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Nutritional and biologically active compounds in Russian (VIR) Brassicaceae vegetable crops collection

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Abstract: The article presents the results of studying the biochemical composition of the large worldwide vegetable crops collection of the *Brassicaceae* family, stored at the N. I. Vavilov All-Russian Institute Institute of Plant Genetic Resources (VIR), St. Petersburg, Russia, consisting of 7303 accessions of different status (approximately 50% unique accessions) from 98 countries. Studied vegetable brassicas collection includes representatives of all botanical varieties, agroecological groups and cultivar types of the species cole crops *Brassica oleracea* L. and related wild Mediterranean species, leafy and root vegetable crops *B. rapa* L., leafy and root vegetable accessions of Indian mustard *B. juncea* Czern. subsp. *integrifolia* (H. West) Tell. and subsp. *foliosa* L. H. Bailey, radish and small radish *Raphanus sativus* L., garden cress *Lepidium sativum* L., salad rocket *Eruca sativa* L. The application of complex analysis for the study of nutrient and biologically active compounds of economically important crops from six species of *Brassicaceae* family, which determine the quality of vegetables and feeds, also the search within each crop for sources of valuable biochemical traits for breeding has been presented. The broadest variability of all studied traits between and within crops was revealed, the limits of natural variability were determined. The average values of the studied traits in six species within the family varied to varying degrees: they were similar in the studied species in terms of dry matter content (%), protein, total acidity; differed between species to a moderate degree in terms of the content of ascorbic acid, carotene, and the amount of volatile phenolic compounds. The species differed to a very high degree from each other in terms of the average content of sugars (total, monosaccharides, etc.), carotenoids, β-carotene, chlorophylls *a* and *b*, anthocyanins, free amino acids, and free fatty acids. Studied crops, belonging to *Brassica oleracea,* have the highest total sugar content among the all studied crops. *B. rapa* leafy crops have the highest content of phenolic compounds; *B. juncea* – **β**-carotene and chlorophylls; *Raphanus sativus* – carotenes and anthocyanins; *Lepidium sativum* – the highest content of protein, total acidity, free amino acids; *Eruca sativa* – carotenoids and free fatty acids. The maximum dry matter content was detected in the forage turnip *B. rapa* and Brussels sprout (*B. oleracea)*, protein in leafy *B. rapa* crops and cauliflower (*B. oleracea)*, total sugars and ascorbic acid in head cabbage (*B. oleracea)*, carotenoids in *L. sativum* and *E. sativa*, carotenes, including **β**-carotene, chlorophylls, phenolic compounds, free fatty acids in *B. rapa*, anthocyanins in *R. sativus*, free amino acids in *B. rapa* and *R. sativus*. Among the studied variety types of each crop, sources of nutrients and biologically active substances were identified, including types with an optimal biochemical compounds composition for the human nutrition, which are proposed to be useful in breeding of the new cultivars for healthy diet and medical applications, as well as for expanding the range of brassicas crops in the diet for the population of the Russian Federation.

Key words: Brassicaceae, nutritious and biologically active biochemical compounds, sources of valuable traits, vegetable crops

1. Introduction

In modern conditions, the dietary and medicinal properties of nutrition are becoming the most important factors in solving the task of food quality improvement. Functional foods are defined as "Natural or processed foods that contain known or unknown biologically active compounds, which is defined, effective nontoxic amounts, provide a clinically proven and documented health benefit for the prevention, management, or treatment of chronic daises" (Martirosyan and Miller, 2018).

The Cruciferae (Brassicaceae Burnett) family involving one of the most economically important vegetables has been traditionally consumed by humans as fresh and preserved foodstuffs, vegetable oils, and condiments,

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from ancient to the present time. Nowadays Brassicaceae vegetables are highly diversified in Mediterranean Europe, Asia, and North America owing to their availability at local markets, cheapness, and consumer preference (Hounsome et al., 2009; Herr and Büchler, 2010; Kapusta-Duch et al., 2011; Lee et al., 2011). The Cruciferae family is one of the most important angiosperms; according to A. L. Takhtajan (1987), there are up to 380 genera and about 3200 species in the family, The Plant List (http://www.theplantlist.org) includes 372 genera and 4060 species in the Cabbage family.

The peculiarity of the chemical composition Brassicaceae vegetables is a high content of water and low-fat, which causes a low caloric content of plants. They are characterized by a relatively high level of carbohydrates; contain proteins that include essential amino-free acids, and many mineral elements. The high value of Brassicaceae vegetables for human nutrition is =determined by the composition of biologically active compounds (BAC)—enzymes, pigments, vitamins, and secondary metabolites. Phytochemicals features of *Brassica* vegetables assist to prevent oxidative stress, stimulate immune system, decrease the risk of cancers, inhibit malignant transformation and carcinogenic mutations (Cohen et al., 2000; Knekt et al., 2002; Zhang and Hamauzu, 2004, Boivin et al., 2009; Herr and Büchler, 2010; Thomson et al., 2010, Singh et al., 2010; Kestwal et al., 2011, Kapusta-Duch et al., 2012, Manchali et al., 2012).

Breeding for the high content and valuable composition of BAC has been declared a priority by the world scientific community in the 21st century (XXVI International Horticultural Congress, 2002).

The priority direction of modern breeding strategy is the expansion of the range of products for functional, therapeutic and prophylactic nutrition, due to the proposal of new varieties, such demanded as Brassicaceae crops, with an optimal biochemical composition.

Thus, fundamental knowledge of the patterns of the nutrients and biologically active substances accumulation in vegetable crops is necessary.

Sources for the breeding of the new and improving existing varieties of crops Brassicaceae vegetables can be found in the collections of plant genetic resources, including the collection of All-Russian Institute of Plant Genetic Resources named after N.I. Vavilov (VIR). VIR is the only plant gene bank in Russia that collects preserves and comprehensively studies natural biodiversity in various ecological and geographical zones for different scientific purposes.

The world collection of VIR maintain more than 51,600 accessions of vegetable crops and cucurbits from 98 countries, including 7303 accessions of Brassicaceae vegetables obtained by VIR since 1923. The originality of the collections of the crops of the Brassica family in VIR reaches 50% as indicated in Table 1. The collection includes accessions of various types: landraces, old and advanced cultivars, inbred and double haploid lines, hybrid populations and new achievements of Russian and world selection, including those obtained by biotechnological methods (not GMO). Every year, the collection is replenished with local varieties from various regions of the Russian Federation and the world, accessions collected as a result of expeditions and obtained through exchange with other international genebanks.

The study of the biochemical composition of the Brassicaceae collection began at VIR in 1933. Accessions of Brassicaceae vegetables were assessed by the content of dry matter, sugars, protein, ascorbic acid, carotenoids, and chlorophylls. A number of crops were analyzed for the presence of antinutritional substances: nitrates and mustard oils.

In the VIR, for the first time in Russia, varieties of Brassicaceae vegetables were assessed by the content of ascorbic acid, dry matter, sugars, fiber, mineral elements, carotene, showed the presence of a significant amount of proteins in cabbage, studied the dynamics of accumulation and consumption of nutrients (1951). Previously, the features of genetic and geographical variability of the accumulation of biochemical compounds in cabbage (Lukovnikova, 1959, Lukovnikova and Lizgunova, 1965; Lizgunova, 1965; Artemyeva and Solovyeva, 2006; Solovieva and Artemyeva, 1999, 2004, 2006a, 2006b, 2010), turnips and rutabagas (Shebalina and Sazonova, 1985; Solovieva et al., 2013), radishes and small radishes (Babichev and Lukovnikova, 1961; Lukovnikova, 1973; Shebalina and Sazonova, 1985; Kurina et al., 2018) and garden cress (Girenko et al., 1988) have been established.

The study of the chemical composition of the garden cress accessions began in 1966–1967. The content of dry matter, ascorbic acid and carotenes were studied. It was revealed that the varieties of garden cress differ from each other in chemical composition, depending on the variety and origin. In whole-leafed (var. *latifolium* DC.) and sowing (var. *sativum*) varieties, the content of total sugars and ascorbic acid is slightly lower, and carotene is higher than in varieties with finely dissected (var. *nanum* Schtschenk.) and curly leaves (var. *crispum* (Medik.) DC.) (Girenko et al., 1988).

The main objective of this work was to study the variability of the content of primary and secondary plant biochemical compounds, to reveal characteristics of the accumulation of nutritive and biologically active compounds, such as proteins, sugars, carotenoids, chlorophylls, organic acids, free amino acids, phenolic compounds, free fatty acids by crops in the accessions of six species of Brassicaceae family using a wide genetic, botanical and geographical variety of Brassicaceae cole crops of the VIR collection.

Table 1. VIR vegetable Brassicaceae collections: 7303 accessions.

Crop	Botanical name	Number
Cole	*Brassica oleracea* L.	2472
Turnip	*B. rapa* L. *rapifera*	605
Asian *brassicas*, broccoletto	*B. rapa* L. *pekinensis, chinensis, narinosa, rosularis, ruvo, nipposinica, rapa*	1048
Indian mustard	*B. juncea* Czern.	117
Rape vegetable	*B. napus* L. var. *pabularia*	10
Swede	*B. napus* L. ssp. *rapifera* Metzg.	277
Radish, small radish	*Raphanus sativus* L.	2381
Garden cress	*Lepidium sativum* L.	310
Salad rocket	*Eruca sativa* L.	45
Horse radish	*Armoracia rusticana* L.	5
	Brassicaceae sp. /12	24

2. Materials and methods

2.1. Plant material and experimental site

The material of the study comprised all botanical varieties, ecogeographical groups and cultivars types of *Brassica oleracea* L., leafy and root vegetable *B. rapa* L. crops, leafy vegetable forms of Indian mustard *B. juncea* Czern., radish and small radish *Raphanus sativus L.,* garden cress *Lepidium sativum* L., salad rocket *Eruca sativa* Mill. —a total of 2425 accessions as indicated in Table 2. Brassicas accessions were grown at the VIR Pushkin and Pavlovsk Branch (St. Petersburg, Northwest Russia) in 2001–2019 years. Each accession was grown for 2–4 years, in three randomized replications, 20 plants per replication each year. The space under accessions during field evaluation was used according to the methodic study and regeneration of VIR worldwide collection for each crop: 0.7 × 0.6 m for cole crops, 0.7 × 0.3 m for leafy *B. rapa* crops, 0.7 × 0.15 m for turnip and radish, 0.1 × 0.04 m for small radish, mustard and cress. For the biochemical study, 5 plants from each replication for all accessions were analyzed. Climatic conditions in the north-western part of Russia are moderate, humid, and favorable for the growing of *brassicas*.

2.2. Biochemical analysis of plant accessions

Biochemical analysis was carried out in the VIR laboratory of biochemistry and molecular biology. Sample preparation was carried out as follows: fresh material of food organs was analyzed: leaves, heads of cabbage, stems, roots at the stage of technical ripeness, in amount of 5 plants per accession. The analysis and processing of the material were carried out according to the VIR methods (Ermakov et al., 1972; Solovyeva et al., 2019).

Dry matter content was measured by a gravimetric method using thermostat FED 400 Binder (Germany) at 105 °C; ascorbic acid content by titration with Tillman's reagent; pigments (chlorophylls *a* and *b*, carotenoids, total carotenes, *β*-carotene) were isolated with 100% acetone and their absorption was measured on an Ultrospec II spectrophotometer (England) at different wavelengths (645, 663, 440, and 454 nm, respectively), anthocyanins were extracted by 1% hydrochloric acid, then measured at 510 nm wavelength, in terms of cyanidin-3,5-diglycoside at 453 nm, with a correction for the content of the green pigment at 657 nm (Gashkova et al. 2021); total (titratable) acidity – by titrating with 0.1 N of alkali, the protein content was measured using the Kjeldahl method on a Foss Kjeltec 2200 Auto Distillation Unit (Sweden); sugars, free amino acid, organic acid, and phenolcarboxylic acid compositions by gas-liquid chromatography with mass spectrometry (GC-MS). For GC-MS analysis 10 g of accession was weighed and homogenized with an adequate amount of ethanol; then, the sample was infused for 30 days at 5–6 °C. The extract (200 μL) was vaporized to dryness on a CentriVap Concentrator (USA). The dry precipitate was silylated with bis(trimethylsilyl) trifluoroacetamide, then silylated compounds were separated on an HP-5MS capillary column (5% phenyl 95% methylpolysiloxane, 30.0 μm, 250.00 μm, 0.25 μm) using an Agilent 6850 chromatograph with a quadrupole mass selective detector (Agilent 5975B VL MSD, USA). Conditions of the chromatographic analysis were as follows: Helium flow in the column was 1.5 mL/min. The heating program for the column was from +70 °C up to +320 °C, at a heating rate of 4 °C/min injector temperature +300 °C; sample size 1 μL. Tricosane solution in pyridine (1 μg/μL) served as the internal standard (Jonsson et al., 2002). Libraries used in the process of analysis were NIST2010 (National Institute of Standards and Technology, USA), and the collections

Table 2. Composition of the studied VIR Brassicaceae collections and intraspecies variability of the nutrient and biologically active compounds content.

Compounds	*Brassica oleracea* (586 acc.)	*Brassica rapa* leafy crops (320 acc.)	*Brassica juncea* (34 acc.)	*Raphanus sativus* (leaves) (15 acc.)	*Lepidium sativum* (52 acc.)	*Eruca sativa* (15 acc.)
Dry matter content, %	9.1 ± 2.3**b 4.6 ÷ 22.4	8.1 ± 3.3**a 2.5 ÷ 18.7	8.3 ± 3.4**a 4.8 ÷ 21.2	8.9 ± 2.0**a 5.3 ÷ 10.9	7.8 ± 2.4**c 4.9 ÷ 12.8	9.5 ± 0.8**b 8.2 ÷ 11.3
Protein, % (in dry matter)	20.1 ± 9.7**a 6.6 ÷ 44.6	22.8 ± 7.8**a 5.1 ÷ 40.3	13.6 ± 4.2**b 8.5 ÷ 24.7	15.3 ± 3.9**b 6.9 ÷ 22.3	33.4 ± 2.1**c 28.9 ÷ 36.8	28.1 ± 1.4**d 25.1 ÷ 30.3
Total sugars, %	3.8 ± 1.6**a 1.2 ÷ 9.1	1.2 ± 1.0**b 0.2 ÷ 4.9	1.3 ± 1.0**b 0.2 ÷ 4.1	0.5 ± 0.3**c 0.1 ÷ 1.2	0.6 ± 0.2**c 0.1 ÷ 0.9	0.6 ± 0.2**c 0.2 ÷ 0.8
Monosaccharide, %	3.1 ± 1.3**a 1.0 ÷ 6.6	1.0 ± 0.8**b 0.1 ÷ 3.6	1.1 ± 0.9**b 0.2 ÷ 3.7	0.4 ± 0.2**c 0.1 ÷ 1.2	0.5 ± 0.2**c 0.1 ÷ 0.8	0.6 ± 0.2**c 0.2 ÷ 0.8
Ascorbic acid, mg/100 g	33.2 ± 23.5a 9.2 ÷ 212.5*	32.3 ± 21.8a 12.4 ÷ 126.7*	37.0 ± 15.5**b 11.4 ÷ 80.4	39.1 ± 5.2**b 21.6 ÷ 50.8	18.9 ± 14.9**c 12.8 ÷ 64.8*	19.0 ± 2.6**c 14.4 ÷ 24.0
Carotenoids, mg/100 g	5.3 ± 4.6a 0.2 ÷ 39.0*	18.4 ± 8.4b 0.2 ÷ 60.1	22.6 ± 10.9b 0.6 ÷ 41.1	43.6 ± 7.1**c 18.0 ÷ 73.8	45.6 ± 14.0**c 12.1 ÷ 66.2	46.1 ± 7.2**c 35.5 ÷ 64.8
Carotene, mg/100 g	5.1 ± 3.5a 0.4 ÷ 15.3*	6.4 ± 3.0b 0.4 ÷ 16.9*	6.6 ± 2.2**b 2.7 ÷ 9.5	6.8 ± 1.5**b 5.5 ÷ 8.9	5.4 ± 1.5**a 2.3 ÷ 9.8	4.7 ± 0.8**c 3.7 ÷ 6.6
β-carotene, mg/100 g	0.8 ± 0.3a 0.1 ÷ 8.4*	3.9 ± 1.9b 0.4 ÷ 12.6*	4.9 ± 1.7c 0.1 ÷ 8.2*	4.8 ± 0.6**c 2.9 ÷ 6.3	3.9 ± 0.8**b 2.4 ÷ 5.4	4.0 ± 0.7**b 3.2 ÷ 5.8
Anthocyanins, mg/100 g	27.0 ± 13.2a 0.7 ÷ 921.7*	27.2 ± 21.3a 0.8 ÷ 1114.21*	43.0 ± 12.1b 1.8 ÷ 782.6*	9.4 ± 1.4**c 0.3 ÷ 11.3	18.3 ± 8.9**d 3.9 ÷ 45.3*	7.5 ± 2.2**c 4.5 ÷ 12.9
Chlorophylls, mg/100 g	21.4 ± 16.5a 0.2 ÷ 183.4*	90.0 ± 44.1b 40.8 ÷ 390.1*	115.9 ± 38.9**c 2.8 ÷ 185.5*	110.1 ± 17.4**c 61.4 ÷ 137.7	89.4 ± 16.6**b 56.5 ÷ 124.5	85.7 ± 14.1**b 64.3 ÷ 123.2
Chlorophyll *α*, mg/100 g	14.0 ± 10.3a 0.1 ÷ 126.8*	60,5 ± 28,6b 30.4 ÷ 227.3*	78.4 ± 26.2**c 1.3 ÷ 126.1*	77.6 ± 14.1**c 45.9 ÷ 98.7	65.3 ± 12.0**b 38.6 ÷ 88.3	62.1 ± 10.3**b 45.2 ÷ 89.2
Chlorophyll *β*, mg/100 g	7.1 ± 5.9a 0.1 ÷ 56.7*	29.7 ± 16.5b 10.4 ÷ 162.8*	37.4 ± 13.7c 1.5 ÷ 59.4*	26.9 ± 4.4**b 15.5 ÷ 37.7	24.1 ± 5.2**b 11.5 ÷ 36.2	23.6 ± 3.9**b 18.6 ÷ 34.0
Total acidity, %	0.4 ± 0.3a 0.1 ÷ 1.4*	0.4 ± 0.2**a 0.1 ÷ 0.8	0.3 ± 0.2a 0.1 ÷ 0.6	0.3 ± 0.1**a 0.3 ÷ 0.4	0.4 ± 0.1**a 0.2 ÷ 0.6	0.3 ± 0.1**a 0.3 ÷ 0.4
Free amino acids, mg/100 g	83.7 ± 73.9a 2,57 ÷ 466,73*	97.4 ± 86.8a 10.9 ÷ 715.8*	4.8 ± 3.6b 0.9 ÷ 11.4	6.7 ± 2.6**b 3.9 ÷ 11.2	261.1 ± 133.6**c 101.3 ÷ 545.9	65.2 ± 61.5d 1.9 ÷ 269.9*
Volatile phenolic compounds, mg/100 g	24.6 ± 20.3a 0.7 ÷ 254.4*	45.9 ± 24.5b 2.01 ÷ 422.2*	4.9 ± 2.9**c 2.2 ÷ 10.0	6.6 ± 3.2**c 3.1 ÷ 10.8	44.5 ± 20.0b 19.5 ÷ 93.1*	18.2 ± 6.6**d 0.7 ÷ 138.5*
Free fatty acids, mg/100 g	18.7 ± 13.6a 0.2 ÷ 100.3*	61.4 ± 49.1b 0.4 ÷ 111.4*	14.8 ± 4.9**c 8.5 ÷ 21.4	21.5 ± 9.5**a 8.8 ÷ 39.4	52.6 ± 24.1**b 18.9 ÷ 99.34*	82.8 ± 54.9d 3.7 ÷ 317.9*

All data are given as the mean ± SD; min ÷ max.
* The data have abnormal distribution.
** Differences between accessions are significant at a significance level of $p < 0.05$.
a–d: Values with a different superscript in a row differed significantly ($p < 0.05$).

of standard compound mass spectra were maintained by St. Petersburg State University and the Komarov Botanical Institute, with an affinity index no less than 80 (Shtark et al., 2019). Software used: UniChrom; AMDIS (Automated Mass Spectral Deconvolution and Identification System) (Sokolova et al., 2021).

All data are presented on raw material, with the exception of protein content, which is expressed in terms of absolutely dry matter.

2.3. Statistical processing of experimental data

Statistical data processing was performed using descriptive statistics and analysis of variance using the STATISTICA v.12.0 software (StatSoft Inc., USA), and cluster analysis using the Past software (Hammer et al., 2001). Since each accession was grown for 2–4 years, we calculated the average value for each biochemical trait for a single accession and for the species/subspecies as a whole. For the statistical analysis, the growing years were used as replicates. Data testing for normality of distribution was performed using the Shapiro–Wilk test and the quantile-quantile plot (QQ plot). The mean values of data with normal distribution were compared using Tukey's HSD test one-way analysis of variance (ANOVA); data with nonnormal distribution were compared using the Kruskal–Wallis test. Relationships between *brassicas* crops were elucidated through the construction of an unrooted Neighbor Joining (NJ) dendrogram based on Gower's similarity index. To compile the dendrogram, the average values of the studied biochemical compounds were used. A bootstrap value of 1000 replicates was used to test the reliability of the NJ dendrogram.

3. Results and discussion

The average values of the studied traits in six species within the family varied to varying degrees: they were similar in the studied species in terms of dry matter content (%), protein, total acidity; differed between species to a moderate degree in terms of the content of ascorbic acid, carotene, and the amount of volatile phenolic compounds. As indicated in Table 2, the species differed to a very high degree from each other in terms of the average content of total sugars and monosaccharides, carotenoids, β-carotene, chlorophylls *a* and *b*, anthocyanins, free amino acids, and free fatty acids.

On average, the species of *Brassica oleracea* has the highest total sugar content among the studied cultivated species; in leaf crops of *B. rapa* has the highest content of phenolic compounds; *B. juncea* – *β*-carotene and chlorophylls; *Raphanus sativus* – carotenes and anthocyanins; *Lepidium sativum* – the highest content of protein, total acidity, free amino acids; *Eruca sativa* – carotenoids and free fatty acids.

The maximum values of the dry matter content were noted in the forage turnip *B. rapa* and Brussels sprout *B. oleracea*, protein in leaf crops *B. rapa* and cauliflower *B. oleracea*, total sugars and ascorbic acid in cabbage *B. oleracea*, carotenoids in *L. sativum* and *E. sativa*, carotenes, including β-carotene, chlorophylls, phenolic compounds, free fatty acids in *B. rapa*, anthocyanins in *R. sativus*, free amino acids in *B. rapa* and *R. sativus*.

The maximum dry matter content was detected in the forage turnip *B. rapa* and brussels sprout (*B. oleracea)*, protein in leafy *B. rapa* crops and cauliflower (*B. oleracea)*, total sugars and ascorbic acid in head cabbage (*B. oleracea)*, carotenoids in *L. sativum* and *E. sativa*, carotenes, including β-carotene, chlorophylls, phenolic compounds, free fatty acids in *B. rapa*, anthocyanins in *R. sativus*, free amino acids in *B. rapa* and *R. sativus*.

At the same time, the variability of all the studied characters within each species is very high, reaches more than 100 times, and significantly exceeds the average intraspecific differences as indicated in Tables 3–5.

3.1. Variation in the content of nutrient and biologically active compounds in *Brassica oleracea*.

Biochemical studies have shown that the average dry matter content in the collection of the species *B. oleracea* was 9.12%. In the all studied *B. oleracea* crops, the highest average and maximum accumulation of dry matter were observed in Brussels sprouts and kale (cultivar types Curly green and Slovenian) and tronchuda. For other crops, the average values were close.

Among the white cabbage cultivars with a high dry matter content, the cultivars of the Japanese early-ripening Fuji type, the late Dutch types Amager and Langedijk winter, the early-ripening German type Ditmar early, the southern Balkan-Turkish cultivar types Likurishka, Marnopolka, and Georgian type were prominent above another accessions. A high dry matter content was found in central European red cabbage Erfurt cultivar type, Savoy cabbage cultivar types Winter and Victoria, Erfurt early and Ideal cauliflower cultivar types, Transcaucasian kohlrabi cultivar types, including local primitive cultivars, and the forage kohlrabi cultivar types Goliath white and blue.

B. oleracea varieties differed greatly in protein content. The average protein content in the collection was 20.1%. The highest protein content was found in broccoli, cauliflower, Chinese kale and collard. The greatest range of variability was observed in white cabbage (6.6%–24.0%). Sources of high protein content (more than 10% of dry matter) in white cabbage were found in cultivar types from the Netherlands Dutch early and Dutch flat and cultivars of the southern European group Bull heart. Russian cultivar types Kaporka and Yuryevetskaya stand out with a high protein content (up to 24%). Among the cauliflower cultivar types, high protein content was found in the early ripening Central European cultivar types Ideal and Erfurt early (30% and 27%, respectively), red cabbage Gako cultivar type, Savoy cabbage Advent cultivar type.

The total sugar content among the all studied crops was 1.2%–9.13%, 80%–90% of sugars were represented by monosugars, which play a significant role in respiration and photosynthesis (Solovieva and Artemyeva, 2006a). The

Table 3. Variability of nutrient and biologically active compounds content in *Brassica oleracea* species.

Compounds	White cabbage (314 acc.)	Red cabbage (27 acc.)	Savoy (11 acc.)	Kohlrabi (25 acc.)	Cauliflower (85 acc.)	Broccoli (76 acc.)	Kale (13 acc.)	Brussels sprout (14 acc.)	Tronchuda (9 acc.)	Chinese kale (13 acc.)
Dry matter content, %	8.1 ± 1.2^{**a} 4.6 ÷ 13.9	8.8 ± 1.1^{**a} 6.2 ÷ 10.7	8.4 ± 1.7^{**a} 6.1 ÷ 12.2	8.9 ± 1.9^{**a} 6.0 ÷ 12.9	9.4 ± 1.4^{**b} 7.2 ÷ 14.3	10.9 ± 1.5^{**b} 8.0 ÷ 16.4	14.6 ± 1.8^{**c} 10.5 ÷ 17.0	17.6 ± 2.1^{**d} 14.9 ÷ 22.4	12.4 ± 2.3^{**c} 8.5 ÷ 16.2	8.1 ± 0.9^{a} 6.8 ÷ 10.4
Protein, % (in dry matter)	10.7 ± 3.2^{**a} 6.6 ÷ 24.0	17.0 ± 1.7^{b} 15.8 ÷ 20.0	16.4 ± 2.5^{**b} 14.2 ÷ 19.9	19.4 ± 3.4^{**c} 13.9 ÷ 25.8	23.6 ± 5.1^{**d} 9.3 ÷ 34.9	30.4 ± 4.2^{**e} 20.3 ÷ 44.6	21.9 ± 2.5^{c} 17.1 ÷ 23.9	22.1 ± 2.0^{**c} 19.2 ÷ 25.0	15.1 ± 1.9^{b} 12.5 ÷ 18.7	26.6 ± 4.5^{**d} 15.2 ÷ 32.3
Total sugars, %	4.5 ± 1.2^{**a} 1.9 ÷ 9.1	5.3 ± 1.0^{**b} 3.9 ÷ 8.0	4.3 ± 1.2^{**a} 2.2 ÷ 6.3	4.1 ± 1.3^{**a} 1.7 ÷ 7.5	2.1 ± 0.7^{**c} 1.1 ÷ 4.4	2.2 ± 0.7^{**c} 1.0 ÷ 4.5	3.3 ± 0.8^{d} 2.2 ÷ 4.7	5.3 ± 1.9^{**b} 2.3 ÷ 8.5	3.5 ± 0.6^{d} 3.0 ÷ 4.5	1.5 ± 1.4^{e} 0.2 ÷ 5.1*
Monosaccharides, %	3.8 ± 0.9^{**a} 1.9 ÷ 6.3	4.3 ± 0.9^{**b} 2.9 ÷ 6.6	3.7 ± 1.1^{**a} 1.9 ÷ 6.0	2.4 ± 0.9^{**c} 1.7 ÷ 4.3	2.0 ± 0.7^{**c} 1.4 ÷ 4.4	2.0 ± 0.6^{**c} 1.0 ÷ 3.7	2.8 ± 0.9^{**c} 1.9 ÷ 4.5	2.7 ± 1.3^{**c} 1.9 ÷ 6.1	3.1 ± 0.5^{d} 2.5 ÷ 3.9	1.3 ± 1.0^{e} 1.1 ÷ 4.6*
Ascorbic acid, mg/100 g	25.2 ± 11.8^{a} 15.2 ÷ 106.0*	49.8 ± 12.8^{**b} 15.4 ÷ 71.4	35.9 ± 19.7^{**c} 13.0 ÷ 68.6	26.3 ± 12.5^{a} 9.4 ÷ 66.9*	41.9 ± 20.9^{b} 10.4 ÷ 103.8*	44.7 ± 27.0^{b} 9.2 ÷ 129.7*	73.4 ± 51.4^{d} 15.4 ÷ 170.0*	109.0 ± 66.0^{**e} 11.8 ÷ 212.5*	46.8 ± 10.1^{**b} 34.0 ÷ 68.0	47.6 ± 15.7^{**b} 31.3 ÷ 85.3
Carotenoids, mg/100 g	4.5 ± 2.7^{a} 0.5 ÷ 8.6*	5.7 ± 3.1^{**b} 1.8 ÷ 11.7	0.7 ± 0.3^{**c} 0.2 ÷ 2.4	2.8 ± 0.6^{d} 2.4 ÷ 3.4	4.5 ± 3.4^{a} 0.5 ÷ 8.6*	7.8 ± 3.5^{c} 1.6 ÷ 20.2*	58.1 ± 24.8^{d} 22.9 ÷ 92.8*	32.0 ± 15.1^{e} 12.8 ÷ 57.5*	14.9 ± 1.8^{f} 12.9 ÷ 18.8	33.2 ± 20.2^{e} 2.4 ÷ 76.9*
Carotene, mg/100 g	0.5 ± 0.3^{**a} 0.1 ÷ 3.1	0.8 ± 0.2^{**a} 0.1 ÷ 0.9	0.7 ± 0.3^{**a} 0.1 ÷ 1.5	0.3 ± 0.2^{**a} 0.1 ÷ 0.8	1.4 ± 1.0^{b} 0.6 ÷ 12.1*	1.5 ± 0.8^{**e} 0.4 ÷ 3.2	9.5 ± 3.5^{**f} 3.5 ÷ 13.0	5.0 ± 1.8^{**a} 2.2 ÷ 6.9	6.7 ± 1.4^{**b} 3.6 ÷ 8.8	10.2 ± 1.9^{**f} 7.0 ÷ 15.3
β-carotene, mg/100 g	0.10 ± 0.06^{**a} 0.02 ÷ 0.61	0.12 ± 0.03^{**a} 0.02 ÷ 0.14	0.14 ± 0.03^{**a} 0.04 ÷ 0.31	0.15 ± 0.03^{**a} 0.02 ÷ 0.34	0.27 ± 0.12^{b} 0.04 ÷ 1.13*	1.2 ± 0.5^{c} 0.1 ÷ 3.3*	5.1 ± 2.3^{d} 2.0 ÷ 8.4*	3.4 ± 1.1^{**e} 1.6 ÷ 5.9	3.9 ± 0.8^{**e} 2.4 ÷ 4.9	4.6 ± 2.3^{f} 0.2 ÷ 7.7*
Anthocyanins, mg/100 g	11.3 ± 8.5^{**a} 0.1 ÷ 32.6*	356.6 ± 200.0^{**b} 122.2 ÷ 921.7	N\D	6.2 ± 2.3^{**c} 4.6 ÷ 7.8	7.1 ± 4.1^{**c} 0.3 ÷ 16.8*	13.6 ± 11,4^{a} 0.8 ÷ 103.9*	317.9 ± 209.1^{d} 0.6 ÷ 808.9*	25.1 ± 10.8^{e} 0.9 ÷ 400.3*	N\D	9.2 ± 5.5^{**c} 0.3 ÷ 22.4
Chlorophylls, mg/100 g	1.9 ± 1.5^{a} 0.2 ÷ 13.3*	1.5 ± 0.6^{**a} 0.1 ÷ 2.5	4.2 ± 3.2^{b} 0.2 ÷ 6.5*	1.2 ± 0.8^{**a} 0.2 ÷ 3.3	3.8 ± 2.4^{b} 0.2 ÷ 24.1*	27.0 ± 12.1^{c} 3.0 ÷ 77.0*	106.4 ± 24.8^{**d} 42.0 ÷ 183.4	83.5 ± 23.2^{**e} 28.2 ÷ 136.3	89.7 ± 22.4^{**e} 51.0 ÷ 119.6	104.6 ± 52.2^{d} 4.0 ÷ 172.8*
Chlorophyll α, mg/100 g	1.2 ± 0.7^{a} 0.1 ÷ 18.9*	0.6 ± 0.2^{**b} 0.1 ÷ 0.9	2.8 ± 2.2^{c} 0.1 ÷ 4.4*	0.7 ± 0.4^{b} 0.1 ÷ 1.9*	1.9 ± 1.5^{a} 0.1 ÷ 16.1*	17.2 ± 8.0^{d} 1.5 ÷ 51.5*	74.6 ± 33.5^{**e} 28.7 ÷ 126.8	51.1 ± 32.7^{**f} 19.0 ÷ 90.4	60.1 ± 14.1^{**f} 34.9 ÷ 78.3	73.5 ± 37.3^{e} 2.7 ÷ 122.1*
Chlorophyll β, mg/100 g	1.0 ± 0.8^{a} 0.1 ÷ 8.8*	0.8 ± 0.4^{**a} 0.1 ÷ 1.6	1.4 ± 1.0^{b} 0.1 ÷ 2.1*	0.5 ± 0.4^{a} 0.1 ÷ 1.5*	1.8 ± 1,1^{b} 0.1 ÷ 9.8*	9.8 ± 4.4^{c} 0.1 ÷ 27.2*	31.8 ± 15.0^{**d} 13.3 ÷ 56.7	32.4 ± 11.1^{**d} 9.1 ÷ 45.9	29.6 ± 8.4^{**d} 16.1 ÷ 42.1	31.1 ± 15.0^{d} 1.4 ÷ 50.7*
Total acidity, %	0.2 ± 0.1^{**a} 0.1 ÷ 0.9	0.4 ± 0.1^{**a} 0.2 ÷ 0.7	0.3 ± 0.1^{a} 0.2 ÷ 0.4	0.3 ± 0.1^{**a} 0.1 ÷ 0.9	0.3 ± 0.1^{**a} 0.1 ÷ 0.9	0.5 ± 0.2^{**b} 0.2 ÷ 0.9	0.6 ± 0.1^{b} 0.5 ÷ 0.7	0.3 ± 0.2^{a} 0.1 ÷ 1.4*	0.2 ± 0.1^{a} 0.1 ÷ 0.3	0.3 ± 0.1^{**a} 0.1 ÷ 0.6
Free amino acids, mg/100 g	62.4 ± 49.8^{a} 6.0 ÷ 210.5*	55.2 ± 27.4^{b} 11.6 ÷ 315.3*	61.3 ± 31.5^{a} 17.6 ÷ 307.9*	65.8 ± 25.1^{a} 13.3 ÷ 295.3*	84.5 ± 46.1^{c} 4.4 ÷ 168.7*	147.3 ± 112.3^{d} 12.5 ÷ 659.6*	75.3 ± 19.4^{**a} 15.6 ÷ 173.7	35.8 ± 9.4^{**e} 11.4 ÷ 93.8	39.8 ± 5.6^{e} 5.6 ÷ 65.7*	204.3 ± 106.2^{f} 78.4 ÷ 466.7*
Volatile phenolic compounds, mg/100 g	17.7 ± 9.9^{a} 0.7 ÷ 50.1*	49.7 ± 29.3^{b} 1.9 ÷ 254.4*	15.3 ± 5.5^{**c} 1.1 ÷ 37.9	18.3 ± 3.8^{**a} 16.5 ÷ 27.6	14.7 ± 6.0^{**c} 5.3 ÷ 33.8	50.1 ± 30.8^{b} 13.5 ÷ 121.9*	18.1 ± 11.3^{**a} 10.2 ÷ 98.7	10.1 ± 5.3^{**d} 4.2 ÷ 38.7	13.2 ± 8.5^{**c} 1.8 ÷ 26.6	35.8 ± 22.8^{**e} 10.4 ÷ 99.4*
Free fatty acids, mg/100 g	5.2 ± 4.6^{a} 0.2 ÷ 20.8*	4.6 ± 3.4^{a} 0.3 ÷ 23.2*	5.1 ± 4.2^{a} 0.4 ÷ 23.2*	35.3 ± 19.9^{**b} 7.9 ÷ 72.4	8.4 ± 4.8^{**c} 1.5 ÷ 23.1*	45.3 ± 19.2^{d} 7.9 ÷ 100.3*	39.8 ± 13.5^{**b} 15.4 ÷ 63.9	40.3 ± 21.7^{**d} 17.9 ÷ 88.5	9.9 ± 4.3^{**c} 0.5 ÷ 16.9	34.2 ± 14.5^{**b} 13.9 ÷ 62.9

All data are given as the mean ± SD; min ÷ max.
* The data have abnormal distribution.
** Differences between accessions are significant at a significance level of $p < 0.05$.
[a-f]: Values with a different superscript in a row differed significantly ($p < 0.05$).
N\D = not determined.

Table 4. Variability of nutrient and biologically active compounds content in leafy *Brassica rapa* vegetables.

Compounds	Chinese cabbage (191 acc.)	Pakchoi (67 acc.)	Tatsoi, tsoisum (17 acc.)	Mizuna, mibuna (15 aac.)	Komatsuna, shirona, mana, hiroshimana (22 acc.)	Broccoletto (8 acc.)
Dry matter content, %	6.7 ± 2.5**a 2.8 ÷ 18.7	7.8 ± 2.9**b 2.5 ÷ 17.3	9.8 ± 2.9**c 4.4 ÷ 16.0	9.1 ± 2.9**c 4.9 ÷ 15.7	8.1 ± 3.3**b 3.8 ÷ 14.8	7.8 ± 1.6**b 5.6 ÷ 10.3
Protein, % (in dry matter)	21.8 ± 8.3**a 5.1 ÷ 37.3	20.4 ± 7.5**a 5.8 ÷ 38.9	21.6 ± 6.4**a 8.4 ÷ 38.0	19.0 ± 5.7**b 9.3 ÷ 29.6	20.8 ± 8.5**a 7.6 ÷ 40.3	27.9 ± 2.7c 24.1 ÷ 31.8
Total sugars, %	1.0 ± 0.6a 0.1 ÷ 4.1*	1.4 ± 1.0b 0.1 ÷ 5.6*	1.4 ± 0.9b 0.1 ÷ 3.5*	1.3 ± 0.9**b 0.1 ÷ 2.9	1.3 ± 0.9b 0.3 ÷ 4.9*	0.6 ± 0.2c 0.2 ÷ 1.8**
Monosaccharides, %	0.9 ± 0.4a 0.1 ÷ 3.6*	1.3 ± 0.9b 0.1 ÷ 5.2*	1.1 ± 0.8b 0.1 ÷ 2.6*	1.1 ± 0.8b 0.1 ÷ 2.5*	1.2 ± 1.0b 0.1 ÷ 4.3*	0.3 ± 0.1c 0.1 ÷ 1.1
Ascorbic acid, mg/100 g	27.0 ± 16.8a 13.2 ÷ 87.0*	33.8 ± 21.8b 13.6 ÷ 118.1*	31.4 ± 16.7**b 15.3 ÷ 70.7	41.8 ± 21.8c 12.4 ÷ 126.7*	35.3 ± 22.4b 15.0 ÷ 92.4*	57.9 ± 17.6**d 40.8 ÷ 72.1
Carotenoids, mg/100 g	14.7 ± 6.8a 0.2 ÷ 36.4*	21.1 ± 10.4b 0.6 ÷ 60.1*	25.5 ± 7.9c 1.7 ÷ 40.2*	25.7 ± 7.1**c 12.6 ÷ 40.1	22.5 ± 8.7b 8.8 ÷ 42.1*	14.5 ± 2.2**a 12.1 ÷ 18.9
Carotene, mg/100 g	4.4 ± 2.0a 0.4 ÷ 11.0*	6.9 ± 2.8b 1.6 ÷ 16.9*	8.4 ± 2.9**c 2.5 ÷ 14.7	8.0 ± 2.7**c 3.1 ÷ 13.2	6.8 ± 3.1**b 2.5 ÷ 13.6	11.3 ± 2.6**d 7.7 ÷ 16.6
β-carotene, mg/100 g	2.7 ± 1.4a 0.1 ÷ 7.6*	4.2 ± 2.0b 0.1 ÷ 12.6*	5.6 ± 1.9c 0.3 ÷ 9.4*	4.9 ± 2.7**b 2.9 ÷ 7.1	4.4 ± 1.8**b 0.2 ÷ 9.2*	5.9 ± 0.9**c 4.5 ÷ 6.9
Anthocyanins, mg/100 g	18.9 ± 10.4a 0.9 ÷ 368.6*	11.2 ± 7.8b 0.1 ÷ 53.8*	22.6 ± 18.1c 0.8 ÷ 561.1*	22.6 ± 13.7c 0.3 ÷ 102.9*	26.8 ± 16.3c 0.5 ÷ 1114.0*	N/D
Chlorophylls, mg/100 g	63.1 ± 31.2a 40.8 ÷ 175.7*	97.0 ± 44.5b 42.3 ÷ 279.4*	124.8 ± 44.3**c 47.3 ÷ 208.6	110.0 ± 26.9**c 66.6 ÷ 163.2	99.1 ± 40.9**b 45.7 ÷ 212.9	157.8 ± 31.9**d 107.2 ÷ 195.8
Chlorophyll α, mg/100 g	43.4 ± 20.9a 30.4 ÷ 125.8*	65.7 ± 29.6b 31.7 ÷ 194.4*	84.1 ± 28.8**c 34.8 ÷ 142. 5	74.8 ± 17.3**d 46.7 ÷ 112.0	67.2 ± 27.9**b 32.4 ÷ 149.6	95.5 ± 13.6**e 73.4 ÷ 112.4
Chlorophyll β, mg/100 g	19.7 ± 10.9a 10.4 ÷ 79.1*	31.5 ± 16.3b 10.6 ÷ 89.1*	40.7 ± 16.3**c 12.5 ÷ 78.1	35.2 ± 11.8**b 19.7 ÷ 77.5	31.9 ± 14.4**b 13.3 ÷ 67.1	62.3 ± 20.0**d 33.8 ÷ 86.2
Total acidity, %	0.3 ± 0.1**a 0.1 ÷ 0.7	0.4 ± 0.2**a 0.1 ÷ 0.8	0.4 ± 0.2**a 0.1 ÷ 0.7	0.3 ± 0.2**a 0.1 ÷ 0.7	0.3 ± 0.1**a 0.1 ÷ 0.6	0.3 ± 0.2**a 0.1 ÷ 0.8
Free amino acids, mg/100 g	81.3 ± 68.4a 0.9 ÷ 520.7*	115.7 ± 52.1b 2.1 ÷ 678.1*	106.6 ± 88.8c 5.4 ÷ 314.2*	103.4 ± 65.2**c 35.4 ÷ 229.5	151.4 ± 122.7d 10.3 ÷ 688.1*	97.4 ± 49.9e 21.3 ÷ 715.8*
Volatile phenolic compounds, mg/100 g	45.0 ± 30.8a 2.3 ÷ 422.2*	61.9 ± 22.2b 2.8 ÷ 252.0*	50.6 ± 47.5c 2.0 ÷ 147.6*	71.5 ± 53.6d 9.6 ÷ 190.9*	67.8 ± 44.6b 5.3 ÷ 261.8*	38.9 ± 14.5e 4.3 ÷ 165.6*
Free fatty acids, mg/100 g	64.4 ± 24.4a 12.8 ÷ 793.0*	53.0 ± 49.3b 5.5 ÷ 232.1*	46.1 ± 36.5c 6.9 ÷ 146.8*	106.7 ± 93.0d 22.9 ÷ 742.4*	56.2 ± 25.9b 3.8 ÷ 221.1*	48.9 ± 37.6c 7.4 ÷ 135.6*

All data are given as the mean ± SD; min ÷ max.
* The data have abnormal distribution.
** Differences between accessions are significant at a significance level of $p < 0.05$.
a-e: Values with a different superscript in a row differed significantly ($p < 0.05$).
N\D = not determined.

variability of total sugars and monosaccharides content within crops is very high, especially in cauliflower, broccoli and Chinese kale. The maximum values of the total sugar content were found in white cabbage (Dutch cultivar type Langedijk winter, old Russian cultivar Val'vatievskaya, several cultivars of the southern group Likurishka cultivar type), red cabbage (Zenith cultivar) and Brussels sprouts (cultivar Hercules). A high total sugar content was found in

Table 5. Variability of nutritive and biologically active compounds content in root crops of the Brassicaceae family.

Compounds	Turnip (172 acc.)	Small radish (121 acc.)	Radish (120 acc.)
Dry matter content, %	9.4 ± 1.9**[a] 4.3 ÷ 16.9	5.8 ± 1.2**[b] 3.7 ÷ 8.6	8.2 ± 1.9**[c] 5.3 ÷ 13.9
Protein, % (in dry matter)	12.8 ± 4.4**[a] 5.2 ÷ 28.8	10.3 ± 5.4**[b] 3.1 ÷ 25.4	11.8 ± 4.6[c] 4.1 ÷ 31.4*
Total sugars, %	4.1 ± 1.8**[a] 0.4 ÷ 8.1	2.3 ± 1.2**[b] 0.2 ÷ 5.5*	1.4 ± 1.3[c] 0.1 ÷ 4.5*
Monosaccharides, %	3.5 ± 1.6**[a] 0.2 ÷ 6.2*	2.1 ± 1.1**[b] 0.1 ÷ 4.6*	1.2 ± 1.1[c] 0.1 ÷ 3.5*
Ascorbic acid, mg/100 g	27.1 ± 10.4[a] 3.9 ÷ 87.0*	28.9 ± 6.8**[a] 17.6 ÷ 57.7	43.9 ± 14.4**[b] 14.4 ÷ 78.9
Carotenoids, mg/100 g	0.5 ± 0.3[a] 0.1 ÷ 5.02*	0.7 ± 0.2**[a] 0.4 ÷ 0.9	0.9 ± 0.4[b] 0.2 ÷ 2.1*
Carotene, mg/100 g	0.5 ± 0.3**[a] 0.1 ÷ 0.8	0.5 ± 0.3**[a] 0.1 ÷ 1.3	0.7 ± 0.3**[b] 0.2 ÷ 1.5
β-carotene, mg/100 g	0.4 ± 0.1[a] 0.1 ÷ 1.4*	0.1 ± 0.0[b] 0.1 ÷ 0,2	0.4 ± 0.2[a] 0.1 ÷ 1.3*
Anthocyanins, mg/100 g	42.9 ± 12.7**[a] 0.3 ÷ 4171.2*	970.8 ± 841.2[b] 0.9 ÷ 2779.2*	337.9 ± 254.8[c] 0.8 ÷ 2070.2*
Chlorophylls, mg/100 g	N/D	6.1 ± 1.7**[a] 2.8 ÷ 8.6	1.8 ± 1.5[b] 0.4 ÷ 7.1*
Chlorophyll *α*, mg/100 g	N/D	2.1 ± 0.6[a] 0.9 ÷ 3.0*	0.7 ± 0.3[b] 0.2 ÷ 4.3*
Chlorophyll *β*, mg/100 g	N/D	3.9 ± 1.1**[a] 1.8 ÷ 5.6	1.1 ± 0.8[b] 0.3 ÷ 3.5*
Total acidity, %	0.4 ± 0.2[b] 0.1 ÷ 0.8	0.2 ± 0.0[a] 0.1 ÷ 0.3	0.2 ± 0.1[a] 0.1 ÷ 0.3
Free amino acids, mg/100 g	55.5 ± 35.6[a] 4.7 ÷ 248.6	84.4 ± 56.2[b] 8.8 ÷ 265.5*	69.5 ± 28.5[c] 23.5 ÷ 713.2*
Volatile phenolic compounds, mg/100 g	9.9 ± 5.9[a] 0.2 ÷ 20.8*	35.6 ± 33.9[b] 6.9 ÷ 192.5*	14.5 ± 8.3[c] 0.6 ÷ 102.9*
Free fatty acids, mg/100 g	13.9 ± 9.4[a] 0.2 ÷ 141.3*	70.7 ± 22.3[b] 8.6 ÷ 668.9*	8.9 ± 8.2[a] 1.8 ÷ 54.2*

All data are given as the mean ± SD; min ÷ max.
* The data have abnormal distribution.
** Differences between accessions are significant at a significance level of $p < 0.05$.
[a–c]: Values with a different superscript in a row differed significantly ($p < 0.05$).
N\D = not determined.

cauliflower from Perfection cultivar type, Savoy – Winter and Victoria cultivar types, kohlrabi Transcaucasian, local Central Asian cultivars of the Turkestan cultivar type, as well as Bohemian white, and Curly green.

Ascorbic acid performs the biological functions of a reducing agent and a coenzyme of some metabolic processes and is an antioxidant (Boivin et al., 2009). The content of ascorbic acid varied greatly both between crops and within them. The highest content of ascorbic acid was found in Brussels sprouts; in average, it has four times more ascorbic acid in comparison with white cabbage.

It was found that sources of the high content of ascorbic acid (more than 65 mg/100 g) are in the composition of the following white cabbage cultivar types: Russian type Ladozhskaya, Dutch cultivar types Dutch flat, Langedijk winter, Central European (German) cultivar Ditmar early, southern (Turkish-Balkan) cultivar types Likurishka, red cabbage Erfurt and Dutch late, Savoy cabbage Yellow butter and Winter, kale Slovenian, Flanders, Brain green.

In the collection of cauliflower, increased content of ascorbic acid was found in Central European cultivar types Ideal and Erfurt, as well as the Mediterranean mid-late cultivar types Neapolitan Early, Western European Lenormand, and Northern European cultivar type Perfection (up to 100 mg/100 g).

The presence of carotene, including β-carotene, is an important component of vegetable product quality. β-carotene serves as a precursor of vitamin A (retinol) and is an antioxidant, has immune stimulating and adaptogenic effects (Zhang et al., 2004).

The richest sources of carotenoids are kale, Chinese kale and Brussels sprouts. The studied accessions of these crops has high variability of this trait. In cole crops, about 25% of the carotenoid fraction is carotenes. The accessions of kale, Chinese kale, tronchuda and Brussels sprouts were noted for their high β-carotene content. These crops had approximately the same average content of β-carotene. Several collards and Chinese kale accessions contained the maximum amount of β-carotene. Central European white cabbage cultivar types Glory and Ditmar early, southern cultivar type Zavadovskaya, Savoy cultivar type Yellow butter has the highest carotenes content.

Chlorophyll take an important role in dietary nutrition (Solovyeva et al., 2006b). Consumption of the green leafy vegetables increases the amount of hemoglobin and red blood cells. On average, the content of chlorophylls α and β varied greatly across the cole crops. The most stable in chlorophylls content (especially chlorophyll α) were kale and tronchuda; these crops were distinguished by the smallest range of variability for this trait. A high amount of chlorophylls among the studied cole accessions was noted in kale (especially cultivars Brain green and Curly green), Chinese kale, Brussels sprouts and tronchuda. Among the white cabbage cultivar types, the highest content of chlorophylls was found in early ripening cultivar types with a conic head of the Bull Heart type, the Dutch flat cultivar type, Russian Ladozhskaya cultivar type, German Ditmar early, red cabbage Erfurt cultivar type, Savoy – Ulm cultivar type.

The color of the leaves of cole leafy crops varies from light green to very dark green and dark purple. Content of anthocyanins varies in hundreds of times within the crop. Obviously, the greatest amount of anthocyanins was observed in the red cabbage and kale accessions with a rich dark purple color of leaves and heads. Several dark-colored broccoli and Brussels sprouts were also rich in anthocyanins. The lowest content of anthocyanins was found in kohlrabi, cauliflower, Chinese kale and white cabbage. Most of accessions of these crops were almost completely lacking anthocyanin coloration, and in tronchuda anthocyanins were completely absent. But the heads of white cabbage cultivar type Dobrovodskaya, including local cultivars from the Czech Republic, and southern cultivar type Zavadovskaya also contained anthocyanins (up to 32 mg/100 g). The highest content of anthocyanins was observed in the red cabbage cultivar type Langedijk winter red (anthocyanin content 600–900 mg/100 g), as well as kale Red curly type (above 800 mg/100 g).

Organic acids in plants are formed during the most important biological processes of photosynthesis and respiration, taken part in synthesis of amino acids, fats, carbohydrates and other compounds. Organic acids are active metabolites of carbohydrate metabolism, have a disinfecting function, participate in digestion processes, and give products a brighter taste (Babichev and Lukovnikova, 1961).

The limits of variability in the content of organic acids are similar for all cole crops. The highest organic acid content was found in Brussels sprouts accessions.

The high total acidity (above 1 mg/100 g) distinguishes white cabbage Dutch cultivar types Amager and Langedijk winter, of the Central European Schweinfurt cultivar type, as well as Molokanka landraces from the South Russia cultivar type (Zavadovskaya cultivar type of the Southern ecogeographical group. A high content of organic acids was noted in Danish cultivar type of cauliflower and Winter cultivar type of Savoy.

The crop average free amino acid content was highest in broccoli and the lowest in tronchuda. The maximum free amino acid content was found in broccoli and Chinese kale. A high total content of free amino acids was found in white cabbage Dutch cultivar types Amager and Langedijk winter and southern cultivar type Likurishka.

Phenolic compounds are one of the most widespread and numerous classes of natural compounds with biological activity, a distinctive feature of which is the presence of free or bound phenolic hydroxyl. Phenolic compounds are found in plants in the form of glycosides or in a free state; they are biologically active substances and have antioxidant properties (Moreno et al., 2006).

The maximum values of phenolic compounds were observed in early ripening accessions of red cabbage and broccoli. A high content of phenolic compounds was found in certain cultivars of white cabbage: the highest in Schweinfurt cultivar type and cultivars of the Southern cultivar group Likurishka.

Free fatty acids are involved in one of the most important processes in the body – fatty acid oxidation, which provides about half of all the energy needed by a person (Solovieva and Artemyeva, 2004). The highest crop average fatty acid content was found in broccoli, Chinese kale and kohlrabi. A high content of fatty acids was found in Schweinfurt cultivar type of white cabbage and in the Northern Russian cultivar type Ladozhskaya.

In the studied white cabbage collection the late cultivar types from the Netherlands Amager and Langedijk winter, Russian cultivar type Ladozhskaya and southern cultivar type Likurishka have the most valuable biochemical composition; in cauliflower collection —early cultivar types Erfurt and Ideal. The source of complex biologically active compounds is the tronchuda cultivars from Portugal and Spain.

Among the red cabbage accessions, the most favorable chemical composition from a consumer point of view is that of mid-season cultivars of the Erfurt cultivar type of German and French origin. Among them, several sources of high dry matter content (more than 10%), total sugars (more than 6%), ascorbic acid (average content for the type 75 and 84 mg/100 g), chlorophylls (average 124 mg/100 g), anthocyanins (506 mg/100 g), carotene (7.4, up to 11.6 mg/100 g) were revealed.

In the Savoy accessions, the most valuable biochemical composition was noted in the cultivars of the medium late cultivar type Victoria, late cultivar type Winter and early maturing cultivar types Ulm, Advent and Early yellow, which can be used as sources for quality breeding programs.

Cultivar types of kohlrabi, Vienna white and Goliath blue stand out for their valuable properties, which are characterized by the highest content of dry matter, total sugars and ascorbic acid.

Brussels sprouts is notable for an increased nutritional value, especially types Hercules and Erfurt, which have a high content of dry matter (up to 22,4%), protein (up to 25%), ascorbic acid (up to 212.5 mg/100 g), chlorophylls (up to 136.3 mg/100 g).

The most valuable cultivar type of broccoli is the Sicilian purple. The cultivars of this type are distinguished by a high content of ascorbic acid (72.8–95.3 mg/100 g), β-carotene (up to 3.3 mg/100 g) and anthocyanins (up to 103.9 mg/100 g).

3.2. Variation in the content of nutrient and biologically active compounds in leafy crops of the *Brassica rapa*.

On average, tatsoi, tsoisum, mizuna and mibuna, and leafy turnips stood out with high dry matter content, and the least – Chinese cabbage, while the maximum values were noted in Chinese cabbage of the Dungan leafy cultivar type, Granat and Hetou cultivar types with cylindrical heads. Among the pakchoi types, the highest dry matter content was found in Yutsai cultivar type, in hybrids of pakchoi and tatsoi, in mibuna.

On average, in terms of protein content, *B. rapa* crops differ insignificantly; however, within each crop, there are types with a relatively high protein content exceeding the average value by 2 times. These are Kaga and Hotoren headed cultivar types of Chinese cabbage, mainly of Japanese origin, Taisai cultivar type of pakchoi, wutacai, shirona Japanese leafy turnip.

The total sugar content in *Brassica rapa* crops is small, on average 1.0%–1.4%, with the maximum values reaching 4.9%, 80%–90% of sugars were represented by monosugars. The variability of the content of total sugars and monosaccharides within a crop is very high. In the plants, grown at the field, the total sugar content is 2–4 times higher than the total sugar content in greenhouse plants.

The maximum values of the total sugar content were found in modern Chinese accessions of the Syusman cultivar type of pakchoi, Japanese leafy turnip mana, modern Japanese cultivars and hybrids of Chinese cabbage of the mid-early maturity Nozaki cultivar type, and Korean cultivar type with open top Kasin. Broccoletto contains the lowest amount of total sugar.

The content of ascorbic acid in *B. rapa* leafy crops varied widely and depended on both genotype features and growing conditions. Amount of ascorbic acid in plants, grown in field and greenhouse conditions in all crops and cultivars was differing in 2–4 times. The maximum accumulation of ascorbic acid from the field plants was observed in pakchoi, from the greenhouse plants —in Chinese cabbage, mizuna and leafy turnip.

The maximum content of ascorbic acid for the species was noted in the accessions of pakchoi and mizuna. The cultivar types with a high vitamin C content have been determined. Among the Chinese cabbage accessions, these are semiheaded cultivars and cultivars with an open top of head Santo, Siao, Kasin, including more often landraces, mainly from Japan, China, and Korea. In the collection of pakchoi, a high content of ascorbic acid was distinguished by the Piorbay cultivar type, in tatsoi by the Chrysanthemum type and in the leafy turnip by the komatsuna forms. The heads of all studied broccoletto cultivars had consistently high ascorbic acid content.

On average, for the collection of *B. rapa* leafy vegetable crops, carotenoids were significantly more actively accumulated in a greenhouse, which is especially important in winter and spring time in Russia, when diet is poor of vitamins. The richest source of carotenoids in the greenhouse are the plants of mizuna and mibuna, followed by decreasing pakchoi and leafy turnip. In the field, cultivars of mizuna, pakchoi, tatsoi and leafy turnip were dominant. In Chinese cabbage, the level of carotenoids in greenhouse conditions was more than 2 times higher than that recorded in the field. In tatsoi, tsoisum and leafy turnip, the amount of carotenoids was relatively stable despite the different growing conditions.

The highest content of carotenoids on average for the crop was noted in cultivars of tatsoi, tsoisum, mizuna and leafy turnip hiroshimana, and the highest in the species — in some accessions of pakchoi Yutsai cultivar type.

Approximately 30% of the carotenoid fraction is carotenes in leafy crops of the species and up to 70% in broccoletto. The 60%–80% of carotenes fraction represented by the β-form. Its accumulation was stable under different growing conditions in pakchoi, mizuna and leafy turnip, in Chinese cabbage it was significantly higher in the greenhouse, in tatsoi, tsoisum, leafy turnip it was higher in the field conditions, and the highest accumulation on average for the crop was found in tatsoi and broccoletto. Broccoletto generally has the narrowest range of variation of this trait.

The maximum amount of β-carotene in Chinese cabbage was found in Dungan cultivar type, including local Dungan cultivar types of Central Asia, Japanese Nagasaki cultivar type, heaving the morphological traits of tatsoi, and cultivar type Chosen, which includes mainly Korean cultivars. The maximum values were observed in accessions of pakchoi Yutsai cultivar type, in accessions of tatsoi from South China with a very small rosette, and in hiroshimana leafy turnip.

On average for the collection of leafy *B. rapa* vegetables, the content of chlorophylls a and b was slightly higher in the greenhouse. Almost stable content of chlorophylls (especially chlorophyll a) during field and greenhouse cultivation was noted for mizuna and mibuna, and leafy turnip, increasd in the greenhouse for pakchoi and Chinese cabbage, and in the field for tatsoi. Simultaneously with the shortage of fresh salad vegetables in the winter-spring period, mainly fast-growing crops (pakchoi and Chinese cabbage) are grown in greenhouses, the value of which, therefore, increases due to the ability to accumulate green pigments under these conditions. Tatsoi, mizuna and leafy turnip can also be recommended as greenhouse crops, which significantly exceed Chinese cabbage in chlorophyll content.

The high amount of chlorophylls among the studied crops of the species was noted on average for the crop in tatsoi, mizuna and leafy turnip, and the highest in broccoletto. The maximum amount of chlorophylls was accumulated in the Yutsai type of pakchoi, as well as tatsoi and hiroshimana turnip, that is, the same types and forms that accumulated the maximum amount of carotenoids, the content of which is highly correlated with the content of chlorophylls.

The color of the leaves of all leafy crops of the species ranges from light green to very dark green and dark purple. Accordingly, the content of anthocyanins varies within the crops by tens times. It should be noted that the smallest amount of anthocyanins was observed when the plants were grown in a winter greenhouse, more in the spring greenhouses, while when they were grown in field conditions it was the highest.

The maximum values of the anthocyanin content were observed in the purple accessions of komatsuna leafy turnip and tatsoi from the Netherlands, and tsoisum from China. Colored cultivars of Chinese cabbage and mizuna contained significantly fewer anthocyanins.

The limits of variability in the content of organic acids were similar in all studied crops in *B. rapa*. The highest content of organic acids was determined in some broccolletto cultivars, followed by a decrease in pakchoi Yutsai cultivar type, mizuna and mibuna, tatsoi, and Chinese cabbage Kasin and Chosen cultivar types.

The average free amino acid content was highest in the leafy turnip and pakchoi cultivar types and the lowest in Chinese cabbage. The maximum values of the free amino acid content were observed in broccoletto, followed by decreasing values in pakchoi Taisai cultivar type, komatsuna leafy turnip and Chinese cabbage Dungan and Siao cultivar types.

On average for the crop, the largest amount of phenolic compounds was found in mizuna and mibuna, then in leafy turnip and pakchoi, and the least in broccoletto. The maximum content of phenolic compounds was found in leafy and semiheaded cultivar types of Chinese cabbage, on average, two times less in leafy turnips komatsuna and hiroshimana and pakchoi Yutsai cultivar type.

The highest crop average free fatty acid content was noted in mizuna and mibuna, while in other crops of the species it was similar. The maximum values were observed in Chinese cabbage and mizuna.

3.3. Variation in the content of nutrient and biologically active compounds in root crops of the Brassicaceae family

The chemical composition of small radish and radish roots varies considerably. The overall range of accessions variability was quite high. Dry matter is an indicator that demonstrates the nutritional and feed value of root crops. The dry matter content in root crops varied in small radish from 3.7 to 8.6% (C_v = 20.3%), in radish from 5.3 to 13.9% (C_v = 24.2%), in leaves 5.3–9.3 (C_v = 21.1%) and 9.8–10.9 (C_v = 5.0%), respectively.

Most of the studied small radish accessions had dry matter content in the range of 6.0%–7.0%; these are early-maturing varieties of var. *rubescens* Sinsk. and mid-season var. *chloris* Alef., *violaceus* Sinsk. and *radicula*. Ultraearly ripening accessions had a small percentage of dry matter (up to 4%), from 4.0 to 6.0% contained early ripening accessions of pink-red and red type with rounded and oval root crops and mid-ripening accessions var. *striatus* Sinsk. and var. *radicula*. The largest amount of dry matter (more than 7.0%) was observed in the accessions of the Chinese subspecies, as well as in several accessions of the European subspecies of var. *chloris*, *radicula* (type White round), *rubescens* (type Pinkie and Long scarlet).

Compared to small radish, radish accessions accumulated more dry matter, which directly reflects their biological characteristic. Most of the radish accessions showed a dry matter accumulation in the range of 6.0%–8.0%, these are mainly accessions of Japanese radish (daikon) from Japan and China of type Minowase, and several accessions of the white Chinese radish (lobo) from South Korea and Vietnam, green (var. *virens* Sazon.) and red (var. *rubidus* Sazon.) accessions from China and the countries of Central Asia. Accumulation of a small percentage of dry matter (up to 6%) was noted in local accessions (var. *lobo*) from Kyrgyzstan and Egypt, as well as in accessions of lobo from Chile, Mongolia and Palestine and several daikons. The dry matter content in the range of 8.0%–10.0% was inherent in white accessions (var. *lobo*) from South Korea, the green accessions (var. *virens*) from China and Kazakhstan, the red accessions (var. *rubidus*) from Russia, Turkey and Japan, red meat accessions (var. *incarnatus* Sazon.) from Russia, daikon specimens of European origin and South Korea. The highest percentage of dry matter (more than 9.0%) was accumulated in all European winter accessions of radishes, some accessions of lobo and daikon (convar. *acanthiformis*).

The predominant part of the dry matter of small radish and radish root crops is represented by mono- and disaccharides, and therefore this indicator is of great importance for the comparative assessment of accessions. Depending on the accessions, the total sugar content in dry matter can reach 25%–55%.

According to the VIR standards, the dry matter content in turnip roots is more than 12.2%. Varieties of table turnip Grobovskaya, Petrovskaya 1, and Duniasha had high dry matter content. The first two accessions belong to the northern Russian turnip cultivar group, the third accessions (Duniasha) belong to the Western European group Golden Ball. Varieties of forage turnips were inferior in this indicator to table turnips, the highest dry matter content (11.4%) was in the roots of Volynsky round (Sternovka) accessions. The tendency of the dependence of the dry matter content on the shape of the root was detected.

Not distinguished by the dry matter content, forage turnips are leading among the turnips in terms of protein content. The group with the highest percentage of protein included varieties of related cultivars Osterzundom and Red tankard (some varieties had a protein content higher than 20%). Table varieties were generally inferior to fodder varieties in this indicator; among them, turnips of Petrovsky cultivar group, had the highest protein content.

The content of total sugars in dry matter was 3.5%–76.9% for small radish, 0.8%–62.2% for radish. The high variability of this indicator is associated with both genetic characteristics and climatic conditions of cultivation.

The total sugar content in small radish averaged 2.3% (0.2%–5.5%) in root crops and 0.03% (0.01%–0.07%) in leaves, in radish 1.4% (0.1%–4.5%) and 0.8% (0.5%–1.2%), respectively (Table 5). The percentage of monosaccharide from the total amount of sugars was 86.7% for small radish and 84.7% for radish.

Low total sugar content (less than 1.0%) was observed in most of the small radish accessions of the ultraearly and early-maturing group of ripeness in the type Saxa, Red with a white tip round and French Breakfast. Accessions of the Chinese subspecies var. *lobo* and var. *rubidus*, and some accessions of the European subspecies var. *radicula* (type Icicle) and var. *striatus* were characterized by high total sugar content (more than 4.0%). The rest of the studied accessions accumulated sugar in the range of 1.0%–3.9%.

Most of the radish accessions were characterized by low total sugar content in root crops; about half of the studied accessions accumulated sugars less than 1.0%, 25.5% of the accessions had total sugar content within 1.0%–3.0%. Only 20.5% of the radish accessions accumulated more than 3.0% sugars, these are daikon from China and Japan, red and red meat lobs from Turkey, Russia and European winter black and purple radishes from France and Germany.

Ascorbic acid (vitamin C) is one of the important biologically active substances in *R. sativus* crops. In small radish and radish root crops, it is in a free state. The content of ascorbic acid in small radish roots is 17.6–57.7 mg/100 g and in leaves 39.5–50.8 mg/100 g, in radish 14.4–84.6 mg/100 g and 21.6–42.0 mg/100 g.

The amplitude of variability of ascorbic acid in small radish roots was high (C_v = 23.5%) as presented in Figure 1. A small content (up to 25 mg/100 g) was noted in the accessions of var. *striatus* and *rubescens* of the middle group of ripeness, as well as in single accessions var. *radicula*, *chloris* and *violaceus*. Most of the accessions accumulated ascorbic acid in the range of 25–30 mg/100 g. More than 30 mg/100 g of ascorbic acid contained in type Saxa accessions, as well as some accessions of var. *striatus*. Increased content of ascorbic acid (more than 40.0 mg/100 g) was noted in the accessions of type Saxa.

The variability of the content of ascorbic acid in radish roots was higher (C_v = 32.5 %) than in small radish. The main part of the accessions was characterized by the

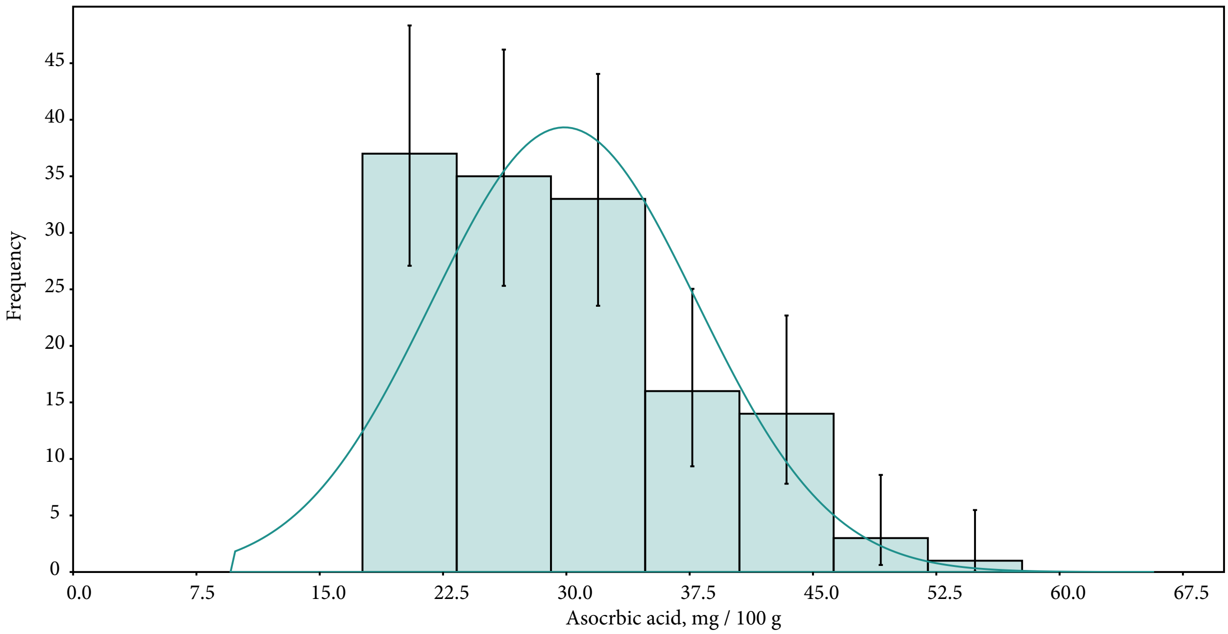

Figure 1. Histograms of distribution of varieties of small radish according to the content of ascorbic acid in root crops.

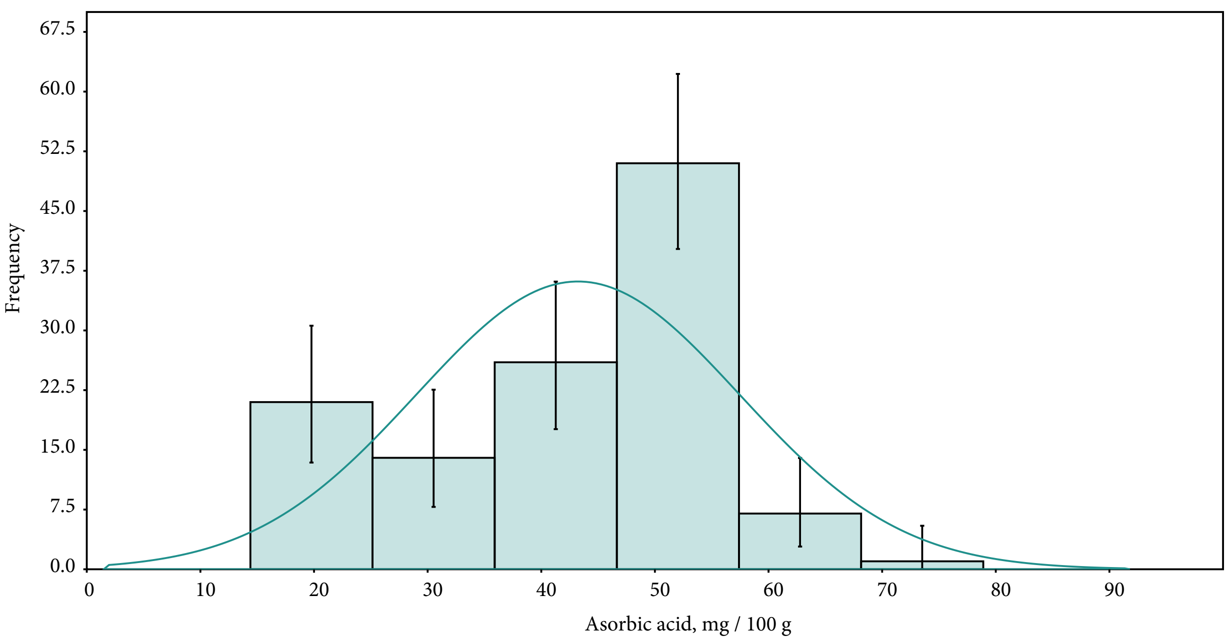

Figure 2. Histograms of distribution of varieties of radish according to the content of ascorbic acid in root crops.

content of ascorbic acid in the range of 50.0–60.0 mg/100 g as presented in Figure 2. The content of ascorbic acid less than 30 mg/100 g was observed in accessions of convar. *hybernus* (Alef.) Sazon., some daikons from China and lobo from Central Asia. The highest content (more than 60 mg/100 g) was noted accession var. *rubidus* and several daikons from Japan.

Petrovsky turnips are characterized by a high ascorbic acid content (a figure above 25.9 mg/100 g is considered high). Among the Petrovsky turnips, there was not a single sample with an ascorbic acid content lower than this value, and the leaders, varieties Petrovskaya 1 and Solovetskaya exceeded it by 1.6 times. Turnip roots have high ascorbic acid content in total. Only 20% of the studied varieties,

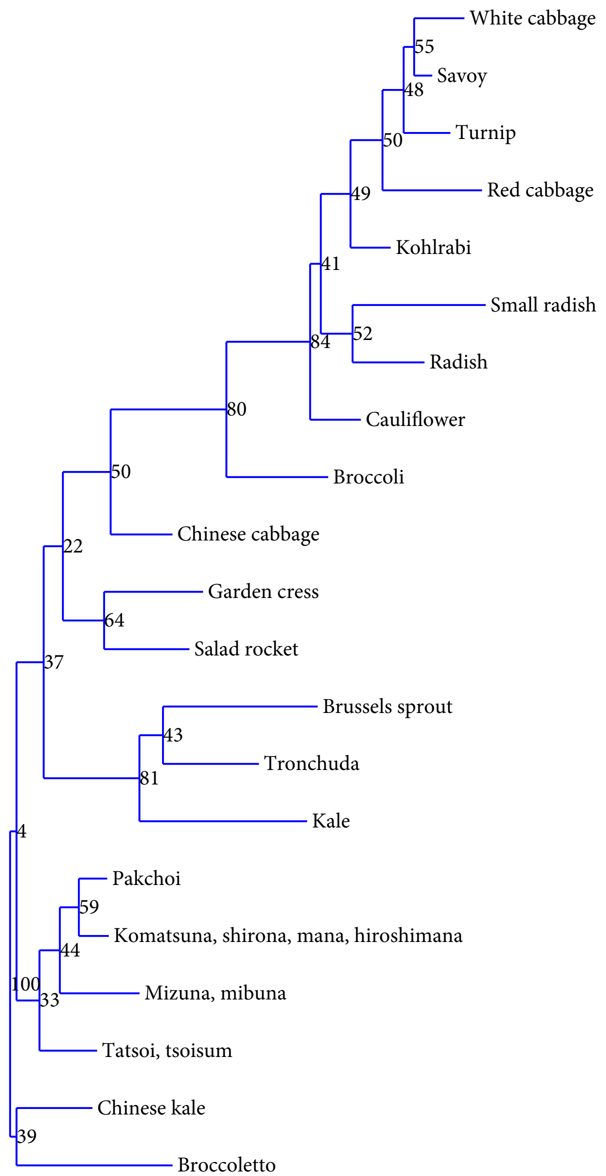

Figure 3. Dendrogram clustering of Brassicaceae family based on biochemical analysis. UPGMA method. The numbers on the dendrogram indicate the size of the bootstrap.

among which the overwhelming majority were forage varieties, showed low indicators of this trait, which is possibly due to the high water content in the roots of some forage turnips.

In *R. sativus* crops, pigments are accumulated in root crops in smaller amounts than in leaves. At the same time, small radishes accumulate more chlorophyll in root crops and fewer carotenoids and β-carotene than radish. Anthocyanins in small amounts contain accessions of small radish with white and yellow roots and accessions of radishes with white, green and black roots. The highest content of anthocyanins was observed in accessions with purple and red coloration of the root crop.

The small radish is characterized by a high content of free amino acids, fatty acids and phenolic compounds, in contrast to the radish. A high content of free amino acids was observed in the accessions of var. *striatus*, *radicula* and *sinensis*. In radish, the lobo and daikon from Japan and South Korea were characterized by a high content of free amino acids (more than 100 mg/100 g). The content of essential amino acids was higher in the accessions of Japanese radish, compared to other subspecies.

The high content of phenolic compounds was noted in the accessions of var. *rubescens* and *radicula* of small radish, the lowest in var. *striatus*. Among the radish accessions, the total high content of phenolic compounds was noted in several daikons from Japan, in the rest of the accessions the total content did not exceed 50.0 mg/100 g.

Accessions of var. *sinensis* and *striatus* type French Breakfast were distinguished by a high total content of free fatty acids. Radish accessions were generally characterized by a low content of free fatty acids, the average content did not exceed 10 mg/100 g, more than 20 mg/100 g contained several accessions of var. *virens*.

3.4. Cluster analysis

According to the analysis results, All *Brassica* vegetable crops were divided into four clusters as presented in Figure 3. The largest cluster includes headed and inflorescent *B. oleracea* crops and kohlrabi and rooted crops —turnip *B. rapa* and radishes. The average values of studied characters are lower than in other clusters. The separate small clusters were formed by the garden cress and salad rocket, close to each other on valuable biochemical content. Relatives to kale cole crops formed the third cluster with Indian mustard. *B. rapa* leafy crops are situated close to each other and together with Chinese kale of *B. oleracea*. Generally, position of B*rassicas* vegetable crops on the dendrogram corresponds to the proximity of their biochemical composition. According to averages of the complex of all studied characters, the most valuable crops are situated in the third and fourth clusters.

4. Conclusion

Created by N.I. Vavilov and his followers, the VIR worldwide Brassicaceae vegetable collection is a leading object of complex researches, including biochemical studies and breeding for quality traits. VIR continue to carry out biochemical analysis of new accessions, to determine the sources of valuable biochemical composition. The brassicas collections with a high degree of completeness were evaluated according to the main quality characters: the content of dry matter, total sugars, protein, ascorbic acid, carotenes, chlorophylls, free amino acids, organic acids, phenolic compounds, free fatty acids. The potential of the variability of all studied traits between and within vegetable Brassicaceae crops was revealed. The ecological and geographical regularities of the accumulation of the main elements of the biochemical composition were determined or confirmed by our research. This is especially relevant in connection with the search for forms within each crop, combining productivity, resistance to biotic and abiotic stressors and valuable biochemical composition when grown in different ecogeographical zones.

The collection revealed sources of nutrients and biologically active substances, including those with an optimal component composition for balanced human nutrition, which is proposed to be used in high-quality breeding, including when obtaining varieties for healthy and therapeutic nutrition, as well as expanding the range of Brassicaceae vegetable crops in the diet of the population of the Russian Federation. On the basis of the research carried out at VIR, new cultivars with a high content of valuable compounds have been created. All brassicas cultivars bred at VIR in the last ten years (cauliflower, kale, Chinese cabbage, pakchoi, tatsoi, mizuna, turnip, radish, small radish, Swede) in addition to high productivity, marketability, early maturity and decorativeness, have a valuable biochemical composition.

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