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Study of correlations between selection traits of oatgenotypes in Akmola region

The aim of the present study was to investigate the correlational relationships between valuable agronomic traits of common oat (*Avena sativa*), important for breeding programs aimed at improving the productivity of agricultural crops. The research was conducted in 2023-2024 on field experimental plots at the A. I. Barayev Scientific and Production Center for Grain Farming. Observations were carried out using biometric measurements of plant height and morphological traits related to productivity. The biological material consisted of 16 oat genotypes. The results were analyzed using correlation coefficients, analysis of variance, multiple regression, and the study of relationships between traits. It was established that productive tillering has a linear relationship with a number of traits, except for the mass and number of grains in the panicle (r = –0.39…0.46). According to the correlation analysis, the following relationships were identified: 1000-grain weight and plant height; seed mass per plant and panicle length (r = 0.38…0.46); productive tillering and seed mass per panicle (r = 0.46). These traits can be effectively used in the breeding process to develop high-yielding oat varieties. According to the results of structural analysis of productive elements, the genotypes featuring a complex of valuable traits were selected: Yarovoy and Fax varieties, as well as the FL 0524 sample. These valuable genotypes can be recommended as sources for increasing productive properties in oat plants.

Keywords: oats, correlation, selection, variety, valuable agronomic traits, vegetation period, productivity.

Introduction

Common oat (*Avena sativa*) is an annual herbaceous plant, a species of the Oats genus (*Avena*), a valuable cereal widely used in agriculture. Oat is tolerant to various soil and climate conditions, has a relatively short vegetation period (75–120 days), and its seeds germinate at +2 °C. Oat seedlings survive slight frosts up to 4-5 °C: cold tolerance of oat culture allows it to be cultivated successfully in the North [1]. Oat straw is soft and more suitable for livestock than the straw from other cereal crops. The health benefits of oats have been recognised only recently. All these characteristics offer opportunities to improve oat as a green fodder crop for intensively cultivated grazing animals and as a dual-purpose crop for resource-limited farmers [2]. According to the Bureau of National Statistics of the Republic of Kazakhstan, oats are cultivated on an area about 231.3 hectaresin our country (https://stat.gov.kz/api/iblock/element/73401/file/ru/).

The present study was conducted to evaluate oat cultivars for various forage and grain yield traits: plant height (cm), panicle length (cm), number of grains per plant, number of grains per panicle, weight of 1000 grains (g) and duration of vegetation period (days). However, to obtain a clear picture of the inheritance of various grain yield traits, the present experiment was conducted to assess the variability of common oat and to identify phenotypic correlations between grain yield and its components, as well as between individual elements.

Even if it is sown in small areas, oat is an important crop not only for its grain purposes but also for the whole food industry. Studies of extensive collections of oats show that oats have a wide genotypic and phenotypic diversity. Most productivity components, including several grains, are highly heritable. Regarding phenotypic expression, the general performance of a genotype depends on its area of origin. The genotypes in a particular region have been found to share a common genetic origin. Even if genetic diversity is limited in plant breeding, the traits that contribute to the plant's productivity maintain high genetic diversity. This also includes plant height and duration of the vegetation period. For valuable genetic resources identification, the studies which include molecular markers are instrumental: they follow and support the studies of phenotypic variability [3, 4]. The evaluation of collections to find sources for plant selection work is continuous. The effect of some traits on panicle productivity, determined by the number of grains per panicle, is significant. This trait also depends on other productivity traits and is affected by environmental conditions. In this regard, our research aimed to study the relationship between the valuable agronomic traits in oat genotypes and to determine the traits that heavily impact plant productivity.

Experimental

The study was conducted in 2023-2024. The research materials were the following oat varieties approved for use in the different regions of Kazakhstan: Mirt, Debut, Lidya, Fax, Ural 2, SIG, Yazdyk, Desant, Antey, Baizat, Syrgalum, as well as samples FL06014, FL0524, FL0538, and FL06006 (Fig. 1).

Figure 1. Regions of the Republic of Kazakhstan where the studied oat varieties are approved for use

Methodology of field experiments. The Duman variety was used as a standard variety in every 10 samples, with three repetitions. Phenological observations, assessment of resistance to environmental stress factors, yield estimation, laboratory analysis of the plants and other indicators are carried out by the methodological VIR (Vavilov All-Russian Institute of Plant Genetic Resources) guidelines for enrichment, conservation and study of the world collection. The accuracy of assessment and estimation at all stages of the sample collection study depended on precise work performance and a correct understanding of plant development phases and their characteristics. During the phenological observations, visits to the experimental plot were repeated every 1-2 days. The observations were recorded in the field journals. General phenological observation of all the plants was carried out to ensure data comparability before plant monitoring, and field germination of plants was also recorded. Oat vegetation and development can be divided into the following phases: seed germination, emergence of seedlings, tillering, stem elongation, flowering and maturation. Related to plant adaptation and productivity component traits were analyzed: vegetation period, plant height, productive tillering, grain weight per plant, grain weight per panicle, panicle length, number of grains in panicle, weight of 1000 grains [5].

Statistical processing of the obtained data. The principal component analysis (PCA) method visualised the relationships and described the distances between the values. Conventional cluster analysis was used to group the varieties featuring the valuable agronomic traits. Coefficients were calculated using the RStudio correlation matrix to determine the relationships between the values.

The meteorological data for the growing experimental period 2023-2024 was gathered at the local weather station (Table 1).

Table 1

Location, environment, and weather data during agronomic seasons

Site/Region	Akmola Region
Latitude/Longitude	51.41′/70.59′
Soil type	dark chestnut (3.6-4.1 % humus)
Conditions	Rainfed

Continuation of Table 1

Year	2023	2024
Annual rainfall, mm	72.2	309
Mean temperature, ºC	18.1	18
Max temperature, ºC	24.4	27
Min temperature, ºC	11.8	14

Results and Discussion

The studies on identifying correlations between the elements that contribute to productivity highlight that understanding the relationships between traits benefits plant selection programmes [6]. Component traits of plant productivity have high variability, most of which are strongly impacted by climatic conditions. Even if variability is high between and within populations, there is a positive linear correlation between them; it primarily concerns such vital traits as panicle length, panicle productivity and weight of 1000 grains [7]. Correlations between traits are essential for all the types of oat plants, whether they are cultivated for fodder or grain. Grain weight per panicle, last leaf weight, protein percentage in grain and chlorophyll content in leaves were studied in addition to the number of grains per panicle. All these traits are positively correlated with grain production [8]. Genotypic correlations must complement phenotypic correlation coefficients. Plant development ensures grain production. Productive tillering, plant height and vegetative mass are the traits that contribute to grain formation in a panicle and the development of a certain amount of vegetative mass in fodder oat. Green forage mass development positively correlates with the number of leaves per plant, plant height, stem to leaf ratio, number of shoots and straw diameter. Due to this fact, all these traits can be improved simultaneously. Grain quality, which is determined by protein and fibre content, is negatively correlated with productivity elements. Grain yield is positively related to the number of seeds per panicle, the weight of 1000 grains and the grain length to width ratio. So, the selection strategy should be considered a combination of activities considering the relationships between all the traits [9]. Other experiments have underlined the importance of the interval before flowering in vegetative plant development and the ratio between foliage and stems because these traits influence yield and quality [10].

Northern Kazakhstan's climate is insufficient to ensure the reliable ripening of medium-ripening and late-ripening oat varieties, complicating the attempts to introduce oats into the region. Oat sprouts tolerate short-term temperature drops to +5 °C. Autumn frosts below +2 °C disrupt seed development and cause leaf freezing. Considering an average daily temperature below 9 °C in May and September in the Akmola region, and frosts can occur in early September, the main requirement for local oat cultivation is a short vegetation-period. In this context, one of the essential objectives of the study was to carry out selection and genetic evaluation of the gene pool and to identify promising forms for developing the new varieties suitable for cultivation in the country's northern regions.

In 2023-2024, the valuable agronomic traits of oat genotypes were evaluated comprehensively. As a result of the research, the promising varieties were selected; the selection was based on the duration of the vegetation period, grain yield per square metre, and weight of 1000 grains. There value was $p<0,05$, which means varieties did not affect the yield, but the traits had p value above 0.05, which proves the influence of varieties on the yield (Fig. 2).

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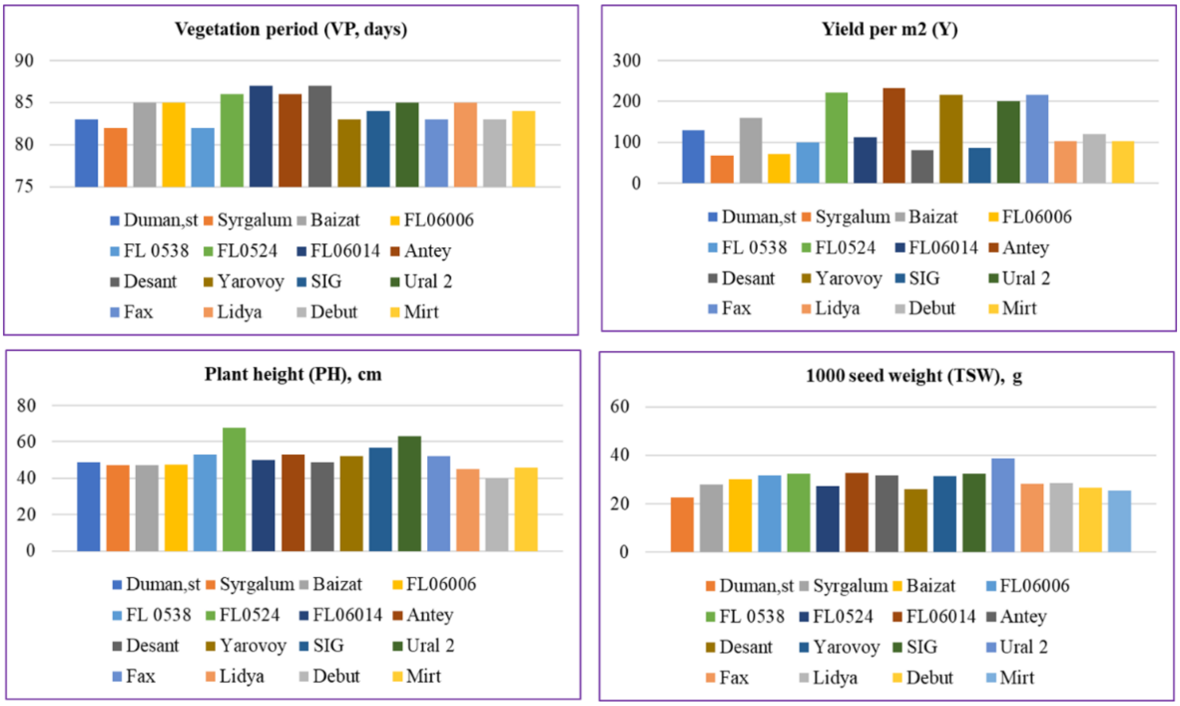

Figure 2. Variation of the genotypes based on the results of the test by the valuable agronomic traits in field conditions

The study of the vegetation period is essential for understanding the life cycle of oat plants, determining optimal conditions for cultivation, and predicting crop yield. Information about vegetation period duration and other characteristics helps to plan crop rotations, select varieties and plant species well-adapted to specific climatic conditions, and effectively use resources in plant selection programmes aimed at crop yield increase. Thus, recording individual phenophases and interphase periods of the oat varieties allowed selecting the earliest-ripening varieties adapted for the conditions of the Akmola region: Syrgalum, FL 0538, Yarovoy, Fax, and Debut. These varieties matured earlier than the standard or showed the same results (82-83 days).

Experimental data obtained in the course of our research evaluate the average value of grain yield and reveal the most productive genotypes cultivated in the northern region of Kazakhstan and formed in the contrasting climatic conditions. On average for two years, grain productivity of the varieties Yarovoy, Antey, Ural 2, and Fax was 200–232 g/m^2, which is higher than the standard variety by 102 g/m2.

Evaluation of structural elements of the oat genotypes. For all years of the research, productive tilleringgave a stable result of 1.8-1.9 pcs/1 plant. The FL06006 sample excelled and showed 1.8 pcs/1 plant for this trait. The trait of grain weight per plant had the most significant difference by year. Thus, the observations on the experimental plots showed fluctuations in the range of 0.7-1.84 g, where the varieties Fax and Ante excelled. According to the data from the experimental plots of the A.I. Barayev Research and Production Centre for Grain Farming, grain weight from the main panicle did not differ that much (0.49-1.24 g), while the number of grains in the panicle was from 15 to 44 pieces. The SIG, Yarovoy, and Fax varieties contained the most grains (34–44 pieces) (Table 2).

Table 2

Results of the productivity elements analysis of the selected oat varieties

Variety samples	Plant height, cm	Productive tillering, pc/1 plant	Grain weight per plant, g	Grain weight per panicle, g	Panicle length, cm	Number of grains in panicle, pc	Weight of 1000 grains, g
Duman, st	48,8	1,6	-	0,52	14,8	32	22,5
Syrgalum	47,1	1,6	0,8	0,54	15,3	20	27,9
Baizat	47	1,2	0,99	0,81	14,2	28	30,1
FL06006	47,6	1,8	0,73	0,65	14,1	20	31,8
FL 0538	53	1,5	0,79	0,49	17,5	15	32,3

Continuation of Table 2

Variety samples	Plant height, cm	Productive tillering, pc/1 plant	Grain weight per plant, g	Grain weight per panicle, g	Panicle length, cm	Number of grains in panicle, pc	Weight of 1000 grains, g
FL0524	68	1,1	1,09	0,79	16,1	29	27,2
FL06014	50	1,6	0,83	0,56	13,5	17	32,7
Antey	53	1,2	1,84	0,98	15,7	31	31,7
Desant	49	0,9	0,72	0,62	12,8	24	26,1
Yarovoy	52	1,1	1,34	1,07	12,8	34	31,5
SIG	57	1	1,17	1,11	17,4	34	32,5
Ural 2	63	1,4	0,88	0,8	16,7	21	38,6
Fax	52	1,5	1,62	1,24	14,8	44	28,2
Lidya	45	1,6	0,7	0,65	13,5	23	28,6
Debut	40	1,5	0,82	0,52	11,9	19	26,7
Mirt	46	1,3	1,18	0,7	12,8	27	25,5

Grain size shows the food significance of a variety, determines its nutrient reserve, germination capability, and food and fodder qualities of a genotype. At the same time, it is limited by the varietal characteristics of the plant and the duration of its development, i.e., varietal specificity in combination with environmental conditions. Lack of productive moisture and high temperatures during the grain filling significantly decrease grain size [11]. Consequently, the need to determine the adaptive potential of the shared oat gene pool on the trait of weight of 1000 grains by experimentation in different conditions is a relevant task for breeding. During the research the most favourable conditions for large grains formation were in 2023: weight of 1000 grains for the Baizat, FL06006, FL 0538, FL06014, Antey, Yarovoy, SIG and Ural 2 varieties was between 30.1 and 38.6 g, that was by 7.6–18.6 g higher than the same metric of the Duman standard variety.

Analysis of correlations between the research results. The success of crop breeding depends on genotypically determined correlations of qualitative traits, selection of parental forms for hybridisation, accurate and objective evaluation and rejection of plant breeding material [12]. Correlation was considered particularly relevant in cereal crop breeding at certain stages of the breeding process due to significant genotypes and a lack of seed material. Also, some unique characteristics of grain quality indicators are essential for plant breeding, such as the extent and variability of the relationship between individual traits and weather conditions in different years. Therefore, plant breeders face the challenge of identifying traits that overlap or have significant differences in the values of the studied indicators. If the absolute value of the correlation coefficient is large enough or close to linear dependence, it is also effective to use the correlation coefficients in the selection process [13, 14]. When sorting by a set of quality indicators, decisions must be made on various models that combine several indicators. To avoid selection bias, plant breeders should focus on critical quality and yield indicators that remain constant yearly and are closely related to other indicators. Thus, correlation analysis aims to identify quantitative traits of common oat genotypes relevant for selection improvement and to identify the best varietal samples for further crop breeding to improve grain quality and yield.

In this regard, PCA analysis was carried out to determine the relationships between the valuable traits of the oat genotypes. The results of PCA analysis demonstrated the degree of relative proximity and distance between the genotypes (Fig. 3).

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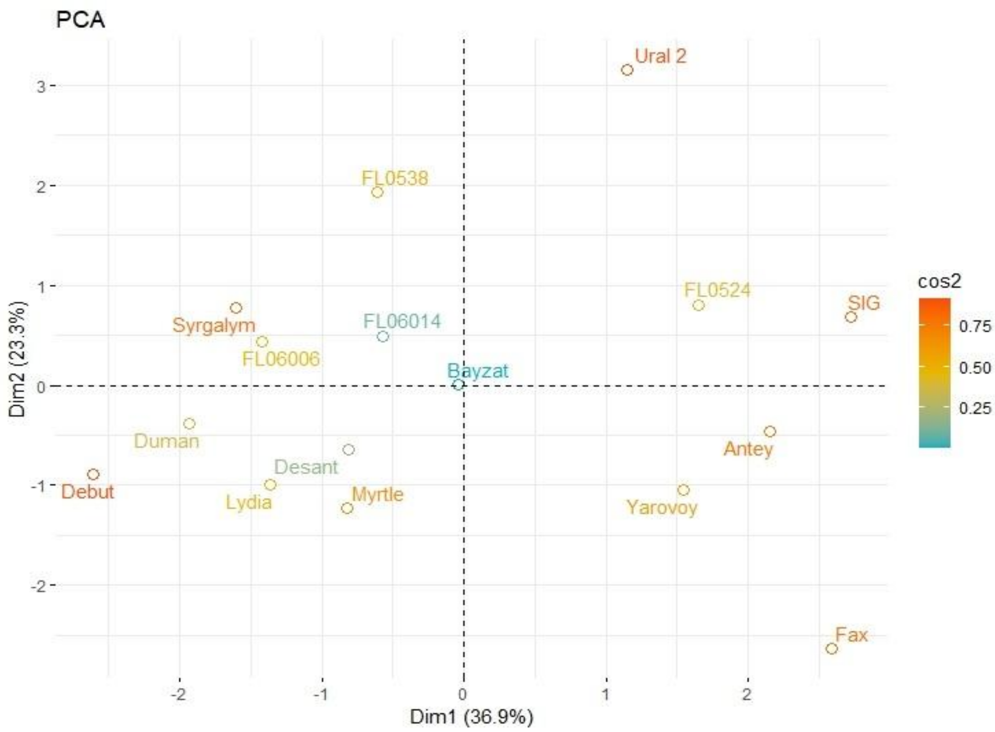

Figure 3. Results of PCA analysis of the yield-determining traits of the oat collection variety samples

The Dim1 and Dim2 axes are the main components: Dim1 (36.9 %) explains almost 37 % of the total variability in the data. Dim2 (23.3 %) explains another 23 %. Together, they provide about 60 % of the information on agronomic differences between the varieties. Each point represents a variety projected onto a new feature axis. The dots' colour reflects the array's contribution (cos2): the lighter the colour (closer to red), the more the variety influences the distribution. Debut, Syrgalum, Duman, and Lidya are on the left side of the graph. These varieties have similar characteristics, although some parameters may have lower values (e.g. weight of 1000 grains, panicle length). Debut stood out, occupying an extreme position in Dim1 and Dim2. Baizat and FL06014 are located near the centre: their characteristics are close to the average sample, i.e. they are "balanced". Antey, Yarovoy, Fax, SIG, and Ural 2 are situated on the right side: these varieties have distinct differences, especially Fax and Ural 2. Fax is highly distorted in both components, probably due to its maximum number of grains per panicle and the length of the plants. Thus, the varieties Fax, Ural 2 and Antey are unique and may be of interest for oat breeding, especially by yield characteristics. Due to its location near the centre, Baizat and FL06014 can be versatile and tolerate different conditions. The Debut and Lidya varieties, shifted to the left side of the graph, may have low values of the valuable agronomic traits.

Regression analysis determined the relationships between the individual traits (Fig. 4).

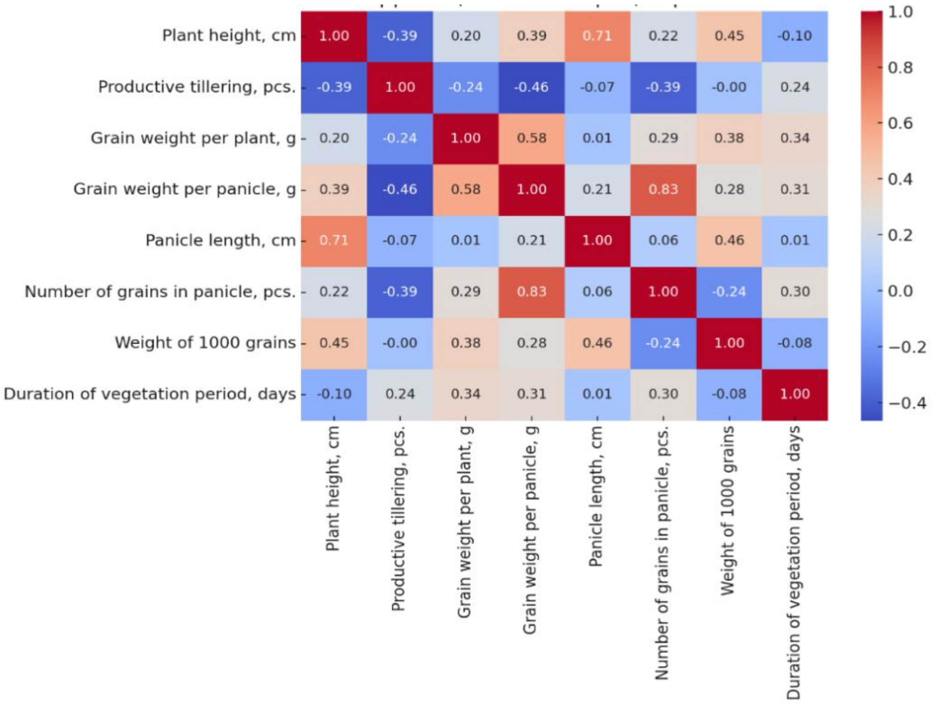

Figure 4. Matrix of the correlation traits of the oat genotypes

Correlation analysis revealed that plant height was moderately correlated with panicle length (r=0.71) and weight of 1000 grains (r=0.45). Number of grains in panicle correlated with seed weight per panicle (r=0.83), and seed weight per plant associated with the traits of seed weight per panicle (r=0.58), weight of 1000 grains (r=0.38) and with duration of vegetation period (r=0.34). A similar stable relationship was found between panicle seed weight and plant height (r=0.39), seed weight per plant (r=0.58) and number of grains per panicle (r=0.83). Other valuable traits, such as the number of grains in a panicle, are closely correlated with grain weight per panicle (r=0.83).

The following traits were negatively correlated: productive tillering and plant height; number of grains in panicle and productive tillering, grain weight per plant and number of grainsin panicle (r= -0.39-0.46). Conventional cluster analysis was used to group genotypes differing in valuable agronomic traits (Fig. 5).

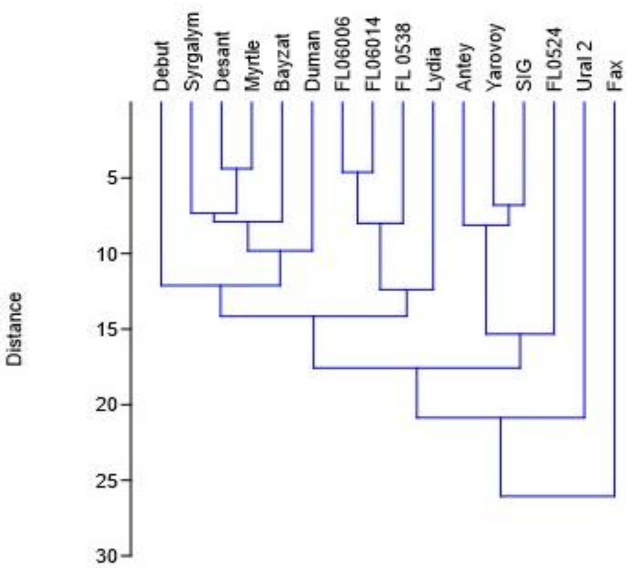

Figure 5. Grouping of the oat genotypes by the valuable traits

Closely related varieties, such as Syrgalum and Desant, FL06014, and FL 0538, have similar characteristics. The most unique (distantly related) varieties are Fax, Ural 2, and FG524, as they are related to others at a long distance (about 25–30).

Thus, after determining the relationships between the valuable agronomic traits of the oat genotypes, it was found that the trait of 1000 grains is positively related to grain weight in panicle and duration of the vegetation period. The obtained results present valuable information for use in the oat breeding process.

Conclusions

Plant breeding on oat at the experimental plots of the A.I. Barayev Research and Production Centre for Grain Farming has selected several valuable genotypes, and various activation methods have increased the efficiency of the crop breeding process. The presented scientific work summarises the phenological characteristics of the varieties and shows the optimal ripening dates for the Syrgalum, FL 0538, Yarovoy, Fax, and Debut variety samples.

According to the results of the productivity evaluation of the genotypes, it can be concluded that some oat varieties are high-yielding. This is confirmed by the performance of the Yarovoy, Antey, Ural 2, Fax genotypes (200–232 g/m2). Highly productive tillering has a positive effect on total yield. Regarding grain yield per panicle, which directly affects yield per unit area, the Yarovoy, Ural 2, and Fax varieties should be highlighted. Analysis of panicle length shows that the FL 0538, FL 0524, Ural 2, and SIG genotypes are characterised by long panicles (16.1-17.5 cm), which contributes to larger grains in the panicle. TheBaizat, Antey, Yarovoy, SIG, Ural 2 varieties, and the FL06006, FL 0538, and FL06014 samples have the most significant weight of 1000 seeds (30.1-38.6 g), which points to high quality and large size of grains. According to the results of correlation analysis, the most closely related pair of traits was identified: productive tillering and grain weight per panicle (r=0.46), which can be effective in oat breeding to achieve high yield.

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Author contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. CRediT: **Dyussibayeva E.N**. – Introduction; Experimental, Results and Discussion, Conclusions; **Dolinny Y.Y**. – Introduction, Experimental, Results and Discussion; Conclusions; **Zhirnova I.A**. – Experimental, Results and Discussion; **Rysbekova A.B**. – Introduction, Experimental, Results and Discussion; Conclusions; **Zeinullina A.E**. – Experimental, Results and Discussion; **Orazov A.E**. – Introduction, Statistical processing of the obtained data; Conclusions; **Izbastina K.S**. – Introduction, Experimental, Results and Discussion; **Abylkairova M.M**. – Introduction, Results and Discussion; Conclusions.

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Ақмола облысы жағдайындағы егістік сұлы генотиптерінің селекциялық белгілері арасындағы корреляцияны зерттеу

Зерттеудің мақсаты ауылшаруашылық өсімдіктерінің өнімділігін арттыруға бағытталған Селекциялық бағдарламалар үшін маңызды сұлы тұқымының (Avenasativa) құнды агрономиялық белгілері арасындағы корреляциялық байланыстарды қарастыру. Зерттеу 2023-2024 жылдары А.И. Бараев атындағы Астық шаруашылығы ғылыми-өндірістік орталығының далалық тәжірибелік учаскелерінде жүргізілді. Бақылаулар өсімдік биіктігінің биометриялық өлшемдері мен өнімділіктің морфологиялық белгілерін қолдану арқылы жүзеге асырылды. Биологиялық материал ретінде сұлы 16 генотиптерден жиналды. Нәтижелер корреляция коэффициенттері, дисперсиялық талдау, бірнеше регрессия және белгілер арасындағы қатынастарды зерттеу арқылы талданды. Өнім сабағының шашақгүліндегі дәндердің массасы мен санын қоспағанда (r = -0,39 0 0,46), бірқатар белгілерге сызықтық тәуелділігі бар екендігі анықталды. Корреляциялық талдау нәтижелері бойынша келесі қатынастар анықталды: 1000 дәннің массасы және өсімдіктің биіктігі; өсімдіктен тұқымның массасы және шашақгүлінің ұзындығы (r = 0,38 0 0,46); өнімнің сабағы мен шашақгүліндегі тұқымның массасы (r = 0,46). Бұл белгілерді сұлының жоғары өнімді түрлерін алу үшін селекциялық процесте тиімді пайдалануға болады. Өнімділік элементтерін құрылымдық талдау нәтижесінде құнды белгілер кешені бар генотиптер анықталды, олар: көктемгі және Факс сорттары, сондай-ақ FL 0524 үлгісі. Осы ген түрлері сұлы өсімдіктерінің өнімділігін арттыру үшін көздер ретінде ұсынылады.

Кілт сөздер: сұлы, корреляция, селекция, сорт, шаруашылық-құнды белгілер, вегетациялық кезең, өнімділік.

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Изучение корреляционных связей между селекционными признаками генотипов овса посевного в Акмолинской области

Целью настоящего исследования было изучение корреляционных связей между ценными агрономическими признаками овса посевного (*Avena sativa*), важными для селекционных программ, направленных на повышение продуктивности сельскохозяйственных растений. Исследования проводились в

2023–2024 гг. на полевых опытных участках Научно-производственного центра зернового хозяйства им. А. И. Бараева. Наблюдения осуществлялись с использованием биометрических измерений высоты растений и морфологических признаков продуктивности. Биологическим материалом послужили 16 генотипов овса. Результаты анализировались с помощью коэффициентов корреляции, дисперсионного анализа, множественной регрессии и изучения взаимосвязей между признаками. Установлено, что продуктивная кустистость имеет линейную зависимость с рядом признаков, за исключением массы и числа зерен в метелке (r = –0,39…0,46). По результатам корреляционного анализа выявлены следующие взаимосвязи: масса 1000 зерен и высота растения; масса семян с растения и длина метелки (r = 0,38…0,46); продуктивная кустистость и масса семян с метелки (r = 0,46). Эти признаки могут быть эффективно использованы в селекционном процессе для получения высокоурожайных форм овса. В результате структурного анализа элементов продуктивности были выделены генотипы, обладающие комплексом ценных признаков: сорта Яровой и Факс, а также образец FL 0524. Эти генотипы рекомендованы в качестве источников для повышения продуктивности растений овса.

*Ключевые слова***:** овес, корреляция, селекция, сорт, хозяйственно-ценные признаки, вегетационный период, урожайность.

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