Lodging resistance of modern domestic rice varieties

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Abstract. Lodging is a complex process that expresses the plant's response to environmental factors. The main direction of breeding grain crops is to increase yields and improve the grain quality indicators. For the plants to form the maximum yield, it is necessary to develop varieties with a high potential for productivity and quality, resistance to biotic and abiotic environmental factors. In this regard, 5 new rice varieties of domestic breeding were studied in comparison with the large-grain standard Favorit on an optimal background of mineral nutrition and they were evaluated for a complex of traits and for lodging resistance. The experiment was carried out in 2019-2020 under the conditions of field experiment on the rice irrigation system of the experimental production department (ROS OPO) "FSC of Rice" (Federal Scientific Rice Centre), Krasnodar. A significant difference was established between the new rice varieties in comparison with the standard in terms of the complex of anatomical and morphological traits - the maximum values of the diameter of the lower internode (0.80 and 0.78 cm) were observed in VNIIR 10275 and VNIIR 10254, respectively; the predominant ratio of the height of the straw to the diameter of the lower internode (90.8 and 120.7) was established at VNIIR 10254 and Veles; the new genotypes showed a reliably high resistance of the stem to bending with the maximum value for VNIIR 10275 (165.75 g). The important structural elements of productivity of new varieties were determined and the excess of some of them over the variety Favorit was revealed: high density of the main panicle in the varieties Romans and VNIIR 10279 (12.2 and 11.8 pcs / cm); VNIIR 10254 has a large caryopsis and the largest weight of 1000 grains at 14% moisture content (43.1 g); at VNIIR 10275 and VNIIR 10279, the maximum productivity of one growing day (100.4 and 110.4 kg / ha / day) and grain content of agrophytocenosis (50.00 and 58.19 thousand pieces / m²) were established. A close positive relationship was revealed between the stem's resistance to bending and the diameter of the lower internode (r = 0.930), as well as a negative correlation of the average degree between the grain mass of the main panicle with the stem's bending resistance (r = -0.552) and the diameter of the lower internode (r = -0.530). Based on the data obtained, it was decided to transfer the variety VNIIR 10279 (Dialog) for 2021 to the State Variety Testing (SVT).

1. Introduction
Until recently, the problem of lodging resistance of grain crops occupied the minds of many scientists and was one of the main tasks in breeding work in all countries. But due to the shift in emphasis towards short-stemmed varieties associated with the intensification of production, interest in this issue has weakened. However, when cultivating short-stemmed varieties of grain crops at the current level of technogenic load (high doses of fertilizers, thickening of agrophytocenoses, etc.), the risk of plant lodging in large areas increases, due to the inability to balance their growth under certain conditions,
which inevitably leads to a sharp decrease in yield, up to its complete loss. Therefore, the problem is not exhausted and remains relevant. [1].

As a result of domestication, each species of cultivated plants has formed one attractive zone - the main object of agricultural production, in which most of the assimilates formed during photosynthesis are concentrated [2]. In rice, it is a panicle. In the process of domestication of rice and most cereals, for centuries, the selection of valuable forms was carried out for productivity. This led to the fact that cultivated cereals, in comparison with wild-growing relatives, have a much more productive panicle (spikelet) and, accordingly, a thinner and thinner stem. [8].

According to some researchers (Timoshenko S.P., 1971; Vakhnenko V.A., Kurchiy B.A., 1990), the thickness of the straw walls is the main parameter of the stem's resistance to lodging [3, 4]. Its increase increases the mechanical strength of the stem and, as a consequence, resistance to lodging. However, thick-stemmed plants often have a reduced productivity of the generative organs due to special donor-acceptor bonds.

Modern researchers have established that lodging resistance is due to a harmonious combination of a complex of certain morphological traits: plant height, diameter of the lower internode, panicle length, angle of the leaf blade to the stem, etc. [5]. Lodging should also be considered as a plant reaction that affects certain aspects of metabolism, in particular, the metabolism of the mechanical tissues of the stem. [6]. Structural polysaccharides protect, shape and support tissue cells and organisms.

Lodging resistance is due to the content and distribution of mineral elements, silica and cellulose in various plant organs. Mineral silicon in rice tissues is present mainly in the form of silica gel, which fills the aperture in the cellulose micelle of the cell walls, forming a silicon-cuticular double layer. The silica gel layers are bound to the cellulose layers in the cell walls, mainly in the integumentary and mechanical tissues. A close connection is noted in the epidermis, sclerenchyma, vascular bundles, internodes of the straw and leaf sheaths [7].

As you can see, many researchers are trying to solve the problem of lodging using various methods and approaches.

*The purpose* of this work was to analyze the morphobiological characteristics of various rice genotypes, as well as the correlations between them, in connection with the problem of lodging.

2. Conditions, materials and methods

The climate of the region is moderately continental. The sum of active temperatures >10 °C for the frost-free period is 3600-4110 °C with an average daily temperature for the summer period of about 23 °C. Short-term precipitation, heavy rain. During rice growing season they fall out about 350-360 mm. The predominant type of soils in the experimental plot is meadow chernozemic solonetzic. These are semi-hydromorphic analogs of chernozems, but there are signs of waterlogging in the lower part of the profile. The humus content is 2.8-3.4%. The absorption capacity is low - 32.0-34.0 meq / 100 g of soil. Mainly neutral, rarely slightly alkaline reaction of the soil solution prevails - pH = 7.2-7.6 [14].

The research material was 5 new large-grain rice varieties developed at FSBSI "Federal Scientific Rice Centre". The setting of the field experiment was carried out according to the type of competitive variety testing (CVT) in accordance with GOST 15.101.80 - "The procedure for conducting research work" and the methods developed at the "FSC of Rice" [9] and the method of experimental work on breeding [10].

For sowing the CVT plots, a SCVN seeder with a central seeding device was used. The plots were laid in four replicates. Plot area 20 m² (length 15 m, width 1.4 m). The number of rows in the plot is eight, the distance between the rows is 15 cm, the distance between the plots is 40 and 50 cm. Mineral fertilizers were applied to the soil before sowing with N120P60K40 and in the tillering phase of N46. The predecessor was winter wheat.

The experimental part of the work was carried out in 2019-2020 under the conditions of field experiment on the rice irrigation system of the experimental production department of "Federal Scientific Rice Centre". Sowing dates - II-III decade of May.
Plants in the amount of 10 pieces from each replication of all varieties were selected at full ripeness to determine morphological characteristics. The main anatomical and morphological traits and traits determining resistance to lodging were measured: plant height, diameter of the lower internode, grain weight per plant and productive tillering; the ratio of the stem height to the diameter of the lower internode, and the bending resistance of the rice stem were calculated.

The results obtained were processed by methods of variance and correlation analyzes [11, 12].

3. Results and discussion
Rice stem is false - a straw formed by sheaths of leaves, reaching various lengths. Straw is divided by stem nodes into internodes, 0.4-1.5 cm thick. A single-layer epidermis is located on the surface of the straw. The outer wall of the epidermal cells is thickened and enriched in silica. Under the epidermis lies a layer of intercellular parenchyma, in which there is a ring of sclerenchymal fibers with thickenings around the circumference. The latter contains closed-type collateral vascular bundles, and in the center of the straw there is a cavity formed as a result of the death of parenchymal cells [13, 15].

Table 1 shows the morphological characteristics of the rice varieties studied in the CVT.

| №  | Variety   | Plant height, cm (h) | Productive tillering, pcs. | Diameter of the lower internode, cm (d) | Ratio of the stem height to the diameter of the lower internode, (h/d) | Bending resistance of the rice stem, g |
|----|-----------|----------------------|-----------------------------|------------------------------------------|-------------------------------------------------|----------------------------------------|
| 1  | Favorit (st) | 102.7                | 2.3                         | 0.68                                     | 151.0                                            | 84.55                                  |
| 2  | Veles     | 86.9                 | 2.7                         | 0.72                                     | 120.7                                            | 127.15                                 |
| 3  | Romans    | 93.7                 | 2.1                         | 0.74                                     | 126.6                                            | 154.75                                 |
| 4  | VNIIR 10254 | 70.8                 | 3.0                         | 0.78                                     | 90.8                                             | 159.75                                 |
| 5  | VNIIR 10275 | 101.0                | 2.6                         | 0.80                                     | 126.3                                            | 165.75                                 |
| 6  | VNIIR 10279 | 95.0                 | 1.7                         | 0.73                                     | 130.1                                            | 125.55                                 |
|    | LSD05     | 2.8                  | –                           | 0.038                                    | –                                                | 35.3                                   |

The presented data show that all studied varieties significantly differed in plant height. One of the important directions of modern rice breeding is development of varieties with a plant height of up to one meter, taking into account biotic, abiotic and anthropogenic stressors. All presented varieties can be classified as medium-sized (86.9-102.7 cm), with the exception of the undersized VNIIR 10254 with a height of 70.8 cm.

The diameter of the lower internode, with a harmonious combination of other morphometric traits, fairly objectively reflects the straw lodging resistance. The studied rice varieties reliably exceeded the standard on this trait. The largest values of the diameter of the lower internode were observed in the varieties VNIIR 10275 and VNIIR 10254 - 0.80 and 0.78 cm, respectively.

The level of values of the ratio of the straw height to the diameter of the lower internode indicate a potential threat of lodging under stressful environmental conditions. With an increase in this indicator, the risk of lodging increases. The smallest values for the trait were noted in the varieties VNIIR 10254 and Veles (90.8 and 120.7, respectively). The varieties VNIIR 10275, Romans and VNIIR 10279 have average values for this trait - 126.3; 126.6 and 130.1, respectively. Favorite turned out to be the most susceptible to the potential risk of lodging - 151.0.

Evaluation of varieties according to the straw bending resistance rather accurately characterizes the resistance of shoots to lodging. The essence of the method consists in fixing a piece of straw, including the first and second lower internodes, in a horizontal position and applying a load (tared calyx + weights) to the other end until the stem segment is bent by 30 ° with subsequent determination of the load mass. It can be seen from the results obtained that more stress was required for the bending the stem of the new rice varieties. The maximum values of the indicator are set for varieties VNIIR 10275, VNIIR 10254 and Romans - 165.75; 159.75 and 154.75 g, respectively. At the same time, it was noted that the
VNIIR 10275 has a height of more than 1 m, and the VNIIR 10254 - 70 cm. It should be assumed that the new rice varieties, in comparison with the standard, are more resistant to stressors that cause lodging of crops, accompanied by loss of yield.

Lodging of rice crops makes it difficult to realize the potential productivity of the variety; therefore, development of genotypes with high productivity must be combined with their increased resistance to lodging [16]. The harmonious combination of the main economically valuable traits in new rice varieties is an important direction in the work of modern breeders (Table 2).

Table 2. Characteristic of new CVT rice varieties by elements of productivity, 2019-2020.

| №   | Variety      | Main panicle | Mass of 1000 grains at a moisture of 14 %, g | Productivity of one growing day, kg/ha/day | Grain content of agrophytocenos, thous. pcs/m² |
|-----|--------------|--------------|---------------------------------------------|--------------------------------------------|----------------------------------------------|
| 1   | Favorit (st) | 10.7         | 168.0                                       | 33.8                                       | 93.6                                         | 44.82                                       |
| 2   | Veles        | 9.4          | 134.0                                       | 30.7                                       | 71.9                                         | 37.50                                       |
| 3   | Romans       | 12.2         | 167.0                                       | 30.3                                       | 87.8                                         | 45.37                                       |
| 4   | VNIIR 10254  | 5.5          | 70.0                                        | 43.1                                       | 71.0                                         | 28.42                                       |
| 5   | VNIIR10275   | 10.8         | 171.0                                       | 31.2                                       | 100.4                                        | 50.00                                       |
| 6   | VNIIR 10279  | 11.8         | 160.0                                       | 31.4                                       | 110.4                                        | 58.19                                       |
|     | LSD05        | 1.35         | 15.7                                        | 0.43                                       | 1.24                                         | –                                           |

The presented data show that the new varieties significantly differ from the standard in some traits, which reflects the correct strategy for selecting genotypes at all stages of the breeding process.

The density of the main panicle (the number of spikelets per 1 cm of panicle length) indicates the potential of the variety to form a certain number of caryopses on a panicle peculiar only to it. Almost all studied varieties have an average density of 9.4 to 11.8 pcs./cm, which is within the standard. The exceptions are: the variety Romans - 12.2 pcs / cm (significantly higher than the standard) and VNIIR 10254 - 5.5 pcs / cm (significantly lower).

The formation of a large number of filled grains per plant determines its high potential productivity. The number of grains of the main panicle is at the standard level in the varieties Romans, VNIIR 10275 and VNIIR 10279 (167.0; 171.0 and 160.0 pcs.). Veles and VNIIR 10254 have significantly lower number of spikelets - 134 and 70 pieces.

The productivity of the main panicle characterizes the productivity of modern rice varieties, along with their productive tillering and plant stand density. The grain weight from the main panicle in the new varieties varied within the range of 3.1-4.5 g, which is lower than that of the standard. This is due to the number of caryopses per panicle and the lower weight of 1000 grains in the studied varieties.

In our experiment, the weight of 1000 grains had a significant effect on the mass of grain per panicle. Favorit formed the largest grain mass from the main panicle - 5.1 g, which is a consequence of the number and size of caryopses on the panicle. Since the weight of 1000 grains in the other four varieties was 30.3-31.4 g, while the weight of Favorit (st) was 33.8 g and practically the same number of grains, we observe significant differences in panicle productivity. A significant excess of the standard for the mass of 1000 grains was noted only for VNIIR 10254 - 43.1 g, but due to the smaller number of filled spikelets, it turned out to be less productive.

The productivity of one growing day characterizes the potential for a certain area of the cenosis to accumulate dry matter during the day. This trait is calculated and is expressed by the ratio of the yield of the variety to the duration of its growing season. Table 2 shows that the value of the trait varied within 71.0-110.4 kg / ha / day. Considering that the maximum values of the trait were noted in the new varieties VNIIR 10275 and VNIIR 10279 - 100.4 and 110.4 kg / ha / day, it can be assumed that they have a
greater potential for the accumulation of dry matter than Favorit. In other varieties, this characteristic is within the standard.

We have also determined the grain content of the agrophytocenosis, expressed by the calculated number of filled grains per unit area. It was found that new varieties formed 28.42-58.19 thousand pieces/m², and the maximum values of the trait were noted in VNIIR 10275 and VNIIR 10279 - 50.00 and 58.19 thousand pieces / m², respectively, in comparison with Favorite (st) - 44.82 thousand pieces / m².

Correlation links of traits in various combinations indicate the mutual influence of traits on each other (Table 3).

Table 3. Correlation of morphological and biological traits of new rice varieties, CVT 2019-2020.

| Q | Mean value | Dispersion | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|---|------------|------------|-----|-----|-----|-----|-----|-----|-----|
| 1 | 91.68      | 11.68      | -   | -   | -   | -   | -   | -   | -   |
| 2 | 0.74       | 0.04       | -0.348 | -   | -   | -   | -   | -   | -   |
| 3 | 124.25     | 19.45      | 0.927 | -0.670 | -   | -   | -   | -   | -   |
| 4 | 136.25     | 30.45      | -0.416 | 0.930 | -0.708 | -   | -   | -   | -   |
| 5 | 33.42      | 4.90       | -0.764 | 0.290 | -0.688 | 0.176 | -   | -   | -   |
| 6 | 4.23       | 0.67       | 0.954 | -0.530 | 0.968 | -0.552 | -0.694 | -   | -   |
| 7 | 10.03      | 2.45       | 0.861 | -0.334 | 0.794 | -0.240 | -0.889 | 0.809 | -   |
| 8 | 144.83     | 38.96      | 0.966 | -0.327 | 0.882 | -0.308 | -0.882 | 0.916 | 0.955 |

Trait (Q):
1 – plant height, cm;
2 – diameter of the lower internode, cm;
3 – ratio of the stem height to the diameter of the lower internode;
4 – bending resistance of the rice stem, g;
5 – mass of 1000 grains at a moisture of 14 %, g;
6 – mass of grain from main panicle, g;
7 – density of main panicle, pcs/cm;
8 – number of filled grains, pcs.

Plant height of the varieties and the diameter of their lower internodes are very strongly positively related to indicators of stem resistance to lodging: the ratio of height to diameter of the lower internode and stem bending resistance. The value of such productivity traits as the density of the main panicle and the number of filled spikelets, in turn, have a strong positive dependence on plant height. To an average extent, height can negatively affect the weight of 1000 caryopses.

The trait of interest to us - the resistance of the stem to bending - strongly positively correlates with the diameter of the lower internode (0.930) and, on average, negatively correlates with the ratio of the height to the diameter of the lower internode (-0.670). An average negative relationship was revealed between the grain mass of the main panicle and the stem bending resistance (r = -0.552). A negative correlation was also established between the grain mass of the main panicle and the diameter of the lower internode (r = -0.530). This is due to the balanced distribution of structural carbohydrates between vegetative and generative organs.

Taking into account the results obtained in previous years on new varieties in CVT, we have identified two promising ones with a harmonious combination of traits of interest to us - VNIIR 10275 (Trio) and VNIIR 10279 (Dialogue), transferred to the State Varietal Testing for 2021.

4. Conclusion

As it can be seen, the new rice varieties significantly exceeded Favorit (st) in terms of the complex of morphological traits: the maximum values of the diameter of the lower internode –0.80 and 0.78 cm
were observed in VNIIR 10275 and VNIIR 10254, respectively; the maximum predominant ratio of the height of the straw to the diameter of the lower internode - 90.8 and 120.7 - was established at VNIIR 10254 and Veles; and also all new genotypes showed a reliably high stem resistance to bending, and the maximum value of the trait in VNIIR 10275 was 165.75 g.

It has been established that new rice genotypes have high rates of some structural yield elements: reliably high density of the main panicle in varieties Romans and VNIIR 10279 - 12.2 and 11.8 pcs / cm; it was noted that VNIIR 10254 has a large caryopsis and the largest weight of 1000 grains at a moisture content of 14% - 43.1 g; varieties VNIIR 10275 and VNIIR 10279 (Dialogue) formed the maximum number of grains per unit area - 50.00 and 58.19 thousand pieces / m², and the highest productivity of the growing day was noted - 100.4 and 110.4 kg / ha / day, respectively.

Based on the data obtained, it was decided to transfer the VNIIR 10279 (Dialogue) variety for 2021 to the State Variety Testing (SVT).

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