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CORRESPONDENCE

Morphological characteristics of a rare endemic species, *Erysimum croceum* M. Pop. (Brassicaceae) from Trans-Ili Alatau, Kazakhstan

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Abstract

Erysimum croceum is a rare endemic species listed in the Red Book of Kazakhstan. In 2015–2017 we studied three populations of this species on the territory of the Ile-Alatau National Park (Trans-Ili Alatau, Northern Tian-Shan). As a result of the inventory of sampling plots, we estimated the elevation range occupied by the species and identified age structure and population density. Our results confirmed earlier reports of low population counts of *E. croceum*. We also studied biometric characteristics of virginal and generative individuals of *E. croceum* from different populations, and measured parameters of their seeds. The morphometric parameters were highly variable across the studied populations. The only exception was the morphometric parameters of the seeds, which had low or very low variability. We conclude that these parameters are the most stable characteristics of the species. The results of the study can contribute to our understanding of population structure and dynamics of *E. croceum* and assist in developing effective conservation strategies for this species.

Keywords: *Erysimum croceum*, population, age structure, virginal individuals, generative individuals, density, biometrics

Introduction

Wallflower (*Erysimum* L.) is one of the largest genera of the family Brassicaceae Burnett representing a monotype tribe Erysimeae Dumort (Al-Shehbaz 2012). Globally, the number of *Erysimum* species ranges from 200 to 350 (Polatschek & Snogerup 2002;

Al-Shehbaz 2012). Wallflowers are perennial or biennial plants distributed throughout Europe, in the Mediterranean, the Middle East and East Asia, and also in North and Central America (Polatschek & Snogerup 2002). South-East Asia and the Mediterranean region are the main centers of species diversity of the genus; recently, several new species have been described in these regions (Mozaffarian 2008; Polatschek 2008, 2010, 2011; Abdelaziz *et al.* 2011; Moazzeni *et al.* 2014).

Some species of *Erysimum* are used in the official and traditional medicine (Varlakov & Masina 1943; Maslennikova *et al.* 1961; Makarevich *et al.* 1974; Lei *et al.* 2000; Grudzinskaya *et al.* 2014).

The majority of publications on *Erysimum* addressed systematic questions (German 2005, 2014; Abdelaziz *et al.* 2011, 2014; Ouarmim *et al.* 2013; Lorite *et al.* 2015; Czarna *et al.* 2016; Moazzeni *et al.* 2016; Mahmoodi *et al.* 2017), and only a few, the phylogenetics and morphology of certain species (Mutlu 2010; Abdelaziz *et al.* 2014).

The Flora of Kazakhstan (Vasiliyeva 1961) listed 15 species of *Erysimum*, while a new taxonomic treatment by Abdulina (1999) mentioned 16 species. However, only one of them, *Erysimum croceum* M. Pop. has been listed in the Red Data Book of the Republic of Kazakhstan (Roldugin 2014) as a rare endemic species. For the first time *E. croceum* was collected and described by M.G. Popov in the gorge of the river Malaya Almatinka. The description first published by Popov (1935) was later cited in the Flora of the USSR and the Flora of Kazakhstan (Bush 1939; Vasiliyeva 1961). Among all Middle Asian representatives of the genus, *E. croceum* is the only species that has bright orange petals; hence the specific epithet "croceum". Some taxonomic treatments reduced *E. croceum* under the synonymy of *E. virgatum* (Polatschek 2010; The Plant List 2013). However, many Kazakh and Russian botanists recognize *E. croceum* as an independent species (Vasiliyeva 1961; Adylov 1974; Baitenov 1985; Czerepanov 1995; Abdulina 1999; Roldugin 2014). Following years of extensive field research, the authors of the present study agree with the latter authors.

Despite a relatively large distribution area which includes Trans-Ily Alatau, Ketmentau, Kungey and Kyrgyz Alatau the species remains poorly studied due to low population numbers and sporadic distribution. Plants occur individually or in small groups up to ten individuals in number. Only on two occasions we found populations consisting of several hundred individuals; even those groups did not exceed 500 plants in number. Population numbers widely fluctuate as a result of the biennial life cycle and preference for frequently disturbed habitats such as rocky cliffs, mudflows, and cascade pebbles. The number of *E. croceum* populations is declining due to habitat destruction and uncontrolled harvesting of flowering plants for ornamental purposes. To protect the species in the wild, all existing populations have to be examined and monitored, and conservation measures developed. This, in turn, requires detailed knowledge of morphology and biology of the species, as well as an assessment of the state of its populations. We have been studying the species since 2015; we have also collected material allowing us to study interpopulation genetic variability.

The novelty of our research lies in the discovery and subsequent study of the three new populations of *E. croceum*, one of which was found at an extremely low elevation of 1728 m a.s.l. Our results allow to estimate more precisely than before the elevational preferences of the species, which was earlier found only between 2000–2600 m a.s.l. For the first time, we collected data on the age structure, population density, morphological characteristics of vegetative and generative plants, and their variability.

Material and methods

The present study was carried out in the framework of the project 0497/GF4 "Assessment of the state of cenopopulations of some rare medicinal plants of the Trans-Ili

Fig. 1. *Erysimum croceum* inflorescence.

Alatau using botanical and molecular genetic methods" funded by the Committee on Science of the Ministry of Education and Science of the Republic of Kazakhstan.

The object of the study was *E. croceum* (Fig. 1). The most detailed description of the plant has been provided by Vasiliyeva (1961: 101). "*Plants* biennial, 9–65 cm tall. *Stems* simple or occasionally branched, straight, pubescent with bifid hairs, edges sharp. *Leaves* 2–5 (8) cm long, 0.5–1.5 (2) mm wide, lanceolate or oblong-lanceolate; margins oblong-crenate, finely toothed or almost entire; basal leaves petiolate, upper sessile, with an indumentum of stellate hairs (mixed with bifid hairs along the veins). *Flowers* on pedicels up to 6 mm long. *Sepals* 6–7.5 mm long, on the dorsum pubescent with mixed hairs. *Petals* reddish orange, yellowish when dry, 9–13.5 mm long, egg-oblong or nearly round, 8–9 mm wide. *Fruit-stalks* up to 9 mm long. *Siliques* straight, tetrahedral, 3.5–8.5 cm long, 1.25 mm wide, with bilobate beaks 2 mm long, gray with stellate hairs. *Seeds* oblong, *ca.* 2 mm long".

In the central part of the Trans-Ili Alatau on the territory of the Ile-Alatau State National Park, we found and examined three new populations of *E. croceum* (Fig. 2). The first population (further in the text referred to as Population 1) was found on the south-east and north-west facing slopes of the Small Almaty Gorge at an altitude of 2413–2597 m a.s.l., on both banks of the river Malaya Almatinka (N 43° 06.316′, E 077° 04.184′). Because the first description of *E. croceum* was made by M.G. Popov in this gorge, it is recognized as a *locus classicus* for the species. The second population (Population 2) was found on the north-facing slope of the Great Almaty Gorge at an altitude of 2236 m a.s.l., on the left bank of the river Kumbelsu (N 43° 04.790′, E 076° 59.512′). The third population (Population 3) was found on the south-west facing slope of the Issyk Gorge at an altitude of 1728 m a.s.l., on the right bank of the river Issyk (N 43° 15.731′, E 077° 29.522′).

Fig. 2. The map of the study area with the locations of the three studied populations of *Erysimum croceum* marked by the red circles.

Wherever possible, at the sites of the populations of *E. croceum*, we established 20 sampling plots with a size 1 × 1 m along each transect. In each sampling plot, we counted the number of individuals of the studied species of the same age group and measured biometric characteristics. When the number of *E. croceum* plants was low, we counted and measured all individuals of the species found on the site. The mean weight of 1000 seeds was obtained by averaging the results of the three measurements. All statistical analyses were carried out in Microsoft Excel 2007.

Results

The analysis of the age structure revealed that the ratio of the virginal and generative individuals varied from one population to another (Fig. 3).

Population 1 had the largest number of generative individuals, while Population 2 had the largest number of virginal individuals; in Population 3, the numbers of generative and virginal individuals were nearly the same. This could be due to the fact that *E. croceum* is a biennial plant; according to Kokoreva *et al.* (2010), the numbers of individuals of different age can fluctuate markedly between years.

It was difficult to calculate population density, because in some places we were able to establish sampling plots of a size 1 m^2, and in other places, we had to count all available individuals. The average population density across sampling plots was 7.3 ± 0.6 and 8.2 ± 1.2 individuals per m^2 in Populations 1 and 3 respectively.

In all populations, we measured morphological parameters of *E. croceum*. The biometric characteristics of the virginal and generative individuals are provided in Tab. 1

and Tab. 2. We found that the morphometric parameters of plants from different populations fluctuated considerably (Tab. 1).

In virginal individuals, the maximum height was recorded in Population 3, and the minimum – in Population 2. The number of leaves in the rosette, the length and width of the leaf were almost the same in individuals from Populations 1 and 3; the values of the same parameters were the lowest in Population 2.

In generative individuals, the maximum height was recorded in Population 2, and the minimum, in Population 3. The largest number of stem leaves was recorded in Population 3, and the smallest, in Population 2. The largest leaf size (length and width) was recorded in Population 2, while in the other two populations the average leaf size was nearly the same (Tab. 2).

When checked against the scale of variation in characteristics developed by Mamaev (1975), the level of variability of morphometric parameters observed in our study could be described as high or very high in both virginal and generative individuals.

In all three populations we studied morphometric characteristics of the generative organs; we calculated the number of flowers and seeds per individual, and measured the length of seed pods (Tab. 3). Unfortunately, we failed to collect seeds in Population 2.

The maximum number of flowers per individual was recorded in Population 3; this can be due to a frequently occurring branching inflorescence. The individuals from Population 2

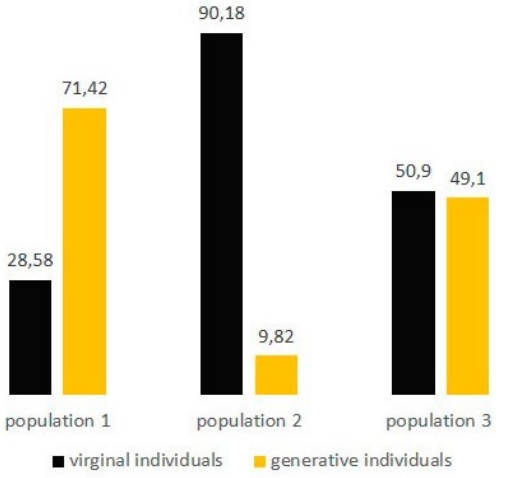

Fig. 3. The ratio of generative and virginal individuals in the three studied populations, %.

Table 1. Morphometric parameters of virginal individuals. **M** – mean value; **m** – standard error of the mean; **C_v** – coefficient of variation.

Population	Height, cm		Number of leaves		Leaf size, cm			
					Length		Width	
	M±m	C_v, %	M±m	C_v, %	M±m	C_v, %	M±m	C_v, %
1	3.6±0.4	66.6	13.6±0.9	41.8	3.0±0.1	63.7	0.6±0.02	41.6
2	1.9±0.3	143.9	6.3±0.3	52.6	1.8±0.1	104.8	0.5±0.01	51.5
3	5.8±0.4	51.7	13.9±1.2	59.9	3.0±0.1	56.1	0.6±0.01	53.7

Table 2. Morphometric parameters of generative individuals. **M** – mean value; **m** – standard error of the mean; **C_v** – coefficient of variation.

Population	Height, cm		Number of stem leaves		Leaf size, cm			
					Length		Width	
	M±m	C_v, %	M±m	C_v, %	M±m	C_v, %	M±m	C_v, %
1	45.9±1.8	26.2	22.0±1.4	42.6	3.8±0.1	28.6	0.9±0.02	32.8
2	49.8±3.6	24.02	15.3±1.0	21.5	6.2±0.2	19.2	1.4±0.05	25.9
3	36.5±2.6	46.1	22.8±1.8	49.8	4.3±0.1	44.5	0.8±0.02	51.0

Table 3. Morphometric characteristics of reproductive organs. **M** – mean value; **m** – standard error of the mean; $\mathbf{C_v}$ – coefficient of variation.

Population	Number of				Length of a seed pod, cm	
	flowers per individual		seeds per individual			
	M ± m	C_v, %	M ± m	C_v, %	M ± m	C_v, %
1	13.8 ± 1.1	51.6	610.8 ± 97.3	90.1	7.5 ± 0.1	11.4
2	11.5 ± 1.5	43.9	na	na	na	na
3	37.4 ± 7.1	119.3	664.7 ± 83.0	48.4	6.2 ± 0.2	22.8

Table 4. Morphometric parameters of seeds from Population 1 and 3. **M** – mean value; **m** – standard error of the mean; $\mathbf{C_v}$ – coefficient of variation.

Population	Size, mm				Weight of 1000 seeds, g	
	Length		Width			
	M ± m	C_v, %	M ± m	C_v, %	M ± m	C_v, %
1	1.96 ± 0.02	8.0	0.96 ± 0.01	8.4	0.58 ± 0.01	1.0
3	1.95 ± 0.02	5.1	0.86 ± 0.02	11.1	0.59 ± 0.01	4.9

had the fewest flowers. The maximum seed pod length was recorded in Population 1. The level of variability in the number of flowers and seeds was very high in both populations, and in the fruit length, medium in Population 1 and high in Population 3. The size and weight of 1000 seeds were nearly the same in Populations 1 and 3 (Tab. 4). The level of variability in the size and weight of seeds was low or very low. Consequently, these characteristics were the least labile.

Conclusions

The results of our study support the earlier evidence of a low population size in *E. croceum* (Kokoreva *et al.* 2010; Ivashchenko 2012). We were able to calculate the average population density only in Populations 1 and 3; the difference between these populations was very small. The difference between the ratios of virginal and generative plants in each studied population was very large; this can be explained by a biennial life cycle. The morphometric parameters of virginal and generative individuals were very labile and had a high or very high level of variability. The large number of flowers in Population 3 was due to a high number of the branching inflorescence; this characteristic also had a high level of variability. The length of seed pods in Population 1 was only slightly different from that in Population 3. The level of variability of this characteristic ranged from low (Population 1) to medium (Population 3). Among all studied characteristics, the seed size and weight of 1000 seeds were the least variable; *i.e.* these characteristics of *E. croceum* were the most stable.

Our study has contributed to earlier morphological descriptions of the species (Bush 1939; Vasiliyeva 1961). According to the results of our study, the stem length is 85–90 cm (against 65 cm stated by the earlier studies); the leaf length is 9–11 cm (against 5–8 cm); the leaf width is 2.1–2.5 cm (against 1.5–2.0 cm); and the length of seed pods is 1.5–9.0 cm (against 3.5–8.5 cm). We have also verified several characteristics of seeds: the seed length is 1.5–2.2 mm; the seed width is 0.7–1.1 mm; and the weight of 1000 seeds is 0.57–0.62 g.

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