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Comparative Study and Adaptation of Promising Varieties of Safflower (*Carthamus tinctorius L.*) For the Production of Fodder and Seeds in a Desert-Steppe Zone

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Production of natural vegetable oil when it comes to health-saving technologies and use of the vegetative mass of oil-bearing crops in fodder production is of current importance throughout the world. In accordance with the biological characteristics, safflower is one of the promising crops not only in Kazakhstan, but also in other regions prone to aridization and desertification. The purpose of the research was a comparative study of the food and fodder value of safflower varieties in the desert-steppe zone in order to address food security and fodder production problems. In the course of work, the generally accepted methods of public variety testing of oilseeds and fodder crops adopted in Kazakhstan were used. The authors developed a correction factor to the leaf area for the studied conditions in order to determine the photosynthetic potential and net production of photosynthesis of safflower. The results of the research revealed that the test varieties of domestic (Nurlan, Akmay) and foreign selection Milyutinsky 114 (Republic of Uzbekistan), Xinjiang 1 and Xinjian 4 (China) differ in seed yield and herbage yield capacity depending on the duration of the generative and vegetative periods. The actual combination of abiotic factors in the study area and the agrobiological features of safflower reflected in the amount of PAR (photosynthetically active radiation), accumulation of energy resources, dry biological yield, oilseed crop capacity, degree of plant foliage allowed recommending cultivation of Xinjiang 1 and Xinjiang 4 for fodder purposes and Akmay, Nurlan– for oilseeds in the *desert-steppe zone*.

Keywords: : safflower, yield capacity, oilseed, fodder purposes, varietal features

INTRODUCTION

Oilseed crops are now becoming an integral part of the agricultural sector. In Kazakhstan, the task is to increase the area under crops and the range of oilseeds to diversify crop production and their use as fodder crops.

Extended arid areas, climate changes, which tend to increased temperatures, require expanding the range of oilseed crops and their varieties for use in production. The harsh ecotopic and climatic conditions of the regions of Kazakhstan limit the number of crops producing stable yields. In this regard, it is important to study and select the range of drought-resistant and heat-loving crops. (Ruzheynikova et al., 2012) According to the conducted literature analysis of the history of the cultivation of safflower (*Carthamustinctorius L.*), a wide range of possibilities of using this crop for dyeing, feeding, oilseed, fodder and technical purposes has been revealed. (Oelke et al., 1992; Temirbekova, 2015) Some Egyptian and Indian scientists have mentioned the use of safflower as an oilseed with high-fat and polyunsaturated fatty acids in semi-arid regions, it is demanded by the industry because of its high oxidative stability for wider use in food, fuel and for other purposes; in Argentina, this crop is attractive as drought-resistant, capable of extracting water from a depth of 3.5-4 m, due to a developed and deeply penetrating root system (2-4 m). A powerful root system helps reduce soil erosion, improves soil structure and complements its potential for growth and development in semi-arid and arid regions for use as an alternative multipurpose crop. (Taha and Matthäus, 2018; Palomo et al., 2017; Flemmer et al., 2015;Anjani and Yadav, 2017)

Currently there is a steady trend of expanding the sowing and production of oilseed crops, including safflower in Kazakhstan to enrich and increase the productive value of fodder. (Shamrinov, 1975; Gylai, 1996) Safflower cultivation is attractive for diversification of fodder resources in the arid climate of south-eastern Kazakhstan. Research on safflower varieties on agronomic and ecophysiological characteristics is being intensified. Since the capacity of a variety depends on the soil and climatic features of the cultivation region, it is necessary to identify those that are the ones, which reveal their potential in these conditions to the fullest for each specific zone.

The purpose of research: identify safflower varieties that produce the greatest herbage yields and highly-oil seeds in the desert-steppe zone of South-East of Kazakhstan.

MATERIALS AND METHODS

The studies were conducted in the desert-steppe zone of Almaty Region (2014-2016) on takyr-like sierozem. The climate of the studied area is continental with high temperature fluctuations between day and night, summer and winter, with cold winters with little snow and hot dry summers. High temperatures (monthly average) in summer range from 23-25°C. The absolute maximum reaches 40-45°C, low temperatures vary from -13-35°C in January and the absolute minimum reaches -45°C. Spring frosts usually stop by April 25, and autumn frosts occur in early October. The amount of precipitation reaches 200 mm with 120-130 mm during the growing season. The depth of soil freezing is up to 40-45 cm with 1 m or more in severe and dry winters.

The *targets of the research* were promising varieties of safflower of domestic and foreign selection for the diversification of crop production. Milyutinsky 114 selected by the Milyutinsky state selection station (Republic of Uzbekistan) was used as a reference. Nurlan and Akmay by Krasnovodopadsky selection station (Republic of Kazakhstan) and varieties of Chinese selection Xinjiang 1 and Xinjian 4 selected in Xinjiang Autonomous Region of China were used as well.

Field studies were conducted in accordance with the generally accepted methods. (Dospekhov, 1985) The following accounting and tests were conducted: phenological observations, field germination, plant integrity, structure elements, and yield capacity. (Dospekhov, 1985; Skokbayev, 2002; Metodicheskiye ukazaniya, 1987)

The leaf surface area of safflower is determined on 10 plants in two non-adjacent repetitions of variants with measurements of the length and width of each leaf. The leaf surface area of a plant is calculated using the formula S = ABNK / 0.707, where A is the average leaf length, B is the average leaf width, N is the average number of leaves, and K is the safflower coefficient we assumed. (Nurgasenov et al., 2007)

- Photosynthetic activity (photosynthetic potential, net photosynthetic yield) is calculated by the method of A. Nichiporovich et al., (1981)
- PAR (photosynthetically active radiation) is determined by the formula of H. Tooming, B. Gulyayev (Tooming and Gulyayev, 1968; Tooming, 1977) using regional coefficients of A.A. Fedyushin (Fedyushin, 1976) and data of the integrated radiation of the Almaty meteorological station.
- Plant samples and safflower seeds were tested for the content of raw fat (by the method of fat-free residue in the Soxhlet extractor with petroleum ether).
- The depth of penetration of the root system is determined by the method of N. Stankov. (1964; 1969)

The yield was recorded by a weight method. (Skokbayev, 2002)

RESULTS

Phenological observations of the growth and development of plants in the field allow us to identify and determine the economic value of varieties. It should be noted that, with the same length of the growing season, among different varieties of safflower (*Carthamustinctorius L.*) the variety with a longer generative period and shorter vegetative period will have a higher seed capacity, and the fodder crop will have an opposite situation. Table 1

We would like to note that the duration of the sowing-to-emergence period was 8-11 days. Seedlings of varieties of local selection (Nurlan, Akmay) emerged on Day 8-9 at the same time as the reference (Milyutinsky 114), and seedlings of Chinese varieties (Xinjiang 1, Xinjiang 4) emerged 2-3 days later than domestic varieties. The budding stage of the reference occurred 69 days after the emergence of seedlings, and 79-84 days after in Xinjian 1 and Xinjian 4.

It should be noted that seeds of the reference (Milyutinsky 114) and varieties of domestic selection (Nurlan, Akmay) ripen in the anthodes on average over the studied years on Day 116-119, and seed ripening of Chinese varieties (Xinjiang 1, Xinjiang 4) delayed and occurred on Day 124-127.

The duration of the vegetative period, as well as the rate of plant development, is of great importance for their adaptation to the habitat under specific climatic conditions and, despite significant advances in agricultural science, is still a factor limiting the agricultural development of certain territories.

The duration of the vegetative period of the tested varieties of safflower ranged from 116-127 days. Reduced vegetative period of domestically selected varieties is a consequence of a more sensitive reaction to an increase in air temperature.

The adaptive capabilities of crop varieties characterize their suitability for cultivation in various soil and climatic conditions, as well as in the development of cultivation technology. Indicators of seeds adaptation in field conditions are field germination rate, plant survival and adaptation rate – these very factors determine the degree of plant adaptation to changing environmental conditions.

The studies have shown a fairly high germination rate for the studied varieties (Table 2). Germination rate of seed varieties varied between 90.8% and 92.2%. It should be noted that safflower is a better cold-resistant crop; safflower seedlings withstand short-term frosts, so they can be sown earlier than grain crops at soil temperature of 4-6 degrees, i.e. in early spring when soil water content is sufficient. Consequently, a high field germination rate was observed in Nurlan, which exceeded the reference by 1.5%.

The adaptation rate of the studied varieties of safflower was quite high and varied within 80.5-84.1%. In accordance with this, the density of standing plants for harvesting ranged between 163 and 168K plants per hectare.

The rate of the form-building process (growth and development) is characterized by increased height and mass of plants. Plant height is determined by the average daily growth and in the desert-steppe zone it depends on the soil water content.

Studies confirm the fact of the active growth of the root system of safflower in the first month of development after germination. Plants demonstrating intensive growth after germination are of great importance, since more powerful plants tolerate weather variations better and are resistant to diseases and pests. The authors (Mamot, 1959; Beylin, 1968; Pryanishnikov, 1963) found that the daily growth of plants in the first period after the emergence of seedlings depends both on the varietal characteristics and on weather conditions, mainly on temperature and moisture.

The growth rate depends on the biological characteristics of the varieties, which is reflected in Table 3.

Safflower starts growing rapidly after the emergence of the 7th leaf, the plants reach the height of 74.0-106.5 cm on the branching stage, 80.8-116.3 cm on the budding stage, 91.5-116.4 cm on the flowering stage, and remain almost at the same level of 92.8-119.7 cm on the ripening stage; further, safflower plants stop growing. According to the data in Table 3, starting from the stage of 7-8 leaves and before flowering, the average daily plant growth varies between 1.47 and 2.86 cm, depending on the variety. Xinjian 1 and Xinjian 4 have the highest daily growth rate of 2.86 cm. In the above periods, the average daily growth rate of Milyutinsky 114 was 1.70 cm and 1.72 cm for Nurlan. The highest growth rates of the stem were observed in wet years. Among the tested varieties of safflower, the tallest ones are Xinjian 1 (112.4 cm) and Xinjian 4 (119.7 cm), and domestically selected varieties reach a height of 92.8-95.3 cm.

Table 1 - Duration of interstage periods and the length of the vegetative period of safflower varieties, days (average for 2014-2016)

#	Variety	Duration of sowing-to-emergence period	Duration of periods from emergence stage to stage				Duration of vegetative period, days
			Stooling stage	budding stage	flowering stage	ripening stage	
1	Milyutinsky 114 (reference)	8	41	69	82	116	116
2	Nurlan	8	43	71	83	117	117
3	Akmay	9	44	73	86	119	119
4	Xinjiang 1	10	47	79	91	124	124
5	Xinjiang 4	11	49	84	95	127	127

Table 2 – Field germination rate of seeds and survival of plants by harvesting (average for 2014-2016)

#	Variety	Field germination rate, %	Number of seedlings, plants/m^2	Adaptation rate,%	Number of plants survived, plants/m^2	Density of crops before harvesting, K plants/ha
1	Milyutinsky 114 (reference)	90.7	18.1	82.2	16.4	164
2	Nurlan	92.2	18.4	84.1	16.8	168
3	Akmay	91.5	18.3	83.3	16.6	166
4	Xinjiang 1	91.1	18.2	80.5	16.4	164
5	Xinjiang 4	90.8	18.2	81.5	16.3	163

Table 3 – Dynamics of linear growth of different varieties of safflower by the main stages of development, cm (average for 2014-2016)

#	Variety	Development stages				
		7-8 leaves	branching	budding	flowering	ripening
1	Milyutinsky 114 (reference)	23.6	74.0	82.7	93.0	94.2
2	Nurlan	24.9	74.6	80.8	91.5	92.8
3	Akmay	24.8	72.8	83.5	94.5	95.3
4	Xinjiang 1	33.5	89.5	98.1	110.1	112.4
5	Xinjiang 4	35.7	106.5	116.3	116.4	119.7

The tested varieties of safflower in the *desert-steppe zone* of Kazakhstan mainly have206.1-226.4 leaves in the stem and its branches, of which mainly 35-39 leaves are located on the core stem – they are larger in size, and there are smaller leaves on the branches of the first and subsequent orders, there are 173.5-187.4 leaves (Table 4).

Safflower has bare, rough, fleshy, and different in shape leaves, i.e. the lower leaves are broadly lanceolate in the core stem, the upper ones are almost ovate, and the leaves have almost a wedge-shaped form on the lateral branches, mostly green in color, jagged, mostly prickly.

Generally, the first pair of leaves appears on Day 3-4 after emergence, the next ones emerge every two or three days after the previous ones. In dry years, new leaves are formed at shorter intervals than in wet ones. The leaves of the lower tier are active until the formation of the inflorescence; from the beginning of flowering, the leaves of the upper quarter of the stem become functionally active.

A study of the safflower plant foliage due to various varietal characteristics showed that the total number of leaves per plant of safflower varieties ranged between 206.1 and 226, *of which 35-39 were leaves of the core stem. The maximum number of leaves falls on the varieties of Chinese selection, which is 223.3-226.4 leaves per plant.* A similar pattern can be observed in the number of large and small leaves.

As a result of the research, it was found out that the varietal characteristics of safflower plants affected not only the number of leaves, but also the leaf surface area. If Milyutinsky 114 (reference) has an average leaf area of 15.9 cm^2, then the other tested varieties have the average leave area of 1-3.8 cm^2 more. We first determined the area of safflower leaves in the field using the correction factor, invented and patented by the authors. According to this document, the correction factor for safflower leaves is 0.707. Therefore, in our work, the leaf area of one plant was recalculated taking into account the correction factor.

According to our calculations, the leaf area of one plant, depending on the varietal characteristics of safflower, ranges between 2,316.8 $cm^2$and 3,153.3 cm^2.

The leaf area per plant of the reference averaged 2,316.8 cm^2 over three years; 2,*518.0 cm^2forNurlan; 2,968.0 cm^2 and 3,153.3 cm^2 for Xinjiang 1 and Xinjian 4,respectively, which is 651.2 and 836.5 cm^2, or 28.1 and 36.1% more compared to Milyutinsky 114.*

The light energy absorption rate of the plants largely depends on the rate of growth and the parameters of the leaf surface of the crop. As the leaf area increases, the amount of absorbed radiation usually increases. In our experiments, it was found that, regardless of the varietal signs of safflower, as the phenological stages of development occurred, the leaf surface area per plant and on the whole per hectare constantly increases. *The growth rate of the leaf surface continues to the flowering stage; on this stage, the maximum leaf area per plant and per hectare was recorded, and a decrease in the area of safflower leaves is observed on the seed ripening stage* (Table 5).

On the flowering stage, safflower varieties formed 38.1-51.3 Km^2 of leaf apparatus area per hectare of sowing. The maximum leaf surface area was recorded in Xinjian 1 and Xinjian 4 – 47.8 and 51.3 K m^2/ha, respectively. The Chinese varieties differed from other tested varieties by their highly foliar plants.

As a space factor by its nature, photosynthetically active radiation (PAR) depends on the geographical conditions of the area, agro technical methods of cultivation and the varietal characteristics of crops. The upper limit of the yield capacity of any agricultural crop is determined by the amount of PAR in the course of vegetation of plants with potential rates of its use for photosynthesis and yield formation. (Mozhayev and Serekpayev, 2008; Arinov et al., 2016) Based on the assumption that the upper yield limit is determined by Q_{par}andC_{par}, we calculated PAR by years of research and, on average, for the vegetative period of safflower varieties.

Based on the data in Table 6, it can be seen that when sowing safflower within the reasonable time for sowing (6-8^{0}C), the solar energy rate was different in different months of research.

Table 4 – The number of leaves and morphological parameters of the leaf apparatus in different varieties of safflower (average for 2014-2016)

#	Variety	Number of leaves on the same plant	Number of leaves on the core stem, of which		Average size of a lamina, cm		Leaf area, cm^2	Correction factor	Leaf area of the same plant, cm^2
			large leaves	small leaves	length	width			
1	Milyutinsky 114 (reference)	206.1	35	171.1	6.1	2.6	15.9	0.707	2,316.8
2	Nurlan	209.5	36	173.5	6.3	2.7	17.0	0.707	2,518.0
3	Akmay	211.6	36	175.6	6.4	2.7	17.3	0.707	2,588.1
4	Xinjiang 1	223.3	38	185.3	6.7	2.8	18.8	0.707	2,968.0
5	Xinjiang 4	226.4	39	187.4	6.8	2.9	19.7	0.707	3,153.3

Table 5 – Dynamics of changes in the leaf area per plant and per hectare of different varieties of safflower depending on the vegetative stage (average for 2014-2016)

#	Variety	Leaf area by vegetation stages					
		per plant, cm^2			per hectare, K m^2		
		budding	flowering	ripening	budding	flowering	ripening
1	Milyutinsky 114 (reference)	980.5	2,316.8	1,916.0	16.1	38.1	31.4
2	Nurlan	1,060.6	2,518.0	2,157.9	17.8	42.3	36.2
3	Akmay	1,023.2	2,588.1	2,124.8	17.0	43.0	35.3
4	Xinjiang 1	1,314.1	2,968.0	2,332.8	21.2	47.8	37.6
5	Xinjiang 4	1,542.7	3,153.3	2,633.0	25.1	51.3	42.9

Table 6 ; PAR by months for safflower crops during the vegetative period (average for 2014-2016)

Energy resources	PAR for April-September, MJ/m^2	Month					∑ PAR for Vegetative period, MJ/m^2
		April	May	June	July	August	
High	1,988	130	310	363	382	356	1,541
Medium	1,847	83	248	349	360	319	1,359
Low	1,712	63	190	340	351	268	1,212

Table 7; Photosynthetic potential of different varieties of safflower, M m^2/day (2014-2016)

#	Variety	Year			Mean
		2014	2015	2016	
1	**Milyutinsky 114 (reference)**	3.600	6.144	4.692	4.812
2	**Nurlan**	4.320	5.670	4.720	4.903
3	**Akmay**	5.099	4.315	5.472	4.962
4	**Xinjiang 1**	6.318	6.723	6.504	6.515
5	**Xinjiang 4**	6.006	7.460	6.168	6.544

According to the average annual data of the Almaty Weather Station, the radiant energy for the warm season of the year (April-September) to this surface is about 1,847 MJ/m^2. We also found that with such values of energy resources, PAR to safflower agrophytocenosis during the sowing-to-ripening period was 1,359 MJ/m^2. The quantitative changes in solar radiation values over the years of research are significant – 1,712-1,988 MJ/m^2 and, depending on this, the energy resources of the safflower to oilseeds over the years were accordingly subject to some fluctuations – 1,212-1,541 MJ/m^2.

In general, such photosynthetically active radiation (PAR) to safflower seedlings is not a limiting factor in the formation of highly productive agrocenoses on the water-provided soil.

Photosynthetically active radiation (PAR) is the most important energy source for the productive process of photosynthesis, during which up to 90-95% of the dry biological yield is produced. As previously noted, the upper limit of yield capacity is determined by the amount of PAR (1,359 MJ/m^2 average annual value), we calculated the potential yields of safflower.

In the calculations, we used mainly the average value of calorific value formed by 1 kg of absolutely dry solids of safflower, equal to 17,600 kJ/kg and PAR utilization factors (2.0–3.0%) typical for the conditions of the southeast of Kazakhstan. The solar radiation utilization coefficient is the most objective and accurate criterion for safflower evaluation.

Hence, the yield of dry biological mass at 2.0% of PAR utilization will be equal to:

Y=Q par X Cpar/C x100

Y –yield of absolutely dry biomass;

Qpar –PAR for the vegetation period, kJ/ha;

C par –PAR utilization coefficient (efficiency factor);

C –calorific value of dry solids kJ/kg of dry biomass;

Y= (1,359 MJ/m^2 •2/ 17,600 KJ/kg)• 100% =

154,400/ha

With known values of the absolutely dry yield and the ratio of safflower seeds to by-products, we can determine the potential yield of safflower oilseeds with standard seed moisture of 8%. According to the results of many years of our research, it has been found experimentally that the ratio of seeds to leafy mass of safflower at 2.0% PAR utilization is 49.3%.

Consequently, with the average annual values of PAR within the studied surface of about 1,359 mJ/m^2, one can get a yield of safflower oilseeds about 76,300 kg/ha. High yields of seeds at 2% PAR can be produced only with areasonable combination of heat, water, air and feed regimes, which at a certain level will not limit the yield capacity of crops.

Photosynthetic potential of safflower varieties. In addition to the leaf surface area, photosynthetic potential (PP) of crops influences the formation of high yields. The photosynthetic potential is the product of the leaf area and the time of leaf work (in days) and is calculated by the formula:

PP = L xT,

where: L is a leaf area, K m^2/ha

Tis the duration of a specific period (days)

The performance of the photosynthesis function can be determined by calculating its potential and net product.

The photosynthetic potential (PP) of safflower is closely related to the active leaf area (Table 7).

The Table above shows that the photosynthetic potential of safflower varieties is different and varies depending on the conditions of the year, as well as on the area of individual plants. In general, the average photosynthetic potential over the years of research ranged between 4.8M m^2/day and 6.5M m^2/day. The highest PP was observed in Chinese varieties (6.515-6.544M m^2/day), while the domestic varieties have PP of -4.903-4.962M m^2/day, which is 0.1Mm^2/day more than that of the reference.

The net photosynthetic yield (NPY) of different varieties of safflower. In order to assess the structure of crops and the PP operating conditions, it is necessary to consider the photosynthetic yield or the net photosynthetic yield (NPY), which characterizes the amount of absolutely dry solids (less the consumption for respiration) synthesized by 1 m^2 of leaf surface per day. (Mozhayev and Serekpayev, 2008)

This indicator is calculated by the formula:

$NPY = (B_2-B_1)/(L_1+L_2):2 \cdot T$

Where NPYis net photosynthetic yield for the period, g/m^2;

$B_1$is yield mass at the previous determination, g/m^2;

$B_2$is yield mass at the previous determination, g/m^2;

$L_1L_2$is leaf area in the same period, m^2;

T is duration of a specific period (days)

One of the important biological effective indicators of the plant ontogenesis process is the net photosynthetic yield (NPY). The production value of this feature is enormous, because carbohydrate produced by the plant has a direct impact on the yield capacity of the vegetative mass and seed yield. NPY varies depending on the leaf area and photosynthetic intensity.

In our experiment, the net photosynthetic yield (NPY) is determined by the changes in the mass of the leaves of one plant per day, this indicator is expressed in grams (Table 8).

The net photosynthetic yield on crops varies depending on the total amount of plant leaf assimilation area. We note that this parameter is subject to change depending on soil and climatic conditions and environmental factors.

The net photosynthetic yield of safflower varieties mainly begins with a stage of 3-4 leaves and increases gradually until the seeds ripen. The highest rate was observed in the budding-to-flowering period. If the varieties of safflower in the initial phase had NPY within 1.93-3.18 g/day, and increased to5.49-6.87 g/day for the period of 3-4 leaves and branching, at the end of the vegetation, NPY increased 3-4 times and reached 15.82–20.76 g/day; during the flowering-to-ripening period, a gradual decline in the photosynthetic yield was observed. Safflower varieties showed different photosynthetic yield. The highest rate of NPY was recorded in Xinjian 4; all other varieties of safflower also had good photosynthetic yield compared to the reference.

Thus, the crops that produce a relatively small leaf surface area, contributing to improved drought resistance due to the presence of an active photosynthetic apparatus, ensuring a net photosynthetic yield (NPY) of up to 11.7-12.6 g/m^2 per day, are capable of producing high yields.

Drought resistance of safflower varieties. The response to this abiotic factor is expressed in the following: growth stops, the supply of nutrients is consumed, the development rate changes, yield capacity decreases, causing the death of weak plants.

When overcoming drought*, the root system feature of safflower varieties* plays an exceptional role, because the temperature increases in the atmosphere and then in the soil. The authors noted above that the safflower root system penetrated to a depth of two meters. (Baytulin, 1976; Norov 2005)

Z. Shamsutdinov (Shamsutdinov, 1962), noting the importance of the root system in drought conditions, wrote that by reducing the water consumption from the surface of the leaves, plants in arid areas provide access to large reserves of water in the soil through the development of deeply penetrating roots. The length of the safflower taproot usually exceeds the height of the stem. In the conditions of Almaty Region, it reaches 1.6 m, some lateral roots reach a depth of 50-60 cm. The later new lateral roots emerge, the more vertically they go into the soil. However, the depth of root penetration does not depend on the time of their emergence, but on the microenvironment of the surrounding soil, where a single root is found.

Safflower roots develop intensively in comparison with the vegetative surface mass, especially in the initial period of growth. So, by the time of the formation of 3-4 leaves, when the plants are as tall as 12-14 cm, the main root has time to penetrate into the soil to a depth of 20-25 cm and give 10-12 lateral roots. Root grows intensively for the budding-to-flowering period, when plants consume the maximum amount of water and nutrient elements from the soil. The study of taproot and lateral branching showed that the root system of safflower and the power of its development depended both on the biological characteristics of the varieties and on the nature of the soil composition.

In developing the drought resistance method for safflower varieties, we applied a biological method, using the adaptive capabilities of plants. When cultivating crops, water consumption of plants is an important indicator. The studied varieties of safflower were compared to each other by the transpiration rate and the content of free and bound water in the leaves of plants.

The transpiration rate is the amount of water needed to produce a unit of dry solid. In many plants, the transpiration rate ranges within 200-500. In addition to the varietal characteristics of the crop, the transpiration rate is influenced by mineral nutrition, moisture, light, and other factors.

With a lack of moisture, drought-resistant plants reduce the transpiration rate by regulating the water regime. This rate is measured by the amount of evaporated moisture for 1 hour from 1 m^2 of area.

The transpiration rate is influenced by solar radiation, air temperature and humidity.

The transpiration rate can be used to determine the capacities of the tested varieties of safflower regarding to drought resistance. In determining the drought resistance of safflower varieties, we took into account the transpiration rate (Table 9). In the aggregate of botanical signs, safflower is a pronounced xerophyte. In relation to moisture, safflower is a plant requiring a minimum amount of water.

The transpiration rate in different varieties of safflower shows dependence on varietal characteristics and varies between 101.2 and 252.6 g/m^2; Milyutinsky 114 and Nurlan demonstrate a rather low transpiration rate, while the Chinese Xinjian 1 and Xinjian 4 demonstrate high rate of 236.8-252.6 g/m^2. According to the data presented, drought-resistant varieties are: Milyutinsky 114 (101.2 g/m^2) and Nurlan (133.3 g/m^2). The results confirm the conclusions of researchers. (Pryanishnikov and Salyukov, 1964), who asserted that safflower, could consume water economically, e.g. 1 g of wet mass of safflower evaporates 0.6-1 g of water per hour; for comparison, sunflower evaporates 1.5-2.5 g, barley – 2-2.5 g

One of the main issues of drought resistance and water regime of plants is the state of water in plants. There is free and bound water. Free water is found mainly in vacuoles, and bound water is found in organelles, membranes, and cytoplasm matrix.

The water-holding capacity of plant organs characterizes its relation to atmospheric and soil drought. The determination of water content in the leaves makes it possible to find out the ecological and physiological characteristics of plants and their adaptability to the environment.

Free water preserves all properties of pure water, such as mobility, freezing at 0°C, solubility, etc. and bound water loses these properties.

In the colloidal and osmotic relations, the mobility of a water molecule decreases, but its other properties change in a positive direction.

High concentrations of cell fluid also confirm its resistance to adverse conditions, as evidenced by the data obtained in the determination of total, free and bound water in the safflower plants (Table 10).

The results of the analysis show that the leaves of different varieties of safflower contained 85.2 to 91.3% of total water.

The leaves contain 17.3-26.5% of free water, considering that free water, unlike bound water, evaporates quickly from plant cells under extreme conditions (high temperature, drought), plants use bound water more actively.

Table 8 – Net photosynthetic yield of different varieties of safflower by the main periods of development, g/m^2, days (2014-2016)

#	Variety	Development period			
		Seedlings – 3-4 leaves	3-4 leaves – branching	branching – budding	budding–flowering
1	Milyutinsky 114 (reference)	1.93	5.49	15.38	15.82
2	Nurlan	2.06	5.53	16.66	17.27
3	Akmay	3.18	5.93	19.14	20.53
4	Xinjiang 1	2.96	6.82	19.21	20.66
5	Xinjiang 4	3.11	6.87	19.52	20.76

Table 9 –Transpiration rate of different varieties of safflower on the flowering stage, g/m^2 (average for 2014-2016)

#	Variety	Transpiration rate by leaf apparatus
1	Milyutinsky 114 (reference)	101.2
2	Nurlan	133.3
3	Akmay	159.5
4	Xinjiang 1	236.8
5	Xinjiang 4	252.6

Table 10 – The content of free and bound water in the leaves of different varieties of safflower,% (average for 2014-2016)

#	Variety	Total water	Free water	Bound water	Share in total water, %	
					free	bound
1	Milyutinsky 114 (reference)	90.1	22.2	67.9	24.6	75.4
2	Nurlan	89.3	17.3	72.0	19.4	80.6
3	Akmay	91.3	17.9	73.4	19.6	80.4
4	Xinjiang 1	89.0	21.0	68.0	24.4	75.6
5	Xinjiang 4	85.2	26.5	58.7	31.1	68.9

Table 11 – Indicators of the elements of the safflower oilseed yield structure for 2014-2016

#	Variety	Number of anthodes, anthodes/plant		Number of seeds in ananthode, seeds		Number of seeds, seeds/plant		Mass of 1,000 seeds, g		Seed mass, g/plant	
		mean	compared to reference, +/-	mean	compared to reference, +/-	mean	compared to reference, +/-	mean	compared to reference, +/-	mean	compared to reference, +/-
1	Milyutinsky 114 (reference)	10.6	-	26.8	-	285.6	-	36.2	-	10.88	-
2	Nurlan	11.3	0.7	29.2	2.4	331.3	45.7	38.5	2.3	12.79	1.91
3	Akmay	11.1	0.5	28.4	1.6	315.3	29.7	37.8	1.6	11.87	0.99
4	Xinjiang 1	10.9	0.3	24.6	-2.2	268.0	-17.6	33.7	-2.5	9.05	-1.83
5	Xinjiang 4	10.7	0.1	25.7	-1.1	274.6	-11.0	34.6	-1.6	9.51	-1.37

The content of bound water by varieties ranged within 58.7-73.4%. The highest content of bound water was recorded for the varieties of Kazakhstan selection (Nurlan - 72%, Akmay - 73.4%). In terms of bound water, they are recognized as more drought-resistant varieties. In Xinjian 1 and Xinjian 4, the content of bound water was 13.3-14.7% lower than that in Nurlan and Akmay, which determines their lower drought resistance.

One of the indicators of oilseed capacity is oilseed yield and its structure (Table 11). Selection of high-yield varieties for specific soil and climatic conditions, adapted in this area determines the potential yield capacity of safflower.

The tested varieties of safflower formed approximately the same number of anthodes on a plant: from 10.6 to 11.3. The varieties of local selection had an average of 11.3 anthodes, which is 0.7 more than that of the reference Milyutinsky 114. The number of seeds in an anthode by varieties also varied from 24.6 to 29.2.Nurlan had the maximum number of seeds in an anthode– 29.2, and Xinjiang 1 had the minimum (24.6 seeds). The number of seeds in an anthode depends on climatic conditions; therefore, in wet years, this number was higher on average by 15-20% of the average level. The number of seeds from one plant by the tested varieties ranged between 268.0 and 313.3. The maximum number of seeds per plant was in the varieties of Kazakhstan selection (331.3-315.3), and the minimum was in the varieties of Chinese selection. The difference can be explained by greater adaptability to the conditions of cultivation of varieties of Kazakhstan selection. One of the indicators determining the quality of the seeds is the mass of 1,000 seeds, which depends on the varietal characteristics and the soil and climatic conditions of the area, as well as on the cultivation technology. Large seeds were formed in the anthode of Nurlan, where the weight of 1,000 seeds reached 38.5 g, which is 2.3 grams heavier than that of the reference. Smaller seeds were formed in Xinjian 1 and Xinjian 4 with a mass of 33.7 g and 34.6 g, respectively. The mass of seeds from one plant, depending on the varietal characteristics of safflower, were different. On average, over the years of research, this indicator varied between 9.05 and 12.75 g. Nurlan had the larger seed yield of a single plant (12.79 g), and Xinjiang 1 and Xinjiang 4 had the lower seed yield (9.05 and 9.51 g, respectively).

The main elements of the yield structure determine the yield ofherbage and oilseeds of safflower varieties (Table 12). Tested varieties show a different picture in terms of yield. Xinjian 1 and Xinjian have high yield capacity. For the years studied, the average yield of herbage was 18.4 and 19.2 t/ha, or 2.5 and 3.3 t/ha more than the reference Milyutinsky 114, and significantly exceeded the yield capacity of varieties of Kazakhstan selection by 2.2-3.0 t/ha. We note that these varieties of Chinese selection (Xinjian 1 and Xinjiang 4) in these climatic conditions are the most productive in terms of fodder.

It should be noted that the yield capacity of oilseeds of the studied varieties of safflower was quite high – 1.46-2.15 t/ha; consistently high rates were observed in Nurlan (215 kg/ha), Akmay (197 kg/ha).

The main criterion for assessing oilseeds is the fat content. According to laboratory tests (Table 13), the fat content in safflower seeds varies depending on the variety.

According to the test results, it was found that the tested varieties had a seed oil content of 33.3-36.8%. The varieties of Kazakhstan selection Nurlan (36.8%) and Akmay (36.5%) had the highest oil content among the studied varieties. Oil content of the abovementioned varieties exceeded that one of the reference variety by 1.5-1.2%. It should be noted that local varieties are more adaptive and had approximately the same oil content over the years (35-36%).

The lowest fat content was found in the seeds of Xinjian 1 and Xinjian 4 – 33.3 and 34.9%, respectively. Studies indicate the effect of abiotic factors on the oil content of safflower seeds, e.g. in wet years with a moderate average daily air temperature, the oil content increases, and in a dry hot year it decreases.

Table 12 – Yield of herbage and oilseeds of different varieties of safflower, t/ha

#	Variety	Herbage yield		Oilseed yield	
		mean	compared to reference, +/ -	mean	compared to reference, +/ -
1	Milyutinsky 114 (reference)	15.9	-	1.78	-
2	Nurlan	16.2	0.3	2.15	0.37
3	Akmay	16.9	1.0	1.97	0.19

4	Xinjiang 1	18.4	2.5	1.46	-0.32
5	Xinjiang 4	19.2	3.3	1.55	-0.23

Table 13 – Oil content of seeds of different varieties of safflower (2014-2016)

#	Variety	Mass of dried seeds, g	Yield of pressed fat, g	Oil content of seeds, %	Oil collection, kg/ha
1	Milyutinsky 114 (reference)	1.16	0.41	35.3	628
2	Nurlan	1.06	0.39	36.8	791
3	Akmay	1.15	0.42	36.5	719
4	Xinjiang 1	1.20	0.41	33.3	486
5	Xinjiang 4	1.23	0.43	34.9	541

Discussion

The tested varieties of safflower, due to the combination of biological, ecological and agronomical properties, have significant oil and fodder potential for diversification of plant growing in the desert-steppe zone.

Safflower has valuable characteristics that enable this species to be an alternative crop adapted to arid areas with a precipitation level of 120–200 mm/year or more, which allows optimizing the occupation of low-yielding land by agricultural crops. As a xerophytic plant, safflower demonstrates high water-holding capacity and has a high concentration of cell fluid. The leaves of the varieties contain from 58.7 to 73.4% of bound water, which is a characteristic sign of drought resistance, which is important for arid regions.

The varieties of domestic safflower (Nurlan, Akmay) and foreign selection Milyutinsky 114 (Republic of Uzbekistan), Xinjiang 1 and Xinjian 4 (China) showed differences in seed and fodder yield capacity depending on the duration of the generative and vegetative periods.

Field germination of safflower seeds ranged between 90.8 and 92.2%, a high field germination rate was observed in Nurlan= 92.2%, 1.5% higher than that of the reference. The adaptation coefficient of the tested varieties was 80.5-84.1%, and the standing density of plants in the studied varieties with wide-row sowing was 161–168K plants/ha.

The biological characteristics of individual varieties under the tested conditions showed different plant growth rates. Thus, the reference and the varieties of the Krasnovodopadsky selection (Akmay, Nurlan) had the average daily growth of 1.70 cm and 1.72 cm, respectively. At the same time, Xinjian 1 and Xinjian 4 had the highest average daily growth and reached 2.86 cm. Active growth was demonstrated by Xinjian 1 (112.4 cm), Xinjian 4 (119.7 cm), while local selection varieties reached a height of 92.8 – 95.3 cm.

We note that leaf formation is completed by the time an anthode emerges. The foliage of safflower plants in different varieties amounted from 206.1 leaves to 226.4 leaves per plant, of which 35-39 leaves were on the core stem. The maximum number of leaves was found in varieties of Chinese selection – 223.3 - 226.4 leaves. Varietal characteristics influenced the area of the leaf blade. Milyutinsky 114 (reference) had the average area of one leaf equal to 15.9 cm^2, while in other tested varieties this indicator was 1.1-3.8 cm^2 higher. The method for determining the area of safflower leaves in the field has been developed and patented by the authors. According to this document, the correction factor for safflower leaves is 0.707. The leaf area of the studied varieties was recalculated with this correction factor. The leaf area of a single plant varied from 2,316.8 cm^2 to 3,153.3 cm^2, depending on the varietal characteristics of safflower. The leaf area per plant of varieties of the Chinese selection Xinjian 1 and Xinjian 4 exceeded the reference by 28.1 and 36.1%, respectively.

Taking into account the yield capacity of crops, determined by PAR (photosynthetically active radiation) amount, accumulation of energy resources, dry biological yield, oilseed yield capacity, plant foliage, according to research results, it is possible to recommend cultivation of Xinjiang 1 and Xinjian 4 in the *desert-steppe zone* for fodder purposes, and Akmay, Nurlan– for oilseeds. A comparative study of safflower varieties shows a high yield of herbage on the budding stage (15.9-19.2 tons per hectare), which indicates the feasibility of growing crops for fodder production in the desert-steppe zone.

CONCLUSION

Global climate change towards aridization and desertification of land requires searching for new *varieties of drought-resistant fodder crops and oilseeds. Safflower can be attributed to the range of water-saving crops.* The results obtained so far indicate *that safflower is a promising and multipurpose crop for the production of oilseeds and herbage for fodder*. Safflower demonstrates water-holding capacities and shows high levels of cell fluid concentration. The leaves of the varieties of safflower contain 85.2 to 91.3% of total water. The transpiration rates in different varieties of safflower show dependence on varietal characteristics and vary between 101.2 and 252.6 g/m^2, while Milyutinsky 114 and Nurlan show drought resistance, demonstrating low transpiration rates (101.2 g/m^2 and 133.3 g/m^2).The test varieties showed seed oil content in the range of 33.3-36.8%. The varieties of Kazakhstan selection Nurlan (36.8%) and Akmay (36.5%) have the highest oil content among the studied varieties. The oil content of the abovementioned varieties exceeds that one of the reference by 1.5-1.2%, which is a stable sign that has been approximately at the same level (35-36%) over the years of testing. As for the herbage yield, Xinjian 1 and Xinjian 4 are highly productive. On average, over the years studied, the herbage yield was 18.4 and 19.2 t/ha, or 2.5 and 3.3 t/ha more than that of the reference Milyutinsky 114, and significantly exceeded the yield capacity of varieties of Kazakhstan selection – by 2.2-3.0 t/ha. We note that these varieties of Chinese selection (Xinjian 1 and Xinjiang 4) in these climatic conditions are the most productive in terms of fodder.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

All authors contributed equally in all parts of this study. All authors read and approved the final version.

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