VARIABILITY OF TRAITS OF INTERNODE LENGTH AND INTENSITY OF LATERAL SHOOT FORMATION IN TOMATO PLANTS

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Abstract: The results of studying the nature of the manifestation of morphbiological traits of plants of different tomato genotypes controlled by mutant marker genes *br* and *ls* are presented. Genetic determinism of growth response, clearly reflecting the features of tomato plant architectonics, is shown. It was found that moderate growth of vegetative mass (short internodes, limited number of lateral shoots) with a lower response to the action of environmental conditions have lines in the genome of which two marker genes *br* and *ls* are present. Lines 183, 186, 196, 234, 237 and 10/16 combining short internodes with complete absence or single poorly developed reduced lateral shoots were selected for their use as donors in heterosis breeding in the process of creating F_1 tomato hybrids with compact plant architectonics.

Keywords: tomato breeding, variability, internode length, lateral shoots, plant architectonics.

INTRODUCTION

At present, heterosis F_1 hybrids grown under protected conditions (68.7%) occupy a significant share in the tomato variety of different countries of the world (Atlas Big, 2018–2020). The advantage of breeding and cultivation of F_1 hybrids is that they have a high heterosis effect on the main economically valuable traits – stable yield, early maturity, product quality (Danailov, 2013; Dowker, 1983; Gavrish, 2016; Ganeva *et al.*, 2015; Kravcenco, 1991; Makovei, 2020, 2021), resistance to diseases and pests, as well as high environmental plasticity (Khotyleva *et al.*, 2016; Makovei, 2008; Micu, 2015). Scientists from different countries of the world (the Netherlands, Bulgaria, France, Russia, Italy, Turkey, Poland, etc.) have experimentally proved the efficiency of growing heterosis F_1 tomato hybrids in practice. Their active use has allowed for the last 15–20 years to increase the yield not only of tomato, but also of other vegetable crops by 25–50%.

A negative indicator in the cultivation of F_1 tomato hybrids in protected soil is the increased intensity of vegetative mass growth, which depends on the length

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of internodes, the number of leaves between them and inflorescences on the main stem of the plant, as well as excessive formation of lateral shoots (stepsons) (Ignatova *et al*, 1998). These shortcomings necessitate the development and application of special techniques of plant girdling, pinching and removal of side shoots, which in turn leads to an increase in manual labor and at the same time negatively affects the fruiting and efficiency of maximum use of the total and vertical area of greenhouses, thereby increasing the cost of production. Consequently, to increase the efficiency of cultivation of heterosis hybrids of tomato in protected conditions, it is necessary to take into account the nature of manifestation of such traits as: length of internodes, intensity of formation of lateral shoots, affecting the habitus and architectonics of plants. The size and quality of fruits, as well as the total and marketable productivity depend largely on the features of their manifestation (Korol, 2022; Makovei, 2021; Markovic *et al.*, 1996; Sibomana *et al.*, 2013).

Early diagnosis of these traits can be carried out at the seedling stage using modern methods (Kyosuke Yamomoto *et al.*, 2016), by analyzing the indicators of such traits as seedling height, size and number of leaves, stem diameter, internode length, as well as by directly considering their characteristics (Korol, 2011). It is well -known that stress abiotic factors (high, low temperatures, sharp difference in night and day temperatures, lack of sunlight), as well as water shortage, water and nitrogen excess, and others [(Bertram *et al.*, 1994; Grimstad, 1998; Koyano *et al.*, 2005; Shimizu *et al.*, 2000; Sibomana, *et al.*, 2013) 2, 8, 14, 23, 24] have a significant impact on the character of manifestation of these traits, including the intensity of formation of lateral shoots (stepsons).

To overcome these problems, in the process of creating heterosis F_1 tomato hybrids with a compact plant habitus with short internodes, a large number of inflorescences on the main stem, limited formation of lateral shoots and with a lower response to environmental stress factors, the tasks aimed at searching, identifying and creating breeding-valuable material with genetically determined formation of these traits are put forward in the foreground. For this purpose, it is necessary to carry out research on determining the threshold values of trait indices and the degree of their variability depending on the features of the genotype and other factors. This will allow the breeder to purposefully and effectively use this material as donors in the creation of heterosis hybrids of tomato F_1.

The aim of our research was to study the nature of manifestation of traits “length of internodes and intensity of formation of lateral shoots” in lines of generation F_5–F_7, obtained from hybrid combinations from crossing forms, carriers of mutant marker genes *br* (*brachytic*) and *ls* (*lateral suppressor*) controlling the manifestation of these traits with cultivated tomato varieties depending on the features of genotype and growing conditions of their plants.

MATERIAL AND METHODS

Twenty – three tomato lines (110, 164, 178, 181, 183, 184, 185, 186, 188, 190, 193, 195, 196, 197, 201, 204, 205, 224, 228, 234, 237, 241, 10/16) of the F_5–F_7 generation served as experimental material for the studies, which are carriers of *ls (lateral suppressor), br* (*brachytic*), *nor (non ripening), rin (ripening inhibitor)* genes with determinant (*sp*) and indeterminant (sp^+) type of plant growth. Observations, records and analyses were conducted on plants grown in early unheated (April–August) and summer (June–September) film greenhouses according to the methods generally accepted for tomato culture (Tomato–UPOV) in different years (2019, 2020 and 2021).

In the studies, we used the method of direct accounting of the indicators of traits "length of internodes, frequency of formation and size of lateral shoots" (Korol, 2011). To evaluate and analyze the nature of manifestation of the marked traits for each line, 10 plants were used in three repetitions. The length of internodes on the plant stem was measured between inflorescences on all fully formed podiums with simultaneous consideration of the number of lateral shoots and their sizes. The internode index (*In*) was determined as the length of the podium (from one inflorescence to the next) divided by the number of leaves between inflorescences (Ignatova *et al.*, 1998). The results were analysed both by absolute indices of the studied traits (Dospehod, 1985) and in the form of graphs of changes in the length of internodes and the number of formed shoots on the plant by years of research – 2019–2021 (Excel). This allowed us to obtain clear information on the variability of trait indices depending on growing conditions, plant growth type and the presence of mutant marker genes *br* (*brachytic*) and *ls* (*lateral suppressor*) in the genome of lines, which contributed to their classification for subsequent effective use in heterosis breeding.

RESULTS AND DISCUSSION

The peculiarities of tomato plant morphology with respect to sympodial branching formed the basis for the methodology of studying the traits "length of internodes and intensity of formation of lateral shoots". The first inflorescence in tomato is set after a certain number of leaves. Its height in different forms of tomato depends on the maturity of the genotype. Above the first inflorescence, a "main axis" is formed, consisting of separate sections – podiums, i.e. a system of successively replacing each other lateral shoots in ascending order (Ignatova *et al.*, 1998; Korol, 2011).

In plants with determinate type of growth with increasing order of sympodial branching, the size of podiums and the number of leaves in them decreases, and in the latter, leaves between inflorescences are absent. In indeterminant tomato plants,

all podiums have three leaves and one inflorescence, which are formed sequentially and continuously, due to which the plants reach significant size during the vegetation period in greenhouse conditions (Makovei, 2021).

The results of the study revealed that plants of lines with different growth type (*sp* and sp^+) are characterized by different degree of variability of traits – length of internodes and intensity of lateral shoots formation under different growing conditions.

In both groups of lines (*sp*, sp^+), the shortest internodes are formed at the base of the stem, before the first inflorescence (podium). With increasing podium order, the patterns of alternation of internodes of different lengths in plants with determinant (*sp*) and indeterminant (sp^+) types are very different (Table 1).

The group of lines with determinant type of growth shows a wide range of variability in internode length depending on both genotype features and growing conditions of their plants (Fig. 1). The maximum length of internodes on the stem was observed at 4–5 podiums in early unheated greenhouse conditions, whereas when plants were grown in summer greenhouse, internodes were longer at 2–4 podiums (Table 1). At the same time, it was revealed that the greatest number of lateral shoots (stepchildren) is formed on podiums of the middle level (3–5) of the plant stem.

The group of lines with the indeterminant type of growth is characterized by certain regularities. Growing plants in early unheated greenhouses showed that the length of internodes was shorter on the lower podiums (1–3) of the plant stem. Stretched internodes and the longest were at the stem section from podium 4 to 7 (Table 1). More intensive growth of lateral shoots is also noted at this stem section, above it begins to slow down the growth of lateral shoots and internodes become shorter.

Under conditions of summer greenhouses, the longest internodes are formed at 3–4 podiums of the stem with simultaneous intensive formation of lateral shoots. As the podium level on the stem increases, the length of internodes decreases and the formation of lateral shoots is attenuated. These features are characteristic of all lines of this group, but they are more pronounced in L196, L201, L224 and L241.

Table 1

Mean values of "internodes length" trait parameters in tomato lines with determinant and indeterminant type of growth when cultivation plants under different conditions (2019–2021ys)

Plants cultivation period	**Podiums – Internode Index (cm)**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Tomato lines with determinant growth type *(sp)*									
Spring – summer	4.8	6.1	8.4	10.8	11.6	9.2	8.4	8.6	7.4	–

Table 1 (continued)

Plants cultivation period	**Podiums – Internode Index (cm)**									
Summer	5.3	9.0	10.6	11.2	10.9	8.3	8.3	8.0	–	–
	Tomato lines with indeterminant growth type (*sp*$^+$)									
Spring – summer	5.4	6.0	5.7	10.7	1.,2	11.8	10.1	9.2	7.1	7.0
Summer	6.2	8.8	11.7	12.8	9.7	8.2	8.6	7.7	6.8	7.2

Individual analysis of variability of the studied traits within the groups of lines with determinant (*sp*) (Fig. 1 and 2) and indeterminate (*sp*$^+$) type of growth (Fig. 3, 4) showed clear differences both between genotypes and by years of research (2019–2021).

The range of variability in the trait "internode length" was wider in lines with determinant type of growth (Fig. 1). Lines L110, L164, L178, L183 and L190, which are carriers of the *br* gene, had a stable indicator of the trait. Whereas lines 184 and 188 showed high variability. This indicates the instability of their genetic systems regarding the nature of manifestation of this trait.

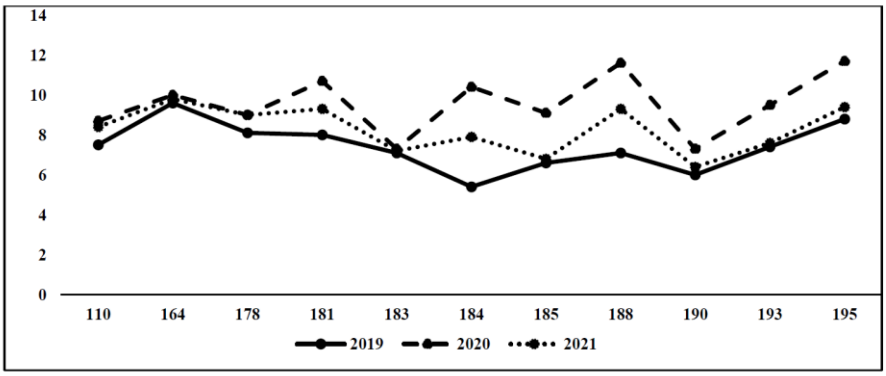

Figure 1. Length of internodes in lines with a determinant (*sp*) type of growth and variability of the trait indicator by year of research.

Similar results for lines with determinant (*sp*) type of growth were obtained when analyzing the indicators of the trait "number of lateral shoots and intensity of their growth" (Fig. 2). Differences are quite pronounced both between lines within the group and in relation to growing conditions when studying them in different years (2019–2021) (Fig. 2). Some lines (181, 188, 193 and 195) form an insignificant number of short lateral shoots, while others (L 110, L178, L184 and

L190) have a large number of strongly developed shoots (stepchildren) with high variability of the indicator by years of research (Fig. 2).

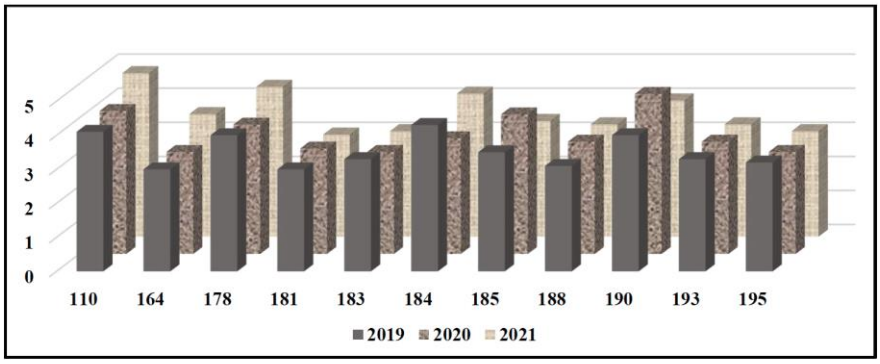

Figure 2. Variability of the indicator of the trait "number of lateral shoots" the years of research in lines with a determinant (*sp*) type of growth.

The degree of variability of the trait "internode length" in lines with the indeterminant (sp^+) type of growth by years of research is insignificant (Fig. 3), except for L201, L204, L205 and L224, where non-significant differences in indices were still observed. This indicates that the trait is genetically determined. This is confirmed by the fact that in the genome of these lines there are two mutant marker genes – *br*, which controls the trait "length of internodes" and *ls* responsible for "intensity of formation and growth of lateral shoots". Different growing conditions practically do not affect the growth and formation of internodes: the curves of index changes in different years of research coincide. But, at the same time, it should be noted that the lines within the group have clearly pronounced differences. Some lines have rather short internodes (from 4.7 to 8.8 cm), while others have a significantly higher index of the trait (from 9.0 to 12.8 cm) (Fig. 3).

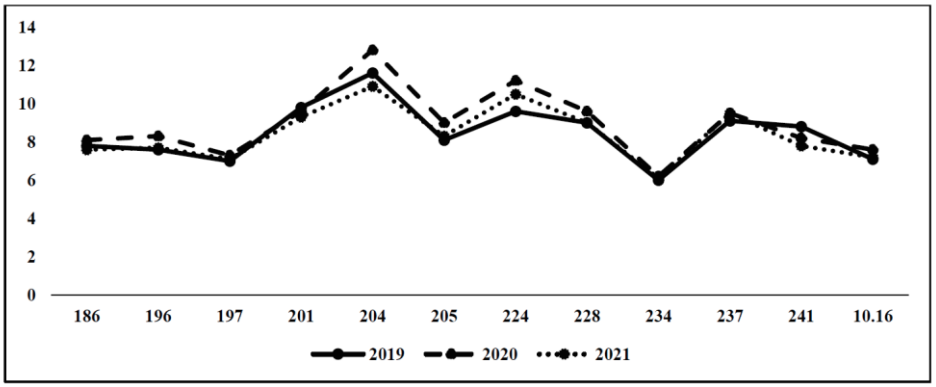

Figure 3. Length of internodes in lines with an indeterminate (sp^+) type of growth and variability of the trait by year of research.

According to the number of formed lateral shoots on the plant stem and the intensity of their growth, the lines with the indeterminate type of growth also have strictly pronounced differences among themselves. In some lines (L186, L196, L224, L234, L237 and L10/16) the frequency of formation of lateral shoots (stepsons) is low (from 1.5 to 4.0 pcs) and stable over the years of research. While other lines (L197, L201, L228 and L241) have a greater number of lateral shoots on the main stem (from 5.0 to 7.6 pcs) with more pronounced variability of their index in different years (Fig. 4).

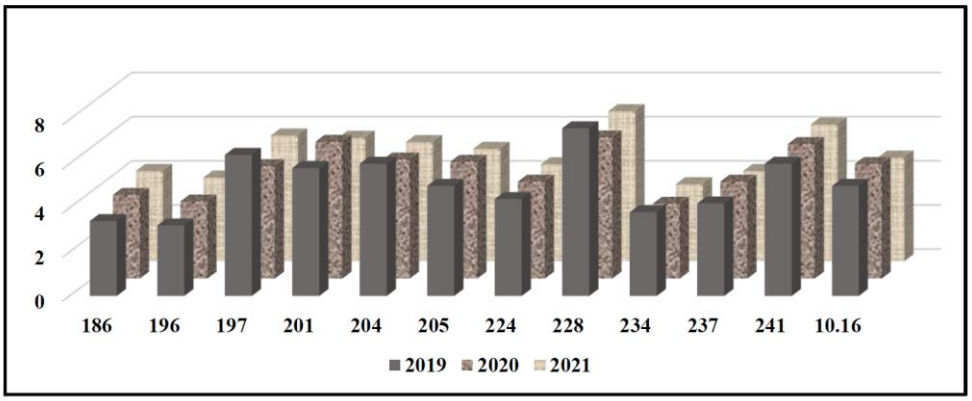

Figure 4. Variability of the trait "number of lateral shoots" on the main stem of the plant over the years of research in lines with an indeterminate (sp^+) type of growth.

In general, the range of variability of the studied traits is much wider in lines with determinant type of plant growth. This is especially pronounced in lines close to cultivated forms, whereas in lines with the *br* gene the size of internodes on podiums of all stem levels during vegetation changes insignificantly. Different growing conditions in three different years of research practically do not affect the growth and formation of internodes in lines with two mutant marker genes – *br* and *ls* – in their genome. Predominantly, these are lines of indeterminant type of growth, most of which are also characterized by lower intensity of lateral shoot formation (from 1.5 to 7.6), whereas genotypes of the cultural type can have from 15 to 21 stepchildren per 25–28 podiums (Korol, 2022). Following the results obtained, the studied lines show a stable nature of manifestation of both traits when growing their plants in spring-summer and summer-autumn film greenhouses in different years (2019–2021). At the same time, the limits of trait variability determined by the hereditary factors of the genome of each line are shown. Some of them are of particular interest for effective use as sources of traits determining moderate vegetative mass growth and weak growth response to changes in growing conditions when creating new tomato forms with a given complex of traits.

CONCLUSION

Comparison of indicators of the traits "length of internodes and number of formed lateral shoots" on the main stem of the plant in tomato lines with different types of plant growth (*sp*, sp^+) when studying them in three different years (2019–2021) revealed their genetic determinacy. A strictly pronounced individual growth response of genotypes to plant growth conditions during the vegetation was established. Of greatest interest are lines 183, 186, 196, 234, 237 and 10/16 combining short internodes with low shoot-forming ability, which are carriers of two mutant marker genes *br* and *ls*. This indicates the advisability of using them in breeding programs as donors for crosses and obtaining high-yielding heterosis F_1 tomato hybrids with compact plant architectonics.

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