Peculiarities of cultivation of broccoli (Brassica oleracea L. convar. botrytis (L.) Alef. var. cymosa Duch.) in the Non-chernozem zone of the Russian Federation (prospects of selection work and agricultural technology)

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Abstract. Broccoli cabbage (Brassica oleracea L. convar. Botrytis (L.) Alef. Var. Cymosa Duch.) was already known in culture more than 2 thousand years ago. Broccoli is still less common in Russia. The research and evaluation of experimental results demonstrates broccoli is a very promising crop, both for scientific research and for commodity production. Simply, its potential is still not fully disclosed, both by agricultural producers and the scientific community in the Russian Federation. This is evidenced by the ever-growing number of foreign hybrids of F1 broccoli in the State Register of Breeding Achievements Approved for Use in 2018. At the same time, the research results reflected in the article can be equally useful for representatives of the agro-industrial complex and agricultural science.

1. Botanical Classification and Morphological Description
Broccoli is the closest relative of cauliflower (Brassica oleracea L. var. Botrytis L.). It is an annual dicotyledonous vegetable plant of the Cabbage (lat. Brassicaceae) or Cruciferous (Cruciferae) family. The Cabbage family, in turn, belongs to the angiosperms division [Magnoliophyta (Angiospermae)], the class of dicotyledons [Magnolietae (Dicotiledones)], and to the order Capparales Hutchinson. This family is very extensive: there are 375 genera and more than 3200 species [9].

Broccoli plants form a stem up to 80 cm high, which ends with a head (also known as a food organ) consisting of shortened peduncles with tightly closed buds. The color of such heads is from green to violet. Moreover, the darker the color of the head, the variety has a later maturation period and high yield, but their taste is somewhat worse. Over-grown heads bloom. The flowers are yellow, rarely white. The fruit is a pod. Seeds are small, round, brown color about 2 mm in diameter.

2. Nutritional Value of Broccoli Cabbage
Broccoli heads are very rich in biochemical composition and can be used in dietary nutrition. They contain 4% methionine, 100–160 mg/% of vitamin C, are rich in sugars and carotene (1-7 mg/%, respectively), unlike cauliflower. The content of carotene broccoli exceeds all other varieties of cabbage, as well as beans, green peas, peppers, apples, and oranges.

The young leaves of broccoli nutritionally equate to spinach and kale. Broccoli heads contain vitamins A, B1, B2, PP, C, K, salts of potassium, phosphorus, calcium, magnesium. According to the content of thiamine, broccoli ranks first among the most important vegetable crops. Its protein contains anti-sclerotic substances (methionine, choline) that prevent the accumulation of cholesterol in the body; therefore, broccoli is considered an important tool against premature body aging [14].

Broccoli can be used in the diet for the treatment of radiation sickness. Its heads are rich in the biological form of iodine. Getting into the human thyroid gland, iodine prevents the penetration of radioactive isotopes there [11]. It contains flavonoids [19], selenium [17], glucosinolates [6]; therefore, it can be used in therapeutic and preventive nutrition for oncological diseases, hypo- and avitaminosis, colitis, diseases of the gastrointestinal tract and heart.

3. Material and Research Methods
Broccoli cabbage plants (Brassica oleracea L. convar. Botrytis (L.) Alef. Var. Cymosa Duch.) of the Tonus variety (Figure 1) are used in our research.

Figure 1. Mature food organ of adult cabbage plant (Tonus).

The studies were conducted on the basis of the Federal State Budget Scientific Institution “Federal Scientific Center of Vegetable Growing” and the Federal State Budget Scientific Institution “All-Russian Scientific Research Institute of Phytopathology” in the Ramensky and Odintsovsky districts of the Moscow region in 2010-2017.

Laboratory studies were carried out according to:

- Guidelines for breeding cabbage in tissue culture [10];
- Methodical recommendations for obtaining transgenic plants of white cabbage [13];
- Methodological guidelines on reproductive biology in the selection of vegetable crops of the genus Brassica L. [3];
- Methodical recommendations for obtaining regenerants of vegetable crops and their reproduction “in vitro” [12];
- Methodical instructions on the culture of tissue and organs in plant breeding [4, 5].

Liquid and agar (solid) nutrient media were also prepared according to the relevant methodological recommendations [12] based on the stock solution MS [18]. Depending on the experience, the necessary changes were made to the composition of the medium.

Cultivation of isolated ovaries and ovules was carried out on liquid and agar medium MS with the addition of various concentrations of sucrose and phytohormones (Figure 2).
Figure 2. Regenerant plants of broccoli cabbage grown on agarized nutrient medium Murashige - Skoog [18].

4. Characteristics of the Climatic Conditions of the Moscow Region
The Moscow region is located in the central part of the East European Plain. Plain relief prevails. In its western part, there are elevations of not more than one hundred and sixty meters. The climate of the Moscow region is moderately continental, with cold winter and warm summer. The coldest month of winter is January (the average temperature ranges from $-9^\circ C$ in the west to $-12^\circ C$ in the east of the region). The warmest month is July (average temperature $+18^\circ C$ in the north-west and up to $+21^\circ C$ in the south-east, respectively).

The amount of precipitation per year averages from five hundred to seven hundred mm. For each summer month, an average of about 75 mm of precipitation falls. Various droughts occur about 3-4 times in one hundred years on the territory of the Moscow region (Atlas of Moscow Region, 2004).

The soils of the region are sod-podzolic, alluvial, gray forest, marsh, sandy. Gray forest soils predominate in the Ramensky district of the region, and sod-podzolic soils prevail in the Odintsovo region [8]. Broccoli cultivars grown in the Russian Federation are prone to maintenance. After cutting the central head, they form new small heads from the leaf axils. Moreover, broccoli is edible, along with the head, the lower part of the tender and fleshy stem.

For the most part, vegetable products in Russia are produced in home gardens and garden plots. In this regard, it is necessary to develop a modern agricultural technology that takes into account the biological characteristics of broccoli to reduce all sorts of risks when growing.

5. Broccoli Cabbage Farming
The most common method of growing almost any cabbage in the Russian Federation is sprouts. The guarantee of high cabbage yield and risk reduction is high-quality varietal seeds. They must have a germination rate close to one hundred percent. At the same time, the seedlings are to be friendly, and even, and the area should be used as efficiently as possible. Seeds are usually sown in a seedling box or on ridges in rows with a row spacing of five to six cm. Before this, the hotbed should be marked. The marker consists of wooden planks with 2 handles on the ends. The pins are inserted into the pins, which are located at a distance of 5 cm from each other.

The most advanced method is sowing in plastic seedlings. The cells of these cassettes must first be filled with a nutrient substrate (as a rule, on the basis of peat) containing mineral fertilizers and an optimal level of acidity. As a result, a powerful root system develops.

Then the seeds are sprinkled with the same substrate, compacted and sprinkled with perlite. This further prevents the rapid evaporation of moisture. After this, watering is required. Shoots appear very quickly (from 3 to 8 days), but they must be provided with a large amount of light so that they do not stretch. The temperature at the same time should be from 6 to 8°C. Next, it is necessary to set the following temperature mode: in the afternoon 15-17°C, from 6 to 8°C at night, with good illumination.
with a longitude of the day 16 hours. It is not allowed to increase the air temperature above 25°C, as it adversely affects plants and contributes to the development of diseases.

With the appearance of the 2nd true leaf, plants feed as follows: 20 grams of ammonium nitrate and superphosphate and 10 grams of potassium chloride per ten liters of water. In the second feeding, 30-40 grams of ammonium nitrate, 40 grams of superphosphate, and 20 grams of potassium chloride are introduced. The third feed usually includes 20 grams of ammonium nitrate, 40 grams of superphosphate, and 40-60 grams of potassium chloride per 10 liters of water.

In addition, 0.2-1.0 grams of boric acid, 1.5-2.0 grams of copper sulphate are added to one of the dressings; 0.5-1.5 grams of zinc sulfate and potassium permanganate. In general, top dressing is performed based on the appearance of the plant, as a rule, after the appearance of the next true leaf. It is allowed, also based on the needs of plants, the use of complex mineral fertilizers.

At the same time, traditional organic fertilizers remain effective:

- Slurry dissolved in water in a ratio of 1: 3-4;
- Mullein in the ratio of 1: 4-5;
- Chicken litter in the calculation of 1 to 8;
- Fifteen to twenty grams of superphosphate is also added to these fertilizers;

Growing seedlings using cassettes significantly reduces the consumption of seed material. Substrate, as a rule, does not contain weed seeds. It should only be watered in a timely manner.

Real leaves and lateral roots usually appear on the seventh-twelfth day of plant development.

At this time, some varieties of cabbage can be differentiated according to a number of morphological features (the form of cotyledons, the shape of this leaf, the color of the perimeter knee and its pubescence, etc.). Also, there is observed an increased growth of cabbage plants, and they need to be transplanted to a permanent place. Transplantation is carried out with the appearance of five or more true leaves in plants or upon reaching the age of 35 to 40 days (Figure 3).

![Broccoli sprouts in open field.](image)

**Figure 3.** Broccoli sprouts in open field.

Before transplantation, it is important to harden the seedlings. For this purpose, it is kept from seven to ten days at reduced positive temperatures (from +6 to +8 °C). Successful hardening (presence of bluish color in seedlings) increases the resistance of plants to adverse environmental factors and the causative agent of the “black leg” (species of mushrooms: Pythium debaryanum Hesse, Olpidium brassicae Wor., Phizoctonia aderholdii Kolosh., and also the genus Fusarium sp.).

To facilitate survival and reduce the load on the root system, cabbage seedlings should not be tall. Before planting, seedlings are watered abundantly to facilitate its removal from the soil or cassettes and to avoid injury to their root system.

In early May, seedlings are planted open ground. The standard planting scheme is 70 × 30, or 60 × 40 cm. At the same time, the size of the plant directly depends on the area of nutrition. The larger it is, the larger the cabbage plant, but the maturation of the food organ is longer.
Seedlings are planted in cloudy, wet weather in the afternoon, and then they are watered with a sprinkler. Planting of seedlings is allowed to combine with treatment with insecticide against cruciferous flea. In the future, it is recommended to cultivate between-rows, to fight weeds, to loosen the root layer of soil, to water it in a timely manner.

In the conditions of an open ground it is expedient to carry out no more than two top dressings. First: after 10 to 15 days from the time, the cabbage seedlings are planted. It should consist of 15 to 20 grams of complex mineral fertilizer per one square meter. Fertilizer must be patched with a hoe, for example, in conjunction with inter-row processing. Do not allow fertilizer to reach the plants.

It is preferable to use granular approvals. They slowly dissolve in water and can supply cabbage plants with batteries for a long time. The need for irrigation is determined by soil moisture. Humidity should be 60-80% of the field capacity (lowest).

With high taste and food qualities of broccoli cabbage, the range of its domestic varieties and hybrids in the Russian Federation is very limited. This creates a wide field of activity and prospects for selection work. Moreover, the range of foreign breeding achievements (mainly F1 hybrids), as a rule, is constantly growing and expanding imported from the Western countries.

6. The main Directions and Features of Breeding with Broccoli Cabbage
At present, 50 varieties and hybrids of broccoli cabbage are included in the State Register of Breeding Achievements Approved for Use in 2018 in the territory of the Russian Federation. Moreover, only 8 of them are varieties, and all the rest are F1 hybrids. As a rule, authors and copyright holders of varieties are domestic commercial and budget organizations, while authors and copyright holders of F1 hybrids are mostly foreign organizations (Sakata, Bejo, Enza Zaden, Syngenta and others).

Hybrid plants due to the phenomenon of heterosis (hybrid power in the first generation - alleles of genes are in a heterozygous state “AaBb Cc ...”, etc.) often surpass varieties in quantitative and qualitative economically valuable traits, which makes them profitable commercially. However, the process of creating “clean lines” with a set of useful traits possessing high homozygosity is quite laborious and expensive and can take several years.

Therefore, the method of cultivation in vitro of microspores, anthers, unfertilized ovaries and ovules is widely used in plant breeding. This is required for the induction of the morphogenesis of haploid cells in microspores or the embryo sac. However, in order to cause the transition of these cells from the gametophytic to the sporophytic developmental path, it is necessary to choose the optimal combination of the following factors: the composition of the nutrient medium, growth regulators and their concentration, the cultivation conditions of donor plants and explants.

In order to obtain gynogenetic haploid and doubled haploid plants, similar to self-pollinated lines, unfertilized ovaries, and ovules isolated from unblown buds of broccoli were used in our research (optimal size 8.1-9.0 mm).

As shown by our research, cells of the female gametophyte are able to continue to develop in ovules transplanted to an artificial nutrient medium in vitro on MS mothers [18]. Thus, this method can be taken as a basis for obtaining analogues of self-pollinated lines of broccoli for further hybridization.

7. Research Results
Even the most popular variety of broccoli in the vegetable market cannot demonstrate its full potential without selecting the optimal conditions for its growth and development. These conditions are made up of a wide range of factors.

First of all, this is zoning in a specific soil-climatic zone. Then it is necessary to establish the type of soil, its fertility, the terrain, the provision of soil moisture. In order for broccoli varieties and currently popular heterotic hybrids to realize their full potential, it is necessary to use agricultural techniques correctly. Strong temperature fluctuations, dry air and soil can dramatically reduce the quality and yield of grocery organs of broccoli (although plants can withstand frosts from -7 to -10 °C,
for example, in the fall). On the heights, freezing is less dangerous for plants than in places of low relief.

Thus, it is necessary to make full use of the natural terrain, and in its absence, to build artificial obstacles, such as ridges, planting, and forest belts from tall trees and shrubs. In this case, planting should be carried out more closely.

It is necessary to take into account other climatic conditions for growing broccoli in the area. For example, in the broccoli growing areas located inside the forest, the frost-free period is much shorter, and the areas near water bodies have a longer frost-free period.

Also, to keep the soil temperature longer, mulching works well. It should be borne in mind that poorly cut soil heats up slowly and cools quickly. An effective measure to combat frosts is: smoking, watering, the use of shelters and other.

A significant contribution to ensuring the high yield of broccoli cabbage is made by soil fertility and the availability of soil with easily accessible forms of nutrients. And the leading importance is the acidity of the soil. When the pH of the soil is close to neutral, the mineralization of nutrients is carried out and they become available for cabbage plants.

Phosphate and potash fertilizers also increase the resistance of broccoli cabbage plants to frost. A significant role in this process is played by soil microorganisms, for which high acidity is harmful as well as to the plants themselves. If the acidity of the soil is too high, the plants themselves cannot normally absorb the existing nutrients.

The broccoli cabbage plants, in addition to all of the above, other nutrients are also needed. Nitrogen is an integral part of plant protein and chlorophyll. It affects photosynthesis and enzyme activity.

Phosphorus plays an important role in metabolism and energy metabolism. With its deficiency, the formation of food organs is slowed down.

Potassium is involved in carbohydrate metabolism, the formation of amino acids and proteins. With a lack of potassium, a stronger damage is observed by leaf-eating pests.

Magnesium is part of chlorophyll. He takes part in the transition of phosphoric acid from mineral compounds to organic. As a rule, magnesium starvation is not observed on loamy soils. Excessive magnesium content in soil harmful to broccoli plants.

Calcium is important for maintaining ionic balance in plant tissues. It is also part of the cell walls. Reducing the amount of calcium in the soil leads to its acidification, and broccoli plants are delayed in growth and development.

Boron, molybdenum, manganese, iron and other trace elements are found in small amounts of broccoli plants. But at the same time they are extremely important for redox reactions, photosynthesis, for energy, carbohydrate and protein metabolism. Their effect on plants is as important as the effect of vitamins and hormones on the human body [1].

On loamy soils in broccoli plants, there is usually no shortage of trace elements. Their lack is observed on peat, marsh, sandy and sandy soils. A lack of boron causes damage to the apical kidney, which leads to a sharp decrease in yield.

Broccoli plants have high nutrient removal from the soil. Accordingly, the lack of crop rotation and the same type of agricultural technology lead to a decrease in yield, starvation of plants and their damage by pathogens.

Since the vegetable crop rotation requires a high financial cost, it is advisable to use a seeding planting with other vegetable crops on broccoli plantations. Studies have shown the positive effect of some vegetable (and other) crops on each other. This phenomenon is often used to increase plant productivity, prevent one-sided removal of nutrients from the soil, use the area of the same area twice, scare away pests and other.

However, not all sealing crops positively affect neighboring plants. It is allowed to grow broccoli cabbage with cucumber, beans, celery, dill, but it does not fit well with tomato, onion, and strawberry.

Soil preparation for broccoli begins in the fall with the introduction of two-thirds of the required complex mineral fertilizers and organic matter. The need for fertilizers for broccoli cabbage is
calculated based on the availability of nutrients to the soil, as well as taking into account the removal of substances by cabbage plants. Together with the application of fertilizers, if necessary, liming can be carried out. This is justified on many types of soil in the Russian Federation.

The broccoli growing area should be well leveled and elevated. In the spring, after the soil dries sufficiently and warms up (the lumps of the soil become crumbly), it must be processed (plowed) to a depth of fifteen cm or cultivation and harrowing.

Broccoli cabbage can be grown and direct sowing seeds in open ground. In this case, the plants will require the same, but more thorough care.

The formation of food organs in broccoli continues until frost occurs. If the summer is dry and hot, they grow quite fast and bloom (Fig. 4). If the term for cutting the head is missed, they begin to become loose, diverge and bloom. Flowering plants no longer form commodity heads. Cut heads are not stored for a long time, they should be immediately used for food. In the refrigerator, they are stored for only two to three days [15].

8. Discussion and Conclusions

Based on the above, a number of conclusions can be drawn. When choosing the cultivation area for broccoli cabbage, it is necessary to take into account both the soil and climatic conditions and the period of formation of the food organ. Although in the State Register of breeding achievements, approved for use in 2018, F1 hybrids of broccoli cabbage with a tolerance for production in all 12 regions of admission dominate (1. Northern, 2. North-Western, 3. Central, 4. Volgo-Vyatsky, 5. Central Chernozemny, 6. North-Caucasian, 7. Middle Volga, 8. Nizhnevolzhskiy, 9. Ural, 10. West-Siberian, 11. East-Siberian, 12. Far Eastern); plots for its cultivation are recommended to be placed on a hill and near water bodies in order to avoid frost damage and to prolong the frost-free period. It is not recommended to place plots inside forests.

Particular attention should be paid to the reaction environment of the soil solution. It is recommended that the reaction is close to neutral, contributing to the mineralization of substances and their transition into a form easily accessible to plants. The mineralization of nutrients in the soil is carried out by microorganisms, and for their activity excessive acidity is also harmful. To combat the increased acidity of the soil, it is advisable to carry out liming.

For the full development of plants, guarantees of high yields and increasing resistance to diseases and pests, they require sufficient supply of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and boron (B), molybdenum (Mo), manganese (Mn), iron (Fe) and other trace elements. When cultivating cabbage on loamy soils, plants, as a rule, do not feel a lack of trace elements. Typically, their lack of occur in peatlands, marsh, sandy and sandy soils.
Broccoli plants with broccoli and cucumber, beans, celery, and dill have a positive effect on cabbage plants. Sealing crops with tomato, onion, strawberry are not recommended.

In addition, it is worth noting that in addition to agrotechnics and the selection of favorable environmental conditions for growing broccoli cabbage, it is recommended to use high-quality breeding seeds.

The feasibility of using biotechnology and other non-traditional breeding methods in a selection process is evidenced by the data obtained when evaluating regenerated broccoli cabbage plants grown from unfertilized ovaries and ovules and then planted in open ground for comparison with the control [16]. As shown by studies presented in Figures 5-7 and Table 1 of the family of regenerated plants No. 8, No. 5 and No. 1 of the first generation (R1) significantly exceeded the control (initial grade Tonus) in productivity, mass of the central head, number of side heads, their mass, precocity, “remontance”, the mass of 1000 seeds, as well as the content of dry matter, ascorbic acid, chlorophyll “a” and “b”, carotene, monosaccharides and antioxidants. They were recommended as promising and transferred for use in breeding practice.
Figure 5. Characteristics of plants R1 by the main economically valuable traits of the most promising families (productivity and mass of the food organ).

Figure 6. Characteristics of plants R1 by the main economic characteristics of the most promising (maturity period).

Figure 7. Characteristics of R1 plants by the main economically valuable traits of the most promising (number of side heads, weight 1000 seeds).
Table 1. Data of biochemical analysis of plants-regenerants R1 broccoli, 2013.

| Analyte, in accepted units | Sample (R1 family) | Control, grade Tonus |
|---------------------------|--------------------|----------------------|
| Dry matter, %             | 13,94              | 13,06                | 12,76 | 10,50 |
| Ascorbic acid, mg /%      | 100,32             | 88,00                | 123,20| 84,48 |
| Chlorophyll “a”           | 0,64               | 0,97                 | 0,74  | 0,88  |
| Chlorophyll “b”           | 0,43               | 0,51                 | 0,42  | 0,50  |
| Carotene                  | 0,26               | 0,32                 | 0,25  | 0,11  |
| Monosaccharides, %        | 1,70               | 1,65                 | 1,55  | 1,09  |
| The content of potassium ions (K +), mg /% | 236,90              | 242,10               | 235,40| 202,60|
| - in units of ascorbic acid | 71,76              | 76,97                | 80,01 | 69,86 |
| - in units of gallic acid | 8,75               | 9,39                 | 9,76  | 8,38  |
| Protein content (raw material), % | 1,95               | 2,35                 | 2,15  | 2,05  |

Thus, based on the above, as well as, according to other researchers, breeding work with broccoli cabbage, in turn, should be aimed at creating as soon as possible highly productive, early ripening varieties and hybrids resistant to pathogens, suitable for modern mechanized cultivation technologies [2].

As research and evaluation of experimental results have shown, broccoli is a very promising crop, both for scientific research and for commodity production. Simply, its potential is still not fully disclosed, both by agricultural producers and the scientific community in the Russian Federation. This is evidenced by the ever-growing number of foreign hybrids of F1 broccoli in the State Register of Breeding Achievements Approved for Use in 2018. At the same time, the research results reflected in the article can be equally useful for representatives of the agro-industrial complex and agricultural science [20].

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