Prospects of potato selection for the improvement of nutritional value of tubers

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Abstract. Successful selection of potatoes in order to increase the nutritional value of potato tubers is limited by the duration of the selection of effective seed parents for hybridization and the need to use express methods for mass assessment of genotypes, according to the biochemical composition of tubers, especially in terms of content and ratio of starch components. The observed transgressive segregation by starchiness of potato tubers with accumulating crosses of highly starchy seed parents significantly increases the level of this trait of offspring, which weakly correlates with productivity. The high correlation between the protein content in tubers of seed parents and the average proteinity of the offspring confirms the presence of control of this trait by additively acting polygenes. This means that in the process of natural meiotic recombinogenesis in hybrid populations, the increase in the protein content of potato tubers of hybrids in the extreme variational classes is possible.

1. Introduction

Potato is the third most important food crop after wheat and corn in most countries of the world, and in the production of protein per unit area it surpasses all crops. Nowadays, the importance of potatoes as a complete and fairly affordable food product has been fully appreciated by the population of different countries, which contributed to the rapid spread of potatoes across all continents [1].

The high nutritional value of potatoes is due to the content of a valuable complex of substances necessary for a healthy human diet: starch, high-grade protein, non-protein compounds (free amino acids and amides), organic acids, sugar, minerals, vitamins, fats and lipids. The total solids content in potato tubers varies from 14 to 30 %, depending on the variety and cultivation conditions [2, 3]. Recently, however, serious changes were made in potato selection programs caused by new consumer requirements related to the need to improve the quality of nutrition in human life – to reduce the calorie content of food, to increase the content of high-grade protein, vitamins and antioxidants [4].

In order to ensure a healthy diet in the near future, potato selection now needs to include work with the source material and crosses in the direction of creating different biochemical indicators of potato tubers, including high and low starch, with a high content of protein, vitamins and antioxidants that strengthen the immune system of a person [5–7].

Of course, to a large extent, the progress of selection towards the increase of the nutritional value of potato tubers is determined by the level of knowledge of the genetic nature of selection traits and the use of modern molecular genetic research methods, including the use of DNA markers, MAS assistive technologies, as well as methods for cloning individual genes and transferring them to the
source material [8–13]. In particular, in a number of studies, the program “from marker to function” is being implemented, which includes experiments not only to identify genotypes using DNA markers, but also to identify the molecular basis of physiological processes in potato plants. At the same time, the relationship between carbohydrate metabolism and starch content in potato tubers and the quality of potato products before and after cold storage was established [14–20].

2. Methods and materials

We used more than 200 varietal samples of the collections of Lorch Potato Research Institute and Magadan Research Institute of Agriculture as objects of research, which were evaluated in the period from 2008 to 2018 in order to identify donors of the most economically useful traits that determine the nutritional value of potato tubers. In order to increase the nutritional value of the newly created hybrid offspring, more than 70 donors of high starchiness, a large fraction of starch granules, protein content and antioxidants were included in the crosses. In the process of research, more than 2000 hybrid populations from crossing backcrosses of high generations, hybrids and varieties of interspecific origin were studied. Breeding nurseries were created in accordance with the methodology of Lorch Potato Research Institute (2006) at the “Pyshlitsy” experimental base in Shatursky district of the Moscow region.

Starchiness was determined by unit weight, and the fractional composition of starch granules was determined by the microscope-free method. The protein content in the potato tubers was evaluated using the Orange-Zh method, and the antioxidant activity of variety specimens (AAVS) was measured by the ampermetric method using the Yauza-01-AA Color instrument. The genetic analysis of hybrid populations according to economically useful traits was carried out in the first tuber generation, growing at least 100 genotypes. The experimental data were subjected to mathematical processing using the MS Excel program.

3. Results

The selection of different levels of starch in potato tubers. Successful selection in the direction of the increase of the starchiness of potato tubers is largely determined by the degree of genetic variation of this quantitative trait [21]. The results of our experimental studies on the starchiness of potato tubers of varieties and hybrids conducted in different weather conditions show that a wide range of variability can be observed during one growing season during the analysis of hybrid populations of different origin.

Thus, the amplitude of variation of starchiness in 6 hybrid populations in 2014, favorable for the formation of the trait, was 14.7–27.6 % (Table I).

This complies with previously obtained data when analyzing the starch content in potato tubers of a large group of hybrid populations of various genetic origins [22].

Under unfavorable conditions for the formation of starch (humidity excess, weak solar insolation, low temperatures), the width of variation of the trait sharply decreases and the lower limit of variation of the trait was 8.9%. It is necessary to note that this quantitative trait is controlled by a series of dominant additively acting genes (polygenes), which are inherited according to the tetrasomic type characteristic of autotetraploids, to which the variety of S. tuberosum belongs. Two independent loci, conventionally designated as A and B, in which the genes are in different states, homozygous (AAAAVBBBB or A4B4) and heterozygous (AAaBBB or A2a2B2v2), are responsible for the difference in the level of starchiness.

In accordance with the revealed patterns of inheritance of the trait, the analyzed parental forms with starchiness of 17–18 %, assessed according to the offspring from self-pollination, had A4B2v2 genotypes containing six dominant alleles (varieties of Zarevo, Adretta, Krebella, Effect and others). Moreover, each allele contributed to the formation of an average of 3.0–3.5 % starch. A4B4 genotypes homozygous for both loci containing 8 dominant alleles were of Zarevo variety and Batya variety originating from it, the starchiness of which under favorable vegetation conditions reached 22–24 %. However, the yields of these varieties were low, which was the result of a negative correlation
between starchyness and yields. At the same time, it was revealed that when crossing or self-pollination of the A4 B2 b2 genotypes, with starchyness of 18–19 %, the offspring was segregated by starch content in the ratio 1: 8: 18: 8: 1.

Table 1. Potato tuber starch variability in hybrid potato populations under different vegetation conditions

| The origin of the hybrid population | Tested hybrids, pcs | Average starchyness, % (X±Sx) | Varying limits, % (min-max) | Coefficient of variation (Cv) | Hybrids selected with starch content ≥ 17 % |
|-----------------------------------|---------------------|--------------------------------|-----------------------------|-----------------------------|------------------------------------------|
| 88.16/20 x Zarevo                 | 154                 | 14.0±0.75                      | 10.9–18.4                   | 19.11                       | 20.8                                     |
| Nida x Saturna                    | 175                 | 15.3±0.48                      | 12.2–18.2                   | 18.75                       | 21.4                                     |
| 1977-76 x Zarevo                  | 172                 | 16.2±0.49                      | 12.8–18.8                   | 16.41                       | 24.6                                     |
| Santana x Innovator               | 153                 | 14.9±0.36                      | 11.4–17.7                   | 20.72                       | 22.9                                     |
| 946-3 x Zhuravinka                | 144                 | 13.5±0.29                      | 8.9–16.9                    | 25.81                       | 18.1                                     |
| Saturna x Nayada                  | 157                 | 15.7±0.64                      | 10.4–16.5                   | 17.21                       | 19.4                                     |
| Freetella x Zarevo                | 162                 | 19.2±0.82                      | 16.2–27.6                   | 29.35                       | 43.1                                     |
| Krebella x Adretta                | 142                 | 17.3±0.61                      | 14.7–20.4                   | 25.70                       | 29.2                                     |
| Adretta x Innovator               | 168                 | 18.1±0.54                      | 15.9–21.2                   | 24.36                       | 30.4                                     |
| Nickulinsky x Zarevo              | 184                 | 18.8±0.78                      | 15.6–22.3                   | 26.13                       | 36.2                                     |
| Freetella x Adretta               | 172                 | 17.5±0.64                      | 14.5–22.0                   | 28.71                       | 41.0                                     |
| Chieftein x Collette              | 138                 | 16.9±0.49                      | 14.8–19.7                   | 26.26                       | 39.1                                     |

Such transgressive segregation is inherent in additively acting polygenes and is characterized by the appearance of both positive and negative transgressions, which in selective use is possible both to increase the level of this trait and to reduce it. Accumulating crosses of highly starchy parents among themselves significantly increase the level of this trait in the offspring. However, a negative correlation with productivity limits the effectiveness of the selection of valuable recombinants.

The selection of genotypes combining both traits is noted only at the level of the average population, which coincides with the average starch content of parents. Therefore, the selection program in the direction of increasing the starch content in potato tubers is determined by the starch level of the hybridization components. The most effective way to increase the average population is to select highly starchy parents that differ in genetic distance. In this case, the recombination of high starch content and productivity is carried out due to transgressive recombinogenesis.

The selection for the quality of potato starch. In the process of the implementation of selection programs according to the results of evaluating hybrids with high starch content (19–21 %), it was found that some of them were characterized by large starch grains (>60 μm), the proportion of which was more than 50 % (Table 2). This makes it possible to purposefully select genotypes with high quality starch, which is consistent with new facts that emphasize the importance of potato starch in everyday human nutrition.

The indigestible component of potato starch, the so-called resistant starch, the content of which in boiled potatoes is 1–6 %, carries an important function of protecting the human body from carcinogens and normalizes the digestive system [1, 4]. The property of indigestible potato starch is such that it is digested and absorbed quite slowly in human body, therefore potato meals are allowed being included in the diet of patients with diabetes mellitus (25).

However, for medical purposes, it is most effective to use the varieties with low starch content that more significantly reduce the risk of carbohydrates being included in the diet of patients. For a certain category of the population, taking into account the calorie content of food, as a necessary basis for a healthy diet, as well as for patients with diabetes, a wide selection of the varieties with low starch content is required. The selection in the direction of low starch content is much easier compared to the
selection of the genotypes of high starch content, since the decrease in the level of manifestation of the trait does not have a negative correlation with productivity.

Table 2. Assessment of highly starchy hybrids by the size of starch granules

| Hybrid origin             | Starch content, % | ≥ 60 mcm | 40–59 mcm | ≤ 39 mcm |
|---------------------------|-------------------|---------|-----------|---------|
| Krebella x Adretta        | 19.2              | 50.6    | 37.1      | 12.3    |
| Freetella x Adretta       | 19.8              | 52.4    | 38.2      | 9.4     |
| Adretta x Innovator       | 20.2              | 55.7    | 36.7      | 7.6     |
| Nickulinskii x Zarevo     | 20.8              | 60.2    | 31.6      | 8.2     |
| Freetella x Zarevo        | 21.1              | 61.5    | 31.1      | 7.4     |

For practical selection, it is effective to use low-starchy parental forms in crosses when selecting them taking into account genetic distance, since it is easy to select genotypes with starch content of up to 8 % in their offspring. In particular, according to the results of our studies, low-starchy forms (6.7–8.5 %) were also noted in populations from crossing mid-ripening and mid-late parents. However, the low starch content of hybrids, as a rule, is associated with a late ripening period and the selection of such samples is not very effective, since they are characterized by instability of indicators and under optimal conditions of vegetation they can have increased starch content. Therefore, the selection of low-starchy forms must be carried out under optimal conditions for the formation of the trait and assess the potential of the selected genotype at the upper boundary of starch accumulation.

The selection of potatoes for the increase of protein content. Potato protein is known to have high biological value. It includes all non-replaceable amino acids and in this respect it is close to the protein of a chicken egg. Therefore, with relatively small protein content, potatoes occupy an important place in human nutrition. In most potato-producing countries, one third of the potato provides the population’s need for complete protein despite the fact that a significant portion of the potato crop is used in processed form.

According to OECD (2002), the average protein content in potato tubers is 2 % by raw weight. The variability of the trait, depending on the influence of various factors, is quite significant and the protein content indices vary from 0.69 to 4.63 %. According to our research on 24 hybrid populations, the range of variability in protein content also has wide limits – from 0.8 to 3.2 %. Moreover, the degree of variability of the trait of protein content approximately in equal proportions depended on the conditions of the growing season and the genotypic characteristics of hybrid populations. At the same time, a high positive relationship was established between the protein content in tubers of parents and the average protein content of offspring (correlation coefficient +0.897).

High values of the coefficient indicate the effectiveness of the selection of parental pairs according to the phenotype and confirm the control of the protein content of the trait by additively acting polygenes, the total effect of which determines the transgressive segregation of the trait of offspring. The obtained data show that due to natural meiotic recombinogenesis in hybrid populations, it is possible to increase the protein content of tubers in hybrids in the extreme classes of the variational series to 3.5–3.9 %, which is 1.5–1.9 higher than the protein content in existing tubers %.

The successful selection for increased protein content is hampered by the lack of an express method for determining the protein content in tubers, which is necessary for the mass assessment of genotypes with a large volume of hybrid populations, which makes it possible to identify extreme variants with high protein content.

The selection for increased antioxidant activity. The creation of potato varieties with antioxidant properties is of great social importance, since the availability of potatoes makes it possible to provide a wide diet with valuable dietary product. The problem of healthy nutrition of the population by creating dietary varieties of potatoes can be solved faster and easier than during the use of any other crops. Therefore, this direction of potato selection is currently receiving much attention in most potato-producing countries.
In Russia, the selection work on the creation of special dietary varieties has been starting since the beginning of the new millennium, and varieties with a high content of carotenoids and anthocyanins with different red and violet pulp of tubers have already been created. These pigments are the basis of biological antioxidants with a high ability to bind free radicals and inhibit the process of their accumulation in human body. In our studies, in order to measure the total antioxidant activity (TAA), the ampermetric measurement method was used using the new highly sensitive instrument “Tsvet-Yauza-01-AA”, which allows direct quantitative measurements of the studied samples.

The analysis of the heterogeneity of different tissues of tuber samples carried out on this device showed that the core parenchyma is the most representative part of tuber by the total antioxidant content. The results of the evaluation of different-quality tubers of the same variety in the samples from the core did not exceed 5 % of confidence level. To study the level of TAA, we evaluated the varieties of the collection nursery and potato hybrids of the selection of Lorch Potato Research Institute. According to the results of studies, it was found that, as a rule, the varieties with colored peel and pulp of tubers differed in the highest antioxidant content. High levels of TAA were observed in the varieties of Rubin with a red color of the peel and yellow tuber pulp (1080 mg/kg) and Vasilek with a red-violet color of peel and white and pink dotted tuber pulp (1052 mg/kg), the antioxidant activity of which is reasoned by the presence of carotenoids and anthocyanins.

During the analysis of the breeding record of hybrids with pigmented coloration of the peel and pulp of tubers, it was found that when parents are crossed with red-colored tubers (genotype RE x RE) (expanded formulation is Rr3Ee3) in hybrid offspring, genotype segregation is expected in relation to 9RE: 3E: 3R: 1re, and by phenotype – in the ratio of 9: 7 (according to the color of tubers). The frequency of occurrence of red-tuberous forms in hybrid offspring will be 56 %. A similar segregation is also possible when parents are crossed with blue and red tubers having the PE genotype (Pp3Ee3). When crossing varietal-colored tubers of varieties (PE x RE), the proportion of hybrids with purple pigmentation in the offspring is much higher than with red, since the P gene inhibits the manifestation of the R gene.

The control of the trait of pigmentation by dominant independent genes provides successful results in recombining color traits with a set of economically valuable indicators. This was confirmed by the results of the assessment of a group of hybrids with blue and red tubers by the level of antioxidant activity.

It is characteristic that all these hybrids originate from the crossing of parents with medium and high TAA values from 432 to 600 mg/kg, which indicates the accumulation of antioxidants in the offspring when parents use appropriate levels of selection trait. It is necessary to note that the average TAA values are inherent in most potato samples. Therefore, in order to increase the antioxidant content in tubers of selection hybrids (up to 2000–3000 mg/kg), the analysis of offspring from different types of crosses is necessary to study the patterns of inheritance of the trait of antioxidant activity.

4. Conclusion

Thus, the creation of potato varieties with increased nutritional value of potato tubers is certainly promising, taking into account the urgent need for natural products that contribute to the improvement of human health. The development of this selection direction will contribute to the formation of a market for new potato processing products, and potato meals of the future may be even more attractive for use in therapeutic and preventive purposes.

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