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COMPARATIVE ASSESSMENT OF SPRING SOFT WHEAT LINES (*Triticum aestivum* L.) IN THE STEPPE ZONE OF THE NORTH KAZAKHSTAN REGION

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Abstract

Spring soft wheat (*Triticum aestivum* L.) is one of the most highly demanded crops in Kazakhstan. In 2020, the gross harvest of spring soft wheat reached in recent years the highest outcome of 18.0 million tons. The most important resource for increasing the yield of spring soft wheat is the adaptability and implementation of the variety according to a complex of economically valuable traits. New varieties must be flexible under different environmental conditions. In the presented work, we, for the first time, have identified lines of spring soft wheat well adapted to the conditions of the North Kazakhstan region, distinguished by productivity, a set of economically valuable parameters, environmental stability and plasticity. The aims of the work were i) a comparative assessment of the lines of spring soft wheat of different ripeness groups to the highest extent adapted to the conditions of the steppe zone of Northern Kazakhstan and ii) the assessment of economically valuable traits and their interrelationship with grain yield. The trial was performed using an extended set of spring soft wheat lines of various ripeness from research centers of Kazakhstan (fallow soil, the North Kazakhstan Agricultural Experimental Station LLP, Republic of Kazakhstan, 2018-2020). A total of 28 lines were studied, including 20 middle-early and 8 mid-season lines. Two cultivars registered in North Kazakhstan region served as the standards, the middle-early cv. Astana and the mid-season cv. Omskaya 35. The duration of inter phase and vegetation periods, yield and the main elements of yield structure were studied. The length of growing season was 79 days for the mid-early lines and 80 days for the mid-ripening lines. A shorter growing season was characteristic for the mid-early lines Lutescens 1125 SP 2/09 (73 days), Lutescens 528 (74 days), Lutescens 630 SP 2/08 (74 days), Lutescens 742 SP 2/19 (74 days), Lutescens 715 SP 2/04 (75 days), Lutescens 687 SP 2/04(75 days), Lutescens 1148 SP 2/09 (76 days) vs. the standard cv. Astana (79 days). In the mid-season group, the Liniya 12/93-01(82 days), Liniya 33/93-01-15 (82 days), Lutescens 2194 (82 days), Lutescens 1919 (85 days) stood out for the optimal length of growing season vs. the standard cv. Omskaya 35 (80 days). In terms of crop yield in the mid-early ripeness group, the following lines were distinguished: Lutescens 588 SP 2/05 (2.3 t/ha), Erythrospermum 738 2/09 (2.3 t/ha), Lutescens 857 SP 2/05 (2.4 t/ha), Lutescens 821 SP 1/08 (2.4 t/ha), Lutescens 715 SP 2/04 (2.4 t/ha) vs. cv. Astana (2.0 t/ha). In the mid-season group, Lutescens 371/06 (2.4 t/ha), Line 12/93-01-10 (2.4 t/ha), Lutescens 1919 (2.5 t/ha), Line 55/94-01 (2.6 t/ha), and Line 33/93-01-15 (2.8 t/ha) were superior to cv. Omskaya 35 (1.8 t/ha). In the studied mid-early lines, the main elements of the yield structure were the number of productive stems (154-244 stems/m^2), the grain number per ear (21-28 grains), and the 1000-grain weight of 36.6-43.4 g. In the mid-season group, the number of productive stems was 170-252 stems/m^2, the number of grains per ear was 23-30 grains, and the 1000-grain weight of was 34.2-45.2 g. The yield of mid-early lines showed correlation with the grain number per ear (r = 0.35-0.86, p = 0.36-1.29) and tight correlation with the number of productive stems (r = 0.68-0.83, p = 0.82-1.18). The yield of mid-season lines correlated with the number of productive stems (r = 0.74-0.86, p = 0.95-1.29) and the grain number per ear (r = 0.31-0.71, p = 0.32-0.88). The correlation between yield of the studied lines and the 1000-grain weight was medium (r = 0.37-0.54, p = 0.38-0.60) and, in a dry year, weakly negative (r = –0.16, p = 0, 16). Therefore, for the North Kazakhstan steppe zone, we propose to involve the mid-early lines Lutescens 715 SP2/04, Lutescens 821 SP2/08, Lutescens 588 SP2/05, Erythrospermum 738 2/09 and mid-season Line 33/93-01-15, Line 55/94-01, Lutescens 371/06, Lutescens 1919, Line 12/93-01-10 in breeding for drought resistance and adaptive potential.

Keywords: spring soft wheat, mid-early lines, mid-ripe lines, growing season length, grain productivity, yield structure elements

Based on the predicted needs of humanity associated with population growth, changing diets and an increase in the need for biofuels, world crop production should double by 2050. However, with the current increase in wheat yields of 0.9% per year, global grain production will increase only by 38%, and therefore the emphasis should be on increasing the yield of varieties [1].

Sustainable crop production [2)] is not possible without the use of high-yielding varieties [3]. Genetic improvement of varieties on the basis of productivity should be up to 1.16-1.31% per year [4]. In recent decades, the world has recorded fewer genetic advances than required [5, 6].

Common wheat (*Triticum aestivum* L.) is a natural allohexaploid that carries the genetic material of several species of the genus *Triticum* L. and *Aegilops* L. due to natural hybridization followed by amphidiploidization [7)]. In the northern regions of Kazakhstan, 15.0 million hectares are occupied by crops of spring soft wheat. The average yield in this zone, depending on climatic conditions, ranges from 0.9 to 1.4 t/ha over the years (https://primeminister.kz/ru/news/uborochnye-raboty-v-kazahstane-zaversheny-na-934 -msh-rk-2281145).

Varieties cultivated in the conditions of the steppe zone of Northern Kazakhstan are characterized by high grain quality. Nevertheless, to obtain a high yield, it is important to study the productive and adaptive potential of a variety, its biological characteristics [8].

Under relatively equal environmental conditions and the same productivity, the yield structure of different varieties is different. Some varieties have a high productive bushiness, others have a high absolute grain mass, and still others have an increased ear grain mass [9]. In obtaining high and stable yields, biological (elements of the crop structure) and technological traits (grain volumetric weight and protein content) are considered as leading ones, though the role of agricultural practices that affect the manifestation of these traits is also importanta [10, 11]. The entire agrotechnical complex must strictly correspond to the characteristics of varieties in specific environmental conditions.

The most important property of any variety is its adaptability, that is, the ability of the genotype to withstand the action of environmental factors that reduce productivity and yield, which is very important for the agroecological zoning of the variety [12].

In the conditions of Northern Kazakhstan, moisture availability becomes a limiting factor in the growth and development of spring soft wheat plants. In addition, high temperatures and low air humidity have a negative effect, especially during critical phases of growth and development (booting—heading). In the spring and early summer periods (June), crops are often damaged by dust storms, frosts, diseases, and pests (bread fleas).

To improve the drought resistance of spring soft wheat, it is necessary to select parental forms that have biochemical and physiological mechanisms that can mitigate the effects of abiotic stress at the grain filling stage [13, 14].

In this work, for the first time, we selected lines of spring soft wheat which are well adapted to the conditions of the North Kazakhstan region, and distinguished by productivity, a set of economically valuable parameters, environmental stability and plasticity.

The purpose of the work is to compare the lines of spring soft wheat of various ripeness groups, maximally adapted to the steppe zone of Northern Kazakhstan for economically significant traits and to evaluate their relationship with grain yield.

Materials and methods. The experiments were laid with the fallow predecessor (the LLP North Kazakhstan Agricultural Experimental Station, Shagaly village, North Kazakhstan region, 2018-2020). We performed ecological testing of an extended set of lines of spring soft wheat of various ripeness groups from various scientific centers of Kazakhstan, 28 lines in total, including 20 mid-early and 8 mid-ripening lines. Two varieties registered in the North Kazakhstan region were used as standards, Astana for mid-early and Omskaya 35 for mid-season lines.

The total plot area was 25 m^2, plants were collected from a 20 m^2 area, The experiment design provided 4-fold repetition. Plots were randomly distributed. Sowing was carried out at the optimal time for the zone (May 20-25), the seeding rate was 3.0 million germinating seeds per 1 ha, the seeds were sown with a selective seeder SSN-7 (Omsk Experimental Plant, Russia)

The soil of the test plots is ordinary calcareous heavy loamy chernozem, pH 8.1. The soil layer of 0-40 cm was 4.5% humus, 16.6 mg/kg nitrate nitrogen, 10 mg/kg mobile phosphorus, abd 630 mg/kg potassium.

Immediately before sowing, soil samples were taken at a depth of 0-40 cm. The humus content was determined by the I.V. Tyurin's method modified by V.N. Simakov [15], the pH of the aqueous extract was measured potentiometrically [16], the content of nitrate nitrogen by the disulfophenyl Grandval-Lage method [17], the content of mobile phosphorus and exchangeable potassium by the method of B.P. Machigin [18].

The yield structure was analyzed in plants from the trial plots in 4 replicates for each sample [19]. Each harvested sheaf was analyzed by the number of plants, the main shoots and productive stems. The elements of the yield structure (the number of grains per ear and the 1000-grain weight) were determined in 25 plants in 4 replications. Harvesting was carried out at full grain ripeness with a Sampo-500 combine (Sampo Rosenlew, Finland). For each variety and line, grain quality parameter were adjusted to 14% moisture and 100% purity.

To assess the meteorological conditions during the years of the experiments, the amount of precipitation and the temperature regime were compared with the long-term average data (http://www.pogodaiklimat.ru). The experimental data were analyzed using the AgStat program (https://www.agstat.com/). Based on the results of the analysis of variance, the least significant difference (LSD_{05}), the means (M) and standard errors of the means (±SEM), coefficients of variation (Cv) and correlations (r) were calculated [20].

Results. In 2018, the reserves of productive moisture in a meter-deep soil layer before sowing amounted to 149.1 mm. The beginning of the summer months was cold, so the sowing was carried out on May 28, which was 3-5 days later than the optimal time for the zone. The average air temperature in May was 9.5 °C, in June it rose to 17.1 °C. Mass seedling emergence and setting of tillering elements occurred. In July, the average air temperature was 20.3 °C, which had a positive effect on the setting of generative organs and ear elements. The average air temperature in August, 16.6 °C, favorably influenced the ear productivity. During the growing season of 2018, 291.7 mm of precipitation fell, or 285% of the long-term norm. The culture was well supplied with moisture, the hydrothermal coefficient

(HTC) ranged from 0.6 to 0.9, with the average annual value of 0.8. It should be noted that the high humidity in August and the air temperature of 16.6 °C lengthened the phase of grain ripening.

In 2019, the reserves of productive moisture in a meter-deep soil layer were optimal and amounted to 128.0 mm. The beginning of May was characterized by hot and dry weather with strong winds. The maximum air temperature in May reached 29.0-31.6 °C. The amount of precipitation in May was low, 12.8 mm, or 46% of the long-term norm. Precipitation was unevenly distributed over decades, which occurs with frequent droughts in recent decades [21]. Rains fell only in the second and third decades of May, and their amount was 58-73% of the norm. June 2019 was cool (the average daily air temperature was 3 °C below the long-term average of 18.6 °C), precipitation amounted to 56.8 mm (129% of the norm). The warm period came late, at the end of June the sum of positive temperatures amounted to 917 °C with a long-term average of 1069 °C. The lack of heat affected the duration of the period from sowing to seedling emergence which was 14-16 days vs. 10-12 days according to long-term data. However, precipitation in the third decade of June had a positive effect on the passage of the tillering phase, in this year the highest tillering coefficient was the highest and accounted for 2.3. July 2019 was dry, the average monthly air temperature was 20.9 °C, 23 mm of precipitation fell vs. a norm of 71 mm (32%). The July maximum of precipitation, typical for the region, was not observed. During the ripening period in August, it was warm, the average daily air temperature was 18.1 °C, or 0.9 °C higher than the long-term average, 43.3 mm of precipitation fell, or 92% of the norm of 47.0 mm. In general, according to meteorological data, August corresponded to the average annual norm, the grain number per ear and the 1000-grain weight were formed under favorable conditions.

In 2020, May in the north of the region was abnormally hot and windy. The maximum air temperature was 33.5-35.6 °C, the sum of positive temperatures at the end of the month exceeded the long-term average by 267 °C. The second ten-day period of May was the hottest, the average daily air temperature was 20 °C vs. the norm of 13 °C. The amount of precipitation (28.1 mm) corresponded to the average annual norm. Despite the prevailing atypical conditions of the sowing period, mass seedlings emergence occurred. There was a 70-day period from sowing to seedling emergence. June 2020 was characterized by very contrasting meteorological conditions. The first two decades were extremely dry with 1.1 mm and 1.8 mm precipitation, or 8 and 16% of the norm. Precipitation in the III decade (33 mm) significantly leveled the situation. In general, 35.9 mm (82%) fell during the month. Excess heat in June reached 211 °C. The created meteorological conditions accelerated the tillering phase. In July 2020, precipitation was extremely uneven. Their amount was 75.6 mm (106%), and the distribution was as follows: the main amount fell in the first decade of July (66.6 mm), in the II and III decades precipitation was extremely low, 0.2 mm and 8.8 mm (1 and 34%). The sum of positive temperatures in July was 1938 °C, which was 268 °C higher than the long-term average values. The created weather conditions had a positive effect on the setting and formation of the ear elements. August 2020 was also dry and hot. The average daily air temperature was 19.8 °C, or 2.6 °C above the norm. Together with elevated temperatures, the precipitation of 2.6 mm (43%) accelerated the onset of the wax ripeness phase of wheat. In 2020, the grain ripening period decreased by 10 days compared to long-term observation. In general, in terms of agrometeorological conditions for the crop growth and development, 2020 was characterized by an early summer and August drought and a pronounced July maximum of precipitation. The provision of crops in 2020 with moisture during the critical period (stem elongation—heading) had a positive effect on the formation of the crop and grain quality.

In conditions of limited water resources, wheat breeding is being updated for traits that increase the efficiency of moisture use [22]. According to A. Nawaz et al. [23], the most detrimental effect on the setting and maturation of grain is drought during the reproductive phase and at grain filling. In the steppe zone of Northern Kazakhstan, early summer drought often occurs, therefore, varieties with an extended interphase period from seedlings to heading and shortened period of heading-grain ripening are more adapted to local conditions.

The average yield of soft wheat in Kazakhstan is due not only to natural and climatic factors, but also to the imperfection of agricultural technologies for the cultivation of new varieties [24].

According to V.A. Krupnov [25], in the dry first half of the growing season, the optimal yield is formed by medium or late-ripening varieties. According to our data, mid-early varieties can also be assigned to this group, since there was no difference in the length of the growing season between them (79 days) and mid-ripening (80 days) lines. In addition, there was no difference in the duration of the interphase period between germination and heading in lines of different maturity groups (Table 1).

1. Interphase periods in vegetation of spring soft wheat (*Triticum aestivum* L.) varieties and lines in the steppe zone of Northern Kazakhstan (North Kazakhstan region, Akkayyn district, 2018-2020)

Parameter	Interphase period, days		
	seedlings—heading	heading—ripening	seedlings— ripening
	Mid-early (n = 21)		
M±SEM	45.0±4.00	34.0±5.50	79.0±1.52
Lim	41-49	29-40	78-81
R	8	11	3
Cv, %	7.3	13.1	1.8
	Mid -ripening (n = 9)		
M±SEM	46.0±4.16	34.0±4.50	80.0±1.52
Lim	43-51	30-39	79-82
R	8	9	3
Cv, %	7.3	10.7	1.6

Not. Lim — limit, R — range, Cv — the coefficient of variation.

The data we obtained show the advantages of mid-early lines and varieties created at the scientific centers of Kazakhstan. Due to the slow development from germination to earing, they are more resistant to spring-early summer drought. It is known that varieties with early earing under conditions of high temperature and lack of water increase the yield index [26, 27]. Improvement of agronomic phenotypes is carried out on the basis of the analysis of the genetic variability of the breeding material [28].

In general, it should be noted that the range of variation and the coefficient of variation in the length of interphase and vegetation periods over the years largely depended on meteorological conditions and genetic backgrounds of the lines. In mid-early and mid-ripening lines, the length of seedlings-heading period was characterized by Cv = 7.3%. For the heading-ripening period, an average trait variability accounted for 13.1 and 10.7%, respectively. Over the growing season, the variability was insignificant and accounted for 1.8 and 1.6%.

The correlation relationship between the length of the growing season and the yield in lines of different types of ripeness was expressed differently. Excessive elongation of the seedling-heading period in mid-early lines had a negative relationship with productivity (r valued from –0.05 to –0.27, p = 0.05-0.27), since it reduced the period of grain formation and filling

In 2018, mid-season lines showed a weak negative relationship between the length of the growing season and yield (r = –0.05, p = 0.05). This is due to the negative influence of high humidity and low temperature during the formation and filling of grain. In 2019 and 2020, the meteorological conditions in the same periods were favorable, which was confirmed by a clearly pronounced correlation of the average strength (r = 0.64-0.68, p = 0.75-0.82) with the yield.

Consequently, the duration of interphase periods and the growing season in the studied lines is genetically determined, but their variability is largely determined by meteorological conditions. According to P.L. Goncharova et al. [29], the influence of a variety genetic background on the length of the growing season in arid conditions is 69.8%. The correlations observed by us between the yield and the length of the growing season in lines of different types of ripeness can be associated with the features of the redistribution of assimilates, genetic systems of photoperiodic reactions, vernalization, signaling, which affect the formation of grain productivity of plants and the area of cultivation of the variety [30-32].

It has been proven that high yields and grain quality are achieved with optimal performance for various elements of the crop structure [33]. Thus, the number of productive stems depends on environmental conditions and genotypic characteristics (with the heritability of the trait at the level of 0.51-0.72) [34]. In cultivars with a longer germination-tillering interphase, an increase in the number of productive stems is observed [35]. According to E.V. Ionova [36], plants of the mid-season type have an extended tillering period, delayed wilting, a flattened plant shape and a good root system; they are characterized by a decrease in assimilation during hot daytime hours. Such plants accelerate development, striving to complete the cycle faster, which sharply reduces their productivity. Plants of mid-early varieties lose turgor, wither, but retain the viability of lateral shoots. When precipitation falls, their rapid growth resumes, the second half of the growing season is reduced. Plants of mid-season varieties suffer from drought, the upper leaves turn yellow, the lower and side shoots die off, only the main ear remains. In our studies, the tillering coefficient averaged 1.2 for mid-season lines and 1.3 for mid-early lines (Table 2).

In wheat breeding, relationships of three components, the number of productive stalks per 1 m^2, the number of grains per ear, and the 1000-grain weight are often studied, which are largely correlated with yield [37]. In our experiments, mid-early and mid-season wheat lines mainly differed in the number of productive stems per unit area. Thus, in mid-season lines this figure was 219 pcs/m^2, which is 15 pcs/m^2 (or 7%) more than in mid-early lines (see Table 2). In the mid-early group, the range of variation and the coefficient of variation (R = 90, Cv = 8.8%) was higher than in the mid-season group (R = 62, Cv = 7.8%), which is due to less fluctuation in the values of the limits over the years

In general, the yield of grain crops depends on a number of factors, including the ability of plants to synthesize and redistribute assimilates, form elements of the crop structure, as well as the timing of the development and maturation phases [38]. Various traits, including the number of grains per ear, yield potential, timing of flowering and grain filling, are considered as a complex indicator that explains 76% of the variation in grain yield (r = 0.70, p = 0.86), which can be used in programs for selection of lines of spring soft wheat for high productivity during droughts [39]. Yield potential can be increased through more efficient fruiting [40], i.e., selection for high ear fertility, which is estimated as the ratio of the number of caryopses to the number of flowers per ear, to achieve high and stable yields [41]. Isogenic mutant lines showed a significant increase in the weight of 1000 grains (by 6.6%), width (by 2.8%) and length of the grain (by 2.1%) in hexaploid wheat, which led to an increase in the mass of grain per ear [42].

2. Element of crop structure of spring soft wheat (*Triticum aestivum* L.) varieties and lines of various ripening groups in the steppe zone of Northern Kazakhstan over the years of observation (North Kazakhstan region, Akkayyn district, 2018-2020)

Variety, line	The productive stem number per m^2				Productive tillering				The grain number per ear.				1000-grain weigh, g			
	2018	2019	2020	*M*±SEM	2018	2019	2020	*M*±SEM	2018	2019	2020	*M*±SEM	2018	2019	2020	*M*±SEM
Mid-early (n = 21)																
Astana (standard)	217	192	260	223.0±29.78	1.0	1.0	1.2	1.1±0.10	14	30	30	24.6±8.00	33.5	43.7	34.2	37.1±4.93
Lutescens 932 SP 2/04	215	231	196	214.0±15.17	1.1	1.8	1.4	1.4±0.30	14	29	27	23.3±7.05	35.2	36.6	43.1	38.3±3.65
Erythrospermum 738 2/09	179	211	221	203.6±19.0	0.9	1.9	1.3	1.4±0.43	22	31	30	27.6±4.27	37.7	36.6	39.2	38.8±1.13
Lutescens 817 SP 2/09	227	263	241	243.6±15.71	1.0	1.6	1.2	1.3±0.26	13	28	27	22.6±7.26	35.6	42.5	39.4	39.1±2.99
Lutescens 753 SP 2/09	172	185	201	186.0±12.57	1.0	1.8	1.2	1.4±0.36	18	28	25	23.6±4.44	37.0	42.5	40.2	39.9±2.39
Lutescens 1125 SP 2/09	214	225	183	207.3±18.86	1.1	1.5	1.3	1.3±0.17	11	33	27	23.6±9.84	36.9	45.1	42.5	41.5±3.62
Lutescens 736 SP 2/04	204	201	237	214.0±17.29	1.1	1.5	1.2	1.3±0.18	19	26	28	24.3±4.09	39.4	41.8	43.8	41.7±1.90
Lutescens No. 528	203	201	165	189.6±18.52	1.1	1.8	1.3	1.5±0.31	13	30	30	24.3±8.50	35.7	46.5	40.1	40.8±4.70
Lutescens 1148 SP 2/09	209	253	163	208.3±38.97	1.0	1.6	1.3	1.3±0.25	12	33	32	25.6±10.25	29.1	42.7	38.0	36.6±5.98
Lutescens 588 SP 2/05	189	204	216	203.0±11.71	1.2	1.7	1.6	1.5±0.22	13	28	35	25.3±9.73	44.3	45.2	40.8	43.4±2.01
Lutescens 857 SP 2/05	239	234	191	221.3±22.85	1.0	1.7	1.1	1.3±0.32	18	28	30	25.3±5.56	36.2	45.7	40.2	40.7±4.13
Lutescens 1206 SP 2/19	176	217	192	195.0±17.89	1.2	2.3	1.3	1.6±0.52	21	29	29	26.3±4.00	36.8	38.0	38.0	37.6±0.60
Lutescens 1143 SP 2/09	216	212	192	206.6±11.13	1.1	2.0	1.1	1.4±0.45	13	27	28	22.6±7.26	31.5	48.2	41.6	40.4±7.28
Lutescens 783 SP 2/07	197	181	219	199.0±16.52	1.2	1.8	1.1	1.4±0.32	11	25	28	21.3±7.85	35.8	47.8	40.4	41.3±5.24
Lutescens 687 SP 2/04	195	181	168	181.3±11.69	1.1	1.4	1.0	1.2±0.18	14	31	29	24.6±8.04	37.8	37.2	42.2	39.1±2.36
Lutescens 821 SP 2/08	186	284	199	223.0±46.09	1.1	1.7	1.5	1.4±0.26	15	31	30	25.3±7.76	33.8	44.1	40.0	39.3±4.49
Lutescens 742 SP 2/19	170	208	199	192.3±17.19	1.0	1.4	1.5	1.3±0.22	15	22	30	22.3±6.50	40.2	36.6	40.0	38.9±1.75
Lutescens 822 SP 2/0927	184	222	201	202.3±16.48	1.1	1.5	1.2	1.3±0.18	13	27	29	23.0±7.54	36.9	42.2	38.2	39.1±2.39
Lutescens 1068 SP 2/09	212	205	189	202.3±10.21	1.2	1.5	1.3	1.3±0.13	15	27	26	22.6±5.76	34.4	45.8	45.7	40.2±5.67
Lutescens 715 SP 2/04	180	273	181	211.3±46.25	1.3	2.1	1.4	1.6±0.37	18	30	28	25.3±5.56	39.3	46.2	42.2	42.6±3.00
Lutescens 630 SP 2/08	154	156	152	154.0±1.73	1.1	1.5	1.1	1.2±0.20	16	31	25	24.0±6.53	39.9	43.3	43.6	42.3±1.77
M±SEM	197.0±21.07	216.1±31.6	198.3±26.6	203.8±18.05	1.1±0.09	1.6±0.27	1.2±0.15	1.3±0.10	15.1±3.06	28.7±2.61	28.7±2.27	24.2±1.49	36.5±3.19	42.7±3.70	40.6±2.48	39.9±1.88
Lim	154-239	156-284	152-260	154-244	0.9-1.3	1.0-2.3	1.0-1.6	1.1-1.6	11-22	22-33	25-35	21-28	29.1-44.3	36.6-48.2	34.2-45.7	36.6-43.4
R	85	128	108	90	0.4	1.3	0.6	0.5	11	11	10	7	15.2	11.6	11.5	9.2
Cv, %	10.6	14.5	13.3	8.8	8.5	16.3	11.8	9.0	20.0	9.2	9.0	6.2	8.7	8.1	6.0	4.6

Continued Table 2

							M i d - r i p e n i n g (*n* = 9)									
Omskaya 35 (standard)	192	237	232	220.3±21.36	1.0	1.0	1.1	1.0±0.05	17	26	27	23.3±4.76	38.8	37.0	34.2	36.7±2.00
Line 55/94-01	213	228	221	220.6±6.50	1.0	1.5	1.5	1.0±0.25	23	35	33	30.3±5.56	33.4	42.6	40.0	38.7±4.10
Line 12/93-01-10	227	196	264	229.0±29.48	1.1	1.0	1.6	1.2±0.27	12	32	29	24.3±9.34	43.3	48.4	41.0	44.2±3.27
Lutescens 2174	300	140	215	218.3±69.32	1.3	1.3	1.5	1.4±0.10	20	26	30	25.3±4.35	36.2	47.0	37.7	40.3±5.06
Lutescens 371/06	225	188	220	211.0±17.38	1.1	1.6	1.4	1.4±0.21	24	31	31	28.6±3.50	39.3	40.6	43.2	41.0±1.71
Lutescens 1919	172	212	300	228.0±56.70	1.0	1.7	1.1	1.3±0.32	16	29	33	26.0±7.69	40.5	40.3	38.3	39.7±1.05
Lutescens 43/01	159	174	237	190.0±35.84	1.2	1.5	1.3	1.3±0.13	18	26	29	24.3±4.92	34.6	46.3	45.2	42.0±5.59
Line 33/93-01-15	201	310	245	252.0±47.48	1.2	2.1	1.5	1.6±0.39	17	31	35	27.6±8.18	32.1	42.3	36.1	36.8±4.45
Lutescens 248/01	232	188	175	198.3±25.86	1.3	1.4	1.5	1.4±0.08	17	28	34	26.3±7.46	34.5	45.3	39.1	39.6±4.69
M±SEM	213.4±39.77	208.1±46.50	234.3±33.59	218.6±19.48	1.1±0.11	1.4±0.32	1.3±0.17	1.2±0.11	18.2±3.52	29.3±3.03	31.2±2.57	26.2±2.18	36.9±3.56	43.3±3.56	39.4±3.27	39.9±2.31
Lim	159-300	140-310	175-300	170-252	1.0-1.3	1.0-2.1	1.1-1.6	1.0-1.6	12-24	26-35	27-35	23-30	32.1-43.3	37.0-48.4	34.2-45.2	36.7-44.2
R	141	170	125	62	0.3	1.1	0.5	0.6	12	9	8	7	11.2	11.4	11.0	7.5
Cv, %	18.1	21.7	13.9	7.8	10.2	22.2	12.5	14.4	19.0	10.2	8.1	8.7	9.5	8.1	8.0	5.7

N o t e. Lim — limit, R — range, *Cv* — the coefficient of variation.

Successful breeding to increase the productivity and adaptability of varieties is based on a detailed analysis of the heritability of yield traits and the influence of the genotype-environment interaction on their manifestation [43], the use of molecular markers to better understand the genetic basis and the relationship of economically significant traits [44].

During the years of our research, the average value of the number of grains per ear in the mid-early group was 24 pieces, in the mid-ripening group 26 pieces. The graininess of the ear in both groups of maturity showed low variation (*Cv* accounted for 6.2 and 8.7%, R = 7). Extreme high limit values were higher for mid-season lines (30 pcs). According to Yu.S. Krasnova [45], between the number of grains per ear and the mass of grain per ear or the yield, there is a positive relationship of medium strength. A higher yield of mid-season forms was due to their good grain content, 33 pcs for Line 55/94-01, 33 pcs for Lutescens 1919, 34 pcs for Lutescens 248/01, 35 pcs for Lines 33/93-01-15 (see Table 2).

The 1000-grain weight compared to the grain number per ear, despite the rather wide range of variation (R = 36.6-43.4 g in mid-early varieties, R = 36.7-44.2 g in mid-season varieties), turned out to be a more stable trait, the *Cv* is 4.6 and 5.7%, respectively, which indicates the efficiency of its selection under local conditions (see Table 2). A decrease in the 1000-grain weight can occur with an increase in the productivity index [46].

In the mid-early group, the lines Lutescens 783 SP 2/07 (41.3 g), Lutescens 1125 SP 2/09 (41.5 g), Lutescens 736 SP 2/04 (41.7 g), Lutescens 1068 SP 2/09 (42.0 g), Lutescens 630 SP 2/08 (42.3 g), Lutescens 715 SP 2/04 (42.6 g), Lutescens 588 SP 2/05 (43.4 g) were characterized by a high 1000-grain weight. In the mid-season group, in terms of this trait, the lines Lutescens 2174 (40.3 g), Lutescens 371/06 (41.0 g), Lutescens 43/01 (42.0 g), Line 12/93-01-10 (44, 2 d) stood out with an average value of 39.9 g. These lines are of interest for selection for the 1000-grain weight.

V.S. Valekzhanin and N.I. Korobeinikov noted [47] that the grain number per ear has a higher variability than the 1000-grain weight. However, in our studies in the steppe zone of Northern Kazakhstan, these traits are more stable with low variation.

Ear productivity (the number of grains per unit mass of the spike rod) provides an opportunity to increase yields in regions with its high potential [48, 49], while low moisture availability during flowering reduces grain yield by 46.7%, an increased air temperature by 33.6% [50]. The results of the experiment showed that the lines we studied were characterized by an average degree of grain yield variability (Cv = 11.4-13.4%). In terms of average yield, mid-early lines (2.1 t/ha) were inferior to mid-season lines (2.3 t/ha). Within the middle early group, the lines Lutescens 817 SP 2/09 (2.2 t/ha), Erythrospermum 738 2/09 (2.3 t/ha), Lutescens 857 SP 2/05 (2.4 t/ha), Lutescens 715 SP 2/04 (2.4 t/ha), Lutescens 821 SP 2/08 (2.4 t/ha) should noted when compared to the Astana standard value of 2.0 t/ha. In the mid-season group, a high yield was formed by the lines Lutescens 12/93-01-10 (2.4 t/ha), Line 1919 (2.5 t/ha), Line 55/94-01 (2.6 t/ha), Line 33/93-01-15 (2.8 t/ha) vs. the value of the Omskaya 35 standard (1.8 t/ha).

In the studied lines, we evaluated the relationship of each element of the crop structure with the yield by years. In mid-early forms, the yield in all years of research had a significantly positive relationship with the graininess of the ear (r = 0.35-0.86, p = 0.36-1.29). In favorable years 2018 and 2019, there was a close relationship between yield and the number of productive stems (r = 0.68-0.83, p = 0.82-1.18). In the same 2018 and 2019 years favorable during the period of grain formation and filling, the relationship between the 1000-grain weight and the yield turned out to be medium (r = 0.37-0.54, p = 0.38-0.60), and under the

August drought in 2020, the relationship was weakly negative (r = –0.16, p = 0.16).

When creating high-yielding varieties, it is proposed to increase the productivity of the main ear and secondary shoots, improve the architectonics of the ear, and select according to the grain filling rate, yield index, and grain size [51-54]. In the group of mid-early lines studied by us, selection for a combination of coarse-grainedness (absolute weight 41.5-43.4 g) with a high grain content of the ear (up to 25-28 pcs) seems to be successful, which was well expressed in the lines Lutescens 588 SP 2/05, Lutescens 715 SP 2/04, Lutescens 687 SP 2/04.

In the mid-season lines studied by us, the most pronounced relationship was between the yield and the number of productive stems (r = 0.74-0.86, p = 0.95-1.29) and grain number per ear (r = 0.31-0.71, p = 0.32-0.88). The relationship with the 1000-grain weight was weak in 2018 and 2020 (r = 0.01-0.24, p = 0.01-0.24) and weak negative in 2019 (r = –0.08, p = 0.08) under unfavorable conditions during the grain formation and filling. Our data are consistent with the results of A.T. Babkenov et al. [55] who reported a weak correlation between yield and the 1000-grain weight (r from 0.03 to –0.33). Hence it follows that when selecting mid-ripening forms in the steppe zone of Northern Kazakhstan, special attention should be paid to the grain number per ear (up to 26-30 pcs) and the number of productive stems (234-300 pcs/m^2). From this point of view, Line 33/95-01-05, Lutescens 371/06, Line 55/94-01 had the best performance.

3. Yields of spring soft wheat (*Triticum aestivum* L.) varieties and lines of various ripening groups in the steppe zone of Northern Kazakhstan over the years of observation (North Kazakhstan region, Akkayyn district)

Variety, line	Yield, t/ha							
	2018		2019		2020		average	
	t/ha	DS, %	t/ha	DS, %	t/ha	DS, %	t/ha	DS, %
Mid-early (n = 21)								
Astana (standard)	0.9		2.5		2.6		2.0	
Lutescens 932 SP 2/04	1.1	122	2.4	96	2.3	90	1.9	95
Erythrospermum 738 2/09	1.6	178	2.6	104	2.6	0	2.3	115
Lutescens 817 SP 2/09	1.0	111	3.1	124	2.6	0	2.2	100
Lutescens 753 SP 2/09	1.4	156	2.1	84	2.3	90	1.9	95
Lutescens 1125 SP 2/09	0.9	0	2.8	112	2.1	90	1.9	95
Lutescens 736 SP 2/04	1.5	167	2.1	84	2.9	112	2.2	100
Lutescens No. 528	0.9	0	2.8	112	2.0	77	1.9	95
Lutescens 1148 SP 2/09	0.8	90	3.5	140	2.0	77	2.1	105
Lutescens 588 SP 2/05	1.1	122	2.6	104	3.1	119	2.3	115
Lutescens 857 SP 2/05	1.6	178	3.0	120	2.7	104	2.4	120
Lutescens 1206 SP 2/19	1.4	156	3.1	124	2.1	80	2.2	100
Lutescens 1143 SP 2/09	0.9	0	3.6	144	2.2	85	2.2	100
Lutescens 783 SP 2/07	0.8	90	3.3	132	2.5	96	2.2	100
Lutescens 687 SP 2/04	1.0	122	2.1	84	2.1	80	1.7	85
Lutescens 821 SP 2/08	1.0	122	3.8	152	2.4	92	2.4	120
Lutescens 742 SP 2/19	1.0	122	1.6	64	2.2	85	1.6	80
Lutescens 822 SP 2/09	0.9	0	2.5	0	2.2	85	1.9	95
Lutescens 1068 SP 2/09	1.1	122	2.6	104	2.2	85	2.0	0
Lutescens 715 SP 2/04	1.3	144	3.8	152	2.1	80	2.4	120
Lutescens 630 SP 2/08	0.9	9	2.6	104	1.6	61	1.7	85
M±SEM	1.1±0.25		2.7±0.59		2.3±0.34		2.0±0.24	
Lim	0.8-1.6		1.6-3.8		1.6-3.1		1.6-2.4	
R	0.8		2.2		1.5		0.8	
Cv, %	23.0		20.7		20.7		11.7	
LSD_{05}	1.87		2.14		1.10		0.20	
Mid-ripening (n = 9)								
Omskaya 35 (standard)	1.1		2.2		2.1		1.8	
Line 55/94-01	1.6	145	3.2	145	2.9	138	2.6	144
Line 12/93-01-10	1.2	109	2.9	131	3.2	152	2.4	133
Lutescens 2174	2.2	200	1.7	77	2.8	133	2.2	122
Lutescens 371/06	2.1	190	2.3	104	2.8	133	2.4	133
Lutescens 1919	1.1	0	2.5	114	3.8	180	2.5	139
Lutescens 43/01	1.2	109	2.2	0	3.1	148	2.2	122
Line 33/93-01-15	1.1	0	4.1	186	3.1	148	2.8	156

Continued Table 3

Lutescens 248/01	1.3	18.2	2.4	9.1	2.4	14.3	2.0	122
M±SEM	1.4±0.43		2.6±0.70		2.9±0.48		2.3±0.30	
Lim	1.1-22		1.7-4.1		2.1-3.8		1.8-2.8	
R	1.1		2.4		1.7		1.0	
Cv, %	28.7		25.4		15.7		14.1	
LSD_{05}	2.21		2.04		1.30		0.30	

N o t e. DS — deviation from standard, Lim — limit, R — range, *Cv* — the coefficient of variation.и.

Fifteen lines out of 30 studied of different types of ripeness turned out to be ecologically plastic in yield (Table 3). In our studies, out of 20 lines of the mid-early group, four were distinguished, the Erythrospermum 738 2/09 (2.3 t/ha), Lutescens 588 SP 2/05 (2.3 t/ha), Lutescens 857 SP 2/05 (2.4 t/ha), Lutescens 821 SP 2/08 (2.4 t/ha), significantly (LSD_{05} 0.2 t/ha) superior in yield to the standard variety Astana by 0.3-0.4 t/ha. These lines were characterized by a higher grain number per ear in combination with a larger the 1000-grain weight. Of the eight lines of the mid-season group, the yield of five is Line 12/93-01-10 (2.4 t/ha), Lutescens 371/06 (2.4 t/ha), Lutescens 1919 (2.5 t/ha), Line 55/94-01 (2.6 t/ha), Line 33/93-01-05 (2.8 t/ha) was significantly (LSD_{05} 0.3 t/ha) higher than the Omskaya 35 standard by 0.6-1.0 t/ha.

Thus, in the mid-early lines of spring soft wheat under the conditions of the North Kazakhstan region, the seedlings—heading interphase period corresponds in duration to that of mid-ripening lines. The vegetation period is reduced due to the accelerated passage of the heading—grain ripening phase. Erythrospermum 738 2/09 (2.3 t/ha), Lutescens 588 SP 2/05 (2.3 t/ha), Lutescens 857 SP 2/05 (2.4 t/ha), Lutescens 821 SP 2/08 (2.4 t/ha) from the mid-early group and Line 12/93-01-10 (2.4 t/ha), Lutescens 371/06 (2.4 t/ha), Lutescens 1919 (2.5 t/ha), Line 55/94-01 (2.6 t/ha), Line 33/93-01-05 (2.8 t/ha) from the mid-ripening group stand out for a higher yield. In mid-ripening lines, a correlation was found between the yield and the number of productive stems (r = 0.74-0.86, p = 0.95-1.29) and the grain number per ear content (r = 0.31-0.71, p = 0.32-0.88). The mid-early lines showed a significant positive relationship between the yield and the grain number per ear (r = 0.35-0.86, p = 0.36-1.29) and a close correlation with the productive stem number (r = 0.68-0.83, p = 0.82-1.18). The relationship between yield and the 1000-grain weight is moderate positive (r = 0.37-0.54, p = 0.38-0.60), and in a dry year it is weakly negative (r = –0.16, p = 0.16). For the steppe zone of the North Kazakhstan region, as a starting material in breeding for drought resistance and increasing adaptive potential, we propose to use the mid-early lines Lutescens 715 SP 2/04, Lutescens 821 SP 2/08, Lutescens 588 SP 2/05, Erythrospermum 738 2/09 and mid-ripening Line 33/93-01-15, Line 55/94-01, Lutescens 371/06, Lutescens 1919, and Line 12/93-01-10.

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