International Journal of Agriculture and Biosciences 2024 13(3): 340-346.
https://doi.org/10.47278/journal.ijab/2024.128

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

The Growth and Development of Safflower (*Carthamus tinctorius L.*) in the Conditions of the Dry Steppe of Eurasia

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ABSTRACT

The article covers 18 years of research on breeding and technology development for the cultivation of safflower varieties, as well as an analysis of crop productivity in the Lower Volga region in the zone of chestnut soils of the Volga Left Bank, Russia. The analysis of data on the natural and climatic conditions of safflower cultivation and its yield enabled us to achieve the study's goal: determine the role of factors influencing crop seed yield in an arid climate. The study of the relationship between seed yield and weather conditions made it possible to divide the yield into favorable and unfavorable years according to natural and climatic conditions. During the period under study, there are periods in the data sample when natural and climatic conditions were favorable for the development of culture: 2012, 2019, 2020: GTK = 1.1, 1.65; 1.13; however, the yield of safflower is low: 0.48, 0.7, and 0.6t/ha, respectively. Also, during the studied period, there were years with unfavorable natural and climatic conditions: 2021, 2022, and 2023, but the seed yield was quite high: 1.05, 0.92, and 0.88t/ha, respectively. We examined the meteorological conditions in the years corresponding to the safflower plant development periods in detail to clarify the reasons for the results. A detailed analysis made it possible to determine natural phenomena that positively and negatively affect the collection of safflower seeds. Data on yield, air temperature, and precipitation were subjected to analysis of variance, as a result of which it was determined that the study results are reliable with high probability and significant ($P<0.005$) in the formation of safflower seed yield.

Keywords: Aridization of territories; Oilseeds; Safflower; Precipitation; Air temperature.

Article History
Article # 24-661
Received: 13-Jun-24
Revised: 02-Jul-24
Accepted: 27-Jul-24
Online First: 28-Jul-24

INTRODUCTION

The safflower (*Carthamus tinctorius* L.) has been known since ancient times, and today has found its use in many areas of the national economy (Belikina, 2016; Turina, 2020; Steberl et al., 2020; Gorshkova & Belikina 2021). Safflower is widespread in places with arid climates in Europe, Africa, North and South America, and Asia (Sazhin et al., 2017; Smetneva et al., 2020). In Russia, safflower is cultivated in the south. The Volgograd region is located in the Eastern European part of the Russian Federation, with a predominantly dry climate, and is one of the major producers of safflower seeds. The area where the region is located is subject to aridization processes (Kulik et al., 1999; Kulik et al., 2023). Chestnut soils predominate on the territory of the region, a small part of the area is represented by ordinary and southern chernozems, with a humus content of up to 5.5-7.0% (Belyakov et al., 2012; Amangaliev et al., 2023). Rainfed farming is carried out on chestnut and dark chestnut soils. The southern regions of the region and the Volga region, represented by light chestnut soils, are relatively suitable for agricultural production. The temperature regime on the territory of the Volgograd region changes from north to south. During the growing season, the sum of positive temperatures varies from 27 to 35˚C, which contributes to the cultivation of many crops (Belyakov et al., 2012; Smetneva et al., 2020). In the region, the amount of precipitation varies from west to east. The highest formation of precipitation is in the northern and northwestern regions of the region, their amount decreases with movement in the eastern and southern directions (Sazhin et al., 2017; Sukhareva et al., 2022; Solonkin et al., 2023).

Cite this Article as: Solonkin A, Sukhareva E and Belikina A, 2024. The growth and development of safflower (*Carthamus tinctorius L.*) in the conditions of the dry steppe of Eurasia. International Journal of Agriculture and Biosciences 13(3): 340-346. https://doi.org/10.47278/journal.ijab/2024.128

A Publication of Unique Scientific Publishers

In the structure of sown areas, the main oilseed crop, sunflower, makes up 22.9% (Belyakov and Nazarova, 2023; Solonkin et al., 2023). Environmental problems associated with the production of sunflower seeds consist of non-compliance with scientifically based crop rotations, where the return of the crop to its original place is recommended no earlier than after 5-6 years (Vasilenko et al., 2018; Vasiliev, 2019; Guo et al., 2024). To obtain seeds with high oil content, farmers should sow safflower at a favorable time for its growth using adaptive technologies for the growing location (Roche et al., 2019; Kuleshov, 2020; Solonkin et al., 2023). However, market conditions contribute to the disruption of crop rotations, as a result of which environmental problems increase in the form of erosion and deflationary processes, the spread of specific weeds, pests, and diseases for sunflowers (Lukomets & Krivoshlykov, 2015). An analysis of the current situation in the production of oilseeds in the Volgograd region revealed existing problems and opportunities for stabilization, including the introduction of alternative crops into crop rotation (Belikina, 2016; Turina, 2020). Such a crop could be safflower, which is not yet widespread in crops but is in demand in food markets (Solonkin et al., 2023). It can be grown to produce seeds from which vegetable oils are produced, suitable for various purposes in the national economy while reducing the area occupied by sunflowers. The oil obtained from safflower seeds is not inferior to sunflower oil in its usefulness for human nutrition and contains monounsaturated and polyunsaturated fatty acids. Safflower oil contains linoleic, palmitic and oleic acids with admixtures of stearic, arachidic, and meristic acids (Sazhin et al., 2017; Norov, 2019; La Bella et al., 2019; Smetneva et al., 2020; De Oliveira et al., 2021). The predominant acid in safflower oil is linoleic acid, the content of which is 78.5% (Mateev et al., 2017; Smetneva et al., 2020; Rathaur et al., 2023). Vegetable oils help reduce diseases of the cardiovascular system and metabolic diseases and help normalize painful human conditions (Smetneva et al., 2020). Growing safflower for use in feeding cattle and small ruminants, poultry farming also has a positive effect in the summer in eliminating the deficiency of protein and fat in animal diets (Belikina et al, 2021; Belyakov & Nazarova 2023; Rathaur et al., 2023). In scientific studies on the introduction of safflower feed types into diets for lactating cows, it was found that when using cake, the average daily milk yield per head was 0.5 liters higher (Kott et al., 2010; Voronov et al., 2022; Vincent et al., 2024). The dry matter content in milk increased by more than 0.5%, including the fat content increased by 0.07% (Sukhareva & Belikina 2022; Guo et al., 2024). The introduction of green safflower into the diets of lambs helped improve the quality of their meat (Hans-Henning, 2008; Ghiyasi et al., 2023).

Thus, growing safflower to obtain vegetable oils from its seeds will help enrich human diets with monounsaturated and polyunsaturated fatty acids that are beneficial for human health and replenish the diets of farm animals with green mass, vegetable proteins, and fats.

Work on creating highly productive, drought-resistant varieties of safflower in the Volgograd region has been carried out since the 1990s of the last century (Dajue et al., 1996; Kulik et al., 2023; Guo et al., 2024). Currently, three varieties of safflower have been created and introduced into the real sector of the economy, and two are under variety testing.

Safflower is considered an insurance crop in case of unfavorable conditions for traditional oilseed crops, as it can withstand extreme heat and produce seed yields. In 2002, during the growing season (May-August), 41.4mm of precipitation fell, the average daily temperature in July at the time of "budding-flowering-fruit formation" was 26.3°C, with moisture input only 0.4mm, and the number of dry days reached 21. Under these conditions, safflower generated a seed yield of 0.76t/ha, which is a good indicator (Solonkin et al., 2023). The results of studies in countries with dry climates are known, which indicate that an increase in precipitation during the growing season, safflower forms a higher seed yield (Sukhareva & Belikina 2022; Voronov et al., 2022; Abou Chehade, et al., 2022; Zanetti et al., 2022; Solonkin et al., 2023). Studies in hot climates with limited availability in sediments for plants have established that foliar fertilizing with chemical elements allows plants to withstand hot environmental conditions and successfully form a seed crop (Ghiyasi et al., 2023; Guo et al., 2024).

Changing climatic conditions and the increasing frequency of drought events in the summer period necessitate the search for crops that can tolerate unfavorable climatic events and produce crops to ensure economic stability (Akentyeva et al., 2017).

The purpose of the research is to determine the influence of meteorological conditions on the yield and quality of safflower seeds in the dry steppe of the Eurasian continent.

MATERIALS & METHODS

Description of the Research Location

Observations on the yield of safflower (*Carthamus tinctorius L.*) were carried out based on breeding data for 18 years. The scientific site is located on the Left Bank of the Volga River. The geographic coordinates of the observed area are 50°01′39″ N. w. 45°07′39″ E. above 160m above sea level in the Kamyshinsky district, Volgograd region. The climate of the area is temperate continental. The duration of the summer period is about 145 days, and the sum of active temperatures is 28.5-30.5˚C. The average annual precipitation is 300-350mm. The bulk of precipitation in the spring-summer period occurs in July, up to 35mm. (Sazhin et al., 2017; Zinkovsky & Zinkovskaya 2018; Smetneva et al., 2020).

The soil on the site is chestnut, its mechanical composition is heavy loamy, and there are medium and deep solonetzic areas. The soils of the experimental plot have a slightly alkaline reaction. During the research period, it did not change and was equal to 7.6-8.0. The soils are poorly supplied with nitrogen, moderately supplied with phosphorus, and highly supplied with potassium. Humus content 2.0%.

Methods of Data Collection and Analysis

The article uses data on weather changes in the area of the experimental site of the meteorological station of the Federal Scientific Center for Agroecology of the Russian Academy of Sciences, which has been observing the weather since 1905 of the last century. We used data on average daily temperatures for the month and separately per day during the safflower growing season, the number of dry days, as well as the amount of precipitation. Phonological observation of safflower plants was carried out. Photographing of plants was carried out.

Information about the morph metric structure and dynamics of plant development was carried out in phases in areas with different rates of safflower seeding. Quantitative data on the morphometric structure of safflower plants were measured in cm pcs. Qualitative by weighing 1000 seeds.

Methods of Analysis

Data on the meteorological conditions of the analyzed years and the safflower harvest were studied by graphical, analytical, and statistical methods.

Weather data during the years of research were processed and hydrothermal coefficients were calculated:

GTK = R×10 / Σt, where (1)

R – the amount of precipitation in millimeters for the period with temperatures above +10 ^{0}C,

Σ t is the sum of temperatures in degrees for the same period.

The obtained values of GTK years were grouped according to the characteristics of aridity (Dajue et al., 1996; Amangaliev et al., 2023).

The results of the safflower harvest were analyzed and distributed over the years with different natural and climatic conditions and processed using the analysis of variance method (Solonkin et al., 2023).

The data processing tool was Microsoft Excel 10.

RESULTS

It is known that meteorological conditions directly affect seed yield. Moreover, the closest connection exists between precipitation, temperature, and quality of seeds during the periods of their formation (Zinkovsky & Zinkovskaya 2018; Solonkin et al., 2023). In Fig. 1 presents information on weather conditions (CTC) for growing the safflower crop and its yield from 2005 to the present.

The data presented in Fig. 1, demonstrate that the natural and climatic conditions in the Kamyshinsky region, during the growing season of tincture safflower, have different moisture content values from 0.3 to 2.1. The most favorable years in terms of moisture supply are 2005–2010 and 2016–2018, with crop yields of 1.13, 1.48, 1.1, 1.9, 0.95, 0.99, 1.91, 0.91, and 1.1t/ha, respectively.

However, during the research period, there are years in the data sample in which the natural and climatic conditions are favorable for crop development, but the yield is low: 2012, 2019, 2020: GTK = 1.1; 1.65; 1.13 respectively: 0.48, 0.7 and 0.6t/ha. And, conversely, in unfavorable, dry years 2021, 2022, 2023, the seed yield is sufficient at 1.05, 0.92, 0.88t/ha, respectively, by year. To answer the questions that arise about the reasons for the lack of seed harvest in favorable years and the sufficient collection of seeds in extreme years due to natural and climatic conditions, we will consider in more detail the phases of safflower development.

Meteorological conditions according to the phases of safflower development (Fig. 1, 2, 3) show that in all years during the "sowing-sprouting" phase, there was enough moisture and temperature conditions contributed to the friendly germination of safflower plants. During the period of "sprouting", "the first pair of true leaves" and "a rosette of 3 true leaves", the formation of the above-ground part of the plant is not so active, but the powerful root part of the safflower develops, which helps to search for moisture reserves in the deep layers of the soil. During this period, the safflower plant intensively develops the root system, which is 150-200% of the size of the rosette (Fig. 1).

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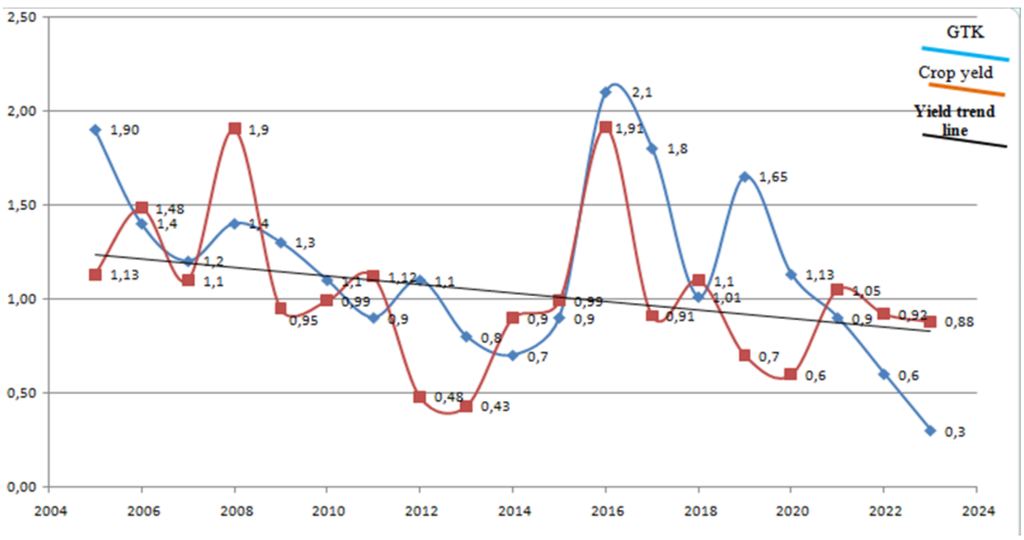

Fig. 1: Crop yield and meteorological data 2005-2023 during the growing season of tinting safflower in the Kamyshinsky district, Volgograd region.

Fig. 2: Safflower plants, "sprouting" phase.

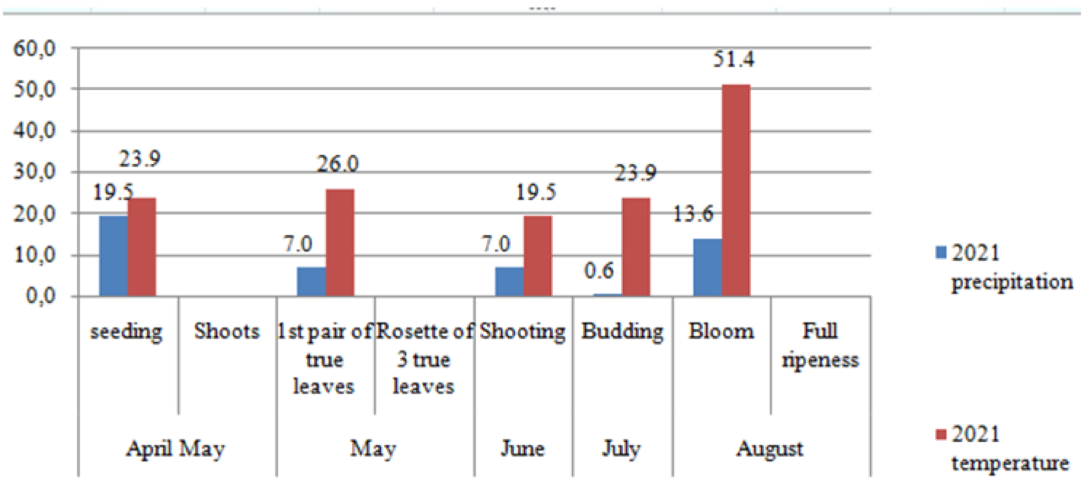

Fig. 3: Weather conditions for the growing season of safflower in 2021.

which the natural and climatic conditions are favorable for crop development, but the yield is low: 2012, 2019, 2020: GTK = 1.1; 1.65; 1.13 respectively: 0.48, 0.7 and 0.6t/ha. And, conversely, in unfavorable, dry years 2021, 2022, 2023, the seed yield is sufficient at 1.05, 0.92, 0.88t/ha, respectively, by year. To answer the questions that arise about the reasons for the lack of seed harvest in favorable years and the sufficient collection of seeds in extreme years due to natural and climatic conditions, we will consider in more detail the phases of safflower development.

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All this continues in the first three above-mentioned phases of plant development, but starting from the "stemming" phase, the above-ground part of the safflower in crops develops, since the main part of the root system is formed and the plant needs moisture to a greater extent (Table 1).

Fig. 3, 4, and 5 present unfavorable meteorological conditions for 2021-2023 with extreme drought conditions, however, during these years, safflower was able to produce a sufficient seed yield of 0.9;0.6; 0.3t/ha.

To check the degree of influence of factors on safflower yield, data on meteorological factors and seed yield were processed by analysis of variance (Dospehov, 2014). As a result of the two-factor analysis of variance, it can be seen that the options reflecting the variability of yield according to the factors of meteorological conditions are highly likely reliable, and the results of the environmental test are significant ($P<0.005$) (Table 2).

It has been determined that all factors are significant in the formation of safflower seed yield. Factor A (air temperature) is 31.2%, factor B (precipitation) - is 18.7%, and other factors account for about 50% (technological, organizational, and economic measures) Table 2.

Table 1: Dynamics of development of safflower plants, 2021-2023*.

	Seed rate (25kg/ha)					Seed rate (35kg/ha)				
	Seedlings, rosette of the first two leaves	Stemming	Budding	Flowering	Full ripeness	Seedlings, rosette of the first two leaves	Stemming	Budding	Flowering	Full ripeness
Root length, cm		11	17	17.5	17.5		8	13	14	14
Plant height, cm		26	60	72	72		46	55	59	59
Number of branches, pcs.		2	6	11	11		3	4	5	5
Number of baskets/flowers, pcs.			6	8/4	12/1			4	1/6	7
Basket diameter, cm			1.3	2.5	3			1.7	2	2.5

*An average value of safflower plant parts in development phases 2021-2023.

Table 2: The results of the analysis of variance of the influence of meteorological conditions on the yield of safflower in 2021-2023

Option	Share of factor influence (%)	Degree of freedom (df)	Mean square (ms)	Fisher criterion (F)
Factor A (temperature)	31.2	11	89.97844	0.6239828
Factor B (precipitation)	18.7	1	594.214	4.1207573
Random deviations	50.0	11	144.2002	-

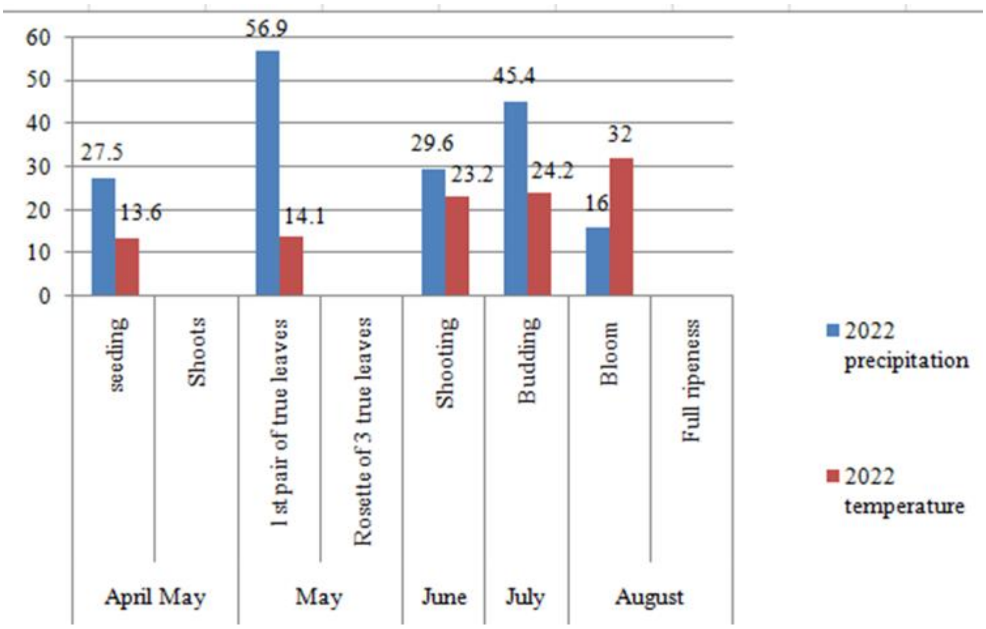

Fig. 4: Weather conditions for the growing season of safflower in 2022.

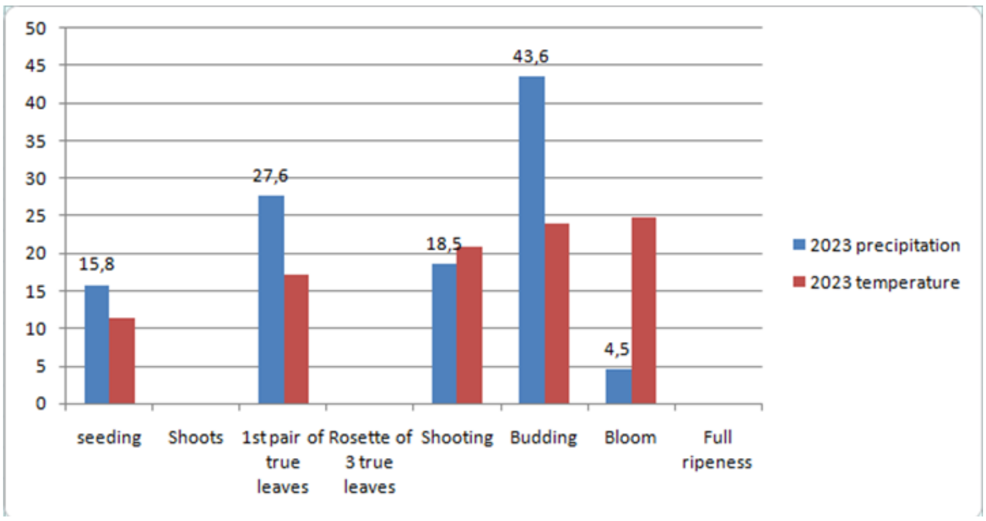

Fig. 5: Weather conditions for the growing season of safflower in 2023.

DISCUSSION

The development of safflower plants during the period of their growth and development is influenced by all biotic and biotic factors (Smetneva et al., 2020). Considering abiotic factors, we study the effect on the growth and development of safflower plants and the production of seeds in favorable and unfavorable years in terms of moisture (Guo et al., 2024).

Considering the meteorological conditions of the growing season of plants, it can be noted that in all years the sowing-emergence period in all phases of plant development was provided with heat and moisture, but the least precipitation fell in 2023 and the average daily temperature was also lower. However, this did not affect the plant density, 72 pcs/m^2.

The phase of development of safflower plants "1st pair of true leaves" - "rosette of 3 true leaves" in 2022 and 2023 was mostly provided with moisture of 29.6 and 56.9mm, which made it possible to successfully increase the above-ground vegetative mass of safflower plants.

The main growth of the vegetative parts of safflower plants in all variants of the experiment was observed in the “stemming” and “budding” phases; in the “flowering – full ripeness” phase the number of baskets and their size increased (Table 1). In the “full ripeness” phase, plant growth decreased and only the diameter of the basket became larger since all the plant’s resources in this phase were aimed at filling seeds. According to the data presented in Table 1, the increase in height from the “stalking” phase to “full ripeness” for options with different seeding rates ranged between 46 and 13 centimeters. Plants grew higher in plots with a seeding rate of 25 kg/ha at 46 cm.

Even though in 2021-2023, during the growing season of safflower, the GTK corresponded to drought (Dajue et al., 1996), and in 2022, due to severe drought, safflower plants were able to form a seed yield of 1.05; 0.92; 0.88t/ha. Average daily temperatures in the second half of August reached 30-33°C, however, we believe that the formation of the seed harvest was facilitated by precipitation during this period of 13.6; 16.0; and 4.5mm respectively. During the “blooming” phase, there were no critical average daily temperatures at which pollen becomes sterile and incapable of fertilization; such temperatures occurred only in the second half of August when the phase of full ripeness began.

The quality of the obtained safflower seeds during the years of research: weight of 1000 safflower grains 40.0; 39.8; 37.9g, respectively. As you can see, the weight of 1000 grains is 40.0t/ha in 2021, and the generated seed yield volume is 1.05t/ha; in 2022 -0.92t/ha, the weight of 1000 grains -39.8g; 37.9g weight of 1000 grains in 2023, yield 0.88t/ha.

However, during the period of sampling data on safflower yields, there were also years with favorable meteorological development conditions for the crop in 2012, and 2019-2020. GTK 1.1, 1.65, 1.13, and its productivity was low 0.48, 0.7, 0.6t/ha. A detailed examination of meteorological conditions allowed us to conclude that in 2012, the abundance of precipitation could contribute to the rotting of seeds (Kushnir et al., 2016). During the growing season, namely in the phases of "budding," "flowering," and “full ripeness," the precipitation amounted to 42.1 and 24.3mm, and the average monthly sum of temperatures was 25.6 and 24.9°C in 1993 and 2008, respectively (Kulik et al., 1999; Kulik et al., 2023). The same meteorological conditions influenced the development of safflower plants in 2019, and in 2020, during the “budding” phase, precipitation was minimal at 0.6mm, and the average daily air temperature was 28.8˚C; probably the resulting moisture reserves were not enough for the formation of flower organs safflower in full and not all flowers produced a harvest of safflower seeds.

Thus, despite extreme weather conditions, a harvest of safflower seeds was obtained. The formation of the harvest was favorably influenced by precipitation during “flowering” and before “full ripeness,” i.e., during formation and filling of seeds, which helped to produce seeds with a mass of 1000 grains of 40.0, 39.8, 37.9g.

Conclusion

After analyzing data on meteorological conditions from 2005 to 2023 and safflower yield, the role of factors influencing the yield of safflower seeds in the arid climate of the Lower Volga region has been established. Directly, the influence of the environment on the growing season of safflower in the dry climate of the region; temperature plays a greater role in the formation of its seeds. Precipitation also contributes, however, technological factors, which include moisture-saving soil cultivation, selection of an adaptive variety, etc., can mitigate the influence of natural factors.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

This study was funded within the framework of State Assignment No FNFE-2022-0010 «Creation of new competitive forms, varieties and hybrids of cultivated, woody and shrubby plants with high productivity, quality and increased resistance to adverse environmental factors, new innovative technologies in seed production and nursery, taking into account varietal characteristics and soil and climatic conditions of arid territories Russian Federation» to Federal Scientific Center of Agroecology, Complex Melioration and Protective Afforestation, Russian Academy of Sciences.

Author Contributions

All authors contributed equally to the conception, execution, data collection, data analysis, and writing of the manuscript, critically revised the manuscript, and approved the final version.

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