AGRICULTURAL BIOLOGY,
2020, V. 56, Iss. 1, pp. 103-120
(SEL'SKOKHOZYAISTVENNAYA BIOLOGIYA)

ISSN 2412-0324 (English ed. Online)
ISSN 0131-6397 (Russian ed. Print)
ISSN 2313-4836 (Russian ed. Online)

UDC 635.33:581.1:631.588.5

doi: 10.15389/agrobiology.2021.1.103eng
doi: 10.15389/agrobiology.2021.1.103rus

BIOLOGICAL FEATURES OF *Brassica rapa* L. VEGETABLE LEAFY CROPS WHEN GROWING IN AN INTENSIVE LIGHT CULTURE

A.M. ARTEMYEVA[1, 2] ✉, N.G. SINYAVINA[2], G.G. PANOVA[2], Yu.V. CHESNOKOV[2]

[1]*Federal Research Center Vavilov All-Russian Institute of Plant Genetic Resources,* 42-44, ul. Bol'shaya Morskaya, St. Petersburg, 190000 Russia, e-mail akme11@yandex.ru (✉ corresponding author);
[2]*Agrophysical Research Institute,* 14, Grazhdanskii prosp., St. Petersburg, 195220 Russia, e-mail sinad@inbox.ru, gpanova@agrophys.ru, yuv_chesnokov@agrophys.ru
ORCID:
Artemyeva A.M. orcid.org/0000-0002-6551-5203
Sinyavina N.G. orcid.org/0000-0003-0378-7331
Panova G.G. orcid.org/0000-0002-1132-9915
Chesnokov Yu.V. orcid.org/0000-0002-1134-0292
The authors declare no conflict of interests
Received May 12, 2020

Abstract

One of the main components of the successful production of plant products is the choice of crops with a high realization of their production potential under the formed conditions, including in the conditions of intensive light culture. The problem of compensating or eliminating the deficit of green crops is currently quite acute in Russia and in the world. The genetic diversity of the most widespread green *brassicas* plants of the species *Brassica rapa* L. for use in protected ground facilities has developed in Southeast Asia and includes numerous morphotypes of Chinese cabbage, pakchoi, tatsoi, wutacai, mizuna, and leafy turnip. In Russia, leafy *B. rapa* vegetables are used to a limited extent, mainly as salad vegetables. The main areas of *B. rapa* crops breeding for artificial light culture include a high growth rate (the duration of vegetative period is not more than 28-35 days, depending on the biological characteristics of the crop), the yield is not less than 3-8 kg/m^2, depending on crops, a certain compact plant habit, high quality of leaves, valuable biochemical composition, resistance to early bolting, resistance to possible low light and high air temperature, suitability for growing in a thin layer of soil or hydroponics. The biological features of the diversity of *B. rapa* leafy crops as sources for breeding for intensive light culture conditions have not been sufficiently studied, first of all, this concerns little-known crops (tatsoi, wutacai, mizuna) and certain morphotypes within common crops (Chinese cabbage and pakchoi). In this study, for the first time, we studied the wide genetic diversity from the Russian worldwide *B. rapa* collection of the Russian Federation, stored in the VIR, and morphotypes within them (72 accessions), including genotypes contrasting in morphological characteristics, under different supply light intensity for the development of energy-saving agro-technologies in intensive light culture. For the first time, correction factors were determined for calculating the leaf surface area from easily measured linear dimensions for each studied crop and type of leaves, which will speed up the calculations of photosynthesis characteristics. A different degree of variation in the variability of the size and weight of plants of various crops, depending on the illumination, is shown, the highest in Chinese cabbage and leafy turnip. It was found that the intensity of the light regime is largely determined the increase in the productivity of plants of all studied crops, mostly of Chinese cabbage and pakchoi and leafy turnip. High-yielding accessions of Chinese cabbage, pakchoi and leafy turnip were identified (more than 6.3 kg/m^2 for 28 days of growing season). The studied accessions of wutacai and mizuna are low-yielding and have a longer growing season, but are of interest as vegetables for functional nutrition and for decorative purposes. Semi-headed types of Chinese cabbage (Shantung, Santo, Xiao), which are of primary interest for light culture, have been identified. We recommend Chinese cabbage accessions vr.k-1375, Bice (vr.k-1376), and pakchoi k-647 for thickened cultivation, and pakchoi Extra Dwarf Pack Choi (vr.k-1405) and tatsoi Xiao Ba Je Ta Cai (k-695) for growing with a small distance between the shelves of 25 cm. Accessions of Chinese cabbage Chokurei (k-177), Tokyo Bekana (k-395), Zao Shi No. 5 (vr.k-1120), and Fun jen F$_1$ (vr.k-1410) showed the highest salad qualities of the leaves. Under the conditions of a biopolygon, we managed to determine accessions with a stable manifestation of the traits, of early maturity and high productivity, practically independent of light intensity. These are accessions of Chinese cabbage Harumaki Shin Santousai (k-270), Tokyo Bekana (k-395), Xiaobaikou (k-74), pakchoi Kangre 605 (vr.k-1131), Gai Lang Jin Pin 25 F$_1$ (vr.k-1124). In addition, it was shown that the Chinese accession of Chinese cabbage Zao Shi No. 5 (vr.k-1120) and the Russian cultivar of the leafy turnip Selecta (vr.k-1371) have increased the activity of the photosynthetic apparatus. The obtained data on the crops in general and the determined accessions of *B. rapa* are of interest for the practice of vegetable growing, in the development of elements of cultivar technology of *B. rapa* crops under conditions of light culture and as sources of valuable traits in breeding programs, including the development of city farming.

Keywords: *Brassica rapa* L., leafy crops, controlled-environment agriculture, artificial lighting, valuable traits, genetic sources

The main genetic diversity of the most common plants of the species *Brassica rapa* L. (turnip) for the protected ground has been formed in Southeast Asia: initially in China, then in Japan and Korea. It includes numerous morphotypes of pakchoi, Chinese cabbage, wutacai, tatsoi, mizuna, and leafy turnip. Chinese cabbage is the most widely cultivated on the globe, pakchoi is common in Central and Southern China, wutacai and tatsoi in Southern China, mizuna and leafy turnip in Japan [1].

In many industrially developed countries (Japan, USA, China, Singapore, South Korea, EU countries), fast-growing leafy *brassicas* crops with a valuable biochemical composition, in addition to traditional methods of cultivation (open field and greenhouses), have been grown along with lettuce (*Lactuca sativa* L.) in artificial lighting conditions of a new intensively developing type of plant production — vertical farms (plant factories) [2-7].

In Russia, *B. rapa* vegetables are traditionally used to a limited extent – mainly as salad vegetables. Chinese cabbage is grown in open field and protected ground, including industrial vegetable growing. Although the first Russian cultivar of Chinese cabbage Khibinskaya was created in 1962 at the Polar experimental station of VIR (Apatity, Murmansk Region) and was widely cultivated, later in greenhouses, Chinese cabbage gave way to lettuce. Pakchoi and mizuna in Russia are grown very limitedly in private vegetable growing (the first cultivars were included in the State Register of Breeding Achivements Allowed for Use in 2000 and 2002, respectively), leafy turnip and tatsoi are little known, wutacai is unknown (the State Register of Breeding Breeding Achivements Allowed for Use. Vol. 1. Plant varieties. Official publication. Moscow, 2020). It should be noted that all leafy *B. rapa*crops have a set of valuable features. They are early-maturing, productive, cold-resistant, and relatively easy in growing. According to the biochemical composition of these crops (especially rare), they are superior to lettuce (the content of vitamin C 40-80 mg/100 g, β-carotene 2-10 mg/100 g, chlorophylls 50-200 mg/100 g, a large number of organic acids, phenolic compounds, red-colored forms contain anthocyanins), which is due to the growing interest in such crops [8-11].

Eighty-fou cultivars and hybrids of leafy *B. rapa*crops were included in the State Register of Breeding Breeding Achivements Allowed for Use (Vol. 1. Plant varieties. Moscow, 2020) in 2020. Among 57 samples of Chinese cabbage, 75% are F_1 hybrids, including 19 of Russian breeding, among 18 samples of pakchoi, 7 are hybrids, including 5 Russian hybrids, 5 samples of mizuna and 4 samples of leafy turnip are mainly represented by cultivars of Russian breeding. However, it should be noted that greenhouse farms in Russia so far provide only half of the required volume of green crops. At the same time, the State Register has no cultivars of leafy *B. rapa* crops created specifically for artificial lighting.

Intensive artificial lighting is increasingly used in the world and actively used in modern protected ground facilities, being an integral element of urbanized agricultural production, the development of which, according to experts, will steadily increase in the coming decades. It is due to its higher productivity and efficiency in the use of resources – space, soil, water, the number of crops, the volume of fertilizers, etc. (15-90 times higher compared to open field and 1.5-10 times – compared to modern greenhouse complexes of the protected ground) [2, 12, 13], as well as the gradual reduction (according to UN and FAO forecasts) of highly productive land due to their absorption by growing megacities, an expressed tendency of population concentration in cities, and the inability to ensure quantitative and qualitative demand for food through the traditional production chain and food supplies [14, 15].

One of the main components of the successful operation of urbanized plant production, especially in the case of energy-intensive production with the use of artificial lighting, is the choice of crops with a high realization of the productive potential in the conditions being formed. Studies of the influence of agrotechnical growing features in the protected ground and artificial lighting, including the level of irradiation and the spectral composition of light, on the productivity and biometric indicators of various vegetable crops, are conducted in Russia [16-19] and abroad [5, 7, 20-23], but many issues related to ensuring sustainable profitability of production have not been resolved yet.

Systematic fundamental long-term research work on physical modeling and the study of the influence of life-support factors of cultivated plants on their production process, the quality of formed plant products under regulated conditions is carried out in Russia only in several research institutes, including the Agrophysical Research Institute (ARI), where, based on a systematic approach, developments are carried out to optimize methods for obtaining consistently high crops of high-quality plant products in fully formed conditions of light, air, root environment, and depending on agrotechnological factors [24]. Prototypes of mobile and stationary plant factories with original technologies developed and tested at the Institute~~'s~~ biopolygon showed high efficiency and productivity [25].

Biological features of the diversity of leafy *B. rapa* crops of the worldwide VIR collection in the conditions of artificial lighting have not been sufficiently studied. The criteria for the selection of genotypes for growing in conditions of intensive artificial lighting, which is necessary for the breeding of forms for innovative urbanized agricultural production — city farming, have not been developed yet. First of all, it concerns little-known crops in Russia (wutacai, tatsoi, mizuna) and different morphotypes within common crops (pakchoi and Chinese cabbage).

This paper is the first to assess the wide genetic diversity of the Russian collection of leafy crops and the morphotypes within them in the species *Brassica rapa* L. by morphological and phenological characteristics associated with productivity, at different light availability in artificial lighting culture. The degree of variation in the size and mass of different types of plants depending on the illumination is estimated. For each of the studied crops (pakchoi, Chinese cabbage, watucai, tatsoi, mizuna, and leafy turnip), the sources for breeding for yield, early maturity, salad qualities, and resistance to low illumination conditions have been identified. Correction factors have been established for calculating the leaf surface area for each crop and leaf type, which will speed up the calculations of photosynthetic characteristics.

The work objective was to study the growth reactions of the genetic diversity of leafy *brassicas* crops in different illumination conditions when using low-volume technologies for growing plants in intensive artificial lighting.

Materials and methods. The sample of leafy crops of the species *Brassica rapa* L. included 72 samples of different origin (VIR collection, Federal Research Center, Vavilov All-Russian Institute of Plant Genetic Resources), including 36 samples of Chinese cabbage, 23 samples of pakchoi, 2 samples of watucai, 3 samples of mizuna, 3 samples of tatsoi, and 5 samples of leafy turnip.

The plants were grown under the conditions of a regulated agroecosystem

(ARI development) in an original long-tier vegetation light installation [25] equipped with DNaZ-400 lamps (OOO Reflax, Russia) with a short day (12-hour photoperiod) and two illumination modes, 15-20 klx (high) and 10-15 klx (low). The spectral composition of the radiation of DNaZ-400 lamps is close to sunlight with a predominance of the long-wave range (http://www.reflux.ru). The distance from the lamp to the soil surface was 55 cm, from the lamp to the top of the plant 25-50 cm, depending on the age of the plants and the height of the rosette of the studied samples. Daytime ambient temperature was 24±2 °C, night 20±2 °C.

As a substrate, we used terrestrial peat with mineral additives [26], the thickness of the root layer was3-4 cm. Watering was carried out daily, three times a week, instead of tap water, root fertilizing with 0.5 normal Knop's solution was used. The crops were thinned twice, at 2 weeks of age (the cultivation scheme was 10×8 cm, for some samples of pakchoi, watucai, tatsoi, and leafy turnip − 10×5 cm, two samples of pakchoi were also grown according to the scheme of 10×10 cm). The replication in each variant was 12-20 plants.

Samples of pakchoi and tatsoi were also grown in the Pushkin laboratories of VIR in a glazed greenhouse in the early spring period (sowing on March 1) and in the open field (sowing on July 1). The growing scheme is the same under all conditions.

For biometric evaluation and statistical data processing, 5 plants per option were analyzed. Harvesting was carried out on the 28th day after sowing with sprouted seeds. During harvesting, the main biometric indicators were evaluated: the habitus and plant weight, the number of leaves, the size of the leaf lamina, and petiole [27].

The coefficient for determining the area of different types of leaves was calculated after processing photos of plants with smoothed leaves in Adobe Photoshop (Adobe, Inc., USA). The area of one leaf was determined as the result of multiplication of the length and width of the leaf lamina and the coefficient calculated for each sample, the area of the leaf surface of the plant — as the result of multiplication of the obtained value and the number of leaves.

Statistical data processing was performed by the method of variance analysis using the program STATISTICA v. 12. 0 (StatSoft Inc., USA). The mean value of each feature (*M*), the standard error of the mean (±SEM), the LSD at the 5% significance level, the coefficients of variation of the feature values, and the correlation coefficients of the studied features have been determined. The significance of the differences between the options has been determined by the indicator of the least significant difference.

Results. In the VIR worldwide collection, there are more than 1050 samples of all morphotypes of vegetable leaf crops of the *B. rapa* species, received since 1924, including 470 samples of Chinese cabbage, 123 samples of pakchoi, 7 samples of wutacai, 23 samples of tatsoi, 21 samples of mizuna, and 58 samples of leafy turnip. The uniqueness of this collection reaches 50%. When selecting from existing cultivars and creating special ones that allow getting 10-12 crops per year per unit area, the profitability of their cultivation can be very high, despite the cost of lighting in traditional protected ground facilities and intensive artificial lighting [2, 19, 24].

For growing in artificial lighting, representatives of *B. rapa* species must have a high growth rate (the duration of one turn is no more than 28-35 days, depending on the biological characteristics of the crop), a yield of at least 3-8 kg/m^2, a certain habitus of the plant (preferably an erect leaf rosette up to 30 cm high, a lower high is desirable), high leaf quality (no hairiness or weak hairiness, delicate consistency, good taste, valuable biochemical composition), resistance to early bolting, resistance to possible low illumination and high air temperature, suitable for growing in a thin layer of soil substrate or on hydroponics.

In long-day leafy *brassicas* crops used in Russia mainly for salads, the morphological and physiological features of the production process, including the time of transition to flowering, largely depend on the duration of the light period, illumination, spectral composition of light, adaptive reactions to growing in unfavorable light conditions, including in artificial lighting at a relatively high temperature [28].

We selected 72 samples of leafy crops of the species *B. rapa*, including landraces and samples of modern breeding, of various origins, mainly from countries where the consumption of this species is developed and the selection of its varieties is carried out (Table 1). Previously, the morphological description of the samples of the collection was carried out when growing in the field and the winter glazed greenhouse of the Pushkin laboratories of VIR (St. Petersburg) [29] and selected samples that are presumably close to the model of the desired variety for artificial lighting in terms of a set of characteristics. The number of samples of each crop in the selected option depended on the existing natural diversity of the culture morphotypes.

1. Origin and belonging to the ecological and geographical cultivar type of samples of East Asian leafy crops of *Brassica rapa* L. from the VIR collection selected for study (biopolygon of the Agrophysical Research Institute, St. Petersburg, 2019)

Catalog No.	Name	Varietytype/subtype	Origin
	Chinese cabbage *Brassica rapa* L. subsp. *pekinensis* (Lour.) Hanelt		
k-74	Xiaobaikou	Xiao	China
k-112	Round Shantung	Shantung	Japan
k-123	Xiaobaikou	Xiao	China
k-126	Kairyochitose	Matsushima	Japan
k-177	Chokurei	Shantung	Japan
k-185	Mestnyi	Xiao	China
k-201	Hsiao Pai kou pai tsai	Kasin	China
k-227	Pyacha	Xiao	Kazakhstan
k-230	Digeson	Xiao	Korea
k-236	Untitled	Chosen	Mongolia
k-252	Untitled	Santo	Japan
k-270	Harumaki Shin Santousai	Santo	Japan
k-294	Xinfeng 2	Shantung	China
k-306	Zelenaya Malenkaya 1	Kasin	Korea
k-307	Osennyaya 3	Kasin	Korea
k-309	Chammad-baechu	Chosen	Korea
k-311	Pyongyang 2	Kasin	Korea
k-329	Maruba Santo	Santo	Japan
k-359	Nagaoka F_1 Azuma	Shantung	Japan
k-387	Untitled	Xiao	China
k-395	Tokyo Bekana	Santo	Japan
k-406	Shantung Tropical Round (F_1)	Shantung	Japan
k-410	Shirokuki Santousai	Santo	Japan
k-440	Hakata Chirimen	Chirimen	Japan
k-457	Osennyaya 2	Chosen	Korea
k-497	No. 55	Kasin	China
k-578	Teplichnaya 56	Kasin	China
k-629	Yoko F_1	Datsinkou	The Netherlands
k-645	Beijingxiaoza 56	Kasin	China
vr.k-965	Kikunishiki F1	Kaga	Japan
vr.k-1120	Zao Shi No. 5	Shantung	China
vr.k-1375	Untitled	Chosen	Kyrgyzstan
vr.k-1376	Bitse	Santo × Hatou	Kyrgyzstan
vr.k-1400	Chirimen Hakusai	Chirimen	USA
vr.k-1410	Funjen F_1	Santo	USA
vr.k-1557	MiniRaioh F_1 50	Matsushima	Japan
	Pakchoi *Brassicarapa* L. subsp. *chinensis* (L.) Hanelt		
k-116	Taisai	Taisai	Japan
k-470	F_1 Mei Qing Choi	Syusman	The Netherlands
k-529	Zelenaya 9	Syusman	China
k-538	Green Boy	Piorbai	China
k-558	Joi Choi	Joy Choi	China
k-583	94 No. 6	Chinese × rosellate	China

Continued Table 1

k-584	Xia L V No. 2 Pakchoi	Syusman	China
k-585	Lingguan No. 1 PC	Syusman	China
k-647	Untitled	Taisai	Tajikistan
vr.k-932	Pack Choi F_1	Piorbai	Japan
vr.k-1107	Heiyekuishantian	Chinese × rosellate	China
vr.k-1124	Gai Lang Jin Pin 25 F_1	Syusman	China
vr.k-1128	Hanging	Syusman	China
vr.k-1130	Wuyemanyoucai	Syusman	China
vr.k-1131	Kangre 605	Syusman	China
vr.k-1251	Untitled	Syusman	China
vr.k-1343	Shatu	Syusman	China
vr.k-1403	Chinese Pack Choi	Piorbai	USA
vr.k-1404	Dwarf Pack Choi	Joy Choi	USA
vr.k-1405	Extradwarf Pack Choi	Joy Choi	USA
vr.k-1406	Petitestar F_1	Babysyusman	USA
vr.k-1408	Redchoi F_1	Syusman × Piorbai	USA
vr.k-1521	Untitled	Leychoy	Kyrgyzstan
	Tatsoi *Brassica rapa* L. subsp. *narinosa* (Bailey) Hanelt		
k-695	Xiao Ba Je Ta Cai	Tatsai	China
vr.k-1398	Yukina Savoy	Chrysanthemum	USA
vr.k-1409	Redtatsoi F_1	Tatsai	USA
	Wutacai *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt var. *pupuraria* Kitam		
vr.k-1357	Untitled	Untitled	The Netherlands
vr.k-1358	Untitled	Untitled	Unknown
	Mizuna *Brassica rapa* L. subsp. *nipposinica* (Bailey) Hanelt		
k-463	Shirojuki Sensujo Kyo Mizuna Nakate	Mizuna	Japan
k-506	Sensuji Kio Mizuna	Mizuna	Japan
bp. k-1360	Untitled	Mizunamagenta	The Netherlands
	Leafy turnip *Brassica rapa* L. subsp. *rapifera* Hook. var. *komatsuna* Makino		
k-335	Hiroshimana	Hiroshimana	Japan
k-598	Dapungrudatoubaixinie	Chinese × leafy turnip	China
vr.k-1371	Selecta	Komatsuna	Russia
vr.k-1372	Biryuza	Komatsuna	Russia
vr.k-1418	Komatsuna	Komatsuna	USA

The set of Chinese cabbage studied in this work included mainly early-maturing samples of semihead Shantung type (including the Santo subtype with exceptional salad qualities), Xiao, open-topped head Kasin and Chosen, as well as some samples of common head Chifu type (the Matsushima subtype from Japan), Kaga, Dacinkou, a hybrid between the Santo and Hetou types, as well as the leafy type Chirimen, bearing the features of a leafy turnip (the presence of a short petiole and a thickened root). The samples are salad, with a compact leaf rosette, a large leaf lamina (often length is more than 40 cm), a dense consistency, without hairiness or with weak soft hairiness. The rosette leaves are directed mainly obliquely upright [30].

The study included all cultivar types of pakchoi, except for the relatively late-maturing Yutsai. Cultivars of the Taisai type have a closed rosette of upright leaves, with a very long (more than 25 cm) white or pale green petiole. The Piorbai type with a semi-spreading rosette and relatively numerous leaves on petioles of medium length (15-20 cm) includes productive samples, often resistant to alternariosis and peronosporosis, with a dense, tender consistency of a dark green leaf lamina and a light green petiole.

The most popular samples of pakchoi belong to the Syusman type. This is a typical pakchoi, with a compact leaf rosette of the "vase" type, often the plants are resistant to thickening. Petioles are relatively short (8-13 cm), very wide (5-7 cm), thick, light green. Special attention should be paid to the samples of mini-pak-choi (baby-pak-choi), very early-maturing (25-28 days), with a small compact rosette (15-18 cm).

The Leychoi type is represented by stable hybrids between samples of the Yutsai and Syusman types, tatsoi, and leafy turnip. They are characterized by thick bright white petioles of shiny dark green convex leaves, relatively high productivity (5-7 kg/m^2), resistance to bolting. In samples of a similar type of Joychoi, the leaf rosette is small (18-20 cm), spreading and semi-spreading, the leaves are weekly uprisen, the consistency of the leaves is very dense, crisp.

Tatsoi samples are characterized by a compact leaf rosette with obliquely upright (Chrysanthemum) and slightly raised numerous indistinctly lyre-shaped leaves (Tatsai, flat cabbage, black Chinese cabbage); petioles are short and of medium length (6-13 cm), narrow, green, leaf lamina of deep dark green color, shiny, convex, plicate-rugate. Tatsoi includes cultivars with a leaf rosette of small and very small sizes (12-18 cm), decorative, similar to a flower. The samples are low-yielding but have a very valuable biochemical composition, 35-60 mg/100 g ascorbic acid, 125-230 mg/100 g chlorophylls, and 4-7 mg/100 g β-carotene.

Samples of Japanese cabbage of the Mizuna type with strongly dissected leaves are decorative, with a semi-spreading rosette, resistant to bolting. Wutacai samples have long petioles (20-25 cm), upright and obliquely upright, purple; they are characterized by a high content of biologically active substances with average productivity.

Leafy turnip leaves are large, upright, entire and lyre; petioles are long (15-25 cm) and of medium length, light green. The samples are productive, resistant to bolting, and used after cooking.

Thus, the formed set of samples of *B. rapa* leafy crops had a potential diversity of qualitative characteristics and adaptive responses to environmental conditions, including light and temperature.

The main limit factor when growing *brassicas* crops in winter and early spring periods in greenhouses is insufficient illumination. It is shown [31] that at low illumination, plant adaptations manifest themselves in the enhanced development of the light-harvesting complex due to an increase in the assimilation surface and the number of photosynthetic pigments, with more economical use of assimilates for growth with a decrease in the specific surface density (SSD) of leaves, although an increase in SSD was observed in tuberous rooted mustard plants with strongly dissected leaves. For example, Tohoku Hakusai turnip plants were distinguished by increased shade tolerance compared to a sample of k-18 rooted mustard [31]. In low illumination conditions, turnip plants had an increased leaf area and an increased content of photosynthetic pigments [31].

The length of the light period (12-hour day) and high illumination in biopolygon conditions prevent the transition of long-day plants of the species to the reproductive phase of ontogenesis. Most crops of the *B. rapa* species are cold-resistant, in the centers of diversity formation they are often grown in the autumn, winter, and early spring periods, usually in fertile soil with a large space (especially Chinese cabbage). To identify samples with a stable display of valuable traits associated with productivity, we studied the morphophysiological features of the genetic diversity of the selected samples under light installation conditions at temperatures above the biological requirements of crops, in a thin layer of soil substrate, and at different luminous power. In addition, we took into account the fact that in the absence of separate rooms for each crop, the temperature regime is determined by the requirements of crops with a narrow reaction rate, grown together with greengrocers (in this study tomato and cucumber).

The leaves are the main photosynthetic and food organ of green *brassicas* crops. The important features that characterize the activity of the photosynthetic apparatus of plants include the leaf surface area. The area of the leaves in the study of the photosynthetic apparatus is determined in modern conditions using a photoplanimeter or a digital image analysis system SIMAGIS ®MesoPlant™ (Smart Imaging Technologies Co., USA). At the same time, methods for calculating the leaf area from easily measured linear dimensions also retain value. The leaf area of some vegetable crops can be calculated using the regression equations according to Konyaev [32, 33]. Young entire leaves of Chinese cabbage and leafy turnip are most similar in shape to the leaves of white cabbage young plants, and the lyrate-sected leaves of mizuna are most similar to the leaves of radish, for which Konyaev proposed calculation formulas. Nikolenko and Kotov proposed a method for calculating the area of a strawberry leaf, Kiseleva for the area of a pear leaf [34, 35]. In the available literature, we did not find the leaf area calculations for pakchoi, wutacai, tatsoi, and crops with a similar leaf shape. In addition, the type and shape of the leaf lamina of samples of the same crop, primarily pakchoi and Chinese cabbage, which include a wide diversity of morphotypes, differ significantly. The leaves of the adult Chinese cabbage plant are mostly entire sitting, whereas the first true leaves in most samples are entire with a petiole of different length. The calculated coefficients obtained by the authors for determining the leaf area of the studied images differ (Table 2). For calculations based on the photo, the leaf was inscribed in a rectangle, the length and width of which correspond to the largest length and width of the plant leaf (excluding the petiole). The correction factor for the analyzed leaf was the quotient of dividing the leaf area in pixels by the rectangle area. The average for 5 leaves was taken as the average correction factor for the studied plant, then the coefficients for each sample were calculated as the average of five plants in the sample. By grouping the samples by leaf type, the authors found the average values for each leaf type.

2. Correction factors obtained for calculating the leaf surface area of samples of East Asian *brassicas* crops from the VIR collection (n = 5, biopolygon of the Agrophysical Research Institute, St. Petersburg, 2019)

Leaf type	Leaf lamina shape	Coefficients		
		min	max	mean
Chinese cabbage *Brassica rapa* L. subsp. *pekinensis* (Lour.) Hanelt				
Entire	Broad-lanceolate	0.567	0.802	0.671±0.055
	Elongate inversely egg-shaped	0.607	0.628	0.618±0.012
	Inversely egg-shaped	0.646	0.672	0.660±0.027
	Oval	0.684	0.698	0.690±0.011
	Wide-oval	0.717	0.748	0.729±0.031
	Rounded	0.778	0.802	0.790±0.035
Pakchoi *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt				
Lyre-shaped	Truncated-elliptical/oval	0.552	0.821	0.651±0.073
Unclear lyre-shaped	Truncated-elliptical/oval	0.633	0.645	0.640±0.018
Entire	Egg-shapedt	0.660	0.682	0.672±0.230
	Oval	0.690	0.719	0.703±0.238
	Rounded	0.733	0.794	0.765±0.042
	Wide-round	0.805	0.821	0.818±0.016
Tatsoi *Brassica rapa* L. subsp. *narinosa* (Bailey) Hanelt				
Unclear lyre-shaped	Wide-oval	0.645	0.655	0.649±0.016
Mizuna *Brassica rapa* L. subsp. *nipposinica* (Bailey) Hanelt				
Lyre-shaped	Unpaired pinnatis sected	0.443	0.464	0.451±0.011
Wutacai *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt var. *pupuraria* Kitam				
Entire	Oval	0.663	0.721	0.692±0.041
Leafy turnip *Brassica rapa* L. subsp. *rapifera* Hook. var. *komatsuna* Makino				
Entire	Wide-egg shaped/wide-oval	0.791	0.814	0.801±0.028

It was reported [31] that reduced illumination caused the formation of a larger leaf surface area in turnips and mustard. In our studies, the size of the leaf rosette, the number of leaves, and the linear dimensions of the leaf lamina of *brassicas* crops, depending on the illumination, differed on average by 9-25% (Table 3, Fig. 1) and were in all cases larger in high illumination conditions. This conclusion is consistent with the results of the study of cutting lettuce *Lactuca sativa* L. [35-37], tatsoi [38], and wutacai [39] at different levels of irradiation.

3. Morphological characteristics and yield in samples of East Asian *brassicas* crops from the VIR collection in the intensive artificial lighting at different levels of illumination (n = 5, M±SEM; biopolygon of the Agrophysical Research Institute, St. Petersburg, 2019)

Illumination level	Rosette dimensions, cm		Number of leaves, pcs.	Leaf lamina dimensions, cm		Area of one leaf lamina/leaf surface of the plant, cm^2	Plant weight, g	Yield, kg/m^2
	height	diameter		length	width			
Chinese cabbage *Brassica rapa* subsp. *pekinensis Brassica rapa* L. subsp. *pekinensis* (Lour.) Hanelt (36 samples)								
High (15-20 klx)	26.60±0.83	26.50±0.71	8.60±0.24	25.70±0.80	11.90±0.37	204.91/1762.23	50.40±3.49	6.30±0.32
Cv, %	19.56	16.65	17.44	19.37	19.61		43.26	
Low (10-15 klx)	23.80±0.65	24.20±0.56	8.20±0.21	22.90±0.67	10.40±0.30	159.57/1308.47	33.90±2.25	4.24±0.23
Cv, %	16.49	13.97	15.55	17.55	17.44		39.79	
Pak choi *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt (23 samples)								
High (15-20 klx)	23.30±0.94	19.80±1.14	8.30±0.29	11.20±0.58	8.80±0.40	73.92/613.54	41.50±4.01	5.19±0.37-8.30±0.57[a]
Cv, %	19.78	28.26	17.08	25.26	22.21		48.33	
Low (10-15 klx)	19.90±1.13	15.80±1.04	7.90±0.33	9.20±0.60	7.30±0.44	50.37/397.92	30.10±3.59	3.76±0.31-6.02±0.48[a]
Cv, %	27.32	31.68	20.42	31.29	29.11		57.38	
Tatsoi *Brassica rapa* L. subsp. *narinosa* (Bailey) Hanelt (3 samples)								
High (15-20 klx)	22.00±1.55	20.70±2.02	15.40±6.21	9.40±1.33	7.20±0.88	43.99/677.45	33.60±3.30	4.20±0.28-6.72±0.49[a]
Cv, %	15.76	21.81	69.73	31.71	27.34		21.96	
Low (10-15 klx)	17.90±1.16	17.50±2.9	13.60±2.91	7.50±1.15	6.50±0.94	31.69/430.98	25.90±8.27	3.24±0.49-5.18±0.78[a]
Cv, %	11.21	28.68	47.86	26.36	25.14		55.36	
Mizuna *Brassica rapa* L. subsp. *nipposinica* (Bailey) Hanelt (3 samples)								
High (15-20 klx)	23.60±1.91	19.10±0.93	13.70±4.12	10.70±0.45	7.10±0.29	34.19/468.40	22.70±1.97	2.84±0.22
Cv, %	14.00	8.45	52.03	7.30	7.06		15.00	
Low (10-15 klx)	20.80±0.20	17.20±1.25	12.10±3.23	9.80±0.91	7.10±0.74	31.31/378.85	17.80±1.39	2.23
Cv, %	1.67	12.58	46.16	16.09	18.20		13.49	
Wutacai *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt var. *pupuraria* Kitam (2 samples)								
High (15-20 klx)	23.10±1.30	22.40±3.00	5.70±0.30	10.30±1.45	8.50±1.25	60.58/345.31	19.50±0.50	2.44±0.06-3.90±0.08[a]
Cv, %	7.96	18.94	7.44	20.01	20.92		3.59	
Low (10-15 klx)	21.50±1.10	19.00±0.40	5.30±0.10	8.60±0.25	7.40±0.60	44.04/233.41	14.60±3.93	1.83±0.27-2.92±0.44[a]
Cv, %	7.24	2.98	2.67	4.14	11.47		37.99	
Leafy turnip *Brassica rapa* L. subsp. *rapifera* Hook. var. *komatsuna* Makino (5 samples)								
High (15-20 klx)	29.00±3.16	29.90±5.19	8.30±0.78	24.70±3.65	12.60±1.54	248.98/2066.53	63.80±14.40	7.98±1.11-12.76±1.91[a]
Cv, %	24.41	34.80	21.03	33.07	27.35		50.47	
Low (10-15 klx)	24.40±2.47	27.20±3.16	7.60±0.64	20.30±2.93	10.50±1.21	170.52/1295.95	33.70±7.37	4.21±0.63-6.74±01.01[a]
Cv, %	22.64	26.01	18.82	32.28	25.84		48.88	
Averaged	23.00±0.62	21.60±1.07	9.60±0.80	14.20±1.77	8.80±0.50	96.20±19.23/831.60±149.65	32.30±3.04	
LSD_{05}	1.85	3.20	2.39	5.32	1.49	57.69/448.96	9.13	

Note. The values ([a]) are given for a group of samples grown according to the 5×10 cm seeding scheme.

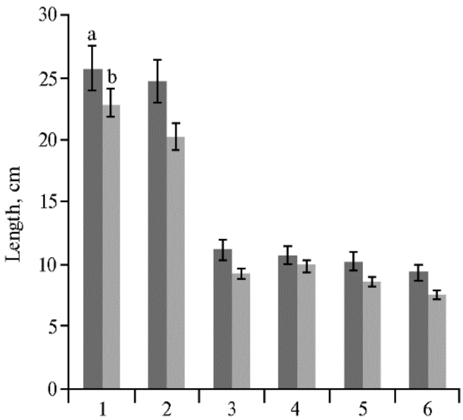

Fig. 1. Leaf lamina length in samples of East Asian *brassicas* crops from the VIR collection in the intensive artificial lighting at high illumination (a, 15-20 klx) **and low illumination** (b, 10-15 klx)**:** 1 — *Brassica rapa* L. subsp. *pekinensis* (Lour.) Hanelt, 2 — *Brassica rapa* L. subsp. *rapifera* Hook. var. *komatsuna* Makino, 3 — *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt, 4 — *Brassica rapa* L. subsp. *nipposinica* (Bailey) Hanelt, 5 — *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt var. *pupuraria* Kitam, 6 — *Brassica rapa* L. subsp. *narinosa* (Bailey) Hanelt (n = 5, M±SEM; biopolygon of the Agrophysical Research Institute, St. Petersburg, 2019).

Significant differences were noted for the rosette height in all crops (except for wutacai), the lamina width, the plant weight, and the yield of pakchoi, Chinese cabbage, and leafy turnip, the leaf surface area of the leafy turnip.

In all likelihood, it is due to the plant nutrition area, which is close to optimal under these growing conditions, allowing plants to avoid mutual shading, and the presence of a relatively large number of shade-tolerant genotypes, as well as the optimal regime of mineral nutrition. At the same time, the leaf surface area of one plant between the crops differed depending on the illumination by 24-59%, while the smallest difference between the leaf surface area with different illumination was noted in mizuna, the largest – in leafy turnip, pakchoi and tatsoi.

The coefficients of variation of the morphological characteristics of each crop, regardless of the illumination, were average and did not exceed 20% in the samples of Chinese cabbage and wutacai, as well as in tatsoi and mizuna (in the latter two crops – except for a highly variable number of leaves), that is, the growth strength (size) of the plants studied samples of *brassicas* crops were close. The samples of pakchoi and leafy turnip differed significantly with coefficients of variation up to 32% in pakchoi, up to 35% in leafy turnip.

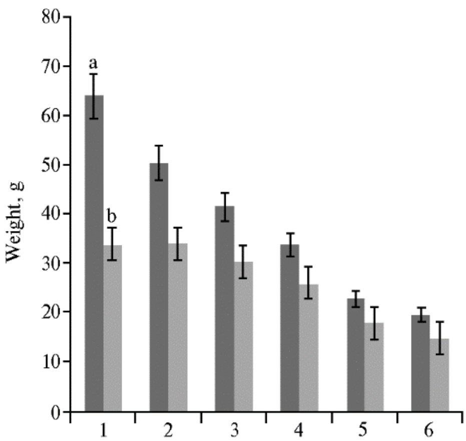

Fig. 2. Plant weight in samples of East Asian *brassicas* crops from the VIR collection in the intensive artificial lighting at high illumination (a, 15-20 klx) **and low illumination** (b, 10-15 klx)**:** 1 — *Brassica rapa* L. subsp. *rapifera* Hook. var. *komatsuna* Makino, 2 — *Brassica rapa* L. subsp. *pekinensis* (Lour.) Hanelt, 3 — *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt, 4 — *Brassica rapa* L. subsp. *narinosa* (Bailey) Hanelt, 5 — *Brassica rapa* L. subsp. *nipposinica* (Bailey) Hanelt, 6 — *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt var. *pupuraria* Kitam (n = 5, M±SEM; biopolygon of the Agrophysical Research Institute, St. Petersburg, 2019).

The differences in plant weight and, accordingly, yield depending on the illumination was significant (more than LSD_{05} 9.13 g) and especially significant in leafy turnip and Chinese cabbage, to a lesser extent in pakchoi; the excess plant weights of wutacai, tatsoi, and mizuna at a high level of illumination were unreliable (see Table 3, Fig. 2). The variability in plant weight was very strong between the samples of pakchoi and Chinese cabbage, and leafy turnip (coefficients of the trait variation were 40-57%).

A relatively low yield (more than 2 times lower than the yield of Chinese cabbage and leafy turnip) was noted in mizuna and wutacai, but the decorative and valuable biochemical composition, especially the high content of chlorophylls, carotenes, and anthocyanin [7] make them also promising for growing in artificial lighting.

All the studied quantitative characteristics (plant size and weight) correlate to a high degree (correlation coefficients r = 0.72-0.98; $p \leq 0.05$), including the average leaf surface area and plant weight of the studied set of samples that are strongly correlated (r = 0.88; $p \leq 0.05$). The number of leaves is associated with a weak to medium-strength inverse correlation dependence (r from –0.11 to –0.38; $p \leq 0.05$) with all indicators of the size of the rosette and leaves and does not correlate with the plant weight.

Among the studied samples of *brassicas* crops, the authors identified sources for breeding for early maturity, productivity, and resistance to early bolting and marginal blight. Thus, 44% of the samples of Chinese cabbage from the studied set had a plant weight higher than the average (yield higher than 6.3 kg/m^2) in high illumination conditions; in particular, 9 samples of mainly salad types of Shantung, Santo, Xiao had a yield of more than 7.5 kg/m^2, that is, 22-109% higher than the average for the crop. All these samples formed a high yield in 28 days, that is, they showed early maturity. The highest plant weight among the samples of Chinese cabbage was observed in the line isolated from the Japanese hybrid of the semi-headed Shantung type Shantung Tropical Round F_1 (k-406) (105.40±17.50 g) and in local Chinese samples of the Xiao type k-185 (97.00±22.25 g), and k-123 (73.90±6.31 g). However, with a decrease in illumination, their productivity fell by 46-125%, which indicates their high demands on the illumination level (Table 4).

4. Variability of productivity indicators in perspective samples of East Asian *brassicas* crops from the VIR collection in the intensive artificial lighting depending on the illumination level (n = 5, M±SEM; biopolygon of the Agrophysical Research Institute, St. Petersburg, 2019)

Catalog No.	Sample name	Leaf surface area, cm^2		Plant weight, g		Yield, kg/m^2	
		high	low	high	low	high	low
Chinese cabbage *Brassica rapa* subsp. *pekinensis* *Brassica rapa* L. subsp. *pekinensis* (Lour.) Hanelt							
k-406	Shantung Tropical Round (F_1)	3106.55	1460.67	105.40±17.50	46.80±3.71	13.18±1.80	5.85±0.45
k-185	Mestnyi	3191.37	2682.94	97.00±22.25	55.50±8.72	12.13±1.98	6.94±0.70
k-270	Harumaki Shin Santousai	3143.61	3473.24	86.40±6.97	71.70±5.98	10.80±0.65	8.96±0.54
k-629	Yoko F_1	2368.28	1952.48	82.40±7.23	68.20±3.48	10.31±0.72	8.52±0.34
vr.k-1120	Zao Shi No. 5	1273.59	934.61	77.40±7.50	58.60±1.85	9.68±0.78	7.32±0.22
k-123	Xiao bai kou	1908.81	1444.41	73.90±6.31	50.50±2.90	9.24±0.74	6.32±0.25
vr.k-1410	Funjen F_1	2191.75	1446.71	71.50±5.46	47.70±1.27	8.93±0.63	5.97±0.16
vr.k-1376	Bitse	2050.61	1602.77	68.60±8.00	48.50±2.50	8.57±0.86	6.06±0.24
k-395	Tokyo Bekana	2006.45	1557.81	65.90±16.80	62.80±10.33	8.24±1.49	7.85±1.01
k-74	Xiao bai kou	1938.98	1636.79	65.70±4.11	56.30±5.80	8.21±0.37	7.04±0.56
k-457	Osennyaya 2	2158.34	2081.80	59.50±6.08	53.40±4.58	7.44±0.51	6.68±0.46
Pakchoi *Brassica rapa* L. subsp. *chinensis* (L.) Hanelt							
k-116	Taisai	1087.59	901.55	82.80±17.10	65.10±12.15	12.85±2.31	8.14±1.38
vr.k-1128	Hanging	899.90	742.28	77.20±13.25	57.90±7.91	9.65±1.54	7.24±0.80
vr.k-1131	Kangre 605	836.71	828.79	67.20±8.52	64.70±3.82	8.40±0.92	8.09±0.48
vr.k-1124	Gai Lang Jin Pin 25	675.73	576.68	54.80±6.30	55.10±7.51	6.85±0.62	6.89±0.88
vr.k-932	Pack Choi	606.21	494.74	50.50±7.88	42.90±4.25	6.31±0.82	5.36±0.43
vr.k-1405	Extra dwarf PC	415.81	324.56	44.70±5.94	42.30±6.39	8.95±0.90	8.46±1.02
Tatsoi *Brassica rapa* L. subsp. *narinosa* (Bailey) Hanelt							
k-695	Xiao Ba Je Ta Cai	613.86	544.99	40.10±4.38	39.70±5.17	8.01±0.64	7.94±0.80
vr.k-1398	Yukina Savoy	721.59	539.01	32.30±2.37	26.10±3.30	6.45±0.38	5.23±0.53
Leafy turnip *Brassica rapa* L. subsp. *rapifera* Hook. var. *komatsuna* Makino							
vr.k-1418	Komatsuna	3720.04	2966.65	102.20±11.10	61.50±17.27	12.78±1.28	7.69±1.69
k-335	Hiroshimana	3307.82	1084.51	90.30±9.50	30.00±4.18	11.29±0.91	3.75±0.43
vr.k-1372	Biryuza	2533.19	1755.17	75.00±4.16	52.70±2.15	9.38±0.37	6.59±0.20
vr.k-1371	Selecta	1263.09	896.37	68.70±7.88	46.40±2.94	8.59±0.86	5.80±0.35

In addition, the old Japanese cultivars of type Santo Harumaki Shin Santousai (k-270) (86.40±6.97 g) and Tokyo Bekana (k-395) (65.90±16.80 g), and the old Chinese sample of the type Xiao Xiao bai kou (k-74) (65.70±4.11 g) were distinguished by a high plant weight, while the morphological parameters of plants, including their weight, decreased by no more than 5-20% with reduced illumination, and the highest stability was achieved by the Tokyo Bekana sample which showed traits at different illumination conditions (the differences between the plant weight indicators at high and low illumination conditions are 3 times lower than LSD_{05}).

The remaining samples of Chinese cabbage were characterized by a yield of less than 6.3 kg/m^2 and a reduced growth rate. Despite the resistance of most of them to low illumination, they are not recommended for intensive artificial lighting, although they can be included in breeding programs as sources of adaptability, such as the Korean cultivars with high leaf quality traits Osenyaya 2 (k-457) of the Chosen cultivar type.

Three samples of pakchoi in high illumination had a plant weight of more than 60 g: this is an old Japanese sample with the long-petiole Taisai type (k-116) (82.80±17.10 g) and modern Chinese cultivars of the Syusman type with a closed compact rosette Hanging (vr.k-1128), and Kangre 605 (vr.k-1131) (77.20±13.25 and 67.20±8.52 g, respectively), while for the first two cultivars, the trait values under high illumination level were 27-33% higher, and of the last one were almost independent of the illumination level.

The representatives of the Piorbai, Syusman, Joychoy, and Leychoy cultivar types — four modern pakchoi cultivars from China, Japan, and the United States had a plant weight of 50-60 g, and four other samples from China, the United States, and Kyrgyzstan 40-50 g. The samples of pakchoi high-yielding Gai Lang Jin Pin 25 F_1 (vr.k-1124) and Pack Choi F_1 (vr.k-932) with an average yield practically did not react to the change in illumination. Samples of pakchoi with a yield below 5 kg/m^2 are not recommended for growing in artificial lighting culture.

Among the studied samples with consistently high productivity, there were samples with a super-compact rosette, i.e., pakchoi Extra Dwarf Pack Choi (vr.k-1405) (8.46-8.95 kg/m^2) and tatsoi of Xiao Ba Je Ta Cai (k-695) (7.94-8.01 kg/m^2), suitable for thickened cultivation with a planting scheme of 10×5 cm. The samples are squat, they can be grown at a distance between the shelves no more than 30 cm, if modern LED lamps with high efficiency are used as light sources, which emit significantly less heat energy than the DNaZ-400 lamp. For thickened cultivation, a sample of tatsoi Yukina Savoy (vr.k-1398) (yield 5.20-6.40 kg/m^2) with relatively stable productivity and a very valuable biochemical composition is also of interest.

The studied samples of mizuna for 28 days could not form a plant weight higher than 25 g, while in two cultivars, the excess plant weight under high light was 36-66%; in the mizuna cultivar with red-purple leaves (vr.k-1360), the productivity parameters were the lowest (2.05-3.80 kg/m^2, depending on the illumination level). With thickened cultivation, the yield of mizuna in high illumination was 3.80-5.10 kg/m^2, it was the highest (5.10±0.48 kg/m^2) in the Japanese cultivar Shirojuki Sensujo Kyo Mizuna Nakate (k-463).

Samples of wutacai from the Netherlands also require longer cultivation: for 28 days, the plant weight was 19-20 g only, and in the sample vr.k-1357, it practically did not depend on illumination.

Four samples of leafy turnip Komatsuna and Hiroshimana types showed good productivity. Under high illumination conditions, the plant weight in the

Komatsuna sample (vr.k-1418, USA) was 102.20±11.10 g, in the Hiroshimana sample (k-335, Japan) 90.30±9.50, in the Russian cultivars Selekta (vr.k-1371) and Biryuza (vr.k-1372) 68.70-75.00 g, that is, the yield reached 8.59-12.78 kg/m^2. However, in low illumination conditions, the productivity of all leafy turnip samples fell by 43-81%.

Some of the studied samples formed a high plant weight with a small leaf surface area, for example, the Chinese sample of Chinese cabbage Zao Shi No. 5 (vr.k-1120), the Russian cultivar of leafy turnip Selecta (vr.k-1371), which indicates the intensive work of their photosynthetic apparatus.

The *brassicas* samples were mostly resistant to early bolting, although up to 10% of the plants entered to bolting of three samples of Chinese cabbage, two samples of pakchoi, and one sample of leafy turnip (all samples of South Chinese and Japanese origin).

In Chinese cabbage of the Kasin type (headed with an open-top) and three samples of the Shantung and Xiao types, the onset of the marginal blight was observed – a physiological disorder caused by calcium deficiency (observed mainly in headed Chinese cabbage, which develops rapidly at elevated temperature and humidity).

5. Variability of plant size and weight in samples of pakchoi and tatsoi *Brassica rapa* L. from the VIR collection under different growing conditions (n = 5, M±SEM; biopolygon of the Agrophysical Research Institute, St. Petersburg, winter glazed greenhouse and experimental open field of Pushkin laboratories VIR, Leningrad Province, 2019)

Growing conditions	Dimensions, cm				Plant weight, g	Yield, kg/m^2
	leaf rosette		leaf lamina			
	diameter	height	length	width		
Sample Gai Lang Jin Pin 25						
Biopolygon:						
high illumination (15-20 klx)	24,40±0,92	16,20±0,8	11,10±0,55	8,20±0,49	54,76±5,88	5,48±0,49
low illumination (10-15 klx)	22,00±1,89	15,00±0,95	10,40±0,51	7,60±0,51	55,28±6,83	5,53±0,61
Greenhouse	24,30±1,38	15,30±0,91	10,10±0,74	7,30±0,62	52,20±6,43	5,22±0,57
Field	22,10±1,47	14,80±0,83	9,70±0,73	7,00±0,65	50,60±6,21	5,06±0,53
Cv, %	3,22	3,18	5,15	4,35	3,82	3,91
Sample Kangre 605						
Biopolygon:						
high illumination (15-20 klx)	26,20±1,74	20,40±1,12	12,60±0,74	9,60±0,58	65,22±4,78	6,52±0,38
low illumination (10-15 klx)	25,80±0,86	22,00±1,86	13,80±0,97	10,20±0,38	66,88±7,94	6,69±0,72
Greenhouse	24,30±1,28	21,40±1,33	13,00±1,12	9,20±0,35	61,40±5,15	6,14±0,46
Field	23,70±0,92	20,60±1,75	12,50±0,87	9,10±0,43	60,20±4,83	6,02±0,42
Cv, %	5,28	4,47	3,90	3,82	4,95	5,04
Sample Extra dwarf Pack Choi						
Biopolygon:						
high illumination (15-20 klx)	18,60±0,74	10,00±0,54	7,30±0,58	8,90±1,32	42,30±6,39	8,46±1,02
low illumination (10-15 klx)	18,40±0,86	9,00±0,32	6,50±0,71	8,30±0,70	44,70±5,94	8,95±0,78
Greenhouse	17,40±0,92	10,80±0,45	7,20±0,47	7,80±0,82	41,10±5,11	8,22±0,83
Field	17,00±1,14	9,10±0,28	6,60±0,52	7,40±0,57	40,80±5,43	8,16±1,06
Cv, %	5,31	4,82	6,45	5,38	6,07	6,24
Sample Xiao Ba Je Ta Cai						
Biopolygon:						
high illumination (15-20 klx)	20,80±1,31	13,40±0,59	6,40±0,69	5,90±0,29	39,70±5,17	7,94±0,80
low illumination (10-15 klx)	19,40±0,94	13,60±0,51	5,80±0,20	5,20±0,30	40,10±4,38	8,01±0,64
Greenhouse	20,20±0,85	12,30±0,62	5,70±0,44	5,70±0,47	36,50±4,12	7,32±0,66
Field	20,90±0,12	13,36±0,93	6,40±0,54	5,40±0,38	35,60±3,61	7,11±0,57
Cv, %	3,25	4,14	5,26	3,38	5,66	5,79

The highest salad quality of leaves was recorded in samples of Chinese cabbage Chokurei (k-177), Tokyo Bekana (k-395), Zao Shi No. 5 (k-1120), and Fun jen F_1 (k-1410). In terms of quality, the samples of vr.k-1375 and Bitse (vr.k-1376) from Kyrgyzstan with an erect rosette of upright leaves are also of interest, as well as a sample of pakchoi k-647 with a green petiole from Tajikistan.

In the studied set, among the samples of pakchoi and tatsoi we identified highly stable, preserving morphological and phenological parameters in contrasting conditions of open field, greenhouses, and agricultural biopolygon, with very low variability of traits, which is mainly determined by the genotype. These are some modern cultivars, including, most likely, those carrying dwarfism *dwf* genes [40] (Table 5). The selected forms, in our opinion, should be included in the breeding process.

Thus, as a result of the research, it was found that the increase in plant productivity of all leafy crops of the *Brassica rapa* species was largely determined, as a rule, by the light flux intensity. For the conditions of intensive artificial lighting, the most high-yielding (more than 6.3 kg/m^2) samples of cabbage and leafy turnip, as well as some samples of pakchoi, were selected. The studied samples of wutacai and mizuna are low-yielding and have a longer growing period, but are of interest as vegetables for functional nutrition and decorative purposes. The Chinese cabbage types (Shantung, Santo, Xiao), which are of primary interest for artificial lighting, have been identified. Under biopolygon conditions, we found perspective samples with a complex of valuable traits for various directions of breeding. Thus, the samples of Chinese cabbage Harumaki Shin Santousai (k-270), Tokyo Bekana (k-395), Xiaobaikou (k-74), pakchoi Kangre 605 (vr.k-1131), Gai Lang Jin Pin 25 F$_1$ (vr.k-1124) showed stable early maturity and high productivity almost independently of the level of illumination. It is shown that the Chinese sample of Chinese cabbage Zao Shi No. 5 (vr.k-1120) and the Russian cultivar of leafy turnip Selecta (vr.k-1371) have the increased photosynthesis intensity. Samples of Chinese cabbage vr.k-1375, Bitse (vr.k-1376), pakchoi k-647 are recommended for thickening conditions, pakchoi Extra Dwarf Pack Choi (vr.k-1405) and tatsoi Xiao Ba Je Ta Cai (k-695) for thickened cultivation at a small distance between shelves. Samples of Chinese cabbage with very high salad quality of leaves were identified — Chokurei (k-177), Tokyo Bekana (k-395), Zao Shi No. 5 (k-1120), Fun jen F$_1$ (vr.k-1410). The obtained data reveal some features of the reaction of different genotypes of *brassicas* crops of the *B. rapa* species to changes in the illumination level and increased temperature. The morphophysiological diversity of the studied forms will make it possible to manage the production process in vegetable growing more effectively, and the identified samples can be used as sources of valuable traits in the selection of specialized varieties for city farming.

REFERENCES

1. Pivovarov V.F., Startsev V.I. *Kapusta, ee vidy i raznovidnosti* [Cabbage types and varieties]. Moscow, 2006 (in Russ.).
2. *Plant factory: an indoor vertical farming system for efficient quality food production*. T. Kozai, G. Niu, M. Takagaki (eds.). Academic Press, 2019.
3. Beacham A.M., Vickers L.H., Monaghan J.M. Vertical farming: a summary of approaches to growing skywards. *The Journal of Horticultural Science and Biotechnology*, 2019, 94(3): 277 (doi: 10.1080/14620316.2019.1574214).
4. Dou H., Niu G., Gu M., Masabni J. Morphological and physiological responses in *Basil* and *Brassica* species to different proportions of red, blue, and green wavelengths in indoor vertical farming. *Journal of the American Society for Horticultural Science*, 2020, 145(4): 267-278 (doi: 10.21273/JASHS04927-20).
5. Park J.E., Kim J., Purevdorj E., Son Y.J., Nho C.W., Yoo G. Effects of long light exposure and drought stress on plant growth and glucosinolate production in pak choi (*Brassica rapa* subsp. *chinensis*). *Food Chemistry*, 2021, 340: 128167 (doi: 10.1016/j.foodchem.2020.128167).
6. Baek M.W., Choi H.R., Solomon T., Jeong C.S., Lee O.H., Tilahun S. Preharvest methyl jasmonate treatment increased the antioxidant activity and glucosinolate contents of hydroponically grown pak choi. *Antioxidants*, 2021, 10(1): 131 (doi: 10.3390/antiox10010131).
7. Loconsole D., Cocetta G., Santoro P., Ferrante A. Optimization of LED lighting and quality evaluation of romaine lettuce grown in an innovative indoor cultivation system. *Sustainability*,

2019, 11(3): 841 (doi: 10.3390/su11030841).
8. Cartea M.E., Francisco M., Soengas P. Phenolic compounds in Brassica vegetables. *Molecules*, 2010, 16: 251-280 (doi: 10.3390/molecules16010251).
9. Golubkina N.A., Sirota S.M., Pivovarov V.F., Yashin A.Ya., Yashin Ya.I. *Biologicheski aktivnye soedineniya ovoshchei.* Moscow, 2010 (in Russ.).
10. Solov'eva A.E., Artem'eva A.M. *Trudy po prikladnoi botanike, genetike i selektsii*, 2012, 169: 137-146 (in Russ.).
11. Podsędek A. Natural antioxidants and antioxidant capacity of Brassica vegetables: A review. *LWT-Food Science and Technology*, 2007, 40(1): 1-11 (doi: 10.1016/j.lwt.2005.07.023).
12. 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).
13. Shamshiri R.R., Kalantari F., Ting K.C., Thorp K.R., Hameed I.A., Weltzien C., Ahmad D., Shad Z.M. Advances in greenhouse automation and controlled environment agriculture: a transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering* (Beijing), 2018, 11(1): 1-22 (doi: 10.25165/j.ijabe.20181101.3210).
14. Alexandratos N., Bruinsma J. World agriculture towards 2030/2050: the 2012 revision. *ESA Working Paper No. 12-03.* Rome, FAO, 2012 (doi: 10.22004/ag.econ.288998).
15. *FAO. 2019. FAO framework for the Urban Food Agenda.* Rome, 2019 (doi: 10.4060/ca3151en).
16. Kolpakov N.A., Reshetnikova I.M. *Gavrish*, 2012, 6: 10-12 (in Russ.).
17. Kolpakov N.A., Chernysheva N.N., Fedorova M.I., Burkova E.V., Vol Yu.S. *Vestnik Altaiskogo GAU*, 2015, 12(134): 5-9 (in Russ.).
18. Polyakova M.N., Martirosyan Yu.Ts., Dilovarova T.A., Kosobryukhov A.A. Photosynthesis and productivity of basil plants (*Ocimum basilicum* L.) under different irradiation. *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2015, 50(1): 124-130 (doi: 10.15389/agrobiology.2015.1.124eng).
19. Kuleshova T.E., Chernousov I.N., Udalova O.R., Anikina L.M., Khomyakov Yu.V., Aleksandrov A.V., Seredin I.S., Feofanov S.V., Shcheglov S.A., Gall' N.R., Panova G.G. *Biofizika*, 2020, 65: 112-124 (doi: 10.31857/S0006302920010147) (in Russ.).
20. Olle M., Virsile A. The effects of light-emitting diode lighting on greenhouse plant growth and quality. *Agricultural and Food Science*, 2013, 22(2): 223-234 (doi: 10.23986/afsci.7897).
21. Lin K.H., Huang M.Y., Huang W.D., Hsu M. H., Yang Z. W., Yang, C. M. The effects of red, blue, and white light-emitting diodes on the growth, development, and edible 224 quality of hydroponically grown lettuce (*Lactuca sativa* L. var. *capitata*). *Scientia Horticulturae*, 2013, 150: 86-91 (doi: 10.1016/j.scienta.2012.10.002).
22. Li H., Tang C., Xu Z., Liu X., Han X. Effects of different light sources on the growth of non-heading Chinese cabbage (*Brassica campestris* L.). *Journal of Agricultural Science*, 2012, 4: 262-273 (doi: 10.5539/jas.v4n4p262).
23. Qian H., Liu T., Deng M., Miao H., Cai C., Shen W., Wang Q. Effects of light quality on main health-promoting compounds and antioxidant capacity of Chinese kale sprouts. *Food Chemistry*, 2016, 196: 1232-1238 (doi: 10.1016/j.foodchem.2015.10.055).
24. 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 tekhnicheskoi fiziki*, 2020, 90(10): 1633-1639 (doi: 10.21883/JTF.2020.10.49792.429-19) (in Russ.).
25. 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 Rossiiskoi akademii sel'skokhozyaistvennykh nauk*, 2015, 4: 17-21 (in Russ.).
26. Ermakov E.I., Zheltov Yu.I., Mil'to N.E., Kucherov V.I. *Pochvogrunt dlya vyrashchivaniya rastenii «Agrofit». Patent na izobretenie RF 2081555 (RF) MPK A 01 G 9/10.* Zayavl. 13.07.1993. Opubl. 20.06.1997. Byul. № 17.1997 [Soil carrier for growing plants «Agrofit». Patent RF 2081555 (RF) MPK A 01 G 9/10. Appl. 13.07.1993. Publ. 20.06.1997. Bull. № 17.1997] (in Russ.).
27. Boos G.V., Dzhokhadze T.I., Artem'eva A.M., Krivchenko V.I., Simon A.M., Timoshenko Z.V., Petrovskaya N.N., Vlasova E.A., Barashkova E.A., Sinel'nikova V.N., Barashkova E.A., Ivakin A.P., Ermakov A.I., Voskresenskaya V.V. *Metodicheskie ukazaniya po izucheniyu i podderzhaniyu mirovoi kollektsii kapusty* [Guidelines for the study and maintenance of the world cabbage collection]. St. Petersburg, 1988 (in Russ.).
28. Lutova L.A., Provorov N.A., Tikhodeev O.N., Tikhonovich I.A., Khodzhaiova L.T., Shishkova S.O. *Genetika razvitiya rastenii* [Genetics of plant development]. St. Petersburg, 2000 (in Russ.).
29. Artem'eva A.M., Solov'eva A.E., Berensen F.A., Kocherina N.V., Chesnokov Yu.V. Ecological and genetic evaluation of morphological and biochemical characters of quality in *Brassica rapa* L. accessions from VIR collection. *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2017, 52(1): 129-142 (doi: 10.15389/agrobiology.2017.1.129eng).
30. *Donory i istochniki dlya selektsii listovykh ovoshchnykh kul'tur vida Brassica rapa L. Katalog mirovoi kollektsii VIR* /Sost. A.M. Artem'eva [Donors and sources for selection of leafy vegetable crops of the species *Brassica rapa* L. Catalogue of VIR world collection]. St. Petersburg, 2004 (in Russ.).

31. Van Ts. *Morfofiziologicheskie reaktsii na svetovye usloviya rastenii raznykh biomorf iz roda Brassica L. Avtoreferat kandidatskoi dissertatsii* [Morphophysiological reactions to light conditions of plants of different biomorphs from the genus *Brassica* L. PhD Thesis]. St. Petersburg, 2007 (in Russ.).
32. Konyaev N.F. *Doklady VASKHNIL*, 1970, 9: 43-46 (in Russ.).
33. Konyaev N.F. *Nauchnye osnovy vysokoi produktivnosti ovoshchnykh rastenii* [Fundamentals of high productivity of vegetable plants]. Novosibirsk, 1978 (in Russ.).
34. Nikolenko V.V., Kotov S.F. *Ekosistemy, ikh optimizatsiya i okhrana*, 2010, 2: 99-105 (in Russ.).
35. Kiseleva N.S. Method of determination of pear leaf area on linear measurements by calculation of correction factors and variation statistics approach**.** *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2017, 52(2): 211-217 (doi: 10.15389/agrobiology.2017.1.211eng).
36. Weiguo F., Pingping L., Yanyou W., Jianjian T. Effects of different light intensities on anti-oxidative enzyme activity, quality and biomass in lettuce. *Horticultural Science*, 2012, 39(3): 129-134 (doi: 10.17221/192/2011-HORTSCI).
37. Fu Y., Li H., Yu J., Liu H., Cao Z., Manukovsky N.S., Liu H. Interaction effects of light intensity and nitrogen concentration on growth, photosynthetic characteristics and quality of lettuce (*Lactuca sativa* L. var. *youmaicai*). *Scientia Horticulturae*, 2017, 214: 51-57 (doi: 10.1016/j.scienta.2016.11.020).
38. Viršilė A., Brazaitytė A., Vaštakaitė-Kairienė V., Jankauskienė J., Miliauskienė J., Samuolienė, G., Duchovskis P. Nitrate, nitrite, protein, amino acid contents, and photosynthetic and growth characteristics of tatsoi cultivated under various photon flux densities and spectral light compositions. *Scientia Horticulturae*, 2019, 258: 108781 (doi: 10.1016/j.scienta.2019.108781).
39. Hao X., Jia J., Mi J., Yang S., Khattak A. M., Zheng L., Wang M. An optimization model of light intensity and nitrogen concentration coupled with yield and quality. *Plant Growth Regulation*, 2020, 92(2): 319-331 (doi: 10.1007/s10725-020-00641-0).
40. Zanewich K.P., Rood S., Southworth C.E., Williams P.H. Dwarf mutants of Brassica: responses to applied gibberellins and gibberellin content. *Journal of Plant Growth Regulation*, 1991, 10(1): 121-127 (doi: 10.1007/BF02279323).