**Carthamus tinctorius** L. development and productivity under the influence of ecological and climatic factors

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**Abstract.** The authors consider *Carthamus tinctorius* L. development and productivity under the influence of geographical zone conditions defining that plant vigor and reproductive sphere development are greatly influenced by climatic and ecological conditions starting from the virgin stage. A reduction in the duration of plant vegetation period in the conditions of Voronezh Oblast as an adaptation mechanism of the species was established. At the same time, the seed productivity of safflower did not depend much on geographical conditions. The authors present the results of studying the morphogenetic characteristics of species and starting date of each phenophase. The data obtained show the presence of high adaptive potential of the crop under study and the possibility of its cultivation in the conditions of the Central Chernozem Region.

**1. Introduction**

The search for alternative sources of plant raw materials for the production of food, medicines and biologically active substances significantly increases the interest in plants introduced in different geographical latitudes, but cultivated in local territories and not making a significant contribution to certain branches of agro-industrial production, food and pharmaceutical industry. It can be considered that an increase of the resource base of any region due to the introduction of species rich in chemical composition and valuable in terms of practical application is an urgent task today [1].

In this respect, safflower is of particular interest. Safflower has the scientific name *Carthamus tinctorius* L. It is an annual plant that reaches a height of one to four feet. The plant is native to the Mediterranean region, Africa, and Asia but can be grown in many other parts of the world today. It is a member of the aster family, or the Asteraeae (also known as the Compositae), the same family to which sunflowers and daisies belong. Members of the family have composite flower heads, or ones containing multiple flowers.

Safflower is cultivated for the edible oil obtained from the seed. It contains a higher percentage of essential unsaturated fatty acids and a lower percentage of saturated fatty acids than other edible vegetable seed oils. The oil, light colored and easily clarified, is used in salad and cooking oils, margarines, liqueurs, candles, and as a drying oil in paints, linoleum, varnishes, and wax cloths.
Tender shoots are eaten as a salad and potherb. Seeds, both edible and nutritious, are eaten roasted or fried and used in chutney. Safflower oil lowers blood cholesterol levels and is used to treat heart diseases. In the past, a dye was obtained from dry safflower petals to color clothing, food, medicines, and cosmetics. Today safflower is used by people who like to color fibers for clothing and crafts with natural dyes. The flowers contain a yellow dye. Orange or red flowers contain a red dye as well as a yellow one. The red dye is called catharmin today. As a food additive, it is known as natural red 26 [2-4].

Safflower is native to arid environments having seasonal rain. Traditionally the crop was cultivated in arid regions, but its cultivation in the Volga territory and other regions of Russia [5-6] shows the possibility of full use of this crop for agricultural production in temperate latitudes.

In 2018, global production of safflower seeds was 627,653 t, led by Kazakhstan with 34% of the world total. Other significant producers were the United States and India, with 26% of world production combined.

The objective of the presented research was conducting a comparative analysis of the features of development and productivity of *Carthamus tinctorius* when grown in different ecological and climatic conditions.

2. Materials and methods

Experimental part of the study was performed during the 2018-2020 vegetation seasons in field trials on the territory of Botanical Garden of Voronezh State Agrarian University (Voronezh, Russia), the Kunar peasant farm (Jambyl Oblast, Jualy District, Karasu village, Republic of Kazakhstan) and the D. Kholmatov Dehkan farm (Sughd Oblast, Gafurov District, Republic of Tajikistan). The distance between geographical points was as follows: 3,222 km between Voronezh and Khujant, 3,101 km between Voronezh and Taraz, 466 km between Khujant and Taraz.

Voronezh Oblast is located in the central belt of the European part of Russia. The area of the region is 52.4 thousand km$^2$. The climate in the region is temperate continental, with an average January temperature of $-9.5\, ^\circ\text{C}$, and with an average July temperature of $+20.6\, ^\circ\text{C}$. Average annual temperature varies from $+5\, ^\circ\text{C}$ in the north to $+6.5\, ^\circ\text{C}$ in the south. Precipitation varies from 550 millimeters in the northwest to 450 millimeters in the southeast. Much of the area is steppe, among the predominant soil are fertile chernozems (about 80%).

Sughd Oblast is located in the extreme north-west of the Republic of Tajikistan, with an area of 24.4 thousand km$^2$. The territory of the region located in the north-eastern part of the Ferghana Valley is considered an intermountain basin (700-1000 m above sea level) surrounded by mountain ranges with a height of 5000-6000 m. The climate is severely continental, subtropical, dry and depends on the changes in altitude above sea level. The air temperature is characterized by significant daily and seasonal fluctuations. An average January temperatures are $-2\, -5\, ^\circ\text{C}$, an average July temperatures are $+28\, +32\, ^\circ\text{C}$. Annual precipitation varies from 130 to 220 millimeters. The main type of soil on the plateau is gray soil, on the foothills and mountain ranges there are mountain brown soils.

Jambyl Oblast is located in the center of South Kazakhstan, with an area of 145.2 thousand km$^2$. The climate is arid and severely continental, an average July temperature is $+25.4\, ^\circ\text{C}$, an average January temperature is $-3.1\, ^\circ\text{C}$. Annual precipitation varies from 330 to 370 millimeters. The main type of soil are steppe and desert soils, i.e. chernozem soil, chestnut, brown and gray-brown.

The experiments involved the *Carthamus tinctorius* plants of the Irkas variety, recognized for south regions of Kazakhstan. The authors consider it expedient to use one variety in all geographical locations of the study (including the Central Chernozem Region of Russia) to obtain representative data, since they carried out a comparative analysis of the ontogenetic development, seed productivity and vegetation features of safflower. The study of ecological and biological features of potential introducers, seasonal rhythm of development, seed productivity and seed germination requires the use of various approaches and methods. Presented research was based on traditional methods of population biology [7]. Experiments, relevant records and observations were carried out according to standard Methodological Instructive Regulations.
3. Results

In all mentioned above geographical areas, the features of *Carthamus tinctorius* development were studied and the crop ontomorphogenesis was described. *Carthamus tinctorius* is a monocarpic, highly branched, herbaceous, thistle-like annual plant, branching above with a strong central stem to 1.5 m tall; leaves spiny, oblong or ovate-lanceolate, waxy, the upper ones clasping, minutely spinose-toothed; flowers in 1-5 heads per plant, 2.5-3.7 cm across, each head developing 15-50 seeds; corollas yellow, orange, white or red, surrounded by a cluster of leafy spiny bracts, sturdy taproot penetrating to 2.5 m. In the ontogenesis of *Carthamus tinctorius* there were distinguished three periods, i.e. embryonic, pre-generative, generative and six age-specific states, i.e. seed (se), seedling (pl), juvenile (j), immature (im), virginile (v), generative individuals (g).

In the initial states of ontogenesis there were no significant quantitative differences in biometric parameters, size of leaves and height of plants in all geographic areas were approximately the same (Table 1). The influence of cultivation conditions on plant vigor and reproductive system development was registered upon reaching virginal age-specific state by the individuals. Maximum average height of shoots was noted in safflower grown in Tajikistan (about 70 cm); maximum average root length was noted in plants grown in Kazakhstan (up to 110-110 cm). The average height of shoots was 55-60 cm, the root length was 95-100 cm. Root length and the height of plants grown in Voronezh Oblast were 70 cm and 40-48 cm, respectively (table 1).

**Table 1. Morphometrical characteristics of *Carthamus tinctorius* L. pre-generative individuals.**

| Characteristics                        | Ontogenetic periods and age states |
|----------------------------------------|-----------------------------------|
|                                        | j       | im      | v       |
| Height of vegetative shoots (with leaves), cm | 7.55±0.16 | 14.61±0.41 | 69.30±1.94 |
| Total number of leaves on shoots        | 5.10±0.27 | 6.29±0.17 | 44.12±2.17 |
| Length of leaves, cm                    | 4.55±0.16 | 6.30±0.22 | 6.85±0.44 |
| Width of leaves, cm                     | 1.81±0.11 | 1.73±0.09 | 2.79±0.33 |
| Diameter of root, cm                    | 0.36±0.08 | 0.48±0.14 | 0.61±0.19 |
|                                        | 7.21±0.22 | 14.05±0.28 | 57.32±1.07 |
| Total number of leaves on shoots        | 4.73±0.17 | 5.62±0.26 | 39.54±2.14 |
| Length of leaves, cm                    | 4.37±0.18 | 5.87±0.18 | 6.37±0.41 |
| Width of leaves, cm                     | 1.78±0.09 | 1.70±0.21 | 2.43±0.20 |
| Diameter of root, cm                    | 0.35±0.05 | 0.47±0.17 | 0.59±0.14 |
|                                        | 7.55±0.16 | 12.35±0.31 | 43.56±1.85 |
| Total number of leaves on shoots        | 4.39±0.21 | 5.15±0.33 | 31.44±1.77 |
| Length of leaves, cm                    | 4.34±0.27 | 5.74±0.11 | 6.20±0.31 |
| Width of leaves, cm                     | 1.74±0.15 | 1.65±0.25 | 2.15±0.29 |
| Diameter of root, cm                    | 0.31±0.05 | 0.44±0.13 | 0.54±0.24 |

Our observations show that in all the regions, reproductive processes occur rather quickly, from budding stage to maturation of achene 60 days undergo on average. In addition to the formation of the generative sphere, there are no other significant morphological changes in plants, thus, only one age state in the generative period can be distinguished.

The height of stems of powerful plants from Tajikistan can reach 90-105 cm, whereas average height is about 80 cm. On the stems up to 15 baskets can develop on average, this parameter of powerful plants is higher, i.e. 20 baskets. Average height of stems of plants from Tajikistan was 90-105 cm, of powerful plants up to 17-18 baskets were developed on average, whereas average value of
this parameter was 13-14 baskets. The height of plants grown in Voronezh Oblast was up to 65 cm, they formed up to 13-15 baskets (table 2).

Table 2. Morphometrical characteristics of *Carthamus tinctorius* L. generative individuals.

| Characteristics                                      | Ontogenetic periods and age states |
|------------------------------------------------------|-----------------------------------|
| Sughd Oblast, Tajikistan                            |                                   |
| Height of axial generative shoots, cm                | 79.63±2.12                        |
| Number of lateral shoots                             | 5.77±0.56                         |
| Total number of leaves on shoots                     | 47.43±2.21                        |
| Number of inflorescence on shoots                    | 16.23±0.79                        |
| Diameter of root, cm                                 | 1.62±0.18                         |
| Jambyl Oblast, Kazakhstan                            |                                   |
| Height of axial generative shoots, cm                | 67.21±2.43                        |
| Number of lateral shoots                             | 5.13±0.43                         |
| Total number of leaves on shoots                     | 43.26±2.43                        |
| Number of inflorescence on shoots                    | 13.08±1.13                        |
| Diameter of root, cm                                 | 1.45±0.25                         |
| Voronezh Oblast, Russia                              |                                   |
| Height of axial generative shoots, cm                | 61.33±2.76                        |
| Number of lateral shoots                             | 4.72±0.38                         |
| Total number of leaves on shoots                     | 35.58±2.03                        |
| Number of inflorescence on shoots                    | 12.74±0.84                        |
| Diameter of root, cm                                 | 1.25±0.44                         |

In 2019, the rhythm of seasonal development of safflower was studied depending on the geographical growth conditions. It should be noted that significant ecological and climatic differences in the areas under study notably change the schedule of agricultural work, as well as plant observations (table 3).

Table 3. Starting dates of each phenophase of safflower.

| Phenophases                  | Sughd Oblast, Tajikistan | Jambyl Oblast, Kazakhstan | Voronezh Oblast, Russia  |
|------------------------------|--------------------------|---------------------------|-------------------------|
| Sowing                       | 25/03/2019               | 20/04/2019                | 07/05/2019              |
| Emergence of seeding         | 04/04/2019               | 30/04/2019                | 19/05/2019              |
| First true leaf presence     | 11/04/2019               | 07/05/2019                | 26/05/2019              |
| Budding stage                | 22/05/2019               | 09/06/2019                | 02/07/2019              |
| Early flowering              | 07/06/2019               | 04/07/2019                | 25/07/2019              |
| End of flowering             | 29/06/2019               | 09/08/2019                | 19/08/2019              |
| Seed maturation / Drying     | 15/08/2019               | 11/09/2019                | 09/09/2019              |
| **Vegetation period, days**  | **133**                  | **135**                   | **123**                 |

Sowing of safflower seeds was carried out on March 25, April 20, and May 7 in Sughd Oblast, in Jambyl Oblast, and in Voronezh Oblast, respectively. The ‘end of flowering’ and ‘full maturation of achenes’ were observed on June 19 and August 15 in Sughd Oblast, on August 9 and September 11 in Jambyl Oblast, on August 19 and September 9 in Voronezh Oblast. We obtained rather interesting data on the duration of the growing season: when growing in short day conditions, safflower development lasts for 133-135 days, but with an increase in day length, vegetation period grows shorter and lasts for 123 days.

In literature, there were published data [5; 7] that in Penza Oblast located to the north-east of Voronezh Oblast, the duration of the growing season of safflower was 110-118 days. Probably, this is
how the adaptive mechanism of the species manifests itself: when external conditions change, plants tend to form seeds as quickly as possible and complete the development cycle. At the same time, it serves as a proof of the plasticity of the culture and the possibility of its cultivation in different geographical and ecological conditions.

Safflower seed productivity is determined by the number of baskets on the generative shoot (which, in turn, varies depending on the height of the shoot and the number of lateral shoots of orders 1-2) and the number of achenes in the basket. In different geographical conditions, on the shoots of safflower there were from 12 to 18 baskets on average, in which 23-26 achenes were formed on average. It was found that the ratio of ovules and achenes in the inflorescences of safflower plants grown in different geographical conditions practically does not differ (Table 4). Moreover, the absolute values of these indicators for Voronezh Oblast are higher than for the regions of Central Asia, and the seed productivity coefficient is higher than for the arid Jambyl Oblast. Thousand-seed weight also turned out to be low-variable value and amounted to 3.5-4 g for all the regions of the study.

Table 4. Number of ovules and achene per one *Carthamus tinctorius* inflorescence.

|                      | Sughd Oblast, Tajikistan | Jambyl Oblast, Kazakhstan | Voronezh Oblast, Russia |
|----------------------|--------------------------|---------------------------|------------------------|
| Number of ovules     | 31.38±1.97               | 30.46±2.33                | 33.21±2.39             |
| Number of achenes    | 24.22±1.57               | 23.11±0.89                | 25.26±1.14             |
| Seed productivity coefficient, %  | 77.19                   | 75.86                     | 76.06                  |
| Thousand-seed weight, g  | 3.66±0.27               | 3.61±0.34                 | 3.53±0.18              |

We also determined the laboratory germination of achenes matured in different geographical areas. The study was conducted in the spring of 2020 with achenes obtained in the previous growing season (Table 5).

Table 5. Laboratory germination of *Carthamus tinctorius* achenes.

|                      | Sughd Oblast, Tajikistan | Jambyl Oblast, Kazakhstan | Voronezh Oblast, Russia |
|----------------------|--------------------------|---------------------------|------------------------|
| Seed vigor, %        | 78.25±1.49               | 84.75±2.33                | 77.50±2.39             |
| Germination, %       | 92.50±2.32               | 93.25±2.01                | 91.75±1.14             |

It was found that 6 months after harvesting, the achenes of safflower have high rates of seed vigor (77-84 %) and germination (91-93 %). High rates of seed vigor and germination of safflower seeds grown in Voronezh Oblast indicate that they were able to be fully developed in the climatic conditions of the Central Chernozem Region and will later germinate into full-featured plants.

4. Discussion

The ontogenesis of *Carthamus tinctorius* in all the regions under study lasts one growing season and includes three periods (embryonic, pre-generative and generative) and six age-specific states (seed, seedling, juvenile, immature, virginile, generative individuals). The morphogenesis of individuals consists of two phases: 1. Primary shoot (p, j, im, v) means the period from the beginning of germination to generative bud set. The growth is monopodial, the type of biomorph is monocentric. 2. The main axis (g) means the period from the beginning of generation to aging and death of the plant. Throughout life, the safflower retains monopodial growth and monocentric type of biomorphs, there is no disintegration.
The growing season of *Carthamus tinctorius* lasts 133-135 days in the arid regions of Central Asia and 120-125 days in the conditions of the Central Chernozem Region. It was found that changes in the ecological conditions of cultivation (a decrease in the average temperature and an increase in the length of daylight) contribute to a faster passage of ontogenetic phases. This indicates the plasticity of the culture and the possibility of its cultivation in different geographical and environmental conditions.

A comparative analysis of safflower seed productivity revealed that the value of the main indicators that form the yield (i.e. potential and real seed productivity, the coefficient of seed productivity and the weight of the formed achenes) is characterized by constancy and does not depend much on geographical conditions. This allows us to assume that the yield of *Carthamus tinctorius* grown on an industrial scale in Voronezh Oblast is comparable to the yield in the southern regions of Central Asia and Kazakhstan where the crop is growing at present time.

5. Conclusion

In recent decades, there has been a steady trend of global warming, that is an increase in the average annual temperature and a decrease in precipitation. Aridization of climate sharply raises the question of expanding the area of cultivation of drought-resistant oil-bearing crops, which give stable and rather high yields. The main raw material for the production of vegetable oil in the Russian Federation is sunflower. We believe that safflower is one of the most promising oil-bearing crops with high potential productivity and the ability to withstand extreme environmental conditions in arid climates.

Our studies indicate that *Carthamus tinctorius* undergoes through a full cycle of ontogenetic development both in a harsh continental climate with hot dry summers and cold winters, and in temperate latitudes. At the same time, seed productivity does not change much, which makes it possible to predict yields comparable to those of the crop in Central Asia.

A comparison of the characteristics of the development and seed productivity of safflower in Central Asia and the Central Chernozem Region indicates a high adaptive potential of the species and the possibility of growing this crop in order to obtain high yields of plant raw materials for further processing into high-quality oil.

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