early) and Omsky golozerniy 2 (mid-ripening) were studied. These varieties were tested in the conditions of traditional and intensive technology of cultivation. Intensive technology included the use of plant protection means. It has been found that, depending on the conditions of the year, varieties of spring wheat increased the maximum leaf surface by 22-45%, barley - by 39-59%, the average leave area increasing by 25 to 60% and 19 to 46%, respectively. The use of intensive technology ensured an increase in grain yield by 35-55% for soft spring wheat, and by 40-64% for spring barley. The weather conditions mostly influenced the number of grains in an ear. The level of the used technologies mostly determined the weight of 1,000 grains, the number of spikelets in a spike, the content of crude protein in grains. When the intensive technology of cultivating grain crops is used, the yield of the medium early Novosibirskaya 31 wheat is formed mainly due to increasing the number of spikelets in an ear, the number of grains in an ear, while the crucial factors in productivity of the middle-ripening variety Novosibirskaya 18 are grain weight per plant, productive plant stand, and the number of plants per 1 m^2. Against the background of using intensive technology of cultivating spring barley, the critical elements that determine high yield are grain weight per plant, the number of grains per ear, and the weight of 1,000 grains.

Key words: spring soft wheat, spring barley, intensive cultivation technology, grain quality, yield, elements of ear productivity, genetic potential of a variety

Introduction

Spring soft wheat and spring barley are the most important grain crops in Western Siberia. However, productivity of these crops both in the region, and Russia as a whole, is much lower than in developed countries, and is characterized by high variability that indicates insufficient influence of intensification factors in grain farming on yield stability in various conditions. [1; 2; 3; 4]. Besides, insufficient level of intensification results in fairly low use of the genetic potential of varieties in production conditions. [5; 6]. In this regard, when introducing new varieties, improvement of the basic elements of cultivation technology is of particular importance. [7; 8].

Intensification of agriculture brings forward the requirements to developing highly efficient methods of using fertilizers, herbicides and other means of chemicalization, therefore forming at least half of grain and other crops productivity increase. [9; 10; 11; 12].

Implementation of the genetic potential of modern varieties is a major reserve of plant breeding, which contributes to a significant increase and stabilization of agricultural production. [13; 14]. Particularly important are adaptive varieties with complex resistance to harmful organisms and capable of forming high-quality grain in the conditions of limited vegetation. [15; 16; 17].

For the development of technological methods of grain cultivation, allowing to maximize the genetic potential of varieties, it is necessary to study patterns of individual development; variation of the main agronomic traits is influenced by varietal characteristics, climatic conditions, level of mineral nutrition and their interactions in specific ecological conditions. [5; 18; 19; 20; 21; 22; 23].

The research is aimed at **studying** main trends in the production process of spring wheat and spring barley in the extreme climate conditions of the forest-steppe of Western Siberia.

Methods

The main trends in the production process of spring wheat and spring barley were studied in a field experiment in 2014-2016 in the fields of CJSC stud farm "Irmen" in the Novosibirsk region. The soil cover of the experimental plot is represented by leached medium humic medium thick black soil. Humus content in the upper topsoil is 5.7-6.9%, and reduces with increasing the depth. The meter-deep layer contains 400-450 m^3 of humus/ha.

The experiments were laid for four repetitions, the total area of the plot amounted to 476 m^2, the accounting area of the plot was 420 m^2. The crops were sown with sowing complexes "Kuzbass T-12" and "John Deere 730" with the seeding rate of 3 hw/ha. The predecessors of spring soft wheat were peas. Spring barley was cultivated in the fallow-wheat-barley crop rotation.

The studied crops were cultivated according to the traditional and intensive technology. The traditional technology of grain crop cultivation included the introduction of 1hw/ha of ammonium nitrate without the use of plant protection chemical products.

The intensive technology involved the use of fertilizers, herbicides, insecticides, and fungicides. For spring wheat and barley, ammonium nitrate (1.7 t/ha) and NPK (1.2 q/ha) were introduced. Chemicalization means were insecticide Aktara at the end of the tillering period - beginning of the earing period (0.07 l/ha, consumption of the working fluid of 300 l/ha), herbicide Dialen-Super in the phase of tillering (0.6 l/ha, consumption of the working fluid of 300 l/ha), and fungicide Amistar-Trio at the end of ear formation-beginning of flowering (1 l/ha, consumption of the working fluid of 300 l/ha).

During the research, the process of producing varieties Novosibirskaya 31 soft spring wheat (mid-early variety) and Novosibirskaya 18 (mid-ripening variety) and varieties of spring barley Biom (mid-early variety) and Omsk golozerniy 2 (mid-ripening variety) were assessed in accordance with the methods of state variety testing. [24]. The data were statistically processed according to the method of field experiment [25] and with the use of software package SNEDECOR.

RESULTS

The meteorological conditions during the vegetation period of 2014 were generally favorable for crops growth and development. The soil was moist under the snow. The amount of precipitation in the winter-and-spring period exceeded the average perennial norm more than twice. However, deficiency of precipitation was observed in June (35% of the norm), whereas in other months of the vegetation season, the amount of precipitation exceeded the average annual norm. Air temperature during the vegetation period was generally close to the norm.

The weather conditions during the growing season in 2015 were also favorable for crops growth and development. Before the winter period, the soil was moist. In winter and spring, the amount of precipitation was twice the average.

However, deficiency of precipitation was observed in June (35% of the norm), whereas in other months of the vegetation season, the amount of precipitation exceeded the norm. Air temperature during the vegetation period was generally 1-2^{o}C above the norm. During the 2015 vegetation period, the weather could be described as warm and humid.

In 2016, during the autumn-winter-and-spring period, the rainfall was close to the long-term norm. During the vegetation period, precipitation was generally close to the long-term norm. Insufficient deficiency of precipitation was observed in May, during the month the precipitation was evenly distributed. July was characterized by slight excess of precipitation, however, at the end of the vegetation period (August), acute lack of moisture was observed, only 24% of the average annual norm of precipitation fell down. The temperature of all summer months exceeded the norm by 1-2 ^{o}C. Generally, the 2016 vegetation period might be described as hot and medium-humid.

Plant leaf area significantly determines the overall grain yield of the plant. By the results of accounting for the leaf area of spring wheat and spring barley varieties of various ripeness groups, it was found that it changed depending on the conditions of the year and the intensification level. (Table 1). The leaf area in wheat and barley varieties was larger during all years of the study, when the crops were cultivated under intensive technologies. Depending on the conditions of the year, spring wheat varieties increased the maximum leaf surface by 22-45%, barley varieties - by 39-59%, the average leave area increasing by 25 to 60% and 19 to 46%, respectively.

During the study, the yield of grain crops was assessed (Table 2).

Table 1. The dependence of leaf area in varieties of spring soft wheat and spring barley on the level of technological support and conditions of the year

Variety	Technology	Leaves area, thousand m^2/ha							
		maximum				medium			
		2014	2015	2016	av	2014	2015	2016	av
Spring soft wheat									
Novosibirskaya 31	traditional	9.65	10.18	10.76	10.20	7.62	8.65	9.20	8.49
	intensive	12.23	13.57	15.62	13.81	9.56	11.62	14.76	11.98
Novosibirskaya 18	traditional	11.26	11.58	12.13	11.66	8.14	9.76	10.12	9.34
	intensive	13.76	15.65	16.72	15.38	11.25	14.58	15.12	13.65
Spring barley									
Biom	traditional	10.2	10.60	11.40	10.73	8.6	8.80	9.80	9.07
	intensive	14.6	15.40	15.90	15.30	10.3	12.60	13.70	12.20
Omsky golozerniy 2	traditional	10.8	11.40	11.90	11.37	9.8	10.20	11.00	10.33
	intensive	15	17.60	18.90	17.17	12.4	14.60	16.10	14.37

Table 2. Yield rate of spring soft wheat and spring barley varieties, depending on the level of technological support and conditions of the year

Variety	Intensification level	t/ha			
		2014	2015	2016	av
Spring soft wheat					
Novosibirskaya 31	traditional	2.23	3.18	3.65	3.02
	intensive	3.16	4.39	4.93	4.16
Novosibirskaya 18	traditional	2.47	3.56	3.94	3.32
	intensive	3.48	4.89	6.12	4.83
Spring barley					
Biom	traditional	2.63	3.12	3.68	3.14
	intensive	3.72	4.72	5.16	4.53
Omsky golozerniy 2	traditional	2.85	3.12	3.96	3.31
	intensive	4.68	4.93	5.67	5.09

*Note: The results of variance analysis of the three-factor experiment - 2*2*3 (spring soft wheat): LSD_{05} for private differences - 0.19, LSD_{05} for the main effect - 0.12, LSD_{05} for pair interactions - 0.18. Indices of determination for factor A (genotype) - 26.2%, factor B (level of intensification) - 34.5%, the conditions of the year - 22.4%; interactions: AB – 4.2%, BC – 3.8, AC - 2.1, ABC – 0.6%. *Note: the Results of variance analysis of the three-factor experiment - 2*2*3 (spring barley): LSD_{05} for private differences - 0.22, LSD_{05} for the main effect - 0.18, LSD_{05} for pair interactions - 0.19. Determination indices for factor A (genotype) - 24.5%, for factor B (level of intensification) - 32.8%, for the conditions of the year - 21.6%; interactions: AB – 5.4%, BC – 4.6, AC - 3.5, ABC – 1.25%.

Table 3. Valuable traits of the studied varieties of spring wheat, depending on the conditions of the year and the level of intensification

Indicator	Year	Variety and cultivation technology				LSD05
		Novosibirskaya 31		Novosibirskaya 18		
		Traditional	Intensive	Traditional	Intensive	
The number of grains per spike, pcs	2014	35	46	48	52	3.26
	2015	26	29	31	34	1.26
	2016	28	30	27	29	1.42
	av	30	35	35	38	1.98
Weight of 1,000 grains, g	2014	34	42	36	48	2.15
	2015	36	41	38	46	2.46
	2016	38	43	40	48	1.92
	av	36	42	38	47	2.18
The number of spikelets per spike, pcs	2015	11.6	13.6	13.5	16.8	0.86
	2016	12.1	15.2	11.8	17.2	1.43
	av	11.9	14.4	12.7	17.0	1.15
Vitreousness, %	2014	48.6	53.8	57.8	62.5	4.15
	2015	51.2	55.2	58.6	63.4	3.76
	2016	53.6	54.3	59.2	64.8	4.02
	av	51.1	54.4	58.5	63.6	3.98
Crude protein content in grain, %	2014	9.65	11.23	10.25	12.86	0.13
	2015	9.76	11.46	10.38	11.76	0.18
	2016	10.02	11.05	10.30	12.53	0.20
	av	9.81	11.25	10.31	12.38	0.17
Raw gluten content, %	2014	28.5	31.4	30.3	33.2	0.38
	2015	29.3	33.20	33.2	34.70	0.26
	2016	29.0	32.1	31.6	34.0	0.31
	av	28.9	32.30	31.75	33.95	0.32

It has been shown that grain yield changed depending on the year conditions and the cultivation technology. The use of intensive technology ensured an increase in grain yield by 35-55% for soft spring wheat, and 40-64% for spring barley. With that, the yield of wheat variety Novosibirskaya 31 and barley varieties Biom and Omsky golozerniy 2 was more stable and leveled over years when intensive technologies were used. Fluctuations of the yield of spring wheat of the mid-ripening variety Novosibirskaya 18 was higher during cultivation according to the intensive technology than in case of traditional cultivation. This phenomenon may be attributed to longer vegetation season, compared to the mid-ripening variety Novosibirskaya 18, which increases the likelihood of adverse conditions occurrence in the phase of grain formation and ripening. However, regardless of the fluctuations over years, the yield of variety cultivated according to the intensive technology was higher by 37-55%.

In order to reach deeper understanding of the main trends in cereals yield formation, the structure of the yield was analyzed, and the quality of wheat was assessed (Table 3). By the number of grains per spike, significant differences were observed, depending both on the conditions of the year and the level of agriculture intensification. In the varieties of spring wheat cultivated according to intensive technology, an increase in the number of grains per spike by 7-11% was observed, compared to the reference. Moreover, deviations from the average values across the years were about equal in case of both intensive and traditional technologies of cultivation. These data may indirectly indicate sensitivity of this characteristic to the weather conditions.

The weight of 1,000 grains also varied depending on the conditions of the year and the technological support level. With intensive cultivation technology, the weight of 1,000 grains of spring wheat of the variety Novosibirskaya 31 was 13%, of the variety Novosibirskaya 18 - 18-20% higher than in case of cultivation using the traditional method. Regardless of the technology used, virtually no deviations from the average value of this characteristic were observed. This indicates stability of the characteristic, and its independence from the conditions of the year.

The use of intensive technology greatly increased the number of spikelets per spike in wheat varieties (17-45%). No significant deviations from the average value of this characteristic were observed over years. It is possible to assume that the characteristic is relatively stable, and reacts weakly to environmental conditions, while the level of intensification mostly determined its expression.

Crude protein content in grain is more dependent on the technology used, than on the conditions of the year. Deviations from the average value over the years were negligible, while the use of intensive technology increased the content of crude protein by 10-17% in the mid-early variety Novosibirskaya 31, and by 21-32% for the mid-ripening variety Novosibirskaya 18. The data show that manifestation of the characteristic is more dependent on the technology used and the genotype of the variety than on the conditions of the year.

The content of crude gluten is more dependent on the technology used than on the weather conditions. Thus, the use of high-level technological support resulted in increasing the content of raw gluten in the grain by 4-13%.

With the aim of identifying the main trends of the spring barley production process, some elements of spike productivity and grain quality indicators were studied. It has been established that the number of grains in a spike depended on the weather conditions and the level of intensification. The number of grains per spike of variety Biom fluctuated considerably relative to the average, regardless of the technology used, but the average number of grains per spike in this variety in case of intensive cultivation was 11-20% higher. This characteristic depended less on the conditions of the year than in the middle-ripening variety Omsky golozerniy 2. The effect of the increased level of intensification ensured increasing the number of spikelets per spike by 13-15%, compared to the conventional technology.

The mass of 1,000 grains of barley varieties was relatively stable, and depended more on the technology used.

With the application of intensive technology, increase in the weight of 1,000 grains of variety Biom was 31-38%, and that of variety Omsky golozerniy 2 was 26-35%, compared to the traditional technology.

The number of spikelets per spike of studied varieties of spring barley depended less on the conditions of the year than on the level of technological support. The use of intensive technology resulted in an increase in the number of spikelets per spike by 17-27%.

Table 5 shows the data about grain yield of spring soft wheat varieties' dependence on the elements of yield structure in case of various cultivation technologies. In case of spring wheat cultivation according to the traditional technology, the yield of medium early variety Novosibirskaya 31 was determined by the weight of grain per plant and the number of grains per spike, the yield of middle-ripening variety Novosibirskaya 18 – by the weight of plant grains, and number of plants per 1 m^2. When the intensive technology of grain crops cultivation is used, the yield of medium early wheat Novosibirskaya 31 is formed mainly due to increasing the number of spikelets per spike, and the number of grains per spike, while the crucial factors in the productivity of middle-ripening variety Novosibirskaya 18 are grain weight per plant, the productive plant stand, and the number of plants per 1 m^2. During spring barley cultivation according to the traditional technology, the main elements that contribute to the productivity of middle-ripening variety Biom are weight of grains per plant, and the weight of 1,000 grains, and for the middle-ripening variety Omsky golozerniy 2, such elements are the weight of grain per plant, and the number of grains per spike. Against the background of using intensive technology of cultivating spring barley, critical elements that result in high yield are grain weight per plant, the number of grains per spike, and weight of 1,000 grains. This trend is typical for middle-ripening variety Biom, and middle-ripening variety Omsky golozerniy 2.

The shares of the influence of genotype, level of intensification and environmental conditions on the phenotypic variation of agronomic traits of spring wheat such as the number of grains per spike, the weight of grains per spike, and the content of raw gluten in the grain were calculated (Table 6). It has been established that the level of intensification influenced the most the phenotypic manifestations of all three agronomic traits.

The share of factor influence on the structural elements of the barley yield, and on the yield of spring wheat and spring barley had also been established. Dispersion analysis showed that the number of grains per spike, the weight of 1,000 grains, and the number of spikelets per spike depended on the level of technological support by 28%, on the genotype - by 23 %, on weather conditions – by 25%, while the share of interaction of all factors was 11%. The level of intensification influenced the yield rate of soft spring wheat by 35%, genotype – by 26%, the conditions of the year - by 22%, with interaction of all factors – by 10%. The yield of spring barley was mostly determined by technical support – by 33%, genotype - by 25%, and weather conditions – by 24% with interaction of all factors by 13%. These data are to some extent consistent with earlier assumptions.

Table 4. Economy-valuable traits of studied varieties of spring barley

Indicator	Year	BIOM		Omsky golozerniy-2		LSD_{05}
		Traditional	Intensive	Traditional	Intensive	
The number of grains per spike, pcs	2014	39	47	43	49	3.26
	2015	23	26	35	40	1.26
	2016	26	29	33	38	1.42
	av	29	34	37	42	1.98
Weight of 1,000 grains, g	2014	31	43	37	50	2.15
	2015	33	44	38	48	2.46
	2016	35	46	39	51	1.92
	av	33	44	38	50	2.18
The number of spikelets per spike, pcs	2015	10.6	13.5	12.8	15.3	0.86
	2016	13.8	16.2	14.6	17.9	1.43
	av	12.2	14.9	13.7	16.6	1.15
Crude protein content in grain, %	2014	10.53	10.82	10.26	10.05	0.13
	2015	10.76	11.02	10.16	10.56	0.18
	2016	10.62	11.16	10.40	10.36	0.20
	av	10.64	11.00	10.27	10.32	0.17

Table 5. Grain yield of spring soft wheat and spring barley varieties' dependence on the elements of yield structure in case of various cultivation technologies

Crop	Variety	Coefficient of correlation between the yield and the elements of productivity					
		weight of grains per plant	productive plant stand	the number of spikelets per spike	the number of grains per spike	the weight of 1,000 grains	the number of plants per 1 m^2
Traditional technology							
Spring soft wheat	Novosibirskaya 31	0.82*	0.57*	0.72*	0.89*	0.59	0.77*
	Novosibirskaya 18	0.83*	0.71*	0.59	0.75*	0.65	0.77*
Spring barley	Biom	0.79*	0.56	0.55*	0.64	0.69*	0.59*
	Omsky golozerniy 2	0.73*	0.63	0.59	0.81*	0.70	0.48*
Intensive technology							
Spring soft wheat	Novosibirskaya 31	0.70*	0.65*	0.78*	0.80*	0.68	0.68*
	Novosibirskaya 18	0.86*	0.76*	0.67*	0.72*	0.69*	0.79*
Spring barley	Biom	0.84*	0.58	0.56	0.83*	0.81*	0.76*
	Omsky golozerniy 2	0.75*	0.62	0.53	0.74*	0.78*	0.57

Note. * - 5% significance level

Table 6. Share of influence of genotype characteristics and the level of intensification in the general phenotypic variation on some characteristics of spring wheat (2014-2016)

Characteristic	The share of factor influence, %				
	Factor A (genotype)	Factor B (level of intensification)	Factor C (year)	ABC interaction	Random deviation
The number of grains per spike	25.40	34.05	24.80	1.75	2.03
The weight of grains per spike	26.95	36.60	22.30	3.76	2.90
Raw gluten content	28.3	35.6	24.2	11.45	0.45

DISCUSSION

Finding regularities in yield formation and grain quality of important crops such as spring soft wheat and spring barley is very significant. In the zone of risky agriculture in Siberia, it is especially important to regulate the formation of the productive process of grain crops. In this regard, we studied the peculiarities of yield formation and product quality of varieties from various maturity groups (mid-early and mid-ripening) of spring wheat and spring barley. The experiments have shown that the leaf area and productivity of various ripeness groups of spring wheat and barley varieties statistically significantly increased when intensive technologies of cultivation were used.

The level of production intensification of the studied crops is the leading factor in manifestation of grain yield and the agronomic valuable traits. It had been statistically shown that the share of genotype and the year conditions' influence on the productivity was lower than the technological support effect. This proves the profitability of using the intensive technology in area of extremal grain cultivation in Siberia.

CONCLUSION

In the conditions of leached medium humid medium thick black soil of the forest steppe of Western Siberia (Russia) in 2014-2016 that varied in weather conditions, it has been established that the technological support level has greater influence on the growth and development of spring wheat and spring barley, compared to the share of influence of the year conditions.

The use of intensive technology veraciously increases the important valuable traits of spring wheat, such as the number of grains per spike, the number of spikelets per spike, and the content of crude protein in grain from varieties of various ripeness groups. In the conditions of intensive technology of spring barley cultivation, especially important are such productivity elements as grain weight per plant, the number of grains per spike, and the weight of 1,000 grains.

It has been statistically determined that the number of grains per spike, the weight of 1,000 grains, and the number of spikelets per spike depended on the level of technological support by 28%, on the genotype - by 23 %, on weather conditions – by 25%, while the share of interaction of all these factors was 11%. The level of intensification influenced the yield rate of soft spring wheat even more, by 35%, genotype – by 26%, the conditions of the year - by 22%, with interaction of factors – by 10%.

The yield of spring parley depended on the level of technological support by 33%, on genotype - by 25%, and on the conditions of the year – by 24% (interaction of factors - 13%).

Optimization of all elements of the technology in combination with genotype selection allows reducing the influence share of the year conditions on the yield of spring wheat and spring barley.

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