Resistance of carrots to diseases as a factor of increasing production profitability

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Abstract. The main reason for the decline in production of commercial products is the loss of crop during its long storage. From March to July, the difference between demand and production is made up by imported products from near and far abroad. As a result, this leads to an increase in prices relative to the autumn months from April by 44% and from July by 50%, until going of a new crop of domestic products on the shelves. As a result of the conducted research, it is shown that domestic varieties and hybrids due to a higher level of resistance to local populations of pathogens are economically profitable in terms of production costs and crop losses during storage. Growing high-yielding varieties and hybrids of carrots with complex stability, such as Margosha and Shantane 2461, Rif F1 and Nadezhda F1 breeding of FSBSU “Federal Scientific Center of Vegetable Growing” (FSBSU FSCVG) allows for the sale after long-term storage to make a profit of about 240-600 thousand rubles/ha, to achieve profitability of 59-150%. This contributes to solving one of the key tasks - reducing the dependence of the vegetable market on imports and ensuring food security of the Russian Federation.

1. Introduction

Providing the population with high-quality and environmentally safe products is one of the main socio-economic problems of today. Currently, in Russia, vegetable growing is the most important economically profitable branch of agriculture and is of great importance in providing the population with products rich in vitamins and biologically active substances [1]. Due to its high nutritional and medicinal qualities, valuable economic properties in the central region of the Chernozem zone, one of the most common and strategically important vegetable crops is carrots. This crop is the main source of provitamin A, calcium, iron, and potassium, so it is widely used as a raw material for the processing industry [2].

According to science-based nutrition standards developed by the Institute of Nutrition of Russia, it is necessary to consume 9-11 kg of carrots per capita per year. Based on this rate of consumption per person, the population of the Russian Federation needs to produce 1469 thousand tons of carrots per year. In total, 66.3 thousand hectares are occupied under carrot and turnip crops in the Russian Federation (according to FAOSTAT statistics database, 2018). Taking into account the acreage and high gross harvest in some years, Russia’s planned self-sufficiency in carrots should be 90% (2015-2016). But recently there has been a tendency to reduce the acreage under carrot culture and gross harvest (in 2017 by 5.6% and 2.2%, respectively) [3]. The main reason for the decline in production of commercial products is the loss of crop during its long storage. From March to July, the difference between demand and production is made up by imported products from near and far abroad. As a result, this leads to an increase in prices relative to the autumn months from April by 44% and from...
July by 50%, until going a new crop of domestic products on the shelves. The main exporters to Russia are Israel, China, Belarus, and Egypt. Therefore, to solve the problem of year-round supply of fresh carrots to the population, it is necessary to have varieties that maintain high commercial qualities for 220-250 days of storage [4,5]. The total cost of obtaining commercial products of carrots varies significantly and depends on the technical equipment of vegetable stores and the level of qualification of employees, technological techniques, productivity and the degree of resistance of varieties to storage diseases.

Storage conditions require a special microclimate-temperature 0-1°C at high relative humidity (95-98%), as carrots easily lose moisture. Moreover, even a slight increase in temperature at this humidity leads to an increase in the number of diseased root crops and, accordingly, to a decrease in keeping quality [6]. In most existing vegetable stores, the loss of marketable products after 3-6 months of storage in different years can reach 25-60% or higher. During this period, the pathocomplex of affected root crops is represented by a wide range of pathogens (up to 75% of the entire microflora of this economically important crop) [7]. Their composition and ratio varies depending on the year, variety and place of cultivation.

The deterioration of the phytopathological situation is facilitated by the fact that, along with the increasing aggressiveness of local races of pathogens, in recent years there has been the introduction of new races, the source of which is imported into the country commercial products of varieties of foreign selection [8]. In addition, foreign varieties of carrots can often be unstable to local races of phytopathogens, which leads to the need for additional protection measures. In the market economy, the role of reducing the cost of production during storage is high. In this regard, the assessment of resistance to biotic stressors of varieties and hybrids of this economically important vegetable crop in terms of profitability of its production is an urgent task. This direction is also particularly valuable in connection with the solution of another problem of today – environmental protection, reducing the pesticide load.

2. Material and methods
The research material are 33 varieties and hybrids of carrot of leading domestic and foreign companies, including six ones of breeding of FSBSU FSCVG (table), which were grown on the basis of the experimental-production base FSBSU FSCVG, on the experimental fields of JSC “Agrofirm “Bunyatino” and JSC “Ozery” in Moscow region, Russian Federation. Root crops were stored in a vegetable store at a temperature of 1-2°C and humidity of 90-92% for six months (from the third decade of September to the second decade of April). Examination during storage, selection of affected root crops during spring analysis, the degree of damage and the level of resistance of cultivars, identification of the species composition of pathogens were carried out using appropriate methods and determinants [9-17]. The economic performance and profitability in growing and storage roots of carrot was carried out taking into account the yield and storage quality genotypes, the basic cost of labor, cost of materials and the basic means of production, using the actual data of agricultural firms and Economic Department of the FSBSU FSCVG in accordance with relevant guidelines [18,19,20]. The costs were determined according to the technological maps for carrot culture based on the prices prevailing in 2018-2019. To identify the economic effect, the cost and profitability were calculated based on the weighted average basic production costs for growing commercial root crops, which amounted to 350000 rubles/ha, storage costs - 0.16 rubles/kg, costs for manual sorting and disposal of affected root crops – 0.13 rubles/kg and the average wholesale purchase price - 12 rubles/kg (as of April 2019).

3. Results
In the conditions of Moscow region, the greatest damage to carrots in all the studied years is caused by root pit-storage rot caused by a complex of phytopathogens. Monitoring of pathogenic complex in the culture of carrot was carried out in the laboratory of immunity FSBSU FSCVG in the last 40 years, indicating a change in its structure, the change of dominant species, increase virulence and aggressiveness previously weakly pathogenic groups of microorganisms. The reasons for such population shifts are diverse and largely related to environmental factors that determine the relationship in the pathogen-plant system.

The most important factor in this system is the temperature regime of this agricultural and ecological niche. In the conditions of Moscow region, there is a sharp increase in the average daily air
temperature over the past decade, compared with 70-80s of the last century. Since the 2000s, against
the background of an increase in the average annual temperature values, there has been a decrease in the
harmfulness of gray rot (path. – *Botrytis cinerea*) and increase in the prevalence and aggressiveness of
bacteriosis (path. – *Pectobacterium carotovora*), fusariosis and alternariosis.

In pathogenic complex of alternaria or black dry rot the following varieties of alternivene
hyphomycte prevail *Alternaria, Stemphylium, Ulocladium, Embildia*. Fungi of the genus *Alternaria -
A. radicina, A. cheiranthi, A. corotocinulce, A. cinerariae* have the greatest harmfulness, the
distribution of which in some years reaches 54%. Among the fungi of the genus *Fusarium* - causative
agents of Fusarium rot, the following species were highlighted and identified: *F. oxysporum, F. avenacium, F.
nivale, F. chlamidosporum u F. solani, F. culmorum, F. simitectum*. As long-term
monitoring data show, the species composition of micromycetes of this genus in Moscow region has
expanded. This is due to the extreme plasticity of most of them. Having high adaptability and rapid
variability, fungi of the genus *Fusarium* are difficult to eradicate [21]. Recently species *F. solani, F.
simitectum, F. oxysporum* have dominated.

The prevalence of fomosis, as well as particularly harmful low-temperature sclerotic agents of
white rot, despite the variability in particular years, was generally at the same level during the research
periods (Fig. 1B). However, in the last decade, in addition to the previously widespread pathogen
*Sclerotinia sclerotiorum*, there has been an increase in the aggressiveness of fungi *S. nivalis* and less
often - *Phthula ishikariensis* (blight). The *S. nevalis* fungus on carrot roots during storage was first
detected in the pathogenesis of white rot in 2009, and *T. Ishikariensis* – in 2011. It is quite difficult to
get the perfect stage of *S. nevalis*, so to identify this species, globulin electrophoresis in polyacrylamide
gel is used, which clearly identifies *S. nevalis* among the fungi that are close in
systematic terms [22]. The local population of this pathogen is heterogeneous and consists of strains of
different aggressiveness [23]. Crop losses from white rot during storage can reach 10-60%, depending
on the conditions and the set of varieties.

In recent years, the heat-loving fungus *Trichotecium roseum*, which causes wet rot of root crops
during storage, has also been found and identified on affected carrot root crops. In 2013 and 2015, the
incidence of root crops of susceptible varieties reached 23 and 55%, respectively. The reason for
significant losses of the carrot crop during storage in 2014 was the gleocladium rot of carrots, the
causative agent of which is the fungus *Gleocladium roseum*. On the carrot culture, it is little studied,
although it was previously noted in the Far East, causing the wilting of beans, peas, soy, and watery
rot of tomatoes. In Germany, it is described as gleocladium rot of potatoes [24]. According to our data,
the pathogen on carrot roots can occur in mixed dry rot, and independently [8]. In the pathogenesis of
pit-storage rot in combination with the above-listed pathogens, fungi of the genera *Pithium* spp are
found (*Pithium* rot), *Cylindrocarpon* spp, (hollow spot 'Cavity Spot'), *Verticillium* spp, (verticilliose),
*Aspergillus* spp, and *Penicilium* spp, (storage mold).

When evaluating the effectiveness of growing agricultural products, attention should be paid to the
biological characteristics of each crop that affect the final result, in this case, the yield of commercial
products after storage. As it can be seen from table 1, all analyzed samples by yield level can be
divided into six groups: I group - <40 t/ha, II group - 41-50 t/ha, III group - 51-60 t/ha, IV group - 61-
70 t/ha, V group - 71-90 t/ha, VI group - >90 t/ha, in each of them they are differentiated by the degree
of root pit-storage rot damage. The percentage of affected root crops in the whole sample set varied
from 3% to 56% and varied significantly within each group. Storing varieties and hybrids of carrots
with different yields and levels of resistance to phytopathogens leads to different results of economic
efficiency. According to research results, the total cost of commercial production of carrot root crops
after storage for six months is mainly determined by the yield level (r= -0.9). For samples with a yield
of more than 55 t/ha, it amounted to 4.1-7.4 rubles/kg, while for low-yielding samples, the cost price is
higher by 3-6% and in group I reached 11-13 rubles/kg, which indicates the unprofitability of long-
term storage of these samples, regardless of their degree of stability.

In other groups of samples, the resistance of root crops to diseases significantly affects the
profitability of their sale after storage (r= -0.64), which is significantly reduced in group II at a 10%
level of damage to root crops, and in group III - when more than 20% of the stored root crops are
affected. Within the aggregate of crop varieties and hybrids of groups IV-VI, the profitability indicator
decreases exponentially as the proportion of affected root crops in the sample increases. As a result, at
the 20-30% level of damage to root crops, on average, the profitability of selling unstable samples
after long-term storage is 2.6 times, and at 40% damage is 28 times lower than that of stable ones (the degree of damage is <10%).

Table 1. Yield and cost of commercial production of varieties of carrots of domestic and foreign selection.

| Group | Sample       | Original company       | Yield, t/ha | Cost of commercial products, rubles/kg |
|-------|--------------|------------------------|-------------|---------------------------------------|
|       |              |                        |             | growing ** | storage** | total after storage |
| I     | Naval F1     | Bejo zaden B.V         | 30          | 11.7       | 1.00      | 12.67 |
|       | Vak-70days   | Vilmorin               | 32          | 10.9       | 1.06      | 12.00 |
|       | Forward F1   | FSBSU FSCVG            | 30          | 11.7       | 1.64      | 13.31 |
|       | Nantes       | Nickerson-Zwaan        | 39          | 9.0        | 1.74      | 10.71 |
| II    | Oktavo F1    | Vilmorin S. A.         | 43          | 8.1        | 1.04      | 9.18  |
|       | Marlinka     | FSBSU FSCVG            | 46          | 7.6        | 1.11      | 8.71  |
|       | Nazareth F1  | Bejo zaden B.V         | 41          | 8.5        | 1.12      | 9.66  |
|       | Narman       | Bejo zaden B.V         | 42          | 8.3        | 1.19      | 9.52  |
|       | Spedo        | Vilmorin S. A.         | 42          | 8.3        | 1.27      | 9.60  |
|       | Nantes 2 Tito| Nickerson-Zwaan        | 42          | 8.3        | 2.38      | 10.71 |
| III   | Nadezhda F1  | FSBSU FSCVG            | 55          | 6.4        | 0.99      | 7.35  |
|       | Nerak B-MAX F1 | Bejo zaden B.V      | 60          | 5.8        | 1.06      | 6.89  |
|       | Djerada F1   | Rijk Zwaan             | 56          | 6.3        | 1.10      | 7.43  |
|       | Nelix F1     | Bejo zaden B.V         | 50          | 7.0        | 1.21      | 8.21  |
|       | Baltimor F1  | Bejo zaden B.V         | 60          | 5.8        | 1.61      | 7.45  |
| IV    | Shantane 2461 | FSBSU FSCVG          | 69          | 5.1        | 1.03      | 6.10  |
|       | Silvano F1   | Vilmorin S. A.        | 68          | 5.1        | 1.03      | 6.18  |
|       | Fidra F1     | Rijk Zwaan             | 66          | 5.3        | 1.12      | 6.42  |
|       | Kuroda 5 Sun | Sakata                 | 65          | 5.4        | 1.18      | 6.62  |
|       | Nerak F1     | Bejo zaden B.V         | 61          | 5.7        | 1.20      | 6.94  |
|       | Curoda Power | Sakata                 | 70          | 5.0        | 1.69      | 6.69  |
| V     | Rif F1       | FSBSU FSCVG            | 86          | 4.1        | 1.02      | 5.09  |
|       | Pearl Hays F1| Bejo zaden B.V         | 75          | 4.7        | 1.05      | 5.72  |
|       | Emperor      | Gavirish               | 85          | 4.1        | 1.07      | 5.19  |
|       | Morelia F1   | Rijk Zwaan             | 73          | 4.8        | 1.19      | 5.99  |
| VI    | Margoshka    | FSBSU FSCVG            | 99          | 3.5        | 1.03      | 4.56  |
|       | Mello-Yello F1| Bejo zaden B.V      | 115         | 3.0        | 1.04      | 4.09  |
|       | Extremo F1   | Vilmorin S. A.        | 90          | 3.9        | 1.11      | 4.99  |
|       | White-Satin F1| Bejo zaden B.V     | 90          | 3.9        | 1.27      | 5.16  |

*- growing in the field, harvesting, transporting and placing root crops in storage

In the ruble equivalent, losses from storage diseases among resistant samples amounted to 17-98 thousand rubles/ha, among medium-susceptible root crops with a degree of damage of up to 30% - from 64 to 155 thousand rubles/ha, in highly susceptible samples - from 112 to 336 thousand rubles/ha, depending on the yield (table 2). It should be noted that in each of the groups ranked by yield, the lowest losses of commercial root crops during storage were observed in varieties and hybrids of Russian selection (1.4-5.4 t/ha), and although some foreign hybrids exceeded them in yield, the profitability of selling domestic samples after long-term storage was generally higher or on the same level as “foreigners”.

| Group | Sample       | Original company       | Yield, t/ha | Cost of commercial products, rubles/kg |
|-------|--------------|------------------------|-------------|---------------------------------------|
|       |              |                        |             | growing ** | storage** | total after storage |
| I     | Naval F1     | Bejo zaden B.V         | 30          | 11.7       | 1.00      | 12.67 |
|       | Vak-70days   | Vilmorin               | 32          | 10.9       | 1.06      | 12.00 |
|       | Forward F1   | FSBSU FSCVG            | 30          | 11.7       | 1.64      | 13.31 |
|       | Nantes       | Nickerson-Zwaan        | 39          | 9.0        | 1.74      | 10.71 |
| II    | Oktavo F1    | Vilmorin S. A.         | 43          | 8.1        | 1.04      | 9.18  |
|       | Marlinka     | FSBSU FSCVG            | 46          | 7.6        | 1.11      | 8.71  |
|       | Nazareth F1  | Bejo zaden B.V         | 41          | 8.5        | 1.12      | 9.66  |
|       | Narman       | Bejo zaden B.V         | 42          | 8.3        | 1.19      | 9.52  |
|       | Spedo        | Vilmorin S. A.         | 42          | 8.3        | 1.27      | 9.60  |
|       | Nantes 2 Tito| Nickerson-Zwaan        | 42          | 8.3        | 2.38      | 10.71 |
| III   | Nadezhda F1  | FSBSU FSCVG            | 55          | 6.4        | 0.99      | 7.35  |
|       | Nerak B-MAX F1 | Bejo zaden B.V      | 60          | 5.8        | 1.06      | 6.89  |
|       | Djerada F1   | Rijk Zwaan             | 56          | 6.3        | 1.10      | 7.43  |
|       | Nelix F1     | Bejo zaden B.V         | 50          | 7.0        | 1.21      | 8.21  |
|       | Baltimor F1  | Bejo zaden B.V         | 60          | 5.8        | 1.61      | 7.45  |
| IV    | Shantane 2461 | FSBSU FSCVG          | 69          | 5.1        | 1.03      | 6.10  |
|       | Silvano F1   | Vilmorin S. A.        | 68          | 5.1        | 1.03      | 6.18  |
|       | Fidra F1     | Rijk Zwaan             | 66          | 5.3        | 1.12      | 6.42  |
|       | Kuroda 5 Sun | Sakata                 | 65          | 5.4        | 1.18      | 6.62  |
|       | Nerak F1     | Bejo zaden B.V         | 61          | 5.7        | 1.20      | 6.94  |
|       | Curoda Power | Sakata                 | 70          | 5.0        | 1.69      | 6.69  |
| V     | Rif F1       | FSBSU FSCVG            | 86          | 4.1        | 1.02      | 5.09  |
|       | Pearl Hays F1| Bejo zaden B.V         | 75          | 4.7        | 1.05      | 5.72  |
|       | Emperor      | Gavirish               | 85          | 4.1        | 1.07      | 5.19  |
|       | Morelia F1   | Rijk Zwaan             | 73          | 4.8        | 1.19      | 5.99  |
| VI    | Margoshka    | FSBSU FSCVG            | 99          | 3.5        | 1.03      | 4.56  |
|       | Mello-Yello F1| Bejo zaden B.V      | 115         | 3.0        | 1.04      | 4.09  |
|       | Extremo F1   | Vilmorin S. A.        | 90          | 3.9        | 1.11      | 4.99  |
|       | White-Satin F1| Bejo zaden B.V     | 90          | 3.9        | 1.27      | 5.16  |
Table 2. Losses of root crops during storage from diseases, costs and profitability of commercial production of various varieties of carrots of domestic and foreign selection.

| Group | Sample          | Percentage of affected crops, % | Losses, t/ha | Total costs, rubles/ha | Sales revenue, rubles/ha | Profit, rubles/ha | Profitability, % |
|-------|-----------------|---------------------------------|--------------|------------------------|--------------------------|------------------|-----------------|
|       |                 |                                 | t/ha         |                        |                          |                  |                 |
| I     | Naval F1        | 3.4                             | 24 12        | 36 75                  | 21 100                   | 10 800           | 22.5            |
|       | Vak-70days      | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Forward F1      | 35.8                            | 24 1240      | 22 210                 | 64 120                   | 92 400           | 64.0            |
|       | Nantes          | 192.1                           | 12 200       | 74 210                 | 24 120                   | 92 400           | 64.0            |
| II    | Oktavo F1       | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Marlinka        | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Nazareth F1     | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Narman          | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Spedo           | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Nantes 2 Tito   | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
| III   | Narek B-MAX F1  | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Djerada F1      | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Nelix F1        | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Baltimor F1     | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
| IV    | Shantane 2461   | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Silvano F1      | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Fidra F1        | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Karoda 5 Sun    | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Nerak F1        | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Curoda Power    | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
| V     | Rif F1          | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Pearl Hays F1   | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Imperor         | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Morelia F1      | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
| VI    | Margosha        | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Mello-Yello F1  | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | Extremo F1      | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |
|       | White-Satin F1  | 4.7                             | 84 50        | 90 120                 | 47 120                   | 33 800           | 36.5            |

4. Summary
Thus, productive varieties and hybrids of carrots of Russian selection created by the joint efforts of breeders, phytopathologists and geneticists, which are highly resistant to local populations of phytopathogens, should be considered not only as the basis of the strategy of integrated crop protection from diseases, but also as support for the interests of domestic agricultural producers in the framework of the state policy of import substitution and ensuring food security of the country. Growing domestic varieties and hybrids, in particular, such as Margosha and Shantane 2461 varieties, Rif F1 and Nadezhda F1 hybrids of the FSBSU FSCVG, will significantly reduce the cost of storing...
commercial products, increase the profitability of production of carrots, which will significantly reduce the volume of imports in the spring and summer period. It is also important to emphasize that due to the increasing variability of the pathocomplex structure and aggressiveness of pathogens, along with constant phyto monitoring and identification of new economically harmful diseases of carrots, immunological and molecular research aimed at creating donors of complex resistance to storage diseases of various etiologies should now be a priority in the framework of targeted selection.

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