Vegetable crop breeding for increased antioxidant content is a promising direction for healthy food production

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Abstract. The article presents the directions and results of breeding work of FSBSI Federal Scientific Centre for Vegetable Growing for improved biochemical composition of vegetable crops. The gene pool of traditional and rare vegetable crops is evaluated by their antioxidant properties, the best samples with high content of dry matter, sugars, ascorbic acid, carotenoids, phenolic compounds, macro- and microelements are selected as the starting material for further breeding for improved biochemical composition. Especially valuable in this direction are cabbages, onions, pumpkins, nightshades, root crops, greens and low-spreading crops. It is shown that in recent years there has been considerable interest in the food use of seedlings of various vegetable crops. Scientists and breeders are increasingly turning to wild species as sources of new material to expand the genetic basis of crops to enhance their antioxidant status, adaptive potential and resistance to biotic stresses, such crops include chervil, ornamental onions, spicy-flavored crops and others. It is shown that breeding vegetable crops for improving the biochemical composition of fruits has great prospects, since the introduction into production of varieties and hybrids with high antioxidant status will increase their food and medicinal value without additional costs of irreplaceable energy sources and will serve as the basis for creating functional products. Functional foods should be obligatory on the market alongside traditional foods, as they can complement traditional ones by acting as a kind of medicinal or preventive remedy.

1. Relevance

The problems of preserving health and increasing longevity of life depend on many factors, the most important of which is the quality of nutrition. Vegetables are known to be an essential foodstuff and are a major source of vitamins, amino acids, mineral salts, microelements, carbohydrates, proteins, hormones, enzymes, phytoncides, aromatic, essential oils and other valuable substances. In this regard, in the Federal State Scientific Institution "Federal Scientific Center for Vegetable Growing" (FSBSI FSCVG) one of the most important directions of modern breeding of vegetable crops is to increase their nutritional value as food of plant origin, the so-called biofortification. The world scientific community declared breeding for the content and composition of biologically active substances as a priority in the 21st century. For successful breeding for increased antioxidant activity, the available breeding material is screened to create promising varieties and hybrids of various vegetable crops.
2. Results

Cabbage is the most widespread vegetable crop with year-round use in food and accounts for a quarter of the average annual consumption of vegetables per capita, which determines the importance of breeding for increased content of biologically active compounds. Scientists of FSCVG have shown that early maturing varieties of cabbage are characterized by the highest level of vitamin C accumulation. In the hybrid Zarnitsa and the variety lyunskaya 3200 this index is within the range of 45-46 mg/100 g. The maximum levels of iron and copper were recorded in the variety Amager, zinc - in the Number 1 Gribovsky 147, manganese - in the variety Podarok. When consuming about 300 g of white cabbage, the body receives: 14.1% iron, 23.4% manganese, 2.6% zinc and 3% copper [1].

Of particular importance are varieties of cabbage, which are relatively high in carbohydrates, proteins with essential amino acids and many mineral elements.

The popularity of broccoli cabbage around the world is evidenced by the fact that the crop is now cultivated on most continents. It is rich in nutrients and tastes great, and contains as much vitamin C as citrus fruits. Broccoli is also high in vitamin U (of the vegetables, only asparagus contains more of this vitamin). A new hybrid of broccoli cabbage, the Sparta was created in FSBSI FSCVG [2]. It is characterized by high content of sugars (4.9%) and ascorbic acid (139 mg%). Cabbage crops are also of particular interest as a source of high sulphur content, which is easily replaced by selenium under selenium load conditions, which contributes to the anti-cancer activity of different cabbage species and is largely associated with the biosynthesis of selenium-containing glucosinolates [3].

In recent years there appeared a particular interest in the use of vegetable seed sprouts in food. The production of sprouted cabbage seeds attracts particular attention due to the high level of antioxidants in the final product [4,5].

Scientists of FSBSI FSCVG showed that the total content of water-soluble antioxidants in the studied seedlings of cabbage crops was in the concentration range from 3.58-4.57 mg-eq. HA/g (crude weight). The maximum values for this indicator in 8-d-old seedlings were shown in red cabbage. Total content of antioxidants in the alcohol extract was 21.24 to 28.23 mg-eq HA/g (dry weight), polyphenols content was within the range of 16.39-24.94 mg-eq HA/g (dry weight). As a result of researches direct correlations between studied attributes were revealed: high - between the content of water-soluble antioxidants and dry matter (r=0.72...0.98) and between the content of carotenoids and chlorophylls (r=0.98...0.99) [6].

Japanese cabbage (Brassica rapa L. subsp. nipposinica (L. H. Bailey) Hanelt) is one of the little studied non-traditional crops in Russia, which belongs to the East Asian species. However, due to its nutritional qualities, content of ascorbic acid, carotene, vitamins B1, B2, PP, folic acid, chlorophylls, mineral elements - potassium, calcium, phosphorus, iron the demand for fresh herbs increases, which contributes to its popularity. FSBSI FSCVG created a new variety of this type of cabbage characterized by high content of ascorbic acid (37.84±0.88 mg%) and of dry matter (11.3±0.42%). The content of antioxidants in terms of HA and AA varies within 5.72±0.72 and 19.5±2.46 mg/g, respectively [7].

The value of garden onion as a powerful source of natural antioxidants determines the prospects of its breeding for high shelf-life for year-round consumption and for the increased content of biologically active compounds. The study of the regularities of accumulation of biologically active compounds makes it possible to identify a valuable source material for breeding, which may also become the basis for obtaining functional products. The most important biochemical characteristics of onions include the content of dry matter and sugars determine the possibility of long-term storage of bulbs, and the content of quercetin and vitamin C are the most important indicators of the antioxidant system of Allium cepa. The varieties Alvina, Alba, Myachkovskii, Sigma, Strigunovskii, Zolotnichok, Odintsovetov, Ceparius, Zolotye Kupola, Atas, Raniy Rozovy, Kuchum contain from 15 to 20% of dry matter, which classifies them as high storability varieties. It is shown that the total content of sugars negatively correlates with the content of dry matter. The pattern found indicates that the most storable varieties have the lowest monosugar content, while the varieties with a dry matter content of less than 15% (Ambest, Bonus) are rich in glucose, fructose and have an increased level of ascorbic acid. The red-dyed variety Black Prince had the highest vitamin C content [8].
A fairly high total content of flavonoids, represented by mono- and di-glycosides of quercetin, which provide up to 70% of the flavonoids coming with food into the human body, was revealed. Low temperatures are known to promote flavonoid accumulation [9]. The level of quercetin in onion varieties grown in the Moscow region is significantly higher than in \textit{Allium cepa} of Portugal [10]. The maximum concentrations of quercetin were recorded in the varieties Odintsovets, Atas, Globus, Kolobok, Zolote Kupola and Ranny Rozovy (13...15 g/kg of dry weight). Inter-varietal differences in quercetin accumulation (21.4 %) indicate promising breeding of \textit{Allium cepa} according to this indicator. When studying the levels of selenium and quercetin accumulation in onions, an inverse correlation between them was established for the first time, indicating the existence of a strict homeostasis of maintaining a certain level of antioxidant protection [9]. Food plants rich in antioxidant protection components include perennial onions. According to calculations by our scientists, the consumption of 100 g of fresh chives satisfies up to 60% of the daily requirement of the human body for ascorbic acid, up to 94% for manganese, 20% for copper and 12% for zinc [11].

The study of biochemical parameters of 8 perennial onion species (\textit{Allium ramosum}, \textit{A. caeruleum}, \textit{A.erubescens}, \textit{A.obliquum}, \textit{A.moly}, \textit{A.aflatunense}, \textit{A.oreophilum} and \textit{A.ursinum}) revealed a high nutritional value of some ornamental forms, especially blue onion, characterized by the highest vitamin C content (over 9000 mg/100 g) and polyphenols (over 8000 mg of HA/100 g). The following intervals of vitamin C concentrations were established for the studied onion species: 568 (\textit{A. ramosum}) - 9980 (\textit{A. caerulum}) mg/100 g of dry matter; polyphenols: 1392 (\textit{A. obliquum}) - 8582 (\textit{A. caerulum}) mg HA/100 g of dry matter; water-soluble minerals: 28 (\textit{A. aflatunense}, \textit{A.obliquum}) - 69 (\textit{A.ramosum}) mg/kg of dry matter; chlorophyll: 0.54 (\textit{A.oreophilum}) - 1.69 (\textit{A.ursinum}) mg/100 g dry matter; carotene: 0.07 (\textit{A.oreophilum}) - 0.25 (\textit{A.ursinum}) mg/kg dry matter; selenium: 72 (\textit{A.ursinum}) - 245 mg/kg d.m. (\textit{A.ramosum}) mg/kg of dry matter. Adequate human intake of vitamin C can be provided by as little as 6.2 g of blue onion leaves. The level of antioxidant activity of alcoholic extracts ranged from 1.5 (\textit{A.obliquum}) to 6.4 (\textit{A.ursinum}) mg-eq HA/g d.m. [12].

The carrot (Daucus carota L.) is the most popular crop among root vegetables and one of the best sources of β-carotene in our diet, providing 17% of the total β-carotene intake in the human diet. Over the last twenty years, carrots have been available on the global market in a wide range of root colours, from white to purple. White carrots contain almost no pigments but are rich in fibre, which improves human intestinal function. The yellow colour of carrots is due to lutein (xanthophyll), which has a beneficial effect on the retina. Red carrots are characterized by the presence of lycopene, which has antioxidiant properties. Carrots with purple colouring are due to the pigment anthocyanin, which is a powerful antioxidant. The β-carotene and lutein contents in yellow-colored carrots vary from 0.7±0.1 to 1.5±0.2 mg/100 g of crude weight and from 1.1±0.1 to 2.4±0.2 mg/100 g, depending on the intensity of root xylem coloration. Of the samples with orange coloring of the root crop of interest for further breeding are: Feonia (16.8±0.4 mg/100 g raw weight), NIOH 336 (20.2±0.6/100 g). Among the group of specimens with purple colouring, the samples Purple haze (112.4±6.1 mg/100 g crude weight) and Purple haze (102.8±3.7mg/100 g) have a high content of anthocyanins [13].

In recent years there appeared a growing interest in the pumpkin crop as a rich source of carotenoids. Pumpkin fruits contain mainly β-carotene, lutein and violaxanthin. A study of the carotenoid composition of pumpkin pulp of the variety Konfetka selected by FBSBI FSCVG revealed for the first time that this is the only currently known variety accumulating exclusively lutein in the pulp and lutein and zeaxanthin in the rind. Lutein content in pumpkin pulp was 11 mg/100 g, in the peel - 41.3 mg/100 g and in the placenta - 51.2 mg/100 g. Zeaxanthin was absent in the pulp, 28.3 mg/100 g in the peel and 10 mg/100 g in the placenta, β-carotene was found only in the placenta, where its content reached 94.7 mg/100 g. The obtained data indicate the promising use of all parts of the pumpkin variety Konfetka both in the food industry and in the production of children's food and dietary supplements containing lutein and zeaxanthin [14].

The high antioxidant activity of tomato fruit is due to the content of vitamin C, polyphenols and carotenoids. Tomato fruit is known to be the main source of lycopene for humans, providing up to 85% of its intake with food. In this regard, the development of new tomato varieties with an increased
content of carotenoids is a priority for breeders. A study of the β-carotene and lycopene content in varieties with different colouring revealed a characteristic lycopene/β-carotene ratio for pink and red fruits: from 1.5 to 10.25 and for yellow and orange varieties: from 0 to 0.63 [15].

The high content of lycopene in red fruits was observed in the varieties Voskhod VNIISSOKa (10.9 mg/100g), Blagodatny (11 mg/100g), β-carotene in the varieties Dolgorok (6.2 mg/100g), Osennaya Rapsodya (3.6 mg/100g), lines 119-18 (3.8 mg/100g) with orange colouring of fruits [16].

Fruits with pink and raspberry colouring have a high lycopene content (at the level of red-fruited varieties) and quite high β-carotene content (2 times higher than in red-fruited varieties), which gives them food value for dietary nutrition. The sugar-acid index, which reflects the palatability of the pink fruit, is 7-10 and the dry matter content is 6-7%. The tomato varieties Malinka, Lotus and Sodruzhestvo meet these requirements [17].

The fruits of pepper (Capsicum sp.) are a rich source of antioxidants and compounds potentially beneficial for health: carotenoids, vitamins C and E and flavonoids. The creation of new varieties and hybrids with high content of biologically active substances involves the use of species resources to obtain fundamentally new results in breeding. To achieve the required result, a large number of samples were evaluated for antioxidant status of fruits, including pigments. The highest sum of carotenoids was detected in sweet pepper varieties Chocolate (Capsicum annuum) - 0.536 mg/g, and also in hot pepper varieties Purple Tiger (C. annuum) - 0.708 mg/g, Chinese lantern (C. baccatum) - 0.685 mg/g, Idea (C. annuum) - 0.629 mg/g, Chudo Podmoskovya (C. annuum) - 0.628 mg/g. The highest accumulation of ascorbic acid was observed in hot pepper varieties Idea (414 mg%), Christmas bouquet (C. annuum x C. frutescens) (370 mg%), Yubileiny VNIISSOK (C. annuum) (326 mg%), Fire Maiden (C. chinense) (301 mg%). Peppers, both sweet and hot forms, have a leading position in terms of vitamin C content. However, it should be noted that the vitamin C content does not depend on fruit colour and species affiliation. The results of biochemical studies on the content of the sum of antioxidants showed that this value varies greatly between varieties and species. The maximum content of the sum of antioxidants (TOC, mg-eq. HA/g) among the acute forms was noted in the specimens: Christmas bouquet - 2.82, Fire Maiden - 2.65, Idea - 2.57 and Purple tiger - 2.19. Among the sweet peppers, the high content of total antioxidants was observed in hybrid F1 Orange Pleasure (1.25 mg-eq. HA/g) [18].

The samples Christmas bouquet, Chinese lantern, Purple tiger, and Fire Maiden accumulated another strong natural antioxidant, capsaicin, which determined their burning taste. The capsaicin content in the studied samples of hot peppers ranged from 1.36-9.57 mg/g of dry weight [19]. The high content of carotenoids, ascorbic acid, sum of antioxidants in pepper samples combined with capsaicin further increased the total antioxidant status of the samples.

Daikon, due to its chemical composition, is the most important source of carbohydrates, vitamins and biologically active substances of medicinal effect. FSBSI FSCVG has a range of daikon varieties (Sasha, Dubinushka, Dragon, Moskovsky Bogatyr, Favorit) with different root crop shapes. As a result of this research, new experimental data was obtained confirming the prospects of daikon root crops as a source of pectin, and a method for its extraction from squeezed fruits was developed. It was found that the pectins isolated under mechanoacoustic influence are highly esterified (65-70%), of high molecular weight (35-40 kDa) and meet the requirements of GOST (state standard) for food pectin [20].

Parsnip, a vegetable of the celery family, is a rare root crop and is not widely grown in Russia, but it is a favourite delicacy in Scandinavian countries, England and the USA. The root crop is rich in fat, protein, carbohydrates, calcium, potassium, phosphorus, fibre and essential oils. They contain a large number of bioactive compounds, as well as substances with fungicidal and bactericidal properties. It was established that consumption of 100 g of fresh parsnips can provide the intake of 17-18% potassium, 13-14% cobalt, 12-13% iron, 10-17% silicon, about 10% phosphorus, magnesium, manganese and chromium. It was found that the parsnip variety Krugly is able to accumulate relatively high concentrations of iodine [21].

On the basis of parsnips, a functional food was created, which refers to specialized products designed to quickly restore strength after intensive muscle exercise, exposure to stress and accelerate the rehabilitation of patients after severe diseases. The functional food product is characterized by the fact that it represents thermally processed parsnip root vegetables and contains 25.5±4.5% fructose per
dry weight, 25.2±1.9% glucose, and also contains 22.6±2.2 mg-eq gallic acid per 1g of dry weight and has antioxidant activity of 26.1±3.6 mg-eq gallic acid per 1g of dry weight [22].

Celery is one of the most widely used vegetable crops in the world due to its wide range of dietary and medicinal properties. It is an excellent source of antioxidants, minerals and essential oils that are beneficial to human health. All parts of celery are edible: leaves, petioles, roots and seeds, both fresh and in spice form. The comparative evaluation of the accumulation of polyphenols, ascorbic acid, flavonoids and photosynthetic pigments by leaf, petiole and root varieties of celery grown under the same conditions on the experimental fields of FSBSI FSCVG revealed a number of regularities characteristic of each variety. It is shown that antioxidant activity of seeds, leaves and petioles has the ratio 2.7 : 1.74 : 1 - for leafy varieties, 2.88 : 1.99 : 1 for petiolate ones, and for root celery the antioxidant activity of seeds, leaves, root crops and petioles is determined by the ratio 3.66 : 2.78 : 1.42 : 1. Practically equal ascorbic acid content in leaves irrespective of celery variety, the vitamin C concentration in leaves and petioles is (5.31-5.57) : 1 for leafy varieties, 8.1 : 1.1 : 1 for petiolate ones, while for root celery the ratio of vitamin C concentration in leaves and petioles is (8.1 : 1.1) : 1. Practically equal ascorbic acid content in leaves irrespective of celery variety, the vitamin C concentration in leaves and petioles is (5.31-5.57) : 1 for leaf and petiole varieties, while for root ones the vitamin C concentration in leaves, root-crops and petioles is determined by the ratio 8.1 : 1.1 : 1. The distribution of polyphenols in the system seed : leaf : root : petiole in root celery has a ratio of 1.77 : 1.77 : 1.33 : 1, while in petiole celery the ratio of polyphenols leaf/petiole is 1.86 : 1 and in leaf celery the ratio is 1.64 : 1. In leafy celery, the polyphenol levels in its seeds are 1.4-1.5 times lower than in its leaves as opposed to the petiole and root forms of celery, which have the same polyphenol levels in their seeds and leaves. The ratio of flavonoid content of leaves to petioles is highest in the variety Elixir (2.87) and in the variety Atlant (2.41). In the root varieties and the leaf celery variety Samurai, this index is in the range of 1.54-1.71 [23].

Under conditions of climate change, population growth and production intensity, scientists and breeders are increasingly turning to wild species as sources of new material for expanding the genetic basis of crops to increase their antioxidant status, adaptive potential and resistance to biotic stresses. Plants of the *Apiaceae* family, including *Anthriscus cerefolium* and *A. sylvestris*, seem particularly promising in this respect due to their high biological activity, essential oils and antioxidant content. Comparison of the wild form of *A. sylvestris* chervil with the cultivated form of *A. cerefolium* under the conditions of the Moscow region revealed a significantly higher antioxidant status of the wild form: the AOA level was 1.5 times higher, TR - 2.2 times higher, ascorbic acid - 1.7 times higher, and chlorophyll - 2 times higher. Leaves of the wild form contained 1.72 times more water-soluble compounds, and petioles - 4 times more than the cultivated form. Spice and herbs are an irreplaceable source of vitamins, macro- and micro-elements and organic acids. Their regular inclusion in the diet is beneficial for the human body. In Russia, the main period of production and consumption of fresh vegetable products is in June-October. Nowadays, healthy green vegetables are widely grown regardless of the season in the protected ground on hydroponics. More than 30 species of green and odoriferous crops can be cultivated on salad lines in the world, and in Russia - about 12 species. Scientists of FSBSI FSCVG proposed a number of varieties of less common crops: indau, watercress and salad mustard, which are successfully grown on this technology [24].

Studies have shown that the cultivation of melissa cultivar Zhemchuzhina on hydroponics can produce green marketable products of high quality. Thus, in the winter-spring period the average content of vitamin C in melissa was 24.6 mg% and 12.7% of dry matter, which was higher than in plants of the variety Aficion (19.4 mg% and 5.4%) and comparable with Monarda citrica of the variety Simca (23.2 mg% and 12.2%) and Monarda duca of the variety №5 (26.4 mg% and 11.7%) at the same time. Accumulation of significant amounts of water-soluble antioxidants (at the level of crops such as thyme 5.5 - mg-eq. HA/g of crude weight and monarda duca - 6.0 mg-eq. HA/g of raw weight). The total content of water-soluble AO in the marketable melissa leaves of the variety Zhemchuzhina reaches 5.9 mg-eq/g of crude weight in March. HA/g of raw weight, gradually increased in the following months and doubled by September [25].

3. Conclusion

In conclusion, it should be noted that the selection of vegetable crops in terms of antioxidant activity requires a careful study of not only the accumulation of individual biochemical substances, but also
the question of the relationship of the components of these natural elements, as the varieties created will be used as plant raw materials for the production of functional foods.

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