A comprehensive assessment of tomato collection varieties by yield and parameters of adaptability in monsoon climate conditions

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Abstract. Tomatoes are one of the most common vegetable crops in the Khabarovsk territory. This article presents the results of an agrobiological study of tomato collection varieties taken from the Vavilov Institute’s collection of crop production genetic resources of various ecological and geographical origin. The research identified varieties of the intensive type that can provide a maximum yield at a high level of agricultural technology: Denmark, Skorospelka, Chico Grande, Vitaminnyi, Vezha, Slava Moldova and Novoseletsky. It also identified the most valuable varieties for practical breeding: Skorospelka, Dokuchaevsky, Dragotsennost’, Vitaminnyi from Russia, Vezha from Belarus, Novoseletsky from Ukraina, Denmark and Chico Grande from USA, which combine high indicators of marketable productivity and high adaptability to the conditions of the monsoon climate of the Middle Amur region.

1. Introduction

The tomato is one of the main vegetable crops in horticulture and is currently widely grown all over the world, both in open ground and in greenhouses, for fresh consumption or for processing. The development of domestic vegetable growing requires the cultivation of varieties that possess high productivity and the ability to form crops under a wide range of ecological and geographical conditions. The large specific weight in the structure of crop areas is explained by the ability to grow and fructify in various climatic zones (i.e. a sufficiently appropriate temperature and relative humidity), high yield, biological value and high taste qualities of fruits [1-4].

The main problem of obtaining stable, high crop yields in the culture of the Far Eastern region is its complex, unpredictable and exclusive (i.e. not found anywhere else in Russia) monsoon climate. This is clearly manifested in a strong, almost annual over-moistening of the soil in July and August, which corresponds to the period of main yield formation of tomatoes. The weather conditions that develop during this period favour the development of the main diseases of nightshade crops, and often the most aggressive of their species are manifested. The main limiting factors of tomato cultivation in the Khabarovsk territory for this season are a high natural infectious background and a sharply variable hydrothermal regime.

On average, 60–70% of consumed vegetables have been imported to the Khabarovsk territory in recent years, although it was the leader among the regions of the far Eastern Federal district in the production of open ground vegetables in 1990 [5].
This figure is even higher for tomatoes. This crop is not cultivated at all on an industrial scale in the Khabarovsk territory in open ground, due to the almost annual epiphytoties of fungal diseases, which lead to a significant decrease in – and often complete loss of – yield.

The crop areas of tomatoes on the farms of the Russian Federation population over the past 5 years have decreased by 8 –12 thousand hectares and have amounted to 65 thousand hectares, according to Rosstat data for 2019.

The instability of the crop in production conditions such as adverse environmental factors, insufficient active temperatures, high humidity combined with low temperatures and late spring and early autumn frosts is the limiting factor of tomato production in the open ground. Adaptive breeding, which aims to combine productivity and resistance to stress in one genotype, is particularly important in this acquire [1].

Factors that influence potential yield are solar radiation, atmospheric CO\textsubscript{2} concentration, temperature and genotype. As these environmental factors are variable throughout the year, yield potential will depend not only on location but also on sowing and harvest dates [6].

The adaptability of tomato varieties to environmental conditions differs, and the conditions in which varieties grow are constantly changing. This leads to a continuous change in the direction of variability in the phenotypic composition of the variety population and, at the same time, ensures their stability [7].

Consequently, modern tomato varieties must have a stable yield in years with different weather conditions, have high quality fruits and be resistant to diseases and pests.

The solution to this problem includes a comprehensive assessment of the source material on the parameters of adaptability and stability, which allows us to identify promising genotypes by various characteristics. They are of the greatest value for long-term stability in obtaining agricultural products.

A set of varieties with high potential productivity and which have ecological plasticity and stability in various agroclimatic conditions of growing is necessary for effective breeding work [8].

The size and quality of the crop largely depend on unregulated environmental factors, which in 60–80\% of cases control the inter-annual variability in yield with modern technologies of plant cultivation. The low realization of the potential of new varieties in production conditions is a consequence of their lack of adaptability. An adaptive variety is primarily ecologically plastic – that is, adapted to a variety of environmental conditions. As practice shows, with equal yields, the advantage is given to varieties that are characterised by maximum ecological adaptability [10].

The Khabarovsk territory is considered an area of risk farming. It is characterized by a monsoon climate (July–August), with an uneven distribution of precipitation throughout the year and during the growing season, return frosts in spring and early autumn as well as temperature differences. Therefore, the search for tomato varieties that are responsive to environmental changes, with increased or stable yield, is very relevant.

The purpose of this research is to comprehensively assess open-ground tomato collection varieties of various ecological and geographical origin to determine their productivity in and adaptability to the monsoon climate conditions of the Khabarovsk territory, in order to include them in the breeding process.

2. Materials and methods
A collection of tomatoes of various ecological and geographical origin, of Russian and foreign breeding, and obtained from the All-Russian Institute of Plant Genetic Resources (named after N. I. Vavilov), was studied in 2015–2017. Russian samples, as well as varieties of foreign origin, both near and far, were planted: Pushkinsky, Skorospelka, Vitaminnyi, Elochka, Rybka, Dokuchaevsky, Dragotsennoś (Russia), Nobar (Azerbaijan), Vezha (Belarus), Slava Moldova (Moldova), Novoseletsy (Ukraine), Dippes (Germany), C – 17 (Canada), Denmark and Chico Grande (USA).

Grade standard Khabarovsk rozojny 308 was obtained via breeding by the Far Eastern Research Institute of Agriculture (FERIA), Russia. The investigation was conducted in the breeding area of the vegetable growing department of FERIA, located in the Khabarovsk district, Khabarovsk territory.
Tomato plants were planted using the ridge technology recommended for tomatoes in the area of risk farming of the Khabarovsk territory, on square plots of 7 m², with 15 plants of each sample in a scheme of 35 × 140 cm. Seeds for seedlings were sown annually on April 25–26. Seedlings of collection samples were grown in 50 × 50-cm cassettes (64 pieces each) in an unheated film greenhouse, with subsequent planting in the open ground. Transplantation of seedlings in open ground was carried out on June 5–7 during all years of the research study.

The quantitative characteristic of economic productivity was evaluated via the weight method, by taking into account the yield of marketable fruits from all plants on plot in four repetitions.

Soil preparation was carried out in compliance with existing zonal recommendations.

To calculate the environment index (Ij), ecological plasticity (bi) and stability (σd), we used the method of Eberhart and Russel, as presented by Detsyna et al. [10]. Yield variability (coefficient of variation, V) was calculated according to Dospekhov [11]. Resistance to stress (Y1+Y2) and compensatory ability ([Y1+Y2]/2) of the variety were determined according to Rossielle and Hemblin, and the coefficient of adaptability (KA) was calculated according to Zhivotkov, as presented by Nikolaev et al. [12]. The multiplicative coefficient (KM), which allows us to compare the variability of the sign, was determined according to Dragavtsev, as presented by Nikolaev et al. [13]. According to the method of Gryaznov [14], the average index of ecological plasticity (IEP) was calculated. The yield range (d) was calculated by the method of Zykina et al. [15].

The hydrothermal coefficient (HTC) is the ratio of the amount of precipitation to the sum of temperatures, reduced by a factor of 10, and it is used as an indicator of a plant's need for moisture [16]. The years of research were marked by hydrothermal indicators typical for the Khabarovsk territory and differed significantly amongst themselves: HTC = 1.85 (2015); HTC = 2.19 (2016); and HTC = 1.66 (2017). This allowed us to give an objective assessment of the studied material in accordance with the prevailing specific agroclimatic conditions.

3. Results and Discussion

The original experimental data reflecting the ecological changes in the marketable yield of tested tomato genotypes are presented in table 1. As presented, the average yield for all varieties over all of the years of research was 1.48 kg/m².

| Grade                  | Yield, kg/m² | V, % |
|------------------------|--------------|------|
|                        | 2015  | 2016  | 2017  | Average |      |
| Khabarovsky rozovyi 308, st | 2.46  | 2.47  | 5.64  | 3.52    | 19.00 |
| Pushkinsky             | 0.21  | 1.44  | 1.05  | 0.90    | 25.50 |
| Denmark                | 0.36  | 2.70  | 1.74  | 1.60    | 26.84 |
| Nobar                  | 0.35  | 0.62  | 2.45  | 1.14    | 36.59 |
| Skorospelka            | 0.26  | 3.32  | 2.14  | 1.91    | 29.56 |
| Chico Grande           | 0.52  | 3.51  | 0.62  | 1.55    | 40.00 |
| Dippes                 | 0.35  | 1.62  | 0.64  | 0.87    | 27.93 |
| Vitaminnyi             | 0.40  | 1.96  | 2.12  | 1.49    | 23.23 |
| Elochka                | 0.70  | 0.72  | 2.59  | 1.34    | 29.65 |
| Rybka                  | 0.36  | 1.51  | 1.00  | 0.96    | 21.99 |
| Dokuchaevsky           | 1.04  | 2.19  | 2.26  | 1.83    | 13.67 |
| C  – 17                | 0.66  | 1.56  | 0.43  | 0.88    | 24.69 |
| Dragotsennost’         | 0.49  | 2.21  | 1.08  | 1.26    | 25.33 |
| Vezha                  | 0.59  | 3.04  | 1.16  | 1.60    | 29.32 |
| Slava Moldovoy         | 0.47  | 2.41  | 1.09  | 1.32    | 27.34 |
| Novoseletsky           | 0.34  | 2.17  | 2.06  | 1.52    | 24.60 |
| The average variety yield of the year, kg/m² | 0.60 | 2.09 | 1.75 | 1.48 | - |
| Environment index, Ij  | -0.88 | 0.61  | 0.27  | -      | -     |
The environment index was assessed using the Ij index at the first stage of research: the higher the Ij value, the more favorable the conditions for the growth and development of genotypes. The most favorable weather conditions for the formation of the tomato crop occurred in 2016 and 2017. Maximum and minimum productivity values were in the ranges of 0.62–3.51 and 0.43–5.64 kg/m², respectively. The environment index (Ij) in these years turned out to be positive, and amounted to +0.61 and +0.27, respectively. Based on the current dynamics of variation in the productivity indicator, the ecological situation for the studied collection samples was the most favorable for crop accumulation in 2016.

The environment index had a negative value of Ij = -0.88, against a backdrop of excessive over-moistening of the soil and lack of heat in 2015, which affected the quantity and quality of tomato fruits. The yield was the lowest for the years of research – the average for the studied varieties was 0.60 kg/m², which is 4.1 times lower than the standard.

The coefficient of variation (V) varied from 19.00% to 40.00%. The most stable varieties were Dokuchaevsky, Khabarovsk rozovyi 308, Rybka, Vitaminnyi, C-17, Dragotsennost', Pushkinsky and Denmark (V = 13.67–26.84%).

At present, the index of ecological plasticity proposed by Gryaznov is often used when calculating the ecological plasticity of varieties. Accordingly, the most plastic varieties in the studied collection were Khabarovsk rozovyi 308, Dokuchaevsky, Skorospelka and Vezha. Their IEPs were 2.84, 1.36, 1.08 and 1.03, respectively, which makes it possible to predict yield growth when environmental conditions improve (table 2).

Table 2. Indicators of ecological plasticity, stability and stress resistance in the yield of tomato fruits.

| Grade                              | IEP  | CA, % | KM  | Y1-Y2 | (Y1+Y2)/2 | d, % | bi   | σd  | Ranks |
|------------------------------------|------|-------|-----|-------|-----------|------|------|------|-------|
| Khabarovsk                         | 2.84 | 283.78| 1.30|-3.18  | 4.05      | 56.38| 0.71 | 0.435| 64    |
| rozovyi 308, st                    |      |       |     |       |           |      |      |      |       |
| Pushkinsky                         | 0.55 | 54.63 | 2.31|-1.23  | 0.83      | 85.42| 0.80 | 0.001| 78    |
| Denmark                            | 0.96 | 96.19 | 2.36|-2.34  | 1.53      | 86.67| 1.47 | 0.008| 58    |
| Nobar                              | 0.76 | 75.96 | 1.78|-2.10  | 1.40      | 85.71| 0.60 | 0.155| 97    |
| Skorospelka                        | 1.08 | 108.10| 2.51|-3.06  | 1.79      | 92.17| 1.94 | 0.010| 49    |
| Chico Grande                       | 0.97 | 96.75 | 2.44|-2.99  | 2.02      | 85.19| 1.51 | 0.213| 59    |
| Dipes                              | 0.58 | 57.52 | 2.18|-1.27  | 0.99      | 78.40| 0.70 | 0.021| 83    |
| Vitaminnyi                         | 0.94 | 93.85 | 2.15|-1.72  | 1.26      | 81.13| 1.16 | 0.011| 65    |
| Elochka                            | 1.00 | 99.74 | 1.48|-1.89  | 1.65      | 72.97| 0.43 | 0.152| 71    |
| Rybka                              | 0.63 | 63.16 | 2.11|-1.15  | 0.94      | 76.16| 0.71 | 0.003| 72    |
| Dokuchaevsky                       | 1.36 | 135.88| 1.68|-1.22  | 1.65      | 53.98| 0.84 | 0.005| 39    |
| C – 17                             | 0.70 | 69.86 | 1.66|-0.90  | 1.11      | 72.44| 0.40 | 0.037| 82    |
| Dragotsennost'                     | 0.83 | 83.09 | 2.16|-1.72  | 1.35      | 77.83| 0.99 | 0.024| 69    |
| Vezha                              | 1.03 | 103.43| 2.25|-2.45  | 1.82      | 80.59| 1.34 | 0.076| 55    |
| Slava Moldovyi                     | 0.85 | 85.36 | 2.23|-1.94  | 1.44      | 80.50| 1.10 | 0.034| 69    |
| Novoseletsy                        | 0.93 | 92.71 | 2.26|-1.83  | 1.26      | 84.33| 1.29 | 0.004| 60    |

The coefficient of adaptability (CA) allows us to judge the adaptive capabilities of the variety. The values of this indicator obtained in the course of this study confirm the high (>100%) adaptability of the varieties Khabarovsk rozovyi 308, Dokuchaevsky, Skorospelka and Vezha, with CAs ranging from 103.43% to 283.78%, which indicates the potential productivity of these varieties. Low indicators (CA = 54.63–99.74%) are typical for all other varieties.

According to the method developed by Eberhart and Russel, under various environmental conditions, the ecological plasticity of the variety was determined by the linear regression coefficient (bi), which characterizes the average response of the genotype to changes in environmental conditions, and the stability of the variety by the average quadratic deviation from the regression line (σd). It was established that the higher the coefficient value (bi), the greater the responsiveness of the variety. Our research has shown that the following varieties are most responsive to improvements in growing
conditions: Denmark, Skorospelka, Chico Grande, Vitaminnyi, Vezha, Slava Moldova and Novoseletsky (bi = 1.10–1.94). The same varieties have minimal stability coefficient (\(\sigma^2d\)) values. Consequently, the yield of such varieties in all environmental conditions will be higher than the average level. These are varieties that can be referred to as the intensive type, which can produce maximum yield at a high level of agricultural technology. The rest of the studied varieties are referred to as the extensive type, as they were characterized by a weak response to improvement in growing conditions (bi < 1).

The plasticity of varieties is estimated by the multiplicative coefficient (KM), according to the method of V. A. Dragavtsev: the higher its value, the more the level of yield changes in different conditions. As in the calculation of bi, the most plastic varieties of the intensive type were Denmark, Skorospelka, Chico Grande, Vitaminnyi, Vezha, Slava Moldovy and Novoseletsky. The semi-intensive varieties included Pushkinsky, Dippes, Rybka and Dragotsennost'. All other varieties were of the extensive type. In general, the obtained indicators are consistent with the previously calculated indicators of the bi regression coefficient.

The lower the yield range (d), the more stable the object is under specific conditions. In the conditions of the Khabarovsk territory, the minimum values of the yield range were shown by the varieties Jewel and Khabarovsky rozovyi 308 – 53.98% and 56.38%, respectively.

In different growing conditions, favourable or unfavourable, an important indicator of the adaptability of varieties is their resistance to stress, the level of which is determined by the difference between the minimum and maximum values of the yield sign. This parameter has a negative value, and the smaller its value, the higher the genotype's stress resistance for this trait. According to the results of our research, a significant part of the varieties had increased stress resistance (\(Y_1-Y_2\)), which ranged from -0.90 to -1.94. Varieties less resistant to stress conditions were Khabarovsky rozovyi 308, Denmark, Nobar, Skorospelka, Chico Grande and Vezha, with values ranging from -2.10 to -3.18.

The assessment of a variety's stress resistance is supplemented by an indicator of compensatory ability, which reflects how much the genotype of the studied variety corresponds to environmental factors. In our studies, varieties with high compensatory ability included only the standard variety Khabarovsky rozovyi 308 (\(Y_1 + Y_2)/2 = 4.05\), with a medium value being marked in the Chico Grande variety (\(Y_1+Y_2)/2 = 2.02\). All other samples had a low compensatory ability (\(Y_1 + Y_2)/2 = 0.83–1.82\).

Many researchers suggest using the method of ranking varieties and carrying out the final assessment by the sum of ranks when using various methods for analysing the adaptability of varieties. We were guided by the concepts that 1 is the highest rank and 16 is the lowest rank in our research. According to the total number of ranks, based on a comprehensive assessment of varieties by the average yield and adaptability parameters, it was established that the most valuable varieties for the conditions of the Khabarovsk territory are Dokuchaevsky, Skorospelka, Vezha, Denmark, Chico Grande, Novoseletsky, Vitaminnyi, Dragotsennost' and Slava Moldovy.

The samples Denmark and Novoseletsky can be considered valuable source material for creating early-maturing varieties and hybrids as parent forms. The most promising for further inclusion in the breeding work as donors of productivity and marketability of fruit are the domestic collection samples of Skorospelka, Dragotsennost' and Vitaminnyi, as well as Chico Grande (USA).

4. Conclusion
Based on our investigation into the productivity of collection samples of tomatoes in various years, the varieties belonging to the intensive type that can provide a maximum yield at a high level of agricultural technology were Denmark, Skorospelka, Chico Grande, Vitaminnyi, Vezha, Slava Moldova and Novoseletsky.

The varieties Pushkinsky, Khabarovsky rozovyi 308 and Rybka were found to be highly stable.

The varieties Elochka, C – 17, Nobar and Dippes, although they showed relative stability of productivity during the years of research, did not show positive dynamics in the accumulation of crops, which turned out to be at a low level.
In sum, the varieties Skorospelka, Dokuchaevsky, Dragotsennost', Vitaminnyi, (Russia), Vezha (Belarus), Novoseletsky (Ukraine), Denmark and Chico Grande (USA), which combine high indicators of marketable productivity and high adaptability to the conditions of the monsoon climate of the Khabarovsk territory, are the most valuable for practical breeding.

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