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MORPHOLOGICAL AND BIOCHEMICAL VARIABILITY OF VIR GARDEN CRESS (*Lepidium sativum* L.) COLLECTION UNDER INTENSIVE LIGHT CULTURE

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Abstract

The technology of intensive light culture (city farms, vertical farms, plant factories) is actively developing which allows fresh vatable products to be available throughout the year. The search for accessions of various crops that maximize their productive potential under these conditions is of great importance for improving the quality of plant products and breeding work. Among the early ripening crops, garden cress (*Lepidium sativum* L.) is of large interest, since it is characterized by a wide variability of forms that differ in economically valuable traits, primarily yield and biochemical composition. However, the influence of growing conditions characteristic of light culture on the manifestation of traits of productivity and quality in garden cress accessions that differ in ecological-geographical origin and botanical affiliation has been practically not studied. In this work, we for the first time carried out a comprehensive assessment of the variability of economically valuable traits of garden cress under conditions of intensive light culture. The purpose of our work was to study phenological, morphological, biochemical and economic characteristics in 72 accessions of garden cress of three varieties, var. *latifolium* DC., var. *sativum* Alef. and var. *crispum* (Medik.) DC. under conditions of intense light culture, and to identify accessions with valuable traits. Morphological description (height and diameter of the rosette, shape and size of leaves) and biochemical analysis were carried out at the stage of technical ripeness. Biochemical analysis included the determination of the content of dry matter, ascorbic acid, anthocyanins, chlorophylls and carotenoids. The variability of morphological, phenological and biochemical characteristics of garden cress under intensive light culture was determined. It was noted that the greatest variability was observed in the average plant weight (Cv = 40.3 %), yield (Cv = 38.3 %) and anthocyanin content (Cv = 42.5 %), other parameters were characterized by a middle degree of variability. Late-ripening accessions are characterized by late or slow bolting, larger plant weight (mean 3.6 g) and high dry matter content (mean 9.0 %), while early-ripening forms allow for more vegetations per year and accumulate more ascorbic acid (mean 32.8±5.7 mg/100 g). On average, among the studied accessions, the late-ripening accessions of var. *latifolium* from Iran (k-91) and Azerbaijan (k-112, k-125, k-131), as well as the accession of var. *sativum* from Iran (k-92) and the accession of var. *crispum* from Denmark (k-185), turned out to be productive. Statistically significant differences were found between the accessions and varieties in terms of the content of chlorophylls and carotenoids. The greatest variability in the content of carotenes was in the accessions of var. *sativum* (Cv = 24.7 %), in the content of anthocyanins was in the accessions of var. *crispum* (Cv = 44.7 %). The accessions of var. *latifolium* were generally characterized by a high content of the total chlorophylls (124.2±14.0 mg/100 g), carotenoids (37.3±4.4 mg/100 g), carotenes (6.1±0.6 mg/100 g), and β-carotene (5.0±0.6 mg/100 g). We identified accessions of garden cress that are of the greatest interest in terms of development rate, resistance to bolting and formed yield when grown under intensive light culture, as well as potential sources of economically valuable traits for further breeding and obtaining forms of garden cress that are most adapted to conditions of intensive light culture.

Keywords: *Lepidium sativum* L., garden cress, intensive light culture, productivity, ascorbic acid, chlorophylls, carotenoids, variability

Leafy vegetable crops are the most accessible source of bioactive substances, including vitamins and antioxidants necessary for human to maintain a healthy lifestile. However, in the Russian Federation, the provision with these products is only 30-34% of the recommended norm, 20.4 kg per year per person [1, 2]. These plants, due to short vegetation season and compact habitus, may be grown on multi-tier lighting installations and seem to be one of the most promising crops for controlled intensive light culture using phytotechnical complexes [3, 4], city farms [5], and vertical farms [6-8].

In intensive light culture it is possible to create and maintain optimal parameters of light, root and air environments for plant growth, development and maximum productivity [9, 10]. The Agrophysical Research Institute (API, St. Petersburg) has proposed a methodology for multidimensional optimization of intensive light culture parameters for growing samples from collections of genetic resources. In addition, API creates highly productive forms with a complex of economically valuable traits which are maximally realized under completely regulated intensive light culture. Scalable phytotechnical complexes have been developed that can be located close to the consumer for year-round provision with high-quality plant products [11-15]. Controlled conditions increase significantly the accuracy of identifying valuable genotypes and speed up breeding lines and varieties for city farms and plant factories [16-19].

Recently, interest in functional nutrition has been growing worldwide [20]. Plants of the *Brassicaceae* Burnett family are a valuable source of biologically active substances, e.g., phenolic compounds, plant pigments, glucosinolates, terpenes, phytoalexins, and alkaloids [21]. In addition, many cabbage crops have short growing season, compact sizes and, due to intensive growth, produce high yields, that is, may be successfully grown in layered light culture.

Garden cress (*Lepidium sativum* L.) is an annual herbaceous plant of the *Brassicaceae* family known mainly as a leafy and aromatic crop [22]. Fresh rosette leaves and young shoots, which have a pleasant mustard taste, are eatable. The exact place of origin of garden cress is not known, but it is believed to have originated in Northeast Africa (Ethiopia, Eritrea, Egypt) where it was grown more than 2000 years ago as an oilseed plant, and Southwest Asia (Iran) [23]. Gradually, the culture spread to the countries of Central and Western Asia, Transcaucasia and the Mediterranean where a secondary source of origin of vegetable forms appeared [24, 25].

The genus *Lepidium* L. contains more than 175 species [26]. *L. sativum* is a polymorphic species, and attempts at its intraspecific botanical classification have been made several times. N. Sabaghnia et al. [27] divide the species *L. sativum* into three botanical varietates, the var. *vulgare* Alef. (common), var. *crispum* (Medik.) DC. (curly), and var. *latifolia* DC. (broadleaf) depending on the leaf, stem and root morphology. In Russia, according to the accepted classification, the species L. *sativum* has five main varietates, namely, the var. *latifolium* DC. (whole-leaved), var. *sativum* Alef. (common), var. *nanum* Schtschenk. (finely dissected), var. *crispum* (Medik.) DC. (curly), and var. *adpressum* Schtschank. (pinned) [28]. The genetic diversity of garden cress is poorly consistent with its ecological and geographical origin, there is significant variability in quantitative traits which does not depend on the place of origin of the sample [27, 29]. Fresh garden cress leaves are rich in vitamin C (47-74 mg/100 g fresh weight) [30-32]. They also contain vitamins B, PP, A, E, D, K, macro- and microelements P, K, Ca, Mg, Na, Fe, I [24, 33-35], and carotene [36]. Some varieties are characterized by increased contents of macroelements P, K, Ca, Na and Mg in the aerial parts compared to lettuce, spinach, parsley and cabbage [31]. Thanks to its valuable biochemical composition, garden cress is not only a leafy vegetable crop widely consumed in food, but a medicinal plant [37-39] used to treat asthma, headaches, uterine tumors, breast cancer [40], jaundice, liver and spleen problems, and gastrointestinal disorders [41, 42]. Garden cress has antipyretic, analgesic, coagulant [43], hypotensive [44], diuretic [45], anti-asthmatic [46], hypoglycemic, antioxidant and anti-inflammatory [47] properties.

The prospects for intensive light culture of garden cress are also associated with its early ripening which ensures regular harvests, according to original research at the Agrophysical Institute (St. Petersburg), up to 24 growing seasons per year (personal communications). Breeding of garden cress is focused on high-yielding varieties with large, double pinnately lobed dissected curly leaves with a high content of biologically active substances (BAS) and good taste.

Currently, the world collection of the Russian Federation, stored in VIR (Vavilov All-Russian Institute of Plant Genetic Resources, St. Petersburg) includes 323 garden cress samples. The geographical diversity of the collection covers Europe, Asia, the Caucasus and Transcaucasia, Africa, Australia and North Americaб 46 countries in total. The collection cover all botanical varietates of garden cress.

In recent years, the search and selection of various agricultural plants for light culture have been carried out, the purpose of which is to increase the efficiency and profitability of their production and to expand the range of plant products. Cress *Lepidium sativum* L., as an early ripening crop with a wide variety of forms that differ in economically valuable traits, primarily in yield and biochemical composition, is of interest for adaptation to such technologies. However, the influence of growing conditions characteristic of light culture on productivity and quality parameters in *L. sativum* samples that differ in eco-geographical origin and botanical affiliation has been practically not studied.

In this work, we comprehensively assessed the economically valuable traits of *L. sativum* accessions from the VIR world collection and for the first time determined the biochemical composition and limits of variability of the pigment composition of garden cress plants under intensive light culture.

The purpose of this study is to assess the variability of phenotypic traits in a representative sample of garden cress samples, including morphometric characteristics, yield and biochemical composition, in intensive light culture and to identify promising forms for use in vegetable growing and breeding.

Materials and methods. The sample included 72 accessions from the VIR collection that differ in eco-geographical origin and botanical affiliation, including 27 whole-leaved (var. *latifolium*), 35 common (var. *sativum*) and 10 curly (var. *crispum*) cress accessions.

The studies were carried out in the original AFI vegetation light installation [48], equipped with DNaZ-400 lamps (Reflax LLC, Russia). Irradiance in the PAR is 75-80 W/m^2 with 12 h photoperiod, the day/night temperature is 22±2/20±2 °C. A 3 cm layer of Peat nutrient substrate Agrobalt-S (Pindstrup LLC, Russia) was the rooting medium. Watering was carried out with water, fertilizing цшер 0.5 n. Knop solution 3 times a week. Soil humidity was maintained at 60-70% full moisture capacity, air humidity at 60-65%. The experiment was repeated 3 times, with 15 assessed plants per sample, sowing scheme was 5×5 cm.

Phenological observations (dates of emerging single and mass shoots and the beginning of stemming) and morphological description were performed according to the VIR method [49]. In plants, the height and diameter of the rosette, the length and width of the leaf, the length of the petiole were measured, the weight of one plant, the number of leaves (quantitative characteristics) were assessed, and the type of leaf (qualitative characteristics) was described, and the yield was calculated. Description of plants and biochemical analysis were carried out at the stage of technical ripeness (on days 15, 17 and 22 from emergence).

Preparation and biochemical analysis of samples were as described by A.I. Ermakova [50]. The dry matter content was determined gravimetrically, ascorbic acid by direct extraction from plants with 1% hydrochloric acid, followed by titration with 2,6-dichloroindophenol (Tillmans reagent). Carotenoids and chlorophylls were extracted with 100% acetone and quantified by absorbance (OD) at λ = 645 nm (chlorophyll a), λ = 662 nm (chlorophyll b), λ = 440 nm (carotenoids), and λ = 454 (β-carotene). Anthocyanins were extracted with 1% hydrochloric acid, OD was measured at λ = 510 nm and converted to cyanidin-3,5-diglycoside (λ = 453 nm). To correct for the content of green pigments, the optical density of the extracts was simultaneously determined at λ = 657 nm. All OD measurements were carried out using an Ultrospec II spectrophotometer (LKB Vertriebs GmbH, Austria). All values are expressed in fresh weight.

Statistical analysis was performed using STATISTICA v.12.0 software (StatSoft, Inc., USA). Descriptive statistics parameters were calculated for all values (mean *M*, median *Me*, standard deviation SD, range of variability min-max). Data testing for normality of distribution was performed using the Shapiro-Wilk test. Mean values were compared using analysis of variance (ANOVA). LSD_{05} and Tukey's honestly significant difference (HSD) test were used to identify outliers [51, 52].

Results. Morphological and phenological observations, economic value. Variability of traits characterizes the norm of a species' response to environmental factors and its ability to adapt [53]. Understanding the phenotypic variability of economically valuable traits in certain environments [54] provides information about effective traits for breeding [55] and the ability of a cultivated species to realize its adaptive potential for high yield. We determined the limits of variability of phenotypic traits in garden cress plants in light culture. The greatest variability was characterized by the average plant weight and yield (*Cv* of 40.3 and 38.3%, respectively) (Table 1), other parameters vary within a moderate rang.

1. *Lepidium sativum* L. intraspecific variability for phenotypic traits (accessions of the VIR collection, *N* = 3, *n* = 72, the AFI biopolygon, St. Petersburg, 2022)

Trait	*M*	*Me*	min	max	±SD	*Cv*, %
Growing season, days	25.0	27.0	15.0	27.0	3.9	15.5
Rosette height, cm	8.0	7.8	5.5	11.8	1.3	15.7
Rosette diameter, cm	15.2	15.3	8.8	21.2	2.4	15.7
Leaf length, cm	5.8	5.6	3.4	8.9	1.1	19.2
Leaf width, cm	3.3	3.3	2.1	5.2	0.6	17.9
Plant weight, g	2.8	2.4	1.1	6.6	1.1	40.3
Yield, kg/m^2	1.1	1.0	0.5	2.5	0.4	38.3

For light culture, the growing season, plant weight and resistance to early stemming are the most economically important traits which largely determine the yield and commercial qualities of plant products. In light culture, 76% of the studied samples were resistant to early stemming, 24% began stemming on days 15-19.

Early-ripening and ultra-early-ripening forms belonged mainly to var.

crispum and var. *sativum*, late-ripening forms to var. *latifolia*. Late-ripening samples are late or slow stemming and are valuable for their high productivity and 13-14 harvests per year. In early ripening forms, harvesting is more often, and ultra-early ripening forms with a growing season of 15 days give up to 24 harvests per year in light culture. The total annual yield per 1 m^2 in early-ripening and late-ripening forms of garden cress varied little and averaged 16.3±4.5 and 16.1±6.2 kg/m^2, respectively, the yield of Mestny sample (k-112, Azerbaijan) was 33.3 kg/m^2. Similar results confirming the wide intraspecific variability of garden cress have been reported by other researchers [27, 29, 56]).

To identify the contribution of various factors to the variability in phenological and morphological traits, we performed a one-way analysis of variance (Table 2). It was found that from 70.0 to 89.4% variability was due to the genotype, and only 19 to 39% was contributed by the botanical affiliation (see Table 2).

2. Contribution of genotypes (G) **and varietates** (V) **to the total variance of *Lepidium sativum* L. phenotypic traits** (accessions of the VIR collection, $p \leq 0.05$, one-way analysis of variance; N = 3, n = 72, the AFI biopolygon, St. Petersburg, 2022)

Trait	SS		df		MS		*F*		Contribution, %	
	G	V	G	V	G	V	G	V	G	V
Growing season, days	3239.83	681.48	71	2	45.63	340.74	–	28.37	–	21.0
Rosette height, cm	237.84	94.11	71	2	3.35	47.05	4.75	40.86	70.1	27.7
Rosette diameter, cm	1007.80	367.56	71	2	14.19	183.78	9.19	45.38	81.9	29.9
Leaf length, cm	210.97	51.07	71	2	2.97	25.54	8.06	25.55	79.9	19.3
Leaf width, cm	59.97	22.24	71	2	0.84	11.12	7.70	44.27	79.2	29.4
Plant weight, g	237.54	103.78	71	2	3.34	51.89	17.02	68.20	89.4	39.0
Yield, kg/m^2	38.00	16.60	71	2	0.53	8.30	17.02	68.20	89.4	39.0

N o t e. Dashes mean that the variance is not significantly different.

B i o c h e m i c a l   a n a l y s i s. *Dry matter and ascorbic acid conten*t. The content of dry substances determines the nutritional value and useful yield of vegetable products. In our study, the range of variability between the accessions for this trait ranged from 6.3 to 12.7% (*Cv* = 14.4%).

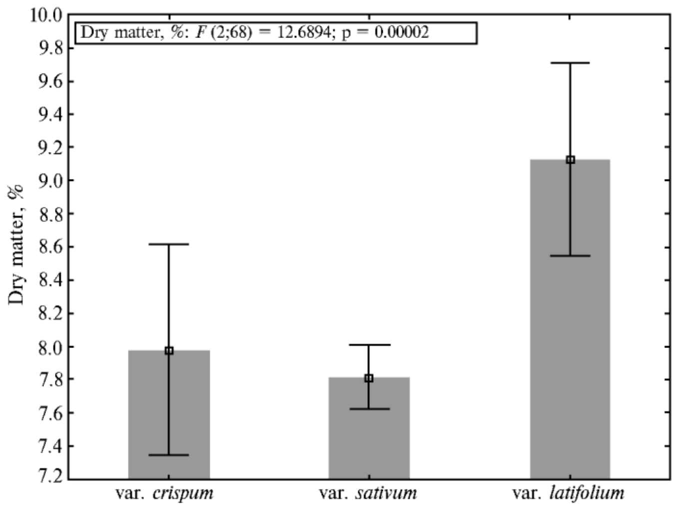

Fig. 1. Variability for the dry matter content in *Lepidium sativum* L. depending on the varietates (accessions of the VIR collection, n = 72, the AFI biopolygon, St. Petersburg, 2022**)**. The figure shows the means and confidence intervals, M±(t0.05 × SD).

In early ripening samples of var. *crispum*, the dry matter content ranged from 7.2 to 9.7%, of var. *sativum* from 6.3 to 8.8%. In ultra-early ripening samples of var. *sativum*, the dry matter content was lower (7.6% on average) compared to early-ripening and late-ripening forms (7.9% on average). Samples of var. *latifolium* accumulated 6.7-12.7% of dry matter, in early-ripening forms of this variety the average was 8.7%, in late-ripening forms 9.4% (Fig. 1). Late-ripening samples of var. *latifolium* from Azerbaijan (k-12, k-15, k-132, k-153) and Georgia (k-100, k-106, k-248) had a high dry matter content, more than 10%. These data are consistent with the reports for various garden cress samples at the stage of economic ripeness, e.g., 8.3-13.6% [24], 11.5-17.0% [33], 4.1-13.6% [28].

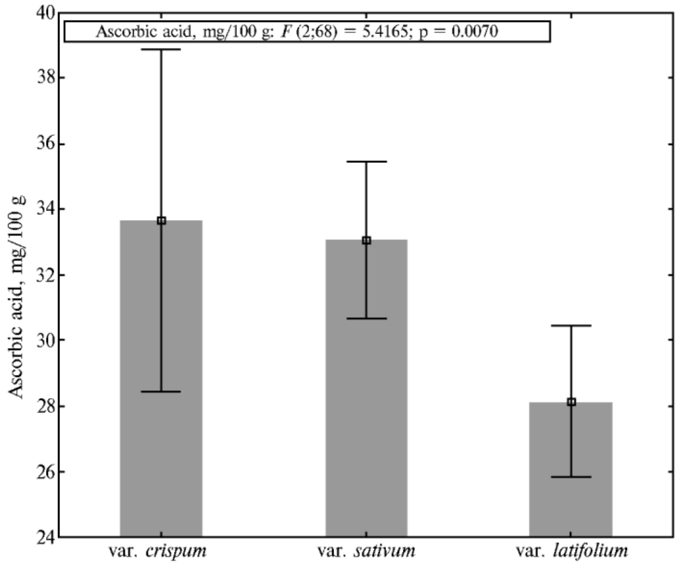

Fig. 2. Variability for the ascorbic acid content in *Lepidium sativum* L. depending on the varietates (accessions of the VIR collection, $n = 72$, the AFI biopolygon, St. Petersburg, 2022**)**. The figure shows the means and confidence intervals, $M \pm (t0.05 \times SD)$.

The content of ascorbic acid, one of the most important bioactive substances, ranged from 20.0 to 44.0 mg/100 g ($Cv = 20.6\%$). In samples of var. *crispum* and var. *sativum* the ascorbic acid averaged 33.7±5.0 and 33.1±6.2 mg/100 g, respectively. For early-ripening and ultra-early-ripening forms of these varietates a higher content of vitamin C was characteristic. Samples of var. *latifolium* accumulated an average of 28.1±5.8 mg/100 g ascorbic acid; we did not find any significant differences between early-ripening and late-ripening forms of var. *latifolium* (Fig. 2). Ultra-early ripening samples of var. *sativum* (k-42, Russia; k-124, Nepal; k-224, Germany) and var. *crispum* (k-245, Zimbabwe) and a late-ripening local accession from Georgia (k-44) were highly active producers of ascorbic acid, more than 40 mg/100 g.

Importantly, the biochemical composition of garden cress in intensive light culture has not been previously studied. Many works assessed the biochemical parameters of one or two varieties during summer cultivation in field and under hydroponic technique [30, 31]. In field, the content of ascorbic acid in two varieties was 54 and 74 mg/100 g.

Pigment contents. The content of pigments and their ratio significantly influence plant metabolism and can vary depending on the plant species or variety, and on the syage of ontogenesis [57].

Our study was the first to determine the limits of variability in the pigment composition of garden cress samples in light culture (Table 3). The greatest variability was noted in anthocyanins ($Cv = 42.5\%$). Most of the samples did not have anthocyanin coloring, but there were forms with such coloring on the stem, e.g., Merezhivo (vr. 334, Ukraine), Cressona le'noir (k-85, France), local samples from Pakistan (k-118), Armenia (k-11, k-51) and Belarus (k-99), which are considered promising for selection. Accumulation of other pigments varied moderately (see Table 3).

3. *Lepidium sativum* L. intraspecific variability for pigments (mg/100 g) (accessions of the VIR collection, *N* = 3, *n* = 72, the AFI biopolygon, St. Petersburg, 2022)

Pigments	*M*	*Me*	min	max	±SD	*Cv*, %
Anthocyanins	13.6	11.8	3.9	27.3	5.8	42.5
Chlorophyll a	85.2	83.4	63.7	118.7	13.4	15.8
Chlorophyll b	24.2	23.9	16.0	34.8	4.3	17.8
Total chlorophylls	109.4	106.4	79.7	153.4	17.6	16.1
Carotenoids	33.2	32.8	24.9	45.7	5.2	15.7
Carotenes	5.7	5.8	2.0	8.1	1.1	19.1
β-Carotene	4.4	4.4	3.3	6.1	0.7	15.5

We found statistically significant differences between samples and varietates in the content of chlorophylls and carotenoids, including carotene and β-carotene (Fig. 3). For the accumulation of carotenes, the greatest variability within the varietas was demonstrated by var. *sativum* (*Cv* = 24.7%), for anthocyanin var. *crispum* (*Cv* = 44.7%). Samples of var. *latifolium* were generally characterized by a high content of the sum of chlorophylls, carotenoids, carotenes and β-carotene.

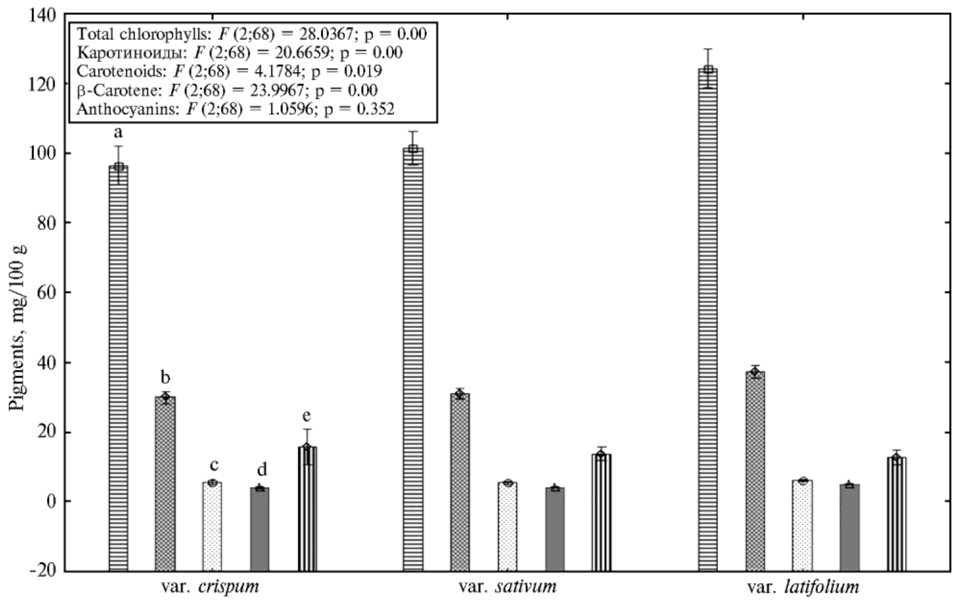

Fig. 3. Variability for pigmet composition in *Lepidium sativum* L. depending on the varietates: a — chlorophylls, b — carotenoids, c — carotenes, d — β-carotene, e — anthocyanins (accessions of the VIR collection, *n* = 72, the AFI biopolygon, St. Petersburg, 2022**).** The figure shows the means and confidence intervals, *M*±(t0.05 × SD).

Previously, we conducted a comparative analysis of pigment accumulation in plants of 35 garden cress samples, depending on the varietates and growing conditions, in field, greemhouses and in light culture [58]. The highest content of chlorophylls, anthocyanins and carotenes was revealed in light culture, while the accumulation of β-carotene decreased. Total carotenoid content increased when grown in field [58]. The same study revealed high accumulation of anthocyanins in var. *crispum*, of total chlorophylls and carotenoids in var. *sativum*, and carotenes and β-carotene in var. *latifolium* on average for all growing conditions [58]. Here, on 72 garden cress accessions tested under light culture conditions we confirmed the high accumulation of carotenes (6.1±0.6 mg/100 g) and β-carotene (5.0±0.6 mg/100 g) in samples of var. *latifolia*.

Sources of valuable traits in garden cress. Based on phenotypic, morphological and biochemical examination of 72 accessions from the VIR collection under intensive light culture, we have identified samples promising for breeding. Local accessions of var. *latifolium* from Iran (k-91) and Azerbaijan (k-112, k-125, k-131), sample of var. *sativum* from Iran (k-92) and early ripening accession of var. *crispum* Almindelig (k-185, Denmark) were highly productive and resistant to early stemming. For the content of ascorbic acid, two samples stood out, the local sample of var. *latifolium* from Georgia (k-44) and a sample of var. *sativum* from Germany (k-224). Samples of var. *crispum* Cressona le noir (k-85, France), Merezhivo (vr. k-334, Ukraine) and Curled (k-245, Zimbabwe) can be considered genetic sources of high anthocyanin content, samples of var. *latifolium* from Azerbaijan (k-15 and k-125) and a sample of var. *sativum* from Armenia (k-167) can be sources of high chlorophylls and β-carotene production (Table 4). The garden cress samples superior in early ripening, yields and accumulation of ascorbic acid and pigments are of greatest interest for growing in intensive light culture and for breeding.

4. *Lepidium sativum* L. accessions superior in complex of economically valuable traits (the VIR collection, a representative sample of *n* = 72, *M*±SD, the AFI biopolygon, St. Petersburg, 2022)

Accession	Resistance to early stemming	Yield per year, kg per m^2	Content, mg/100 g			
			ascorbic acid	anthocyanins	chlorophylls	β-carotene
var. *latifolium*						
k-91, Iran	+	28.77±3.86^b	22.0±2.6^a	6.9±0.8^a	110.4±12.7^a	4.4±0.5^a
k-131, Azerbaijan	+	27.88±1.50^b	22.0±3.1^a	10.0±1.4^b	122.3±16.7^b	4.8±0.6^a
k-112, Azerbaijan	+	33.22±3.14^c	35.0±3.9^b	11.0±1.4^b	105.4±14.6^a	4.2±0.6^a
k-125, Azerbaijan	+	23.61±3.27^a	32.0±4.1^b	9.4±1.2^b	153.4±19.7^d	6.1±0.6^b
k-15, Azerbaijan	+	20.73±1.65^a	22.0±2.1^a	20.8±2.5^c	144.3±19.1^c	5.8±0.9^b
k-44, Georgia	+	20.17±3.20^a	44.0±5.7^c	10.1±1.3^b	133.6±15.9^b	5.5±0.6^b
Varietas average		17.34±5.04	28.2±5.9	12.7±5.2	124.2±14.0	5.0±0.6
var. *sativum*						
k-92, Iran	+	24.82±3.06^d	28.0±3.4^b	9.1±1.2^a	112.2±12.2^c	4.5±0.6^b
k-167, Armenia	+	20.03±2.76^c	22.0±3.7^a	10.6±1.3^a	143.9±18.6^d	5.8±0.7^c
k-224, Germany	–	20.80±2.66^c	44.0±4.6^c	9.0±0.1^a	79.7±10.8^a	3.3±0.5^a
k-42, Uzkolistny 3, Russia	+	8.96±0.73^a	42.0±4.8^c	14.3±1.8^b	96.0±11.5^b	3.9±0.5^a
k-124, Nepal	+	12.27±1.83^b	42.0±5.9^c	19.9±2.6^c	83.5±10.6^a	3.4±0.4^a
Varietas average		15.23±4.39	33.1±6.2	13.7±8.8	101.3±13.8	4.1±0.6
var. *crispum*						
k-185, Almindelig, Denmark	–	22.90±3.04^c	36.0±4.0^b	12.8±1.5^a	87.6±11.4^a	3.6±0.4^a
vr. 334, Merezhivo, Ukraine	+	9.41±1.09^a	28.0±3.6^a	27.3±3.4^c	90.3±11.8^a	3.8±0.5^a
k-85, Cressona le'noir, France	+	11.09±1.20^a	30.0±3.8^a	26.8±3.8^c	111.8±15.9^c	4.5±0.6^b
k-245, Curled, Zimbabwe	–	16.80±2.43^b	42.0±5.0^c	22.2±2.8^b	103.4±12.4^b	4.3±0.5^b
Varietas average		15.11±3.89	33.7±5.0	15.8±7.0	96.4±7.7	4.0±0.3^a
Collection average		16.14±5.44	31.0±6.4	13.6±5.8	109.4±17.6	4.4±0.7
LSD_{05}		3.16	2.3	2.0	6.0	0.2

[a-d] Values with different superscripts in the column differed statistically significantly at $p < 0,05$ (Tukey's HSD test).

Thus, in a representative sample of garden cress var. *sativum*, var. *crispum* and var. *latifolium* accessions of different eco-geographical origin (the VIR world collection) we assessed the variability of morphological, phenological and biochemical traits under conditions of intensive light culture. The most variable parameters are the average plant weight (*Cv* = 40.3%), yield (*Cv* = 38.3%), and anthocyanin content (Cv = 42.5%), other traits show moderate variability, *Cv* no more than 20%. Early- and ultra-early ripening forms belong to var. *crispum* and var. *sativum*, late-ripening forms mainly to var. *latifolia*. Late-ripening samples are characterized by a late or delayed transition to stemming, a larger plant weight (an average of 3.6 g) and a high dry matter content (an average of 9.0%). Early-ripening and ultra-early-ripening forms accumulate greater amounts of ascorbic acid (on average 32.8±5.7 mg/100 g), while a shorter growing season allows for a greater number of harvests per year. As a result, the total productivity per 1 m^2 per year between late-ripening and early-ripening forms differs little and amounts to 16.1±6.2 and 16.3±4.5 kg/m^2, respectively. In the studied sample, the late-ripening samples of var. *latifolium* from Iran (k-91) and Azerbaijan (k-112, k-125, k-131), sample of var. *sativum* from Iran (k-92) and accession of var. *crispum* from Denmark (k-185) are the most productive. Statistically significant differences are found between samples and varietates in the content of chlorophylls and carotenoids. For carotene, var. *sativum* is the most variable (Cv = 24.7%), for anthocyanin content var. *crispum* (Cv = 44.7%). Samples of var. *latifolium* were generally characterized by a higher total content of chlorophylls (124.2±14.0 mg/100 g), carotenoids (37.3±4.4 mg/100 g), carotenes (6.1±0.6 mg/100 g) and β-carotene (5.0±0.6 mg/100 g). Samples of different varietated have been identified that are of the greatest interest in terms of high growth rate, resistance to stemming and yield formation under conditions of intensive light culture. These samples are also potential sources of economically valuable traits in breeding forms of garden cress adapted to conditions of intensive light culture.

REFERENCES

1. Soldatenko A.V., Pivovarov V.F., Kharchenko V.A., Ivanova M.I. *Ovoshchi Rossii*, 2019, 3: 7-14 (doi: 10.18619/2072-9146-2019-3-7-14) (in Russ.).
2. Ludilov V.A. Ivanova M.I. *Azbuka ovoshchevoda* [Vegetable grower's ABCs]. Moscow, 2004 (in Russ.).
3. Benke K., Tomkins B. Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, 2017, 13(1): 13-26 (doi: 10.1080/15487733.2017.1394054).
4. Al-Kodmany, K. The vertical farm: A review of developments and implications for the vertical city. *Buildings*, 2018, 8(2): 24 (doi: 10.3390/buildings8020024).
5. Payen F. T., Evans D. L., Falagán N., Hardman C. A., Kourmpetli S., Liu L., et al. How much food can we grow in urban areas? Food production and crop yields of urban agriculture: A meta-analysis. *Earth's Future*, 2022, 10: e2022EF002748 (doi: 10.1029/2022EF002748).
6. P*lant factory: an indoor vertical farming system for efficient quality food production*. Kozai T., G. Niu, M. Takagaki (eds.). Academic Press, 2019.
7. Reddy R.V.S.K., Omprasad J., Janakiram T. Technological innovations in commercial high tech horticulture, vertical farming and landscaping. *Int. J. Innov. Hortic.*, 2022, 11(1): 78-91 (doi: 10.5958/2582-2527.2022.00008.2).
8. Lubna F.A., Lewus D.C., Shelford T.J., Both A.-J. What you may not realize about vertical farming. *Horticulturae*, 2022, 8: 322 (doi: 10.3390/horticulturae8040322).
9. Wong C. E., Teo Z. W. N., Shen L., Yu H. Seeing the lights for leafy greens in indoor vertical farming. *Trends Food Sci. Technol.*, 2020, 106: 48-63 (doi: 10.1016/j.tifs.2020.09.031).
10. Kozai T. Towards sustainable plant factories with artificial lighting (PFALs) for achieving SDGs. *Int. J. Agric. & Biol. Eng. (IJABE)*, 2019, 12(5): 28-37 (doi: 10.25165/j.ijabe.20191205.5177).
11. Panova G.G., Udalova O.R., Kanash E.V., Galushko A.S., Kochetov A.A., Priyatkin N.S., Arkhipov M.V., Chernousov I.N. *Zhurnal tekhnicheskoy fiziki*, 2020, 90(10): 1633-1639 (doi: 10.21883/JTF.2020.10.49792.429-19) (in Russ.).
12. Egorova K. V., Sinyavina N. G., Artemyeva A. M., Kocherina N. V., Chesnokov Y. V. QTL Analysis of the Content of Some Bioactive Compounds in *Brassica rapa* L. Grown under Light Culture Conditions. *Horticulturae*, 2021, 7(12): 583 (doi: 10.3390/horticulturae7120583).
13. Artemyeva A.M., Sinyavina N.G., Panova G.G., Chesnokov Yu.V. Biological features of *Brassica rapa* L. vegetable leafy crops when growing in an intensive light culture. *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2021, 56(1): 103-120 (doi: 10.15389/agrobiology.2021.1.103eng).
14. Kochetov A.A., Mirskaya G.V., Sinyavina N.G., Egorova K.V. *Rossiyskaya sel'skokhozyaystvennaya nauka*, 2021, 6: 29-37 (doi: 10.31857/S2500262721060065) (in Russ.).
15. Kurina A.B., Artem'eva A.M., Sinyavina N.G., Kochetov A.A., Panova G.G. *Kartofel' i ovoshchi*, 2019, 4: 26-29 (doi: 10.25630/PAV.2019.68.78.004) (in Russ.).

16. Hayashi E., Kozai T. Phenotyping- and AI-Based Environmental Control and Breeding for PFAL. *Smart Plant Factory*, 2018, 405-411 (doi: 10.1007/978-981-13-1065-2_25).
17. Watson A., Ghosh S., Williams M. J., Cuddy W. S., Simmonds J., Rey M. D., Hickey L. T. Speed breeding is a powerful tool to accelerate crop research and breeding. *Nat. Plants*, 2018, 4: 23-29 (doi: 10.1038/s41477-017-0083-8).
18. Ghosh S., Watson A., Gonzalez-Navarro O. E., Ramirez-Gonzalez R. H., Yanes L., Hickey L.T. Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. *Nat. Protoc.*, 2018, 13 (12): 2944-2963 (doi: 10.1038/s41596-018-0072-z).
19. Sinyavina N.G., Kochetov A.A., Egorova K.V., Kocherina N.V., Chesnokov Yu.V. *Genetika*, 2022, 58(6): 668-677 (doi: 10.31857/S0016675822060108) (in Russ.).
20. Fotev Yu.V., Artem'eva A.M., Zvereva O.A. *Vavilovskiy zhurnal genetiki i selektsii*, 2021, 25(4): 442-447 (doi: 10.18699/VJ21.049) (in Russ.).
21. Ramirez D., Abellán-Victorio A., Beretta V., Camargo A., Moreno D.A. Functional ingredients from *Brassicaceae* species: overview and perspectives. *Int. J. Mol. Sci.*, 2020, 21(6): 1998 (doi: 10.3390/ijms21061998).
22. Aqafarini A., Lotfi M., Norouzi M., Karimzadeh G. Induction of tetraploidy in garden cress: morphological and cytological changes. *Plant Cell, Tissue and Organ Culture (PCTOC),* 2019, 137(3): 627-635 (doi: 10.1007/s11240-019-01596-5).
23. Bedassa T., Eshete M. Genetic divergence analysis of garden cress (*Lepidium sativum* L.). *Int. J. Biodivers. Conserv.*, 2013, 5(11): 770-774 (doi: 10.5897/IJBC2013.0626).
24. Tsiunel' M. M. Kress-salat. *Gavrish*, 2006, 6: 8-9 (in Russ.).
25. Sharma A. A comprehensive review on pharmacological properties of garden cress (*Lepidium sativum*) seeds. *Res. in Pharm. Sci.*, 2020, 10: 13-18 (doi: 10.24092/CRPS.2020.100201).
26. Bansal D., Bhasin P., Yadav O., Punia A. Assessment of genetic diversity in *Lepidium sativum* (Chandrasur) a medicinal herb used in folklore remedies in India using RAPD. *Journal, Genetic Engineering & Biotechnology*, 2012, 10(1): 39-45 (doi: 10.1016/j.jgeb.2012.04.002).
27. Sabaghnia N., Ahadnezhad A., Janmohammdi M. Genetic variation in garden cress (*Lepidium sativum* L.) germplasm as assessed by some morphological traits. *Genet. Resour. Crop Evol.*, 2015, 62(5): 733-745 (doi: 10.1007/s10722-014-0192-4).
28. Girenko M.M., Korovina O.N., Dorofeev V.F. *Kul'turnaya flora SSSR. Tom 12. Listovye ovoshchnye rasteniya (sparzha, reven', shchavel', shpinat, portulak, kress-salat, ukrop, tsikoriy, salat)* [Cultivated flora of the USSR. Volume 12. Leafy vegetable plants (asparagus, rhubarb, sorrel, spinach, purslane, watercress, dill, chicory, lettuce)]. Leningrad, 1988 (in Russ.).
29. Bedassa T., Andargie M., Eshete M. Genetic variability and association among yield, yield related traits and oil content in Ethiopian garden cress (*Lepidium sativum* L.) genotypes. *J. Plant Breed. Crop Sci.*, 2013, 7(5): 141-149 (doi: 10.5897/JPBCS2013.0396).
30. Bespal'ko L.V., Molchanova A.V., Pinchuk E.V., Sirota S.M., Kozar' E.G. *Sel'skokhozyaystvennye nauki*, 2017, 7-1(33): 240-244 (in Russ.).
31. Sat I.G., Yildirim E., Turan M., Demirbas M. Antioxidant and nutritional characteristics of garden cress (*Lepidium sativum*). *Acta Sci. Polonorum-Hort. Cultus*, 2013, 12: 173-179.
32. Malar J., Chairman K., Singh A. R. J., Vanmathi J. S., Balasubramanian A., Vasanthi K. Antioxidative activity of different parts of the plant *Lepidium sativum* Linn. *Biotechnology Reports*, 2014, 3: 95-98 (doi: 10.1016/j.btre.2014.05.006).
33. Chizhikova O.G. *Izvestiya DVFU. Ekonomika i upravlenie*, 2017, 1: 113-118 (in Russ.).
34. Ajdanian L., Mehdi Babaei, Hossein Aroiee. Investigation of photosynthetic effects, carbohydrate and starch content in cress (*Lepidium sativum*) under the influence of blue and red spectrum. *Heliyon*, 2020, 6: e05628 (doi: 10.1016/j.heliyon.2020.e05628).
35. Hassan L.G., Hassan S.W., Hashim T., Umar K.J., Sani N.A. Determination of nutritive values of garden cress (*Lepidium Sativum* L.) leaves. *Bayero Journal of Pure and Applied Sciences*, 2012, 4: 18-23 (doi: 10.4314/bajopas.v4i2.4).
36. Pinchuk E.V., Bespal'ko L.V., Kozar' E.G., Balashova I.T., Sirota S.M., Shevchenko T.E. *Ovoshchi Rossii*, 2019, 3: 45-53 (doi: 10.18619/2072-9146-2019-3-45-53) (in Russ.).
37. Ajdanian L., Babaei M., Aroiee H. The growth and development of cress (*Lepidium sativum*) affected by blue and red light. *Heliyon*, 2019, 5(7): e02109 (doi: 10.1016/j.heliyon.2019.e02109).
38. Sharma S., Agarwal N. Nourishing and healing prowess of garden cress (*Lepidium sativum* Linn.) — a review. *Indian Journal of Natural Products and Resources*, 2011, 2: 292-297.
39. Buso P., Manfredini S., Reza Ahmadi-Ashtiani H., Sciabica S., Buzzi R., Vertuani S., Baldisserotto A. Iranian medicinal plants: from ethnomedicine to actual studies. *Medicina*, 2020, 56(3): 97 (doi: 10.3390/medicina56030097).
40. Jahani S., Heidari Z., Azami M., Moudi B. Comparison of anticancer effects of hydroalcoholic extracts of *Camellia sinensis* and *Lepidium sativum* L on hela cell line. *International Journal of Cancer Management,* 2020, 13(11): e98913 (doi: 10.5812/ijcm.98913).
41. Rajab W.J., Ali L.H. Efficacy of *Lepidium sativum* seeds against carbon tetra chloride induced hepatotoxicity in rats. *Biochemical and Cellular Archives,* 2020, 20(1): 1141-1146.
42. Painuli S., Quispe C., Herrera-Bravo J., Semwal P., Martorell M., Almarhoon Z.M., Seilkhan A., Ydyrys A., Rad J.S., Alshehri M.M., Da tan S.D., Taheri Y., Calina D., Cho W.C. Nutraceutical

profiling, bioactive composition, and biological applications of *Lepidium sativum* L. *Oxid. Med. Cell Longev.*, 2022, 2022: 2910411 (doi: 10.1155/2022/2910411.a).
43. Al-Yahya M., Mossa J., Ageel A., Rafatullah S. Pharmacological and safety evaluation studies on *Lepidium sativum* L., Seeds. *Phytomedicine*, 1994, 1(2): 155-159 (doi: 10.1016/S0944-7113(11)80035-8).
44. Yadav Y.C., Srivastav D., Seth A., Saini V., Balaraman R., Ghelani T.K. In vivo antioxidant potential of *Lepidium sativum* L. seeds in albino rats using cisplatin induced nephrotoxicity. *International Journal of Phytomedicine*, 2010, 2(3): 292-298.
45. Patel U., Kulkarni M., Undale V., Bhosale A. Evaluation of diuretic activity of aqueous and methanol extracts of *Lepidium sativum* garden cress (*Cruciferae*) in rats. *Tropical Journal of Pharmaceutical Research*, 2009, 8(3): 215-219 (doi: 10.4314/tjpr.v8i3.44536).
46. Paranjape A.N., Mehta A.A. A study on clinical efficacy of *Lepidium sativum* seeds in treatment of bronchial asthma. *Iranian Journal of Pharmacology & Therapeutic*, 2006, 5(1): 55-59.
47. Raval N.D., Ravishankar B., Ashok B. Anti-inflammatory effect of Chandrashura (*Lepidium sativum* Linn.) an experimental study. *AYU (An International Quarterly Journal of Research in Ayurveda)*, 2013, 34(3): 302 (doi: 10.4103/0974-8520.123132).
48. Panova G.G., Chernousov I.N., Udalova O.R., Aleksandrov A.V., Karmanov I.V., Anikina L.M., Sudakov V.L., Yakushev V.P. *Doklady Rossiyskoy akademii sel'skokhozyaystvennykh nauk*, 2015, 4: 17-21 (in Russ.).
49. Ivanova K.V., Girenko M.M. *Metodicheskie ukazaniya po izucheniyu malorasprostranennykh ovoshchnykh kul'tur* [Guidelines for studying less common vegetable crops]. Leningrad, 1968 (in Russ.).
50. Ermakov A.I., Arasimovich V.V., Yarosh N.P. *Metody biokhimicheskogo issledovaniya rasteniy* [Methods of biochemical research of plants]. Leningrad, 1987 (in Russ.).
51. StatSoft Inc., Electronic Statistics Textbook (Electronic Version), StatSoft, Inc., Tulsa, 2013. Available: http://www.statsoft.com/textbook. No date.
52. Nasledov A.D. *Matematicheskie metody psikhologicheskogo issledovaniya. Analiz i interpretatsiya dannykh* [Mathematical methods of psychological research. Data analysis and interpretation]. St. Petersburg, 2012.
53. Pivovarov V.F., Dobrutskaya E.G. *Ekologicheskie osnovy selektsii i semenovodstva ovoshchnykh kul'tur* [Ecological foundations of breeding and seed production of vegetable crops]. Moscow, 2000 (in Russ.).
54. Zhuchenko A.A. *Adaptivnyy potentsial kul'turnykh rasteniy* [Adaptive potential of cultivated plants]. Kishinev, 1988 (in Russ.).
55. Ludilov V.A., Ivanova M.I. *Redkie i malorasprostranennye ovoshchnye kul'tury (biologiya, vyrashchivanie, semenovodstvo)* [Rare and less common vegetable crops (biology, cultivation, seed production)]. Moscow, 2009 (in Russ.).
56. Kumar V., Kumar Yadav H. Assessment of genetic diversity in *Lepidium sativum* L. using inter simple sequence repeat (ISSR) marker. *Physiol. Mol. Biol. Plants*, 2019, 25(2): 399-406 (doi: 10.1007/s12298-018-0622-4).
57. Belova A.Yu., Murashev S.V., Verzhuk V.G. *Nauchnyy zhurnal NIU ITMO. Ser. Protsessy i apparaty pishchevykh proizvodstv*, 2012, 1(13): 13 (in Russ.).
58. Zheleznova K.O., Solov'eva A.E., Kurina A.B. *Tezisy Mezhdunarodnoy nauchno-prakticheskoy konferentsii «Aromaticheskie i lekarstvennye rasteniya: introduktsiya, selektsiya, agrotekhnika, biologicheski aktivnye veshchestva, vliyanie na cheloveka» (Yalta, 2021 god)* [Proc. Int. Conf. «Aromatic and medicinal plants: introduction, selection, agricultural technology, biologically active substances, impact on humans (Yalta, 2021)»]. Simferopol', 2021: 43 (in Russ.).