International Journal of Design & Nature and Ecodynamics
Vol. 18, No. 5, October, 2023, pp. 1087-1095
Journal homepage: http://iieta.org/journals/ijdne

Harnessing Heterogeneity: Clustering Kazakh Spring Rapeseed for Breeding Value

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https://doi.org/10.18280/ijdne.180509

Received: 2 August 2023
Revised: 22 September 2023
Accepted: 13 October 2023
Available online: 31 October 2023

Keywords:
adaptability, genotype, hybrids, productivity, varieties

ABSTRACT

This study presents an investigation into the breeding genotypes of spring rapeseed (Brassica napus L.) and their subsequent grouping based on ecological adaptability to the northern region of Kazakhstan. Evaluations were made using key quantitative traits such as yield, grains per ear, and weight of 1000 grains to assess breeding value, genotypic effect, stress resistance, and genetic flexibility. Under controlled laboratory conditions, the viability of the rapeseed breeding material was assessed. Findings revealed a seed germination rate between 87% to 96% and a 1000-seed weight of 5.2 to 6.1 grams. These seeds were procured using standard seed production protocols. A comprehensive analysis was conducted on 36 genotypes of spring oilseed rape, each with distinct eco-geographical origins. This was compared to the standard variety of Kazakhstani selection, Maykuduk. The Hierarchical Cluster Analysis (HCA) module within the Statistical Package for the Social Sciences (SPSS) software was employed to perform cluster analysis of samples based on economically valuable traits of spring rapeseed. Findings indicated that samples belonging to the second cluster, exhibiting the highest average productivity indicators, are promising for integration into breeding programs. These samples demonstrated an average two-year yield of 44.4 c/ha, plant height of 142 cm, 4 to 6 branches, an average of 250 pods, 22 seeds per pod, 4095 g seeds per plant, and a seed weight per plant of 15 g. The implications of this research are significant for agricultural enterprises, as the findings may potentially promote an increase in the cultivation area of spring rapeseed. This is anticipated to augment the stability of oilseed raw material production and biodiesel fuel.

1. INTRODUCTION

The Republic of Kazakhstan (RK) offers optimal climatic conditions for rapeseed cultivation, a pivotal oilseed crop. Addressing the demand for raw materials in the processing industry, edible vegetable oil, and livestock feedstock necessitates the development and implementation of high-yielding rapeseed varieties. Rapeseed, as noted by Suleimenova et al. [1], contains high proportions of crude fat, crude protein, starch, and structural carbohydrates. It is exploited across diverse industries, including food, metallurgy, paint and varnish, soap, chemical, textile, and, more recently, biofuels. Post-processing, cakes and meals rich in easily digestible protein are produced, serving as valuable feedstock [2-5].

This study aims to generate breeding genotypes of spring rapeseed and categorize them into clusters based on yield level and ecological adaptability. Commercial varieties and hybrids of oilseed spring rapeseed are subjected to various abiotic stresses, including temperature fluctuations, light intensity variations, water distribution, soil pH, heavy metal concentrations, salinity, nutrient deficiency, and gaseous pollutants. The selection of cultivars and hybrids typically prioritizes the biological benefits of the crop, with hybrids often yielding higher than varieties, particularly under non-extreme conditions [6-8].

Rapeseed is a leading oilseed crop in the European Union (EU) and Canada, with yields averaging 27-35 c/ha [9]. In RK, low erucic and low glucosinolate varieties of spring rapeseed are cultivated extensively across different soil and climatic zones for edible oil production and as high-protein components in animal diets. Oilseed rape (*Brassica napus L.*), a promising crop for temperate climates, is grown for food, feed products, and biodiesel production. As Khan et al. [10] report, rapeseed is the primary oil source for biodiesel production in EU countries, requiring significant chemical fertilizer inputs to sustain an alternative crop.

The North Kazakhstan and East Kazakhstan regions of RK concentrate the majority of oilseed production. According to the Bureau of National Statistics of the Republic of Kazakhstan, as of 2022, oilseed crops and gross yields have increased by 67% and 1.5 times, respectively. Thirteen primary agricultural producers are engaged in rapeseed cultivation in RK. Early maturing, oil-bearing, and drought-resistant varieties of spring rape are particularly well-adapted to RK's soil and climatic conditions, providing high seed and green mass yields [11]. German-bred varieties also exhibit adaptive traits suitable for cultivation in RK.

The present study is nested within the broader context of spring rapeseed breeding research. Significant genetic diversity in spring rapeseed offers potential for trait enhancement, such as yield, oil content, and disease resistance. However, effectively leveraging this variability remains an elusive goal. With the growing demand for vegetable oils and biofuels, enhancing rapeseed yield is a critical focus of breeding programs. Developing varieties with high and stable yields under diverse environmental conditions is essential. Rapeseed cultivation often confronts various abiotic stresses, including drought, salinity, and temperature variations [12, 13]. Breeding for improved stress tolerance is crucial for sustainable production. The use of advanced genomic tools can expedite breeding progress by facilitating efficient identification of desirable traits.

To address these research gaps, this study undertakes a comprehensive analysis of spring rapeseed samples using Hierarchical Cluster Analysis (HCA) within the Statistical Package for the Social Sciences (SPSS) software. Through this, the study endeavors to elucidate the genetic variability, stress resistance, and other economically valuable traits of spring rapeseed, contributing to ongoing efforts to enhance this crop for agricultural and environmental sustainability.

2. THEORETICAL OVERVIEW

There are three main directions in rapeseed breeding: breeding varieties with a high content of food-grade oil; technical use in biodiesel production; for feed purposes. Breeding traits for spring rapeseed include seed yield high in crude fat and protein, early maturity, resistance to cracking, splitting and pod prolapse, adverse environmental conditions, diseases, and insect damage.

In work by Shafighi et al. [14], it is reported that in the climatic conditions of Central Europe and North Asia, varieties of spring oilseed rape are popular with the following characteristics: plant height – 130 cm, number of main branches – 6 pcs., the number of pods per plant – 80 pcs., the number of pods per 1 m² – 2400 pcs., weighing 1000 seeds – 6 g, seed yield 3.5-3.6 t/ha, crude fat content 48-50%. Liang et al. [15] describe varieties of rapeseed that should be free from erucic acid and have a low content of glucosinolates in seeds and green mass, resistant to false saprophytic rot, gray rot, adapted to the soil and climatic conditions of the growing region. Great attention in the breeding of food varieties is given to the colour of the seeds. Navrotskyi et al. [16] report that yellow seed oilseed rapeseed varieties are dominated by fusidan, providing a high content of crude protein and a low content of crude fibre. Research by Kamundia and Mahasi [17] is important. Evaluation trials were conducted on 17 rapeseed genotypes, comprising nine of Canadian origin and eight of European origin, across four locations in Kenya: Endebess, Njoro, Timau, and Mau Narok, spanning a two-year period. An analysis of variance, focusing on seed yields, revealed significant differences among the genotypes (LSD, 0.05). Cluster analysis, based on mean seed yields, indicated the presence of a predominant group within the material. In the first year, genotypes 2, 3, 8, and 9 did not align with the rest, with genotype 8 being the sole exception among Canadian genotypes. Conversely, three European genotypes (2, 3, and 9) did not conform to the others. In the second year, genotypes 10 and 6 did not cluster within the primary group. Notably, genotype 10 originates from Canada. The second-year results revealed a higher degree of similarity among genotypes, primarily due to favorable weather conditions. Interestingly, despite their diverse geographical origins (Europe and Canada), some genotypes shared common clusters, suggesting genetic similarities. These groupings indicated a lack of direct correspondence between geographical diversity and clustering patterns [18].

Sultana et al. [19] characterize new gene pools of spring oilseed rape, which are created using breeding methods: chemical mutagenesis using ethyl methanesulfonate, intraspecific crossings between *Brassica* species with cabbage, superice, and mustard; resynthesis and synthesis of new forms; creation of haploids from anthers, pollen and microspores, which differ from diploids in smaller flowers without fertile anthers.

According to Xie et al. [20], rapeseed breeding is carried out in accordance with the methods used for hybrid plants: when the breeding material is collected in one field, the most common method is the half-sowing method, in which part of the seeds are sown in separate areas for testing, and the second part for propagation. If varieties low in erucic acid and glucosinolates are grown together with varieties high in these substances, it is not possible to determine the content of erucic acid and glucosinolates in seeds [21-23]. In the context of analysing the potential environmental impacts of the release and use of biotechnological forms of rapeseed, most attention is paid to the analysis of the potential for vertical and horizontal gene transfer from genetically modified cultivated rapeseed to related or wild species.

The current study is situated within the context of spring rapeseed breeding research and seeks to address specific gaps and challenges in this field. Spring rapeseed, a vital oilseed crop, plays a crucial role in agriculture and the production of edible oils, biodiesel, and other valuable products. Spring rapeseed exhibits considerable genetic diversity, which is a valuable resource for breeding programs. However, effectively harnessing and utilizing this genetic diversity to develop improved varieties remains a challenge. Rapeseed crops are susceptible to various pests and diseases. Breeding for resistance to these biotic stresses, such as aphids, flea beetles, and fungal pathogens, is essential to reduce the reliance on chemical pesticides. The current study aims to contribute to addressing these research gaps by conducting a comprehensive analysis of spring rapeseed genotypes, utilizing advanced techniques like cluster analysis and multivariate analysis. By doing so, the study seeks to provide insights into genetic diversity, stress resistance, and economically valuable traits in spring rapeseed, ultimately contributing to the development of improved varieties and the sustainability of rapeseed cultivation.

3. MATERIALS AND METHODS

The following methods were used in the experimental study: laboratory methods included monitoring and assessing the quality of plant material; field – parameters of a comprehensive analysis of phenotypic environmental conditions; statistical – analysis of information, construction of a dendrogram for a cluster assessment of varieties of spring oilseed rape.

Growing technology – generally accepted for conditions in the northern region of RK. Variety Maykudyk, approved for use in the Akmola region, was sown as a standard. The research was carried out in the field by the laboratory for the selection of legumes and oilseeds in the period 2021-2022. based on A.I. Barayev Research and Production Centre for Grain Farming, Shortandinsky district, Akmola region. Breeding lines of spring oilseed rape were studied during a two-year competitive variety testing.

Indicators of breeding value, genotypic effect, stress resistance and genetic flexibility were determined by quantitative traits of yield, by the number of grains per ear and the weight of 1000 grains. Under laboratory conditions, the seed suitability of rapeseed breeding material was determined: seed germination averaged 87-96%, the weight of 1000 seeds ranged from 5.2 to 6.1 g. Seeds were harvested in the same way as standard seed. The laying and conducting of experiments, the selection of plant samples, their preparation for analysis, was carried out according to observations and accounting for yields according to the methods of Eberhardt and Thomas [24].

The material for the study is the best basic and some new unknown 36 varieties of spring rapeseed collected in various ecological and geographical zones. The studied spring rapeseed genotypes, grown in 11 countries, are presented in Figure 1.

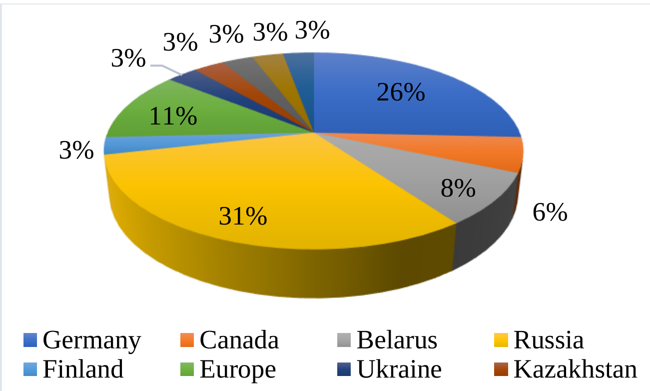

Figure 1. The ecological and geographical diversity of spring rapeseed genotypes
Source: Study [25].

During the growing season, the field crop was carefully cared for, and a planned fight against weeds, diseases, and pests was carried out. Fertilizer Kemira Hydro was applied at a ratio of 10 g/10 l of water once every two weeks, containing magnesium, sulphur, and trace elements. Twice a month with an interval of 10 days, Fitoverm and Fitosporin were treated at a dosage of 1 ml/5 l and 10 ml/10 l of water, respectively. Collection and accounting of the crop was carried out in the phase of full ripeness of spring rapeseed manually from each site of the experiment by the weight method. Spring rapeseed was harvested directly on the Wintersreiger Classic combine, upon reaching full maturity and physiological ripeness at seed moisture from 8 to 12% in terms of the bulk. Seeds were dried as needed, weighed per plot and recalculated in quintal yield units: yield per hectare; herbage height, cm; the number of branches and pods, pcs.; the number of seeds in pods and per plant, pcs.; the weight of seeds per plant and weight of 1000 seeds, g.

Statistical analysis of yield data was performed using the dispersion method based on data from the study by Xiong et al. [26]. Cluster analysis of samples was carried out for a complex of economically valuable traits of spring rapeseed using the Hierarchical Cluster Analysis (HCA) module and Statistical Package for the Social Sciences (SPSS). To construct dendograms, a measure of the difference or similarity of traits in the multidimensional space of grouping selected genotypes according to adaptability to the environment, reflecting the intuitive properties of the distance between points – Euclidean metric, was used.

The number of replicates is 3, in case of this study it's an appropriate. It, thus, depends on the number of treatments, availability of material, experimental unit and expenses. The size of individual plots where spring oilseed rape varieties were cultivated was 2.1 m^2. Cluster analysis was conducted based on a complex of economically valuable traits of spring rapeseed. While it specifies that the analysis was based on quantitative traits like yield, the number of grains per ear, and the weight of 1000 grains, it doesn't provide details about other variables or traits considered in the analysis.

4. RESULTS

An important task in the selection of spring rapeseed is the selection of promising lines with economically valuable traits. Research on plant germplasm collections includes the evaluation of various repositories in a wide range of traits of different quality, which are successfully used in the breeding of many crops, accelerating the process of creating new hybrids and varieties. Multivariate statistics allow breeders to objectively evaluate source material against a set of performance indicators. It is recommended to choose varieties of spring rapeseed, according to two main criteria – plasticity and yield. The seed market of spring rapeseed in RK is filled with hybrids of foreign and Kazakhstani selection, in particular, the national seed potential competes adequately and even surpasses in terms of plasticity and yield. In addition, the price of seeds of Kazakhstani selection is much lower, which makes them more attractive, especially in the northern region with unstable weather conditions. The amount of precipitation is noted in Figure 2 [27], for the growing season of 2022, it amounted to 61.4 mm, which is below the long-term average. One of the methods for separating the genetic diversity of the studied strains into groups is cluster analysis.

The Akmola region of the Northern region of RK, where the experiment was carried out, belongs to the West Siberian climatic zone and is characterized by a sharply continental climate. Winter is cold for about 6 months and summer is moderately warm. Climatic factors vary greatly in intensity and manifestation of climatic factors from year to year. Li et al. [28], state that the data for the growing season 2021-2022. are characterized as dry; the average annual precipitation was 350-650 mm, 70% of which falls during relatively wet, warm periods; the average daily temperature for the 2021 spring green growing season was 17.3°C, which is 1.4°C above the annual average. The main soil varieties are areas with layers of chernozem. The main types of soils are usually chernozems with a heavy loamy texture, limited to shallow lowland areas and gentle slopes. They are found in the form of homogeneous mountain ranges, and homogeneous masses, in the form of complexes with other soil differences. According to Wu et al. [29], the content of humic substances in the soil layer with a depth of 0-40 cm is 3-4.5%, nitrate nitrogen – 60 mg per kg, mobile phosphorus – 14 mg, potassium – 338 mg, pH neutral – 7.85. Soil and climatic conditions in RK – southern medium loamy chernozem, with a humus content (according to Tyurin) in the plow horizon – 0-30 cm no more than 3%, nitrogen content – 19.2 mg/kg and mobile phosphorus – 28 mg/kg, potassium – 331 mg/kg, the reaction of soil solutions is slightly alkaline.

Sowings of spring rapeseed in the farms of Sandyktausky, Zerenda, Shchuchinsky, Bulandinsky, Akkolsky and Shortandinsky districts of Akmola region of RK are economically efficient, and the following varieties and hybrids of spring rape are widely grown: Abilichi, Zolotnovsky, Kavia, Lovets, Okhotnik, Yubileyny, Karibur, Mike Dook, Mobile GL, Ozorno, PR45X73 and RG40301. The creation of crop varieties by breeding methods is a complex and time-consuming process, and the needs of agricultural production often require the rapid replacement of old varieties with new ones, so it is necessary to reduce the time of their production. Sowing of spring oilseed rapeseed was carried out at a temperature of 5.7°C above the norm and with a rainfall of 7 mm, after which the rapeseed plants grew in conditions of insufficient moisture. During the flowering period, the temperature was 3°C above the norm, and 31.9 mm of precipitation in July had a favourable effect on the formation of productivity factors and, accordingly, contributed to an increase in yield.

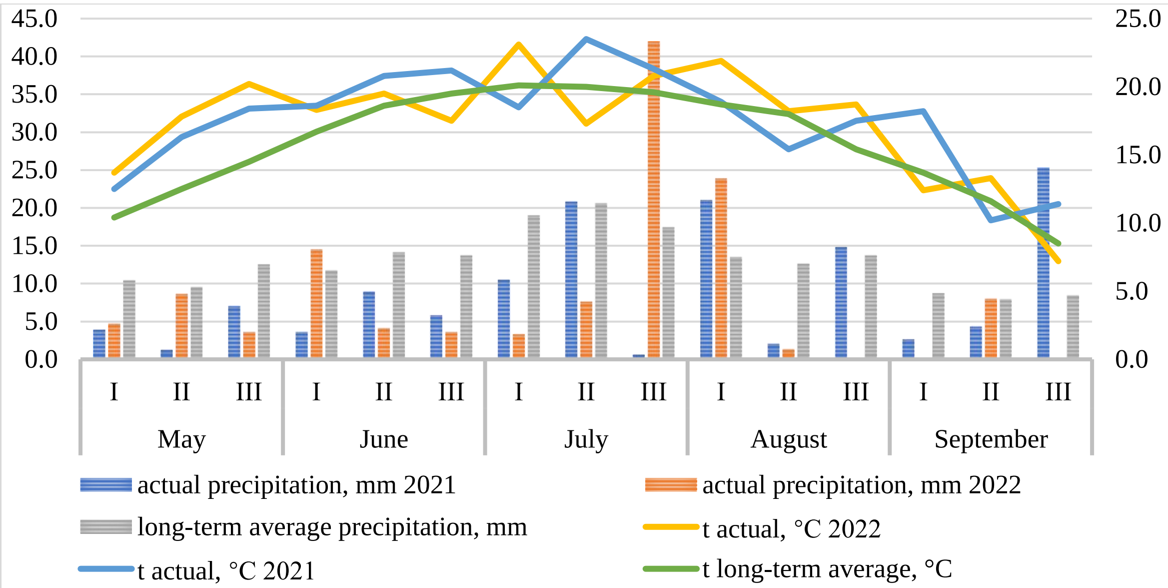

Figure 2. Hydrothermal indicators of weather conditions during the growing season spring rapeseed for 2021 and 2022
Source: Study [27].

The sowing width between the rows of oilseed rape should be 30 cm, in particular large high yields of oilseed rape are obtained with zero sowing. Plant height is 25-30 cm when using direct sowing. The optimal date for sowing spring oilseed rape to obtain a higher yield and quality of oilseeds is the period from May 17 to 25. The optimal sowing method with a seeding rate of 1-2 million pcs. viable seeds per 1 ha. Sowing can begin in the spring, as soon as the temperature rises steadily above 5°C, provided the soil is dry and in mild plastic conditions, between 10 and 20 April. Harvesting maturity of rape crops is observed in the period from late August to early September, when 30-40% of the seeds in the lower pods turn black, and the moisture content of the seeds decreases to 30-35%.

The 2022 growing season witnessed dry conditions as well. The average daily temperature stood at 17.3°C, surpassing the norm of 15.9°C, while only 125.2 mm of precipitation occurred throughout the growing season. An interesting observation was that there was a slight surplus of precipitation during the budding period, with 2.8 mm more than the norm. This surplus had a positive impact on the subsequent growth and development of rapeseed. However, the period from the onset of rapeseed budding to the end of June, just before flowering, experienced notably dry conditions. During this phase, the plants had to utilize the water accumulated in the soil from winter precipitation, which was rapidly depleting due to the lack of rainfall. The heightened average daily temperature led to significantly higher total monthly values and overall indicators throughout the growing season. However, it is noteworthy that this temperature increase did not translate into an increase in crop yield. Cluster analysis of the most valuable indicators under the influence of various environmental conditions made it possible to distribute 36 accessions of spring rapeseed into two clusters marked in the dendrogram in Figure 3.

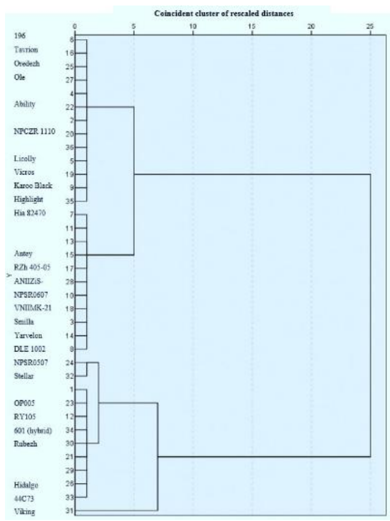

Figure 3. Dendrogram of clustering of spring rapeseed collection samples according to economically valuable traits using the Euclidean distance method
Source: compiled by the authors.

Table 1. Clustering samples of spring rapeseed

Cluster	Subcluster	Genotypes	Origin
1	1A	196, Tavrion, Oredezh, Vanguard, Vikros	Russia
		Ole	Brazil
		Caliber	Belarus
		Ability, Gladiator, NPCR 11109, Licolli, Karoo Black, Highlight	Germany
	1B	NPSR0607	Europe
		Hia 82470	Finland
		Siesta, Jeros	Germany
		Antey, DLE 1002	Belarus
		RJ 405-05	Ukraine
		ANIIZIS-1, VNIIMK-21, Yarvelon	Russia
2	2A	Smilla	Canada
		NPSR0507	Europe
		Stellar	Germany
		Maykudyk	Kazakhstan
	2B	OP005, RY105	Europe
		601	Canada
		Frontier, Krasnodar 3, Hidalgo	Russia
		Mirko	France
		44C73	Australia
	2C	Viking	Russia

Source: Compiled by the authors.

Table 2. Average values of biometric indicators of spring rapeseed

Cluster	Plant Height, cm	Quantity, pcs				Weight, g	
		Branches	Pods	Seed		Seeds from a Plant	1000 Seeds
				In a Pod	From a Plant		
1	133.1	3.5	114.9	20.8	2116.1	12.1	4.2
2	142.3	4.6	250.7	22.1	4095	17.7	3.7

Source: Compiled by the authors.

Table 3. Comparative characteristics of productivity indicators of spring rapeseed clusters in the conditions of cultivation in 2021 and 2022

Indicators	1 Cluster	2 Cluster	1 Cluster	2 Cluster
Conditions:	2021		2022	
Productivity, c/ha	18.74	16.46	24.38	21.65
Oil yield, c/ha	9.12	8.06	11.03	10.14
Protein yield, c/ha	3.26	3.14	4.15	4.02
Erucic acid content, %	0	till 0.2	0	till 0.4
The content of glucosinolates, μmol/g	14	16	13	12
Vegetation period, days	91	95	96	97
Plant height, cm	126	130	133	142
Weight 1000, g	3.6	3.5	4.2	3.7

Source: Compiled by the authors.

As a result of clustering, a group of spring rapeseed varieties was formed, which are most similar, belong to the same cluster – 1A and 1B. And having a set of values with differences in the electrophoresis spectra of hordeins – located in clusters of different blocks, remotely from each other 2A, 2B, 2C. Foreign scientists argue that a sample of distance-maximizing clusters can be used as a parent type for breeding new varieties.

The grouping of samples into clusters, regardless of geographic origin, is noted in Table 1.

The first cluster was a combination of 24 samples divided into two subclusters with different quantitative composition: 13 genotypes belong to subcluster 1A, and 11 genotypes belong to subcluster 1B. The second cluster, containing 12 samples, included three subclusters: 2A – 2 genotypes, 2B – 6 genotypes, 2C – 1 genotype.

Table 2 presents the component yield parameters for the period of 2022: by plant height, number of pods and branches per plant, weight of 1000 seeds and seeds per pod.

Analyzing the data on obtaining the desired hybrid forms, and in the future breeding of new varieties, it is advisable to use samples of the 2nd cluster as parental lines, which were identified according to the main economically valuable traits. Samples from subclusters 1A and 1B were similar in terms of 39.7-36.5 centners/ha, grass stand height – 133.6-132.5 cm, number of branches – 3.6-3.4 pieces, number of seeds in a pod – 21.1-20.4 pieces. and weight of 1000 seeds 4-4.4 g. Samples of subclusters 1A and 1B differed significantly in the number of pods per plant 145.8 and 84 pcs. respectively. However, the Brazilian Accession Ole outperformed all other accessions with a yield of 56.6 q/ha. The genotype of the spring rapeseed sample Jeros (Germany) was distinguished by the highest weight of 1000 seeds – 6.3 g. These samples should be used as productivity donors to increase the yield and weight of 1000 seeds. Subcluster 2A contained two accessions differing in the number of pods per plant. Accessions assigned to subcluster 2B did not differ significantly in the set of traits within the group, except for cultivars RY105 and 601, which stood out as the highest 174.1 cm and 171.6 cm, respectively. Subcluster 2C is represented by the genotype of the Viking variety, which exceeds the other samples in the number of pods per plant –

601.5 pcs and the number of seeds from one plant 6696.3 pcs. By means of selection, the weight of 1000 seeds increased in the following samples: Caliber, 5.0 g; Jeros, 6.3 g; ANIIZiS-1, 5.3 g; NPSR0607, 5.1 g; number of pods and seeds per plant: Viking – 601.5 pcs. pods and 6696, 3 pcs. seeds; grass green mass height: Siesta – 167.8 cm, RY105 – 174.1 cm, 601 – 171.6 cm, Ole – 56.6 cm, 60 – 59.6 cm, Krasnodar – 57.4 cm.

Vegetation weather conditions during the testing period 2021-2022 significantly differed in temperature and precipitation. Spring rapeseed productivity data for clusters 1 and 2 were averaged and divided into two groups, taking into account the yield when cultivated in the Akmola region under relatively unfavourable conditions in 2021 and favourable in 2022, the data are marked in Table 3.

According to the study, the growing season of clusters 1 and 2 of spring rapeseed under the conditions of 2022 was 96 and 97 days from sowing to full seed ripening, and in 2021 – 91 and 95 days, respectively. The yield of 1 and 2 clusters of spring rape per c/ha under favourable conditions in 2022 was 24.4 and 21.7 c/ha, under the conditions of 2021 – 18.7 and 16.46 c/ha, respectively.

The quality indicators of spring rape seeds depend both on the meteorological conditions of the year and on the elements of crop cultivation technology. Precipitation during the growing season of 2022 in the samples of spring rapeseed seeds did not affect the oil content of the seeds in terms of crude fat, in clusters 1 and 2 it was 45.2 and 46.8%, and the total oil yield in terms of yield was noted at the level of – 11 and 10.1 q / ha. In 2021, the oil content of seeds in terms of crude fat in samples 1 and 2 of clusters was set at 48.7 and 49%, and in terms of yield, the total oil content was 9.1 and 8.1 c/ha. Crude protein indicators for clusters 1 and 2 for 2022 were 17.8 and 19.5%, for 2021 – 17.4 and 19.1%, respectively.

In our study, we conducted a thorough analysis to assess the statistical significance of differences between the clusters identified in our dataset. This analysis was performed for multiple variables, including yield, quality parameters, and other relevant traits. A one-way analysis of variance (ANOVA) was conducted to determine if there were statistically significant differences in yield between the identified clusters. The results indicated that there were indeed significant variations in yield among the clusters ($p < 0.05$), with specific clusters outperforming others in terms of yield. For quality parameters such as seed germination rate, oil content, and nutritional quality, similar statistical tests were conducted to evaluate differences between clusters. The outcomes revealed statistically significant variations in these parameters ($p < 0.05$) among the clusters, suggesting that certain clusters exhibited superior quality characteristics.

Additional traits, such as disease resistance, abiotic stress tolerance, and growth characteristics, were also subject to statistical analysis. The results demonstrated statistically significant differences ($p < 0.05$) in these traits across the identified clusters, highlighting the diversity and unique attributes of each cluster.

5. DISCUSSION

The methods of modern breeding in the climate of Northern Kazakhstan allow the cultivation of high-quality spring rapeseed, despite the frequent manifestation of early spring drought and high humidity at low air temperatures during periods of flowering, fruiting, and intensive seed ripening. In modern diversified agriculture, when new hybrids and varieties of spring rapeseed are discovered, breeders need the means to achieve the expected results with minimal effort and time. According to Hu et al. [30], the development of spring rapeseed breeding for resistance to abiotic environmental factors of drought resistance and acid resistance is carried out using breeding, physicochemical and biotechnological methods. No tangible success has been achieved in breeding spring rapeseed in this direction, so the creation of source material with pronounced stress-resistant properties is an important breeding problem [31, 32].

In the conditions of 2021-2022, as close as possible to production, various varieties of spring rapeseed were tested, among which are Kalibr, Jeros, ANIIZiS-1, NPSR0607, Smilla and Yarvelon. A promising result was noted under the conditions of cultivation in 2022, with an average yield of 1 and 2 clusters at the level of 24.4 and 21.7 c/ha, respectively. In the work of Cherkasova and Rzaeva [33], the most promising lines of spring rapeseed with high yields were noted: Maykudyk variety – 29.2 c/ha and Bilder hybrid – 32.7 c/ha. These samples were used as seed material for the creation of new hybrids, with a seeding rate of 2.5 million viable seeds and intensive cultivation technologies in the conditions of Northern Kazakhstan.

Cluster analysis was employed to categorize rapeseed varieties into two distinct groups, primarily based on average yield indicators and physiological and biochemical analyses. The initial cluster, denoted as the first group, comprised spring rape varieties characterized by robust resistance to drought stress. Notable varieties in this cluster included 196, Tavrion, Oredej, Vanguard, Vikros, Ole, Caliber, Ability, Gladiator, NPCZR 11109, Licolli, Karoo Black, and Hight. In contrast, the second group encompassed high-yielding varieties, such as NPSR0507, Stellar, Maikudyk, OR005, RY105, 601, Rubezh, Krasnodar 3, Khidalgo, Mirko, 44C73, and Viking.

This clustering approach aligns with the findings of Fan et al. [34], which suggest a significant positive correlation between yield and specific characteristics, including the flowering period, as well as the number of branches and pods per plant. The utilization of cluster analysis to delineate relationships and distances among spring rapeseed varieties proves to be an effective strategy in the examination of crop collections. It facilitates the efficient and rational utilization of alternative germplasm for the purpose of synthesizing early-maturing, high-yielding varieties and hybrids, thereby contributing to the advancement of rapeseed breeding and cultivation practices [35, 36].

The difference in productive parameters of spring rapeseed varieties of clusters 1 and 2 was noted in terms of plant height – 133.1 and 142.3 cm, the number of seeds in the pod – 20.8 and 22.1 pcs., weight of 1000 seeds – 4.2 and 3.7 g, respectively. The oil content of spring rape seeds in terms of crude fat for clusters 1 and 2 was in the range of 45-49%, the yield was 21-24 q/ha. Given State Data Register of Selection Achievements Approved for use in the Republic of Kazakhstan [37], the spring barley cultivar Maykudyk was separately noted, which was sown as a standard sample. Among its characteristics, it is necessary to highlight the following: plant height 112-130 cm, number of branches – 1-2, weight of 1000 seeds – 3.5 g, seed oil content in terms of crude fat – 48-50%, crude protein content 21.9-27.7%, yield 35.2 c/ha.

The practical value of a culture is determined by the biochemical composition of the seeds. The oil content of wild rapeseed is a determining factor in productivity, its decrease is compensated by an increase in seed yield, hence the yield of oil from 1 ha. Studies have shown that the content of crude protein and fat together make up 68-74% of the total mass of seeds. Based on data from Raza et al. [38], rapeseed protein is characterized by a higher albumin fraction of 36-48% than in other crops, characterized by a high content of essential amino acids, including methionine and lysine. One of the main indicators of the quality of raw fat is the fatty acid composition, with the lowest content of saturated fatty acids.

When conducting research, the weather conditions of the period 2021-2022 differed, which made it possible to give an objective assessment of the studied methods of cultivation of spring rapeseed. The vegetative period of spring rapeseed in clusters 1 and 2 was 91-97 days from sowing to full maturation of seeds. Cultivation of rapeseed as a green fertilizer in the period from sowing to harvesting, the maturation of green mass is 36-38 days. According to Bognár et al. [39], the growing season of spring rapeseed is 97-114 days, but in favourable weather years, a green mass can form, which will be harvested a second time. When sown in summer at a short harvest time, the crop resists frost, which allows extending the late seasonal green conveyor for feeding animals by 1.5-2 months. According to Geddes et al. [40], in their work, the breeding of early maturing varieties can be successfully carried out if it is based on the use of source material from the global and national assortment, which was previously studied for the presence of traits selected under the conditions in which the varieties are created. The earlier maturing varieties have many advantages over regular varieties, including cold hardiness, drought tolerance, disease, and insect resistance. In spring rapeseed, varieties with a growing season of 110 days or more are called late-ripening, varieties with a growing season of 90 to 110 days are called mid-ripening, and varieties with a growing season of less than 80 days are called early-ripening.

During the initial period of growing spring rapeseed, its development is extremely slow, so it is necessary to carry out a targeted fight against weeds, since if the crops are completely drowned out by weeds, seed yield losses can reach 45-60%. In the fight against weeds, planned harrowing was carried out by seedlings with the introduction of herbicide a Buckler. Spring rapeseed is also damaged by rapeseed and cruciferous fleas, rapeseed flower beetle, cabbage mosquito, cabbage aphids, leaf-gnawing pests, therefore, spring rapeseed was treated with insecticides Sufron, which reliably protected crops from damage by pests, while maintaining its growth activity [41, 42]. In the studies of Washuck et al. [43], noted the use of alternative options for crop protection, instead of complex applications of herbicides and insecticides, leading to an increase in protein and fat content in seeds. As an alternative, instead of treating the seeds with insecticides, it is necessary to increase the seeding rates at earlier sowing dates, since the faster-formed pods and the seeds in them are less susceptible to insect attack, beneficially affecting the processes of nutrient accumulation [44].

Enhancing agronomic selection methods for oilseed rape, particularly with the integration of fertilization practices, is imperative to unlock the potential for increased overall yield under ideal growth conditions, ultimately leading to heightened seed productivity. Soil preparation preceding sowing, coupled with the judicious application of mineral fertilizers, has assumed paramount importance [45]. Furthermore, it is advisable to incorporate liming procedures into field management practices, given that soil pH levels below 7 can negatively impact nutrient uptake by plants. Empirical research conducted by Gugala et al. [46] underscores the vulnerability of spring rapeseed during its early growth stages. However, precise sowing techniques on a uniformly prepared and sufficiently compact seedbed promote consistent seeding depth and foster robust seedling development [47]. It is worth noting that specific pH benchmarks have been established, falling within the range of 6 to 7. Maintaining soil pH within this range has been associated with a notable increase in oil content, ranging from 1.6% to 2.2%. Conversely, this optimal pH range is correlated with a reduction in crude protein content by approximately 4.2% to 5%.

One limitation of our study is the relatively limited number of genotypes and growing environments assessed. While our sample provided valuable insights, it may not capture the full spectrum of genetic diversity or environmental variability present in spring rapeseed cultivation. Expanding the study to include a broader range of genotypes and diverse growing environments would enhance the generalizability of our findings. Additionally, factors such as seasonal variations and microclimatic conditions may influence trait expressions and cluster formation. Acknowledging these limitations, we recommend future studies with larger genotype sets and multi-location trials to account for environmental variations. To validate and build upon our findings, future research directions could include conducting multi-year trials to assess the stability of cluster formations across seasons and to account for interannual variability in climatic conditions.

6. CONCLUSIONS

The conducted statistical analysis of 36 varieties of spring rapeseed for the period2021-2022 based on A.I. Barayev Research and Production Center for Grain Farming Shortandinsky district, Akmola region, divides varieties into fairly genetically close or distant groups in terms of adaptability and yield according to cluster analysis, helping to identify and highlight the most valuable and promising parental forms for new breeding processes. The dependence of the adaptive traits of oilseed spring rapeseed on the composition of protein components and oil content has been established, therefore it is advisable to recommend this type of research to identify varieties, determine their origin, economically valuable indicators: yield, c/ha; oil yield, centner/ha; protein yield, c/ha; erucic acid content, %; glucosinolates, µmol/g; the number of days of the growing season; plant height, cm; weight of 1000 seeds, g.

Cluster analysis effectively categorizes rapeseed varieties into distinct groups based on adaptability and yield traits. This stratification aids in identifying promising parental forms for breeding programs. The analysis revealed a strong connection between adaptive traits of spring rapeseed and the composition of protein components and oil content. While the precise quantitative differences between the clusters may vary based on specific traits, the cluster analysis allows for clear differentiation between two primary groups: one characterized by high resistance to drought stress and another composed of high-yielding varieties. The results of this study will contribute to an increase in the area of cultivation of spring oilseed rape due to its use by agricultural enterprises, increasing the stability of oilseed production. One limitation is the study's focus on a subset of genotypes. Future work should encompass a more extensive range of genotypes from diverse geographical regions.

ACKNOWLEDGMENT

This work was carried out within the framework of the Program-targeted financing of the Ministry of Agriculture of the Republic of Kazakhstan (BR10764991).

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