

SOURCES OF ECONOMICALLY VALUABLE TRAITS FOR *BRASSICA RAPA* L. VEGETABLES CROPS BREEDING

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Abstract. Vegetable crops of *Brassica rapa* L. compose an integral part of the world economy, providing fresh vitamin products for humanity. They are actively cultivated in East Asian countries for various purposes: food, medical, cosmetic and decorative. In Russia, most of them belong to the local non-traditional crops, but the interest of the population to these crops is increasing due to their valuable biochemical composition, high yield and simplicity of cultivation.

The aim of the study: to identify the source material in terms of economically valuable traits in the VIR *Brassica rapa* L. crops world-wide collection for use in the breeding process.

The material of the study included 23 accessions of the species belonging to different botanical and ecological-geographical groups: Chinese cabbage - 7 accessions, pak-choi - 2, tacai - 1, mizuna - 1, leaf turnip - 1 and root turnip - 11. The field study was carried out on the basis of NPB «Pushkin and Pavlovsk laboratories of VIR» (St. Petersburg, North-West region of the Russian Federation) in 2024 with the use of VIR Methodic guidelines for the study and maintenance of the world cabbage collection (1988), Methodic of the State cultivar testing of agricultural crops, assessment of the degree of *Alternaria* ssp. - according to the Methodic of Ph.B. Gannibal (2011), biochemical analysis - according to the Methodics of the VIR Department of Biochemistry (Ermaikov et al., 1987).

As a result of the study, valuable accessions with a complex of economic, phytopathologic and biochemical traits were identified, representing promising source material for breeding programs aimed at expanding the range of vegetable crops.

Keywords: *Alternaria* spp., *Brassica rapa* L., breeding value, genetic diversity, sources of resistance for breeding.

INTRODUCTION

Brassica rapa L. is a representative of the widely distributed and multifarious Brassicaceae Burnett family. For thousands of years, this species has accompanied the development of agriculture, shaped the culinary traditions of entire nations, and continued to evolve alongside humanity's needs. The leafy,

rooted, and oilseed crops of *Brassica rapa* are actively used in various spheres including food processing, cosmetic industries, and medicine due to their valuable biochemical composition. The content of vitamin C in the leaves reaches 40-80 mg/100g of fresh weight, β -carotene - 2-10 mg/100g, chlorophylls - 50-200 mg/100g, a large amount of organic acids and essential amino acids (valine, isoleucine, tryptophan), phenolic compounds, fiber, red-colored forms contain anthocyanins, that exhibit antioxidant and anti-inflammatory effects, stimulate the immune system, and prevent the development of cardiovascular diseases. The roots contain 21-35 mg/100 g of vitamin C, 0,09-0,12 mg/100 g of vitamin B6, 0,9-1,1 g of protein, 0,1-0,2 g of fats, and 10-30 mg of glucosinolates. The combination of low fat content with high water and protein levels results in low caloric value, making these plants particularly valuable for dietary nutrition. Furthermore, they serve as an excellent source of essential mineral elements including potassium, calcium, sulfur, phosphorus, zinc, iron, and manganese [1,2,3,4].

The population of Southeast Asian countries has been actively cultivating and using vegetable plants of this species in cooking since ancient times. In Russia, *B. rapa* vegetables are cultivated on a more limited scale and primarily used as salad greens. The most common is Chinese cabbage, which is grown in open and protected ground. The rest of the crops are grown in the field of private vegetable growing. In the modern conditions interest in these crops continues to grow annually due to their early maturity, ease of cultivation, and high nutritional value [5]. There is a need to expand the range of cultivated vegetable crops and create cultivars and hybrids with a complex of valuable characteristics.

Black spot is one of the limiting factors in Russia and around the world that inhibits the growth and development of plants of the species and leads to the loss of marketable qualities of fresh vitamin products. The disease is highly harmful. Under favorable conditions yield losses reach 50-80%. The pathogens *Alternaria brassicae* (Berk.) Sacc. and *A. brassicicola* (Schwein) Wiltshire produce mycotoxins that contaminate agricultural products. Monitoring of the pathogen becomes an important process, as part of the observed range expansion and increased aggressiveness. In the conditions of the North-Western region of Russia, black spot is a serious problem and requires the search for sources of resistance among natural varietal populations [6,7,8,9,10].

The species *Brassica rapa* L. serves as a valuable genetic resource for breeding programs for early maturity, productivity, disease resistance, and a high content of biologically active compounds.

The VIR Brassicaceae Burnett collection is unique, contains 10,997 accessions originating from 98 countries and including representatives of 11 genera and 32 species. The *Brassica rapa* L. vegetable crop collection contains 1,700 accessions of leafy and rooted vegetable crops.

MATERIALS AND METHODS

The study was conducted in 2024 at the experimental site of NPB «Pushkin and Pavlovsk laboratories of VIR» (St. Petersburg, North-West region of Russian Federation). The research material included 23 accessions of various *Brassica rapa* L. subspecies: 7 accessions of Chinese cabbage, 2 of pak-choi, 1 of tacai, 1 of mizuna, 1 of leaf turnip, and 11 of root turnip. Field sowing was performed in early July using a ridge planting system with 70×30 cm spacing, in three replications with 15 plants per replication. The experiment and description of plants were carried out according to the VIR Methodic guidelines for the study and maintenance of the world wide brassicas collection (1988) [11], Methodic of the State cultivar testing of agricultural crops [12] and the «Methodology of field experience in vegetable growing» (2011) [13]. The degree of development of *Alternaria* ssp. was assessed according to the method of Gannibal Ph.B. (2011) [14] according to a 4-point system and to 3 tiers of the leaf rosette of plants. Biochemical analysis was conducted at the VIR Biochemistry Department laboratory - according to the Methodics of Ermakov et al. (1987). The preparation protocol included analysis of fresh material derived from three individual plants representing each accession. Statistical data processing was performed using STATISTICA 12 software (StatSoft, USA).

RESULTS AND DISCUSSIONS

During the study of various cultivars and hybrids representing different crops of *Brassica rapa* L., Table 1 was formed, containing the main agrobiological characteristics. Vegetation Period is one of the key features in the breeding of vegetable crops, it determines the yield potential and adaptation to stress factors. The accessions were classified into the following maturity groups: early-maturing (33-40 days), mid-maturing (45-60 days), late-maturing (70-75 days). Accessions of pak-choi demonstrated particularly early maturity, making them suitable for cultivation in risk farming zones with limited growing seasons. The earliest-maturing accession was pak-choi k-647 from Tajikistan (33-35 days), representing valuable genetic material for breeding ultra-early forms. Tacai, mizuna and leaf turnip showed intermediate growing periods (40-48 days). Chinese cabbage and root turnip exhibited the longest vegetation period (50-75 days).

The variability of morphological features (CV: 12,86-27,37%) reflects the collection's wide phenotypic diversity. According to the parameters of the leaf rosette, the leaders are root turnip (diameter 34,0-46,4 cm; height 25,0-40,3 cm) and Chinese cabbage (diameter 35,75-41,7 cm; height 26,7-39,24 cm). Tacai turned out to be the most compact (diameter 25,1 cm; height 19,1 cm). Chinese cabbage had the highest average leaf size (length 24,1-37,85 cm; width 17,2-24,7 cm). The

leaves of the accession of mizuna Shirojuki Sensuji Kyo Mizuna (k-434, Japan) are strongly dissected, forming a dense spherical rosette. The accession can be used for decorative purposes. Chinese cabbage demonstrated the highest average product organ mass at 1,33 kg. The biggest head weight was shown by the Japanese accessions: Raioh 90 F1 (vr.k-1558) - 1,584 kg, Udzi M80 (k-399) - 1,551 kg, Udzi M70 (k-398) - 1387,3 kg. Pak-choi followed with an average mass of 0,85 kg. The Russian accession Lastochka (k-623) demonstrated leaf rosette mass with 1,004 kg.

Table 1. Phenological, morphological, and phytopathological features of the studied *Brassica rapa* L. accessions

VIR Catalog No.	Name and Origin	Vegetation Period, days	Rosette Diameter, cm	Rosette Height, cm	Leaf Blade Length, cm	Leaf Blade Width, cm	Product Organ Mass, kg	Yield, kg/m ²	Degree of Alternaria Infection, avg. score	
									by tiers	average
<i>ssp. pekinensis</i> (Lour.) Hanelt										
36	Khibinskay, Russia	42-45	40,3± 1,0	35,71 ±0,8	32,8± 1,85	17,47 ±0,8	0,971 ±0,01	4,62± 1,13	3	2,11 ±0,2
									2,13	
									1,2	
1556	Kapella, Russia	48-50	35,75 ±0,71	39,24 ±0,59	37,85 ±0,8	18,7± 0,9	1,298 ±0,04	6,17± 0,76	3,78	2,95 ±0,1 5
									3,11	
									1,98	
405	Spring sun 60 F1, Japan	50-55	37,45 ±0,98	31,8± 1,37	30,9± 3,1	24,7± 2,0	1,545 ±0,19	7,35± 2,11	3,1	1,96 ±0,2 2
									1,77	
									1,03	
1557	Mini raioh 50 F1, Japan	50-55	37±0, 65	26,7± 1,9	24,1± 0,96	17,2± 0,87	1,382 ±0,05	6,57± 2,0	3,82	2,77 ±0,1 3
									3,07	
									1,43	
398	Udzi M70, Japan	60-65	41,7± 0,79	36,48 ±0,9	34,4± 1,89	21,2± 1,3	1387, 3±0,1 1	6,6±1 ,54	2,0	1,28 ±0,3 5
									1,58	
									0,26	
399	Udzi M80, Japan	60-65	40,17 ±1,23	35±1, 14	33,9± 1,7	21,8± 1,27	1551, 1±0,0 7	7,38± 0,89	2,27	1,31 ±0,3 1
									1,52	
									0,2	
1558	Raioh 90 F1, Japan	70-72	41,13 ±1,1	35±2, 2	33,1± 2,0	20,11 ±0,9	1,584 ±0,04	7,53± 0,44	2,0	0,97 ±0,1 9
									0,61	
									0,3	
<i>ssp. chinensis</i> (L.) Hanelt										
647	Unnamed, к-647, Tajikistan	33-35	30,8± 1,4	31,4± 1,76	17,2± 0,99	12,8± 0,76	0,694 ±0,05	3,3±0 ,8	3,42	2,24 ±0,1
									2,16	
									1,13	
623	Lastochka, Russia	38-42	35,81 ±0,76	32,1± 1,0	23± 2,2	14,4± 1,4	1,004 ±0,03	4,78± 0,68	3,27	1,95 ±0,1 8
									1,89	
									0,74	
<i>ssp. chinensis</i> var. <i>rosularis</i> (Tsen et Lee) Hanelt										
695	Xiao Ba Je Ta Cai, China	35 - 40					0,435 ±0,01	2,07± 1,47	1,77	
									0,93	

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			25,1± 1,28	19,1± 0,64	8,4±1 ,4	8±0,7 1			0,1	0,93 ±0,2 4
<i>ssp. nipposinica</i> (Bailey) Hanelt)										
434	Shirojuki Sensuji Kyo Mizuna, Japan	45-48	34,8± 0,7	23±1, 8	11,7± 1,63	7,35± 0,92	0,497 ±0,06	2,36± 1,89	2,73 2,33 1,6	2,57 ±0,1
<i>ssp. rapa</i> L. f. <i>komatsuna</i> Makino										
330	Toraziroh F1, Japan	50-55	39±0, 52	40,3± 0,73	26,17 ±1,0	17,2± 1,2	0,871 ±0,03	4,14± 0,58	3,47 1,99 0,89	2,12 ±0,1 1
<i>ssp. rapa</i> L.										
1398	Palitra, Russia	60-62	44,2± 0,88	28,3± 0,91	28,8± 1,7	14,5± 1,0	0,722 ±0,02	3,43± 2,11	2,37 1,0 0,24	1,20 ±0,2 0
1422	Hinona, USA	60-62	34±0, 55	35,4± 1,27	32,8± 1,17	9,1±1 ,58	0,307 ±0,01	1,46± 1,51	1,25 1,05 0,31	0,87 ±0,1 4
1424	Golden Ball, Finland	58-62	42,1± 0,49	30,2± 0,93	26,4± 1,04	13,8± 0,76	0,389 ±0,07	1,85± 0,14	2,37 1,64 0,81	1,6± 0,15
1121	Repa listovaya. na silos, Finland	60-65	42±1, 23	32,9± 2,5	33,1± 0,95	17±1, 5	0,746 ±0,12	3,55± 1,84	3,23 1,85 1,15	2,08 ±0,1 7
830	Petrovskaya 1, Russia	65-68	41,1± 0,75	25±1, 18	23,2± 1,23	10,3± 0,79	0,678 ±0,01	3,22± 1,72	2,37 1,65 0,95	1,66 ±0,2
803	Solovetskaya, Russia	65-70	41,4± 0,69	26,2± 0,89	26,3± 2,14	16,8± 1,99	0,615 ±0,04	2,92± 0,94	2,93 1,52 1	1,81 ±0,1 2
1421	BRA 2842-96, Iraq	65-70	43±0, 84	38,4± 1,1	37,7± 0,81	16,1± 0,93	0,977 ±0,08	4,65± 0,22	3,0 2,25 1,41	2,22 ±0,1 1
1423	Salusia 4x, Germany	68-70	45±0, 9	38,3± 0,4	35,3± 0,68	17,4± 0,48	0,701 ±0,07	3,33± 0,73	1,09 0,77 0,19	0,68 ±0,1 1
1415	Peterburgskaya noch', Russia	68-72	45,7± 1,04	33,3± 0,55	29,4± 0,58	18,6± 1,83	0,748 ±0,05	3,56± 2,01	2,7 2,04 0,78	1,84 ±0,1 3
1405	Ova daehnfeldt, Denmark	70-75	43,3± 0,93	39±0, 84	35±2, 3	18,5± 0,79	0,899 ±0,02	4,2±1 ,0	2,0 1,25 0,3	1,18 ±0,2 1
1403	Purpumaya Primor'ya, Russia	70-75	46,4± 1,0	38,9± 2,0	32,6± 1,82	18,1± 1,54	0,584 ±0,15	2,77± 0,29	1,94 1,33 0,62	1,29 ±0,1 6
Min			25,1	19,1	8,4	7,35	0,307	1,46	0,68	
Max			46,4	40,3	37,85	24,7	1,584	7,53	2,95	
Std. Dev			5,07	5,75	7,78	4,39	0,38	1,85	0,62	
Std. Err			1,05	1,2	1,62	0,91	0,08	0,386	0,12	
CV, %			12,86	17,61	27,37	27,23	43,53	43,59	36,18	

Source: own research

Chinese cabbage (6,61 kg/m²) and pak-choi (4,04 kg/m²) are the leaders in yield. The following accessions stood out: Chinese cabbage - Raioh 90 F1 (7,53 kg/m²), Udzi M80 (7,38 kg/m²), Spring sun 60 F1 (7,35 kg/m²), Udzi M70 (6,6 kg/m²), pak-choi - Lastochka (4,78 kg/m²), root turnip - BRA 2842-96 (4,65 kg/m²) and Ova daehnfeldt (4,2 kg/m²).

Nine accessions were identified as relatively resistant to *Alternaria* ssp. (infection severity up to 1,35 points), twelve as moderately resistant (1,36-2,7 points), and two as susceptible (2,71-4 points). The lowest degree of infection was noted of root turnip accessions - Salusia 4x (k-1423, Germany) - 0,68 points, Hinona (k-1422, USA) - 0,87 points, Ova daehnfeldt (k-1405, Denmark) - 1,18 points; Tacai - Xiao Ba Je Ta Cai (k-695, China) - 0,93 points; Chinese cabbage - Raioh 90 F1 (vr.k-1558, Japan) - 0,97 points, Udzi M70, (k-398, Japan) - 1,28 points. Figure 1 shows a difference in symptom severity. Outer leaves were commonly affected in all accessions with varying degrees of infection. The middle leaves are affected less often. The internal structures forming the head of the cabbage are affected by a minimum.



Figure 4. Chinese cabbage: Raioh 90 F1 (vr. 1558, Japan)

Source: field trial data, 16.09.2024

The coefficients of variation (36,18-43,58%) confirm sufficient genetic diversity in the studied set for effective breeding work, particularly for yield and resistance to *Alternaria* ssp.

Consequently, the Japanese breeding of Chinese cabbage is distinguished by a combination of key features: balanced rosette structure, high yield, and moderate resistance to *Alternaria* infection. Accessions of pak-choi exhibit moderate yield and early maturity, but intermediate resistance to *Alternaria*. Accessions of root turnip and tacai can be used as sources of resistance. According to the complex of economically valuable characteristics, samples of Chinese cabbage can be distinguished: Raioh 90 F1 (vr. 1558, Japan), Udzi M70 (k-398, Japan), Udzi M80 (k-399, Japan) and root turnip: Ova daehnfeldt (k-1405, Denmark).

Table 2 shows the main components of the biochemical analysis of the accessions.

Table 2. Biochemical characteristics of the studied *Brassica rapa* L. accessions

Accession	Ascorbic acid mg/100g	Monosaccharides%	Chlorophyll a, mg/100g	Chlorophyll b, mg/100g	Carotenoids, mg/100g	β -carotene mg/100g	Phenolic compounds mg *GAE/g	Anthocyanins mg/100g
<i>ssp. pekinensis</i> (Lour.) Hanelt								
Khibinskaya	18,56	2,00	5,88	1,35	5,84	0,366	0,17	-
Kapella	24,32	1,90	1,29	0,05	2,07	0,143	0,26	-
Spring sun 60 F1	24,00	2,92	39,67	18,05	4,61	2,461	0,19	-
Mini raioh 50 F1	27,20	3,03	7,86	2,00	0,53	0,518	0,25	-
Udzi M70	18,40	2,88	1,18	0,23	1,31	0,085	0,16	-
Udzi M80	16,00	2,82	15,17	5,08	12,55	0,852	0,18	-
Raioh 90 F1	24,00	3,23	9,31	2,44	7,97	0,533	0,19	-
<i>ssp. chinensis</i> (L.) Hanelt								
Unnamed, k-647 (leaves)	85,44	2,33	80,55	25,39	14,27	4,751	1,38	-
Unnamed, k-647 (petioles)	19,52	4,58	11,32	2,83	1,50	0,608	0,15	-
Lastochka (leaves)	94,40	3,41	73,94	18,64	16,58	4,264	1,08	-
Lastochka (petioles)	25,60	4,03	17,77	5,45	4,22	0,997	0,18	-
<i>ssp. chinensis</i> var. <i>rosularis</i> (Tsen et Lee) Hanelt								
Xiao Ba Je Ta Cai	72,00	2,45	134,17	47,70	38,88	8,557	1,15	-
<i>ssp. nipposinica</i> (Bailey) Hanelt								
Shirojuki Sensuji Kyo Mizuna	46,40	1,94	20,06	4,72	11,31	1,145	0,60	-
<i>ssp. rapa</i> L. f. <i>komatsuna</i> Makino								
Toraziroh F1	62,40	4,54	122,46	46,79	29,99	7,678	0,86	-
<i>ssp. rapa</i> L.								
Palitra (leaves)	106,65	2,21	40,73	14,86	17,22	2,615	0,96	143,01
Palitra (root)	35,55	7,22	0,87	0,25	1,02	0,104	0,38	369,56
Hinona (leaves)	110,21	2,35	50,85	22,17	20,30	3,249	0,82	1046,40
Hinona (root)	32,00	5,98	0,40	0,13	0,52	0,046	0,35	1906,77
Golden Ball (root)	40,53	5,87	0,19	0,18	0,82	0,108	0,20	-
Repa listovaya na silos (root)	43,37	5,32	1,15	0,33	0,80	0,102	0,17	-
Petrovskaya I (root)	49,77	6,16	0,54	0,25	1,09	0,132	0,27	-
Solovetskaya (leaves)	88,88	3,58	49,96	14,88	19,36	3,085	0,89	-
Solovetskaya (root)	35,55	5,30	1,06	0,27	1,12	0,131	0,27	-
BRA 2842-96 (root)	44,08	5,13	0,40	0,15	0,34	0,050	0,19	362,61
Salusia 4x (leaves)	127,98	4,93	58,70	28,57	22,28	3,811	0,92	266,00
Salusia 4x (root)	32,00	7,32	4,19	1,02	2,25	0,278	0,28	247,49
Peterburgskaya noch' (root)	35,55	4,34	0,14	0,13	0,24	0,040	0,22	-
Ova daehnfeldt (root)	49,77	5,97	0,45	0,20	0,52	0,084	0,22	-
Purpurnaya Primor'ya (root)	37,68	6,01	0,11	0,07	0,21	0,030	0,23	418,82

Source: own research

The leaves of root turnip (108,43 mg/100 g) and tacai (72,0 mg/100 g) are characterized by the highest content of ascorbic acid. They also have a minimal degree of *Alternaria* infection. The maximum vitamin C content was found in the leaves of the Salusia 4x (k-1423, Germany - 127,98 mg/100 g). The largest amount

of sugars was found in root forms – 6,04%. The maximum content was noted in Palitra (k-1398, Russia) - 7,22%. The accumulation of monosaccharides in the leaves of root crops is significantly lower – 3,27%, as well as Chinese cabbage – 3%, which positively affects the degree of *Alternaria* infection (3 resistant accessions of Chinese cabbage and 5 of root turnip). Tacai (181,87mg/100 g) and leaf turnip (169,25mg/100 g) had the highest chlorophyll content. These accessions are also leaders in the content of carotenoids (38,88 mg /100 g and 29,99 mg/100 g) and β -carotene (8,55 mg/100 g and 7,67 mg/100 g). They can be used in breeding process for an increased content of biologically active components and for resistance to stress. The 22-25% β -carotene share of total carotenoids across *Brassica rapa* L. accessions confirms the high bioavailability of provitamin A.

The highest content of phenolic compounds was found in pak-choi (1,23 mg*GAE/g), tacai (1,15 mg*GAE/g), root turnip (0,89 mg*GAE/g) and leaf turnip (0,86 mg*GAE/g). The presence of anthocyanins was noted in 5 accessions. The highest content was noted in the root turnip Hinona (k-1422, USA) - it accumulates a large amount of anthocyanins both in the root crop (1906,77 mg/100g) and in the leaves (1046,40 mg/100g), which exceeds the content in other root crops by 355-426% and leaves by 293-632%. In combination with a low degree of *Alternaria* infection, it is a valuable breeding material.

The biochemical composition in comparison with the degree of *Alternaria* infection revealed correlations (according to Pearson): A strong negative correlation is observed between resistance to the disease and the content of anthocyanins ($r = -0,72$) and phenolic compounds ($r = -0,61$), moderate - between the content of ascorbic acid ($r = -0,45$), carotenoids ($r = -0,39$), beta-carotene ($r = -0,41$) and the content of chlorophyll a ($r = -0,32$), low - between the content of chlorophyll b ($r = -0,28$). A low positive correlation is observed between stability and the content of monosaccharides ($r = 0,12$). Thus, anthocyanins have the greatest protective function, which may be related to their antimicrobial activity. Phenolic compounds have a strong protective function, which may be related to their fungitoxic properties, which inhibit pathogen development, participate in lignification by strengthening the physical barrier to pathogen penetration and act as signalling molecules, activating plant defence genes. Ascorbic acid also influences defence mechanisms, which may be related to its antioxidant function and the synthesis of specific proteins and lignin that prevent pathogen penetration and participate in the activation of signalling pathways associated with systemic acquired resistance (SAR). Carotenoids and chlorophyll have a supporting role in plant defence mechanisms and are involved in photosynthetic activity, providing energy for defence reactions. The stronger effect of chlorophyll a may be due to its higher amount and closer association with carotenoids (including β -carotene), which protect plants against oxidative stress. Thus, selection in breeding for

resistance should be primarily based on the content of anthocyanins and phenolic compounds.

CONCLUSION

The study of a set of accessions of different crops of *Brassica rapa* L. allowed to reveal a diverse manifestation of morphological and economically valuable plant traits under conditions of the North-West region of the Russian Federation. According to the level of resistance to *Alternaria* spp and the content of protective bioactive compounds the most valuable for breeding are accessions of root turnip - Hinona (k- 1422, USA), Salusia 4x (k-1423, Germany), tacai - Xiao Ba Je Ta Cai (k-695, China). Sources of yield and resistance to *Alternaria* spp. - Chinese cabbage accessions: Raioh 90 F1 (vr.k-1558, Japan), Udzi M70 (k-398, Japan), early maturity and high content of biologically active components - k-647 (Tajikistan).

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