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IDENTIFYING PATTERNS IN THE FATTY-ACID COMPOSITION OF SAFFLOWER DEPENDING ON AGROCLIMATIC CONDITIONS

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The object of the study reported in this paper is to establish a dependence of the fatty acid composition of the fast-growing annual plant safflower on the agroclimatic cultivating conditions. The growth rate of safflower and the characteristics of the extracted oil are highly dependent on external temperature and moisture. At low temperatures, for example, the growth of safflower is significantly inhibited. With an increase in temperature and the length of daylight, the central stem begins to branch while growing faster. Flowering is mainly affected by the length of daylight. The period from the end of flowering to maturity is typically 28–30 days. However, the total ripening period of the crop depends on the variety, location, sowing time, and agro-climatic cultivating conditions. The need for water increases significantly during the flowering period of safflower, which ultimately affects the indicators of the fatty acid composition and yield. At the same time, safflower is sensitive to moisture in terms of disease. In case of excess water, it is subject to root rot. In addition, frequent rains and high humidity after ripening can provoke the germination of seeds on the head. Hence, it follows that in order to obtain a high yield with the specified characteristics of the fatty acid composition of safflower oil, it is necessary to take into consideration the quantitative indicators of moisture and its seasonality, as well as the temperature regime during the growing season.

The study was conducted using arid or semi-arid, sharply continental Central Asia with its hot summers and cold winters as an example. The dependence of the physicochemical parameters of plant-derived oils on agroclimatic indicators has been established. The reported results and conclusions will allow farmers to predict the yield of oilseeds with specified characteristics depending on the changing climatic parameters

Keywords: safflower, processing technologies, fatty acid composition of oils, physicochemical properties, climate change, nutritional value

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1. Introduction

According to the calculations of the World Meteorological Organization, the influence of agro-climatic conditions on the quality and properties of vegetation in Kazakhstan and within this region as a whole will increase. At the same time, changes will occur unevenly in terms of seasons and territories. The average annual temperature will increase by 1–2 °C by 2030, and by 2–3 °C by 2050. Such changes in temperature and precipitation will inevitably lead to an imbalance in natural systems, a reduction in water resources, and, as a result, economic losses in agriculture and other sectors of the economy [1].

Agriculture in the Central Asian region is diverse and has the potential for economic revival in Central Asian countries. The climate is mostly arid or semi-arid, sharply continental, with hot summers and cold winters. Precipitation, mainly in winter and spring, averages 270 mm and varies from 600 to 800 mm in the mountain belt and from 80 to 150 mm in arid areas (Fig. 1) [2].

Diversification of crop production in the face of climate change implies flexibility in determining not only traditional crops but also their areas in individual regions, zones, and crops. At the same time, it is imperative to take into consideration the biological characteristics of crops, and their adaptation to local conditions.

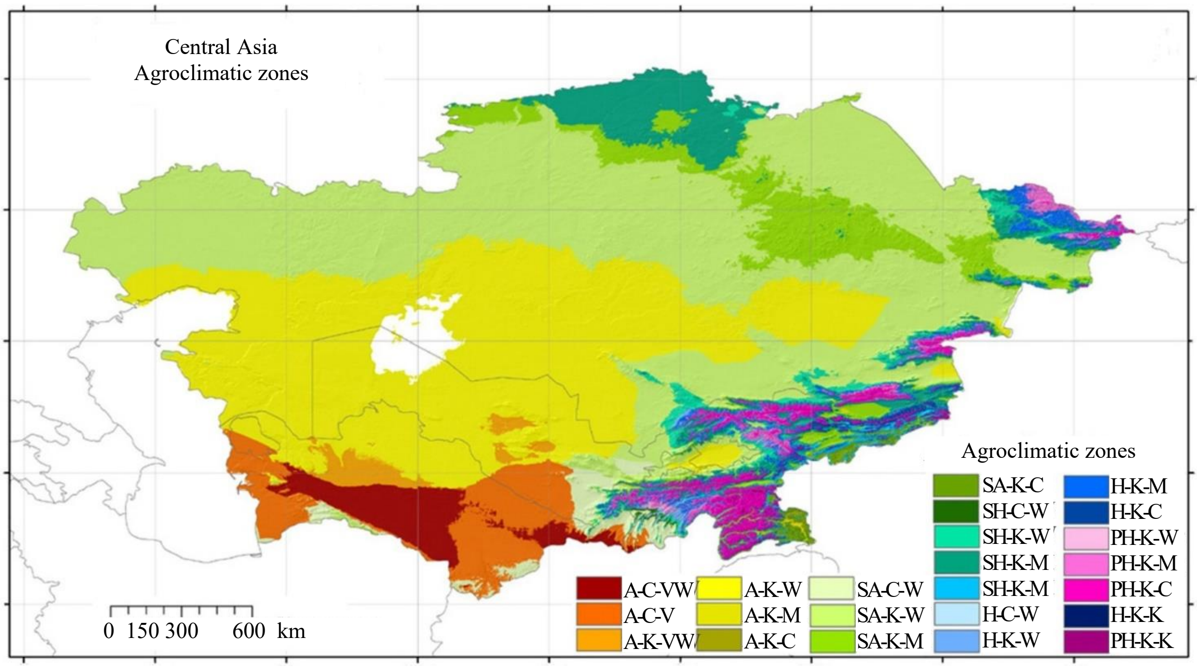


Fig. 1. Quantitative indicators of precipitation in Central Asia

In such a situation, there is a need to search for oilseeds that are more stable to the changing characteristics of the climate and to devise modern approaches to the elements of the technology of their cultivation. This primarily concerns the optimization of cultivation given that this factor, under the conditions of increasing drought, should be selected in order to adjust it to the conditions of moisture supply.

The commercial attractiveness of safflower cultivation is in its high drought resistance and the high quality of the resulting oil. Even though safflower has been known since antiquity, this plant is still poorly studied. Depending on the cultivation region, safflower demonstrates high diversity in terms of morphological features, the content and fatty acid composition of oils. Genetic differences between the geographical clusters of safflower are obvious although not to the extent suggested on the basis of morphology [3]. Moreover, there is a wide variety in the main breeding traits, not only among the populations of different geographical regions but also among varieties of the same region and country [4–6]. Safflower is also characterized by a wide variety of fatty acid compositions of the oil. At the same time, there was no clear relationship between the diversity of safflower in terms of fatty acid composition and the geographical origin of the genotype [7, 8]. The high content of polyunsaturated fatty acids in safflower oil explains the annual demand for this oilseed. However, the content of polyunsaturated fatty acids in safflower oil varies over a wide range and depends on many factors, including external climatic conditions during the growing season. Therefore, studies on the influence of external natural factors in the vegetative period on the quantitative and qualitative indicators of safflower oil are relevant.

2. Literature review and problem statement

The quantitative content and quality of oil in safflower varies greatly under the influence of a number of factors – heat, water regime, variety, sowing time, soil treatment, fertilizer, etc.

Temperature is one of the main factors affecting the duration of the growing season. However, rising temperatures can contribute to the formation of heatwaves and dry growing season conditions. According to the authors of [5], it is necessary to extend the range of oilseeds, among which we can distinguish tinctorius safflower (*Carthamus tinctorius L.*) as one of the most drought-resistant and promising oilseed plants. However, the issue of the influence of rising temperatures, and drier and hotter summers remains poorly understood.

The physicochemical properties and fatty acid composition (consumer characteristics) of the oils of each crop are formed in the process of plant life and are determined by environmental factors that evolve throughout the growing season. The author of [9] predicts that first of all, the ongoing changes in weather conditions will affect the agricultural sector. Calculations of UNDP experts showed that under the conditions of the expected climate, the yield of crops by the 2030s will average 63–91 % of their current level. And if the current level of crop cultivation is maintained, yield indicators will decrease by 13–49 % by 2050. Therefore, it is necessary to study the possibilities of maintaining yields under the conditions of the expected climate.

Many researchers conducted experiments to determine the optimal timing of sowing safflower in various climatic zones and the influence of natural factors on the biochemical characteristics of safflower oil.

Scientists from the West Kazakhstan Agrarian and Technical University named after Zhangir Khan, based on the results of research at the fields of the Daukara peasant farm in the Baiterek district in 2019–2020 [10], recommended technology for growing safflower with high consumer characteristics with a seed sowing rate of 500 thousand pieces/ha. The experimental scheme included two options for safflower cultivation technology:

1. Conventional (control), without the use of biological preparations.

2. Biologized (applying biological preparations).

The study object was the Ahram safflower variety. It was found that the huskness of seeds increased with conventional cultivation technology to 33.6 %, and it turned out to be the lowest when using biotechnology – 32.3 %. The oil content of safflower seeds varied under the influence of environmental conditions, as well as depending on the elements of cultivation technology. The fat content in the seeds was the lowest with the use of conventional technology – 28.8 %, and, using biotechnology, there was a slight increase – up to 30 %. The highest oil yield (0.229 t/ha) was obtained when using biotechnology while with conventional technology, there was a decrease in oil yield by 0.057 t/ha, or 33.1 %. It is shown that under the conditions of the first dry-steppe zone of Western Kazakhstan, it is advisable to use biotechnology to increase the yield and harvest of safflower oil. The application of biotechnology makes it possible to obtain a higher yield of seeds (0.764 t/ha) and oil harvesting (0.229 t/ha), compared to conventional technology. As a result of comparative studies, the oil content of safflower seeds, when using biotechnology, was higher by 1.2 %. However, those authors have not studied the issue of the influence of biotechnology on the physicochemical parameters of oils.

There are, however, unresolved issues related to the resistance and adaptability of safflower to drought, while maintaining high fatty acid characteristics. The author of [11] predicts that first of all the changes taking place are reflected in the agricultural sector. Calculations of UNDP experts showed that under the conditions of the expected climate, the yield of oilseeds by the 2030s will average 63–91 % of their current level in the regions. And if the current level of crop cultivation is maintained, yield indicators will decrease by 13–49 % by 2050.

In addition, the author of work [11] studied the issues of increasing the yield of tinctorius safflower while maintaining its characteristics in arid regions when cultivating it for two or more years in a row in one place. It is proposed to use highly efficient chisel tools for soil tillage and to apply non-conventional ameliorant fertilizers in various dosages from production waste. However, there are no data on specific varieties of safflower that were used in the cited study.

Paper [12] reports a study into the yield and basic parameters of adaptability of varieties of tinctorius safflower under the agroclimatic conditions of the forest-steppe of the Middle Volga region. It was found that the best varieties in terms of ecological adaptability were Zavolzhsky 1 and Alexandrite, the parameters of adaptability of which were b_i=0.99–1.01; σdr^2=0.09) with average productivity of 1.37 and 1.42 t/ha, respectively. Such varieties as Zavolzhsky 1, Astrakhansky 747, and Alexandrite formed large seeds, the mass of 1000 seeds of them reached an average of 41.4–41.6 g. The most stable in terms of yield were the varieties Ershovsky 4 and Astrakhansky 747, whose indicator of the level of stability was 0.26 and 0.22, respectively, which is confirmed by the coefficient of variation in yield – 6.58–7.71 %. However, the cited work does not specify the indicators of climatic parameters in the study period.

When grown under various soil and climatic conditions, crops show noticeable features of the formation of elements of crop productivity.

In safflower, among these indicators, it is necessary to highlight such important ones for creating a crop as the density of standing plants. An important role belongs to the number of completed seeds per 1 basket (pc.), the mass of seeds from one inflorescence (g), and the mass of seeds from one plant (g).

At the same time, according to the authors of [10], the fat content in seeds decreased with an increase in the density of standing plants in crops, and, on wide-row crops, the fat content in seeds was less than on ordinary and row crops. An increase in the fat content in the seeds was noted with the row method of sowing. The reason for this may be the improvement of air access to the roots of plants in the formation of seed productivity.

Such patterns of change in the standing density of safflower plants by the time of ripening and harvesting, depending on the various techniques of sowing and sowing rates, were observed not only in the average long-term data but also in all years of research. Temperature is one of the main factors affecting the duration of the growing season. The higher the average daily temperatures during the growing season, the faster the safflower ripens, but there is no direct relationship between the rate of maturation and the indicators of the fatty acid composition.

It was also established that according to the combination of weather conditions, the growing season of safflower in 2012 was characterized as arid, not quite favorable, for crops. At the same time, the growing season of 2011 and 2013 was characterized as well-provided with moisture, more favorable for plants [12]. In general, the weather conditions of the vegetation periods of safflower in 2011 and 2013 can be considered typical for the dry-steppe zone of the Saratov Volga region. They confirmed the sharply continental characteristic of the climate of the zone when favorable periods alternate with periods of extremely high temperatures, a sharp lack of moisture, and extremely low relative humidity.

The results of studying various varieties from different countries such as Akmai, Akgul (Krasnovodopadskaya experimental station, Republic of Kazakhstan), Center 70 (Kazakh Research Institute of Agriculture and Crop Production, Kazakhstan Sunset, Saffire (Canada), line K – 129 (India), K – 1 (China) show that the characteristics of safflower seeds, depending on the variety, react differently to the amount of moisture.

Paper [10] found that the most oleic acid-rich varieties are Saffire (13.14 %) and Center 70 (13.70 %). At the same time, the content of oleic acid in the Saffire variety and the K-129 line increases when grown under watering conditions. Additionally, for all other varieties, there was a tendency when, with an increase in the percentage of linoleic acid under bogar conditions, the content of oleic acid decreased. Moreover, the content of saturated acids, as a rule, decreases when growing plants under bogar conditions. However, when growing the Akmai variety under the conditions of the southern region, the opposite pattern is observed.

Our review of the scientific literature [9–12] suggests that it is advisable to conduct a study to determine the influence of sharply continental climatic characteristics of regions on the fatty acid composition and nutritional value of safflower.

3. The aim and objectives of the study

The aim of this research is to identify the patterns of the fatty acid composition of plant-derived oils depending on the influence of sharply continental climatic characteristics of regions. This will enable farmers to predict the yield of oilseeds with specified characteristics depending on the changing parameters of the climate.

To accomplish the aim, the following tasks have been set:

– to conduct a comparative analysis of the quantitative and qualitative indicators of the fatty acid composition and nutritional value of the Talap safflower variety grown in the Jambyl and Kyzylorda regions;

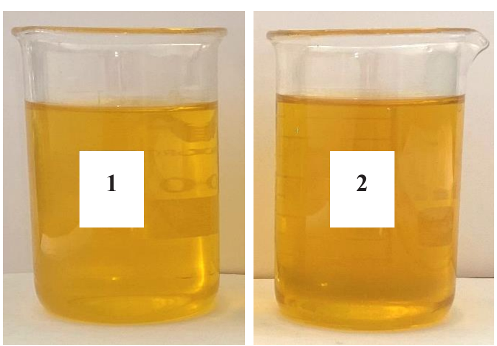
– to determine the dependence of quantitative and qualitative indicators of safflower oil on external factors in the vegetative period.

4. The study materials and methods

The chosen object of our research was the Talap safflower variety grown in 2020 in the Jambyl and Kyzylorda regions, located in the sharply continental climatic zones of the Republic of Kazakhstan (Fig. 2).

Fig. 2. Talap safflower variety

The hypothesis of our study assumed establishing the influence of sharply continental climatic characteristics of the regions on the quantitative and qualitative indicators of safflower oil. To investigate the fatty acid composition and nutritional value, safflower oil was obtained by cold pressing safflower seed kernels using the manual screw oil press «PITEBA» (Fig. 3). The seeds were pre-separated from the shell in a peeling machine.



a *b*

Fig. 3. Oil from the safflower grown in: *a* – Jambyl region; *b* – Kyzylorda region

The research was conducted at the certified laboratory of the Research Institute of Food Safety at Almaty Technological University (Republic of Kazakhstan).

To determine the fatty acid composition and nutritional value of safflower oil, generally accepted procedures were used. Safflower oil was analyzed in accordance with GOST 18-163-74 [13].

The smell, color, and transparency of safflower oils were determined according to GOST 5472-50 [14]. The taste of the oil was determined organoleptically. The density of safflower oil was determined at 200 °C according to GOST 3900-47 [16]. The acid number of safflower oil was determined by the alcohol by ether method according to GOST 5476-64 [17]. The content of moisture and volatile substances in safflower oil was determined according to GOST 11812-66 [18].

Determining the iodine number of safflower oil was carried out by the W_{ijs} method [13]. Determining the fatty acid composition of safflower oil was carried out by gas-liquid chromatography (GLCK) at the chromatograph LHM-8 MD [13]. As a mobile phase, argon was used, which passed through the columns at different speeds (from 60 to 110 ml/min).

The analysis of safflower oils was carried out by converting them into methyl esters of fatty acids. Methylation of fatty acids was carried out with diazomethane. The resulting methyl esters of fatty acids were separated at column temperature of 190–195 °C and the evaporator – 240–245 °C.

The fatty acid composition of safflower oil was calculated from the formula:

$$C_i = \frac{F_i}{\sum F} \cdot 100\ \%, \qquad (1)$$

where *Fi* is the peak area of the desired component; $\sum F$ is the sum of the areas of all peaks of this mixture.

The area of peaks was determined from the formula:

$$F_i = H_i b_i \frac{1}{2}, \qquad (2)$$

where H_i is the height of the peak on the chromatogram; b_i is the width of the peak for height.

We determined acids with conjugated double bonds at the ultraviolet spectrophotometer SF-4 in the range of 220–300 μm [13].

5. Results of the study and comparative analysis of the fatty acid composition and nutritional value of safflower

5. 1. Conducting a comparative analysis of quantitative and qualitative indicators of the fatty acid composition and nutritional value of safflower

The results of experimental studies, specifically acid number, iodine number, moisture, volatile substances, density, and other indicators are given below (Table 1).

The data in Table 1 demonstrate that in safflower oil from seeds grown in the Jambyl region, there is no cloudy shade with a bitter taste. In addition, the safflower oil from the Kyzylorda region is inferior in other quality indicators.

5. 2. Establishing the dependence of quantitative and qualitative indicators of safflower oil on external factors

As a result of our research, it was established that the yield of cold-pressed oil was: from safflower kernels grown in the Jambyl region – 38 %, in the Kyzylorda region – 33 %.

The results of studying the fatty acid composition of safflower oil are given below (Table 2).

Table 2 demonstrates that the indicators of polyunsaturated fatty acids and the content of linoleic acids of safflower oil from the Jambyl region are much higher.

Table 1

Qualitative indicators of safflower oils

Name of indicator	The value of the indicator according to OST 18-163-74	Oil from	
		Jambyl region	Kyzylorda region
Color	Yellow	Yellow	Yellow with a brown tint
Taste and smell	Peculiar to safflower oil, without foreign smell and taste	Peculiar to safflower oil	Peculiar to safflower oil with a bitter aftertaste
Transparency	transparent over sediment	transparent over sediment	transparent with a cloudy tint
Density at 20 °C, g/cm^3	0.916–0.927	0.919	0.938
Acid number, mg KOH/g	not exceeding 6.0	3.5	5.2
Moisture and volatile substances, %	not exceeding 0.3	0.2	0.27
Non-fat impurities (sludge by weight), %	not exceeding 0.2	0.1	0.2
Iodine number, g J/100 g	130–155	142	147
Unsaponifiable substances, %	not exceeding 1.0	0.6	0.8

Table 2

Fatty acid composition of safflower oil

Name of indicator	The value of the indicator according to OST 18-163-74	Oil from	
		Jambyl region	Kyzylorda region
Saturated fatty acids, %	8–10	8.0	9.0
Monounsaturated fatty acids, %	10–13	10.6	11.8
Polyunsaturated fatty acids, %	78–83	81.3	79
Content of linoleic acids, %	55–85	76	65

6. Discussion of results of the study and comparative analysis of the fatty acid composition and nutritional value of safflower oil

Our analysis of the study results (Tables 1, 2) regarding the fatty acid composition and nutritional value of safflower reveals the following:

– the safflower oil from seeds grown in the Jambyl region is rich in polyunsaturated fatty acids and the content of linoleic acids;

– in the safflower oil from seeds grown in the Jambyl region, there is no cloudy shade with a bitter taste;

– the safflower oil from the Kyzylorda region is inferior in terms of quality: acid number, moisture and volatile substances, density, and others;

– the yield of cold-pressed oil from the safflower kernels grown Jambyl region is much higher than that of the safflower from the Kyzylorda region.

The high indicators of polyunsaturated fatty acids, as well as a higher content of cold-pressed oil from the safflower kernels grown in the Jambyl region, can be explained by the agroclimatic conditions of 2020. Thus, in the spring of 2020, the amount of precipitation in the Kyzylorda region exceeded the norm by 232 % but, at the same time, the duration of the rainless period, when the daily rainfall was less than 1 mm, in the Kyzylorda region amounted to 173, and in Jambyl region – 54 days a year. In addition, one of the factors affecting the quality and quantity of safflower oil is the amount of precipitation in the fall. While the amount of precipitation was about normal in the Jambyl region, then, in the Kyzylorda region, the precipitation deficit was 32 % of the norm. It should be noted that the number of hot days when the maximum daily temperature was equal to or higher than 30 °C was observed in the Kyzylorda region for more than 100 days, and in the Jambyl region – 50 days, which also affected the indicators of the fatty acid composition and the nutritional value of safflower [14].

In addition, the climatic conditions of the regions under consideration influenced the quantitative indicators of linoleic acids. The use of our study results will allow farmers to predict the yield of oilseeds with specified characteristics depending on the changing parameters of the climate.

The data from our study show that the climatic parameters of regions have a significant impact not only on the yield of oilseeds but also on the quantitative and qualitative indicators of oilseeds. The dependence of quantitative and qualitative indicators of safflower oil on external factors in the vegetative period has been established.

However, the results of our studies cannot be applied to all existing varieties of safflower. According to [10], some varieties show the opposite pattern with an increase in the amount of moisture. In this regard, we believe it is necessary to continue research into the influence and patterns of climatic conditions on the quantitative and qualitative indicators of oilseeds depending on the regions of growth.

7. Conclusions

1. A comparative analysis of the indicators of the fatty acid composition and nutritional value of safflower grown in different climatic conditions has been carried out. It has been established that the climatic conditions of each region significantly influence the formation of indicators of the fatty acid composition and nutritional value of oilseeds depending on the variety. In addition, a decrease in precipitation in the spring-summer period significantly reduces the yield of oil (Jambyl region – 38 %; Kyzylorda region – 33 %) and the content of polyunsaturated fatty acids (Jambyl re-

gion – 81.3 %; Kyzylorda region – 79 %), which affects the quality of safflower oil and nutritional value. This, in turn, reduces the possibility of using safflower oil in the food and pharmaceutical industries.

2. The dependence of quantitative and qualitative indicators of safflower oil on external factors in the vegetative period has been established. It is confirmed that the physicochemical properties and fatty acid composition of safflower oil are formed during the life of the plant and are determined by environmental factors that evolve throughout the growing season. For example, the acid and iodine numbers in the oil from the Jambyl region are lower, it is also better in color and taste compared to the oil from the Kyzylorda region.

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