QUALIDADES TECNOLÓGICAS DA BETERRABA SACARINA NAS CONDIÇÕES DA REGIÃO CIS-URALS**TECHNOLOGICAL QUALITIES OF SUGAR BEETROOT CROPS UNDER THE CONDITIONS OF THE MIDDLE CIS-URAL REGION****ТЕХНОЛОГИЧЕСКИЕ КАЧЕСТВА КОРНЕПЛОДОВ САХАРНОЙ СВЕКЛЫ В УСЛОВИЯХ СРЕДНЕГО ПРЕДУРАЛЬЯ**

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RESUMO

O O crescimento econômico e o bem-estar do estado dependem em grande parte da eficiência do complexo agroindustrial, incluindo o subcomplexo de açúcar de beterraba. Na Rússia, incluindo a região central dos CIS-Urais, a beterraba sacarina é a principal cultura técnica que fornece matéria-prima para a indústria açucareira. Mais de 70% da área é semeada nos Distritos Federal Central e Sul. No território do médio CIS-Urais, a beterraba sacarina é atualmente cultivada em uma área de mais de 100.000 ha (Kornienko, 2014). O objetivo da pesquisa foi identificar os padrões de produtividade e qualidade tecnológica de novos híbridos de beterraba sacarina, a influência das características varietais sobre o conteúdo de substâncias molassigênicas, dosagem do fertilizante de nitrogênio, densidade da cultura e época de colheita para obter o maior rendimento de raízes com altas qualidades tecnológicas na região central CIS-Urais da Rússia. Quatro estudos de campo foram realizados. O teor de açúcares foi determinado por digestão a frio com sacarímetro-polarímetro. Para determinar o nitrogênio α -amino, foi utilizado o método de Stanek e Pavlas modificado por Wininger e Kubadinov. Os resultados mostraram que, com o aumento da dose de fertilizante de nitrogênio, o teor de açúcar das raízes diminuiu naturalmente. À medida que a densidade da cultura aumentou, o teor de açúcar também aumentou. O maior teor de açúcar nas culturas de raízes foi revelado em uma densidade de cultivo de 95.000 e 110.000 plantas/ha. Os autores propuseram recomendações para obter o maior rendimento bruto de açúcar purificado no cultivo de beterraba sacarina: para colheita precoce - cultivar um híbrido de beterraba açucareira do tipo normal-açucarado (Christella), para colheita tardia - um híbrido do tipo produtivo (HM-1820); aplicar fertilizante nitrogenado na dose de 160 kg de agente ativo/ha; cultivar beterraba sacarina com densidade de 95.000 plantas por hectare; remova as safras de beterraba açucareira com colheitadeiras modernas de beterraba em 10-25 de Outubro.

Palavras-chave: *beterraba sacarina; densidade da cultura; sujidade; dano por geada; tempo de colheita; híbridos.*

ABSTRACT

The economic growth and welfare of the state largely dependent on the efficiency of the agro-industrial complex, including the beet-sugar subcomplex. In Russia, including the middle CIS-Ural region, sugar beet is the main technical crop that provides raw materials for the sugar industry. More than 70 % of the area is sown in the Central and Southern Federal Districts. On the territory of the middle CIS-Ural region, sugar beet is currently cultivated on an area of more than 100,000 ha (Kornienko, 2014) The purpose of the research was to identify the productivity and technological quality patterns of new sugar beet hybrids, the influence of varietal characteristics on the content of molassigenic sub-stances, nitrogen fertilizer dosage, crop density and harvest time to obtain the highest yield of root crops with high technological qualities in the middle CIS-Ural region of

Russia. Four field studies were conducted. The sugar content was determined by cold digestion with saccharimeter-polarimeter. To determine the α -amino nitrogen, the method of Stanek and Pavlas modified by Wininger and Kubadinov was used. The results showed that with an increased dose of nitrogen fertilizer, the sugar content of the root crops naturally decreased. As the crop density increased, the sugar content also increased. The highest sugar content in the root crops was revealed at a crop density of 95,000 and 110,000 plants/ha. The authors proposed recommendations to obtain the highest gross yield of purified sugar in sugar beet cultivation: for early harvesting – cultivate a sugar beet hybrid of normal-sugary type (Christella), for late harvesting – a hybrid of yielding type (HM-1820); apply nitrogen fertilizer at a dose of 160 kg of active agent/ha; cultivate sugar beet with a density of 95,000 plants per hectare; remove sugar beetroot crops with modern beet harvesters on October 10–25.

Keywords: *sugar beet; crop density; dirtiness; frost-damage; harvest time; hybrids.*

АННОТАЦИЯ

Экономический рост и благосостояние государства в значительной мере зависят от эффективности функционирования АПК, в составе которого важное место принадлежит свеклосахарному подкомплексу. В России, в том числе в Среднем Предуралье, сахарная свекла является основной технической культурой, которая обеспечивает сырьем сахарную промышленность. Более 70 % площади посева приходится на Центральный и Южный федеральные округа. На территории Среднего Предуралья в настоящее время сахарная свекла возделывается на площади более 50 тыс. га (Kornienko, 2014). Цель исследований состояла в выявлении закономерностей формирования продуктивности и технологических качеств новых гибридов сахарной свеклы, степени влияния сортовых особенностей на содержание мелассообразующих веществ, установлении дозы азотного удобрения, густоты насаждения растений и срока уборки для получения наибольшей урожайности корнеплодов с высокими технологическими качествами в условиях Среднего Предуралья (Россия). Четыре полевых исследования были проведены. Содержание сахара определяли путем холодного расщепления поляриметром-сахариметром. Для определения α -аминоазота был использован метод Станека и Павласа, модифицированный Винингером и Кубадиновым. Результаты показали, что с увеличением дозы азотных удобрений содержание сахара в корнеплодах естественным образом снижается. По мере увеличения плотности посевов содержание сахара также увеличивалось. Наибольшее содержание сахара в корнеплодах выявлено при плотности посева 95000 и 110000 растений/га. Авторами предложены рекомендации по получению наибольшего валового выхода очищенного сахара при возделывании сахарной свеклы: для ранней уборки возделывать гибрид сахарной свеклы нормально-сахаристого типа Кристелла, для поздней уборки – гибрид урожайного направления ХМ-1820; вносить азотное удобрение в дозе 160 кг д.в. на гектар; возделывать сахарную свеклу с густотой насаждения 95000 растений на гектар; убирать корнеплоды сахарной свеклы современными свеклоуборочными комбайнами с 10 по 25 октября.

Ключевые слова: *сахарная свекла; густоты насаждения; загрязненность; подмороженность; время сбора урожая; гибриды.*

1. INTRODUCTION:

Sugar beet is the only source of raw materials for industrial sugar production in the Russian Federation (Islamgulov *et al.*, 2019). A significant reserve for improving the productivity of sugar beet cultivation and meeting the need for sugar through its production is the use of highly efficient hybrids and the development of sugar beet root technical qualities, which ensure timely delivery of raw materials and products while minimizing financial and environmental losses. Crop formation features and methods of increasing sugar content as one of the leading technical indicators of sugar beet quality have been studied by national scientists (Islamgulov *et al.*, 2018). It is shown that along with the variety, the main elements of sugar beet cultivation

technology affecting the yield and sugar content in root crops include the use of nitrogen fertilizers, crop density and harvest time (Bloch and Hoffmann, 2003a; Hoffmann and Kenter, 2018; Ghorbanian *et al.*, 2019).

Among all macronutrients, nitrogen has the most significant impact on sugar beet root yield and quality (Chatterjee, 2018). Insufficient nitrogen nutrition at the beginning of the vegetation reduces the root yield. Still, the use of nitrogen fertilizers in large doses stimulates growth processes and leads to a decrease in sugar content and deterioration of juice purity (Trimpler *et al.*, 2017).

Russian studies have shown that one of the most critical factors for obtaining a high yield

of sugar beet with high technological qualities is to create an optimal crop density with uniform drilling distance (Jacobs *et al.*, 2018).

Increased sugar production can be achieved by reducing the beet and sugar loss due to optimum harvest time. Early harvesting of raw beet is one of the reasons for low sugar content and decreased keeping quality of root crops (Rother, 1998). Sugar beet harvested at a relatively late date has a higher yield and technological conditions, but also high dirtiness. With a delay in harvesting the number of frozen roots increases, technical qualities reduce and weight loss of conditioned roots increases (Märlander, 1992; Bloch and Hoffmann, 2003b; DeBruyn *et al.*, 2017).

Significant progress has been made in the selection of sugar beet. Currently, hybrids with more advanced technological genotype have been developed (Hoffmann *et al.*, 2009). Along with sugar content, the indicator of root crop technical qualities determining the sugar yield per planted area is the molassigenic substance content, which reduces the sugar yield in the root crops (Hoffmann, 2006; Schnepel and Hoffmann, 2016a; Varga *et al.*, 2017). At the same time, there is practically no scientific information on the regularities of productivity formation and technological qualities of new sugar beet hybrids depending on nitrogen fertilizer dosage, crop density, and harvest time in natural conditions of the middle CIS-Ural region.

In this regard, studies aimed at increased sugar production by increasing yields and technological qualities, including the reduction of the molassigenic substance content in root crops by selecting highly productive hybrids and optimizing the parameters of technical methods of sugar beet cultivation, solve the urgent problem of the country's economy.

2. MATERIALS AND METHODS:

2.1. Field trials

Four field experiences were conducted (3 years each). The soil of the field experiment sites, as well as the soil of beet-growing enterprises in the middle CIS-Ural region, was represented by leached chernozems. In terms of humus layer thickness, leached chernozems are of medium thickness, and their particle size distribution is heavy loam.

In the first experiment, the influence of varietal characteristics on the formation of sugar beet technological qualities were studied

(Buchholz *et al.*, 1995; Schnepel and Hoffmann, 2016b). Such factors as a cultivar were experimentally investigated. The objects of the research were a sugar beet hybrid of Russian breeding – RMC-70 (control); two hybrids of Syngenta breeding – Geracl, HM-1820; two hybrids of KWS breeding – Christella, Dominica; one hybrid of Strube-Dieckmann breeding – Akhat.

The second experiment studied the effect of nitrogen fertilizer dosage on sugar beet technological qualities. The factor considered in the trial was a dose of nitrogen fertilizer application. The objects of the research were Geracl sugar beet hybrid and a dose of nitrogen fertilizer (Dosage N₄₀ (control), N₈₀; N₁₂₀; N₁₆₀; N₂₄₀ kg a.m./ha).

The third experiment was aimed at studying the effect of crop density on sugar beet technological qualities. The factor studied was crop density. The objects of the research were Geracl sugar beet hybrid and crop density (50,000 plants/ha; 65,000 plants/ha; 80,000 plants/ha (control); 95,000 plants/ha; 110,000 plants/ha).

The fourth experiment was devoted to the harvest time effect on sugar beet technological qualities. The factor studied was the harvest time. The objects of the research were RMC-120 sugar beet hybrid of Russian breeding and harvest time (8 harvest periods every ten days from 10.09 to 20.11.).

The variant replication at all points of experimentation was 4-fold. Fertilizers were introduced for the planned yield – 350 kg/ha. Sowing was carried out with a precision seeder (Mudarisov *et al.*, 2017; Khamaletdinov *et al.*, 2018). The plant stand was 90 to 95 thousand plants per ha (except for the experiments with crop density). The predecessor was winter rye. During field experiments, the weather conditions reflected the climate patterns of the natural areas of the Republic of Bashkortostan, where beet-growing enterprises are located.

2.2. Sample treatment and analyses

Sugar content was determined by cold digestion with saccharimeter-polarimeter (Figure 1), which is based on a direct method of obtaining water extract from the pulp of sugar beetroots.

Figure 1. Saccharimeter-polarimeter

To determine the α -amino nitrogen, the method of Stanek and Pavlas modified by Wininger and Kubadinov was used, which is based on the measurement of optical density using a spectrophotometer (Figure 2).

Figure 2. Spectrophotometer

Potassium and sodium content were determined by the Silin method on a flame photometer (Figure 3).

Figure 3. Photometer

Standard sugar losses when molasses was formed were calculated according to Brunswick formula (Equation 1), introduced by Buchholz *et al.* (1995) (Abyaneh *et al.*, 2017; Hoffmann, 2017; Märlander *et al.*, 2018).

The purified sugar content was calculated as the difference between sugar content and standard sugar losses in molasses. The gross sugar yield was defined as the product of yield and sugar content, and the total yield of purified sugar was calculated as the product of yield and

purified sugar content (Draycott, 2006; Koch *et al.*, 2016; Barzegari *et al.*, 2017).

In the second stage, the analysis of the experiment results was carried out in the form of mathematical processing to obtain the statistical estimate of the resulting indicators, identify the empirical dependence, mathematical confirmation of the scientific hypothesis validity and to prove the scientific conclusions. The variance to determine the significance of the results for each factor is analyzed. The essence of variance analysis is to divide the variance and the total number of degrees of freedom into parts corresponding to the structure of the experiment and to assess the significance of the studied factors' action and interaction. The use of these methods allowed to prove the reliability of the differences in the field experiment, the relationship between the studied factors, and to determine the model of the impact of one or more variable field factors (Islamgulov *et al.*, 2019).

This study was carried out following the authors' affiliated institutions recommendations from the IRB. The IRB approved the protocol of affiliated institutions of authors. Under the Helsinki Declaration, all subjects had given written, informed consent.

3. RESULTS AND DISCUSSION:

3.1. Sugar beet varietal characteristics and technological qualities

Crop yield is one of the main indicators of sugar beet productivity. In this experiment, an average of three years, HM-1820 hybrid formed the highest yield (51.8 t/ha), and RMC-70 control hybrid – the lowest (39.5 t/ha). The yield of other hybrids varied from 43.7 to 49.2 t/ha. High productivity of HM-1820 and Dominica hybrids is due to their selection assignment (producing high yield and standard yield). Akhat hybrid showed the highest sugar content (18.10%), HM-1820 hybrid – the lowest (16.70%). The remaining hybrids had a relatively similar sugar content varying from 17.00 to 17.90%.

Potassium content in root crops varied both by year and between hybrids. HM-1820 hybrid had the highest potassium content in the root crops – 4.92 mmol, Akhat hybrid – the lowest – 4.11 mmol. RMC-70 and Dominica hybrids did not differ significantly in this indicator and had 4.86 and 4.85 mmol, respectively. Thus, potassium content in root crops showed the same intervarietal variability. Hybrids of sugary and

normal-sugary types were characterized by lower potassium content in root crops than hybrids of the productive type. Sodium, like potassium, belongs to one of the main molasses makers, which adversely affect the extraction of crystallized sugar. The results showed that HM-1820 hybrid had the highest sodium content in root crops in all years of the research (0.90 mmol), Akhat hybrid – the lowest – 0.45 mmol. Among the nitrogen compounds of sugar beet roots α -amino nitrogen, or "harmful nitrogen", plays the most negative role in sugar extraction. On average, over three years of the research, the RMC-70 control hybrid had the highest α -amino nitrogen content (2.23 mmol), Akhat hybrid – the lowest (1.55 mmol). HM-1820, Dominica, and Geracl hybrids also had a high α -amino nitrogen content of 1.91; 1.87 and 1.80 mmol, respectively. Christell hybrid had a low value of this indicator, as well as RMC-70 hybrid.

Sugar loss in molasses formation is largely due to the technical qualities of sugar beet. The results of three-year studies have shown that the difference in sugar loss between hybrids was significant. The values of standard sugar losses in molasses formation ranged from 1.40 to 1.70%. The values of this indicator in hybrids of yielding and normal-yielding types were relatively higher than in sugary and normal-sugary types of hybrids, which was due to the high content of molasses-forming substances (potassium, sodium, and alpha-aminoazota). The studied hybrids differed in the content of purified sugar: in hybrids producing high yield and normal yield, it was less than in hybrids of sugary and normal-sugary types.

On average, over three years, HM-1820 hybrid had the highest gross sugar yield (8.65 t/ha), RMC-70 hybrid – the lowest (6.91 t/ha). The remaining hybrids had almost the same sugar yield (from 7.91 to 8.36 t/ha). RMC-70 control hybrid had less sugar yield than other hybrids (1.0–1.74 t/ha). The gross sugar yield in yielding hybrids was higher than that of the sugary.

On average, over three years, HM-1820 hybrid had the largest gross yield of purified sugar (7.80 t/ha), RMC-70 control hybrid – the lowest (6.24 t/ha). Dominica and Geracl hybrids formed the same sugar yield 7.57 t/ha, Christella, and Akhat hybrids – 7.62 and 7.30 t/ha, respectively. Thus, hybrids differ in the gross yield of purified sugar. Dominica hybrid exceeds Geracl in gross sugar yield, and Christella is inferior to both of them.

Sugar beet hybrids can be estimated

more objectively by the gross yield of purified sugar than by gross sugar yield (Figure 4). So, Dominica hybrid exceeded Geracl in terms of gross sugar yield, and Christella hybrid is inferior to both of them. Hybrid evaluation of the gross yield of purified sugar shows that Geracl is not inferior in productivity to Dominica, and Christella is superior to both hybrids.

All of the above points to the complex genetic nature of the characteristics determine the technological qualities of beetroots. Differences in sugar content and ash elements in hybrid root crops are probably primarily determined by differences in their heredity, determining the duration and nature of the vegetative phase of sugar beet development in the first year.

3.2. Technological qualities of sugar beet depending on nitrogen fertilizer dosage

The increase in sugar beet yield depending on the year and variant was 2.45–8.6 t/ha. The highest sugar beet yield was formed in N₂₄₀ variant – 37.4 t/ha, the lowest – in N₄₀ (30.4 t/ha). Correlation analysis of the experimental data over three years showed that there is a weak positive relationship between the dose of nitrogen fertilizer and sugar beet yield ($\eta=0.44$).

On average, over three years, the maximum sugar content in root crops was in the N₄₀ variant (17.48%), the lowest – in N₂₄₀ (16.20%). Other variants had relatively the same sugar content – 16.98–17.06%. Correlation analysis showed that there is a weak inverse relationship between the dose of nitrogen fertilizer and sugar content in sugar beetroots ($\eta=-0.41$). Thus, with an increase in the dose of nitrogen fertilizer, the sugar content of sugar beet roots decreases.

The dose of nitrogen fertilizer had an impact on potassium content in root crops. On average, over three years, potassium content in the experiment variants varied from 4.73 to 5.40 mmol per 100 g of wet weight. Correlation analysis showed a moderate positive relationship ($\eta=0.53$) with an increase in the dose of nitrogen fertilizer, potassium content increases.

The dose of nitrogen fertilizer affected the sodium content in sugar beetroots. The highest sodium content was in the N₁₆₀ variant (1.05 mmol), the lowest – in N₄₀ variant (0.8 mmol). N₈₀, N₁₂₀, N₂₄₀ variants slightly differed (0.88–0.95 mmol). The difference in comparison with the control was from 10 to 31.2% (Islamgulov *et al.*,

2019). There is a moderate dependence in the form of parabola between the dose of nitrogen fertilizer, and sodium content in sugar beetroots, (η) is 0.66. With an increase in the dose of nitrogen fertilizer (N_{160}), sodium content in the wet weight of root crops increases and then decreases.

On average, in 2008–2010, α -amino nitrogen content in the root crops was different and depended on the dose of introduced nitrogen fertilizer. The lowest content was noted in the control variant, the highest – at the maximum nitrogen dose. The content of α -amino nitrogen in the N_{160} variant exceeded the control by 1.43 times in the N_{240} variant – by 2.23 times. Correlation analysis showed that there is a strong positive relationship between these indicators ($\eta=0.96$). Increased doses of nitrogen fertilizer caused increased growth of both root crops and sugar beet tops. As a result, there was a sudden accumulation of nitrogenous matter in the root crops, especially of α -amino nitrogen.

The dose of nitrogen fertilizer significantly affects the sugar loss in molasses. Increasing the dose of nitrogen fertilizer increases the standard loss of sugar in molasses. N_{240} variant was characterized by the highest sugar losses, exceeding the control by 0.40%. Sugar losses were primarily associated with high α -amino nitrogen and potassium content in the root crops.

The dose of nitrogen fertilizer significantly influenced the purified sugar content in the root crops. The highest content of purified sugar was in N_{40} variant – 16.10%, the lowest sugar content (14.42%) was in maximum nitrogen dose of N_{240} . N_{80} and N_{120} variants had the same sugar content (15.54%). The difference between the variants ranged from –0.56 to –1.68%. With an increased nitrogen fertilizer dosage, standard sugar loss in molasses also increased.

Studies have shown that, on average, in 2008–2010, the maximum gross sugar yield was while using high doses of nitrogen fertilizers (N_{160} and N_{240} variants), exceeding the control by 14.4 and 14.6%. The increase in sugar yield ranged from 0.36 to 0.77 t/ha. Gross sugar yield increased with increasing dose of nitrogen fertilizer.

On average, over 2008–2010, the N_{160} variant showed the maximum gross yield of purified sugar (5.47 t/ha), N_{40} control variant – the minimum (4.85 t/ha). Sugar yield of N_{120} and N_{240} variants was relatively the same – 5.35 and 5.38 t/ha.

The increase in the gross yield of purified sugar ranged from 0.30 to 0.60 t/ha. The maximum high dose of nitrogen fertilizer (N_{240}) did not give an increase in the gross yield of purified sugar since the sugar loss in the molasses was high.

Studies have shown that the gross yield of purified sugar increases with an increase in nitrogen fertilizer dosage up to a certain limit. Calculations have found that to assess the sugar beet productivity, and it is more appropriate to use the gross yield of purified sugar than the total sugar yield (Figure 5). Thus, the highest gross sugar yield was obtained in the N_{240} variant – 6.04 t/ha. At the same time, the yield of purified sugar, including molasses losses, was higher in the N_{160} variant.

3.3. Crop density and sugar beet technological qualities

On average, over three years of the research, the maximum sugar beet yield was in the variant with a crop density of 95,000 plants/ha. Thinned out (50,000 plants/ha) and thick planting (110,000 plants/ha) formed a lower yield of root crops. With an increase in crop density, the yield of sugar beet increased to a certain limit and varied from 33.4 to 36.0 t/ha. At the same time, the maximum yield was 95,000 plants/ha, and in the variant of 110,000 plants/ha, it reduced due to root crop degrowth.

On average, in 2008–2010, the sugar content of the root crops in the harvest period ranged from 16.95 to 17.62%. With an increase in crop density, sugar content in root crops increased to 17.62% and then decreased. Crop density of 95,000 plants/ha provided the highest sugar content (17.62%).

Potassium content was dependent on the region of plant alimentation. The highest potassium content was found at a crop density of 50,000 plants/ha (5.57 mmol), a little less – at a density of 65,000 plants/ha (5.17 mmol). Variants with a density of 80,000 and 95,000 plantings/ha had a relatively small difference (4.97 and 4.89 mmol). The minimum potassium content was in thick planting at a density of 110,000 plants/ha. In comparison with the control, the difference was from –0.22 to 0.60 mmol. The correlation analysis of the experimental data confirmed that there is an average inverse relationship ($\eta=-0.51$) between the sugar beet density and potassium content.

The variant with a density of 50,000 plants/ha had the largest sodium content in root crops. With an increase in crop density from

65,000 to 95,000 plants/ha, the sodium content in root crops decreased from 0.62 to 0.53 mmol per 100 g of wet weight. The lowest indicator value was in the variant with a density of 110,000 plants/ha – 0.51 mmol. The difference in the variants concerning the control ranged from – 0.06 to 0.13 mmol. The correlation analysis of the experimental data confirmed that there is a very strong inverse relationship ($\eta=-0.91$) between the sugar beet density and sodium content. As the crop density increased, the sodium content decreased.

On average, over three years, the maximum α -amino nitrogen content was in the variant of 50,000 plants/ha, the minimum – in the variant of 110,000 plants/ha. With an increase in crop density from 65,000 to 95,000 plants, α -amino nitrogen content decreased from 1.47 to 1.29 mmol. The deviation from the control was from –0.13 to 0.43 mmol per 100 g of wet weight. The correlation analysis of the experimental data over three years also showed that there is a strong negative relationship between these indicators ($\eta=-0.89$). With an increase in crop density, α -amino nitrogen content in sugar beet roots is reduced.

Research results showed different standard sugar losses of 1.41 to 1.66 percent in molasses formed under different crop densities. The highest standard loss of sugar was at a density of 50,000 plants/ha in the variant. Standard sugar losses in the formation of molasses decreased with crop density increased.

On average, in 2008-2010, the content of refined sugar in root crops ranged from 15.29 to 16.18%. The lowest amount of purified sugar was in the variant with the lowest crop density of 50,000 (15.29%), the highest – with a density of 95,000 plants/ha (16.18%).

On average, in 2008-2010, the gross sugar yield varied from 5.66 to 6.34 t/ha.

The highest gross sugar yield was observed at a crop density of 95,000 plants/ha – 6.34 t/ha. The increase concerning the control was 0.20 t/ha.

In general, in 2008-2010, the value of the gross yield of purified sugar ranged from 5.11 to 5.82 t/ha. The density of 95,000 plants/ha provided the highest gross yield of purified sugar (5.82 t/ha) in comparison with other variants. It was found that a further increase in crop density, as well as its reduction, had a negative impact on the gross yield of purified sugar.

Thus, the gross yield of purified sugar

increases with an increase in crop density to a specific limit (95,000 plants/ha) (Figure 6). The calculations confirmed the correctness of the use of the gross yield of purified sugar to assess the sugar beet productivity as a more objective indicator.

3.4. Sugar beet technological qualities at different harvest time

The studied variants of sugar beet harvest time differed in root yield. On average, over three years, this figure had an increase from the first to the seventh harvest time. During the eighth harvest period, there was a slight decrease. The maximum increase was detected from the second to the fourth harvest time in all years of the research. The correlation analysis showed that there is a strong relationship ($\eta=0.85$) between the harvest time and the sugar beet yield.

Over three years of the research, the sugar content of the root crops naturally increased, and by November 10, it reached its maximum value. During the eighth harvest time, a decrease in sugar content was observed. The reduction in sugar content is associated, apparently, with a reduction of the intensity of growth processes due to a decrease in air temperature and increased sugar use for breathing. On average, over three years, the most intensive sugar formation was observed during the third and fourth harvest periods. In other variants, the accumulation of sugar occurred without any surge. There is a very strong positive relationship ($\eta=0.94$) between the harvest time and sugar content in sugar beetroots.

Potassium content in sugar beet roots changed in different harvest periods. Thus, the highest potassium content was in 2014 (4.01 mmol) in the seventh harvest period, the lowest – in 2015 (3.18 mmol) in the first harvest period. The correlation index (η) between the two indicators was 0.48.

Unlike potassium, sodium content naturally decreased from the first to the seventh harvest period. On average, over three years, it dropped from 0.93 to 0.77 mmol (by 17.2%) from the first to the sixth harvest period. When harvesting on November 10, there was an increase in sodium content to 0.80 mmol, followed by a decrease to 0.74 (November 20).

The most significant decrease in sodium content was found during the fourth and fifth harvest periods. The relationship between these indicators is inverse ($\eta=0.59$).

The changing factor in α -amino nitrogen content was similar to the one in potassium content. The increase in its content occurred until November 10 (0.97–1.46 mmol). In contrast to potassium content, α -amino nitrogen content increased by 50.5%. On average, over three years of the research, the smallest increase of α -amino nitrogen was observed during the third and fourth harvest periods. The correlation analysis showed that there is a moderate, positive relationship ($\eta=0.62$) between these parameters.

Sugar losses ranged from 1.20 to 1.46%. The increase in standard molasses loss at later harvest time was associated with an increase in potassium and α -amino nitrogen content. On average, in 2013–2015, the sugar loss between the third and sixth harvest periods was minimal concerning other harvest periods. The relationship between these indicators is moderate and positive ($\eta=0.65$).

The purified sugar content also depended on the harvest period. On average, this indicator increases over three years from the first to the last harvest period. In 2013–2015, an increase in the purified sugar content fell on the fourth harvest period. Later harvesting accounted for the highest amount of refined sugar. The relationship between these indicators is very strong ($\eta = 0.93$).

On average over three years, the highest value of the gross sugar harvest was at a later date of harvesting – 9.14 t/ha (the seventh harvest period), the intensity of the increase between the terms was maximum at the third and fourth harvest periods (0.77–0.88). There is a strong correlation between these indicators ($\eta=0.90$).

On average, over three years, the highest gross yield of purified sugar was at a later harvest time. From the average for three years, it is clear that the high increase was obtained during the fourth harvest time (October 10) – 0.83 t/ha. There is a strong positive relationship between the harvest time and the gross yield of purified sugar. The correlation index (η) is 0.90.

The main causes of beetroot mass loss, when accepted at a sugar factory, are the dirtiness and frost-damage. High dirtiness of sugar beet roots at a later harvest time was primarily due to a large amount of precipitation during that period, which affected the soil moisture in the arable layer. On average, soil moisture at a depth of arable layer ranged from 15.5 to 33.1%, from the first to the third harvest period, this figure is below normal (25%). From

the fourth to the fifth harvest periods, the soil moisture was within normal limits. In the sixth term, the soil moisture in the arable layer is slightly lower than the optimal value for sugar beet. And during the seventh and eighth harvest periods, it was much higher than in the previous ones.

On average, in 2013–2015, the sugar beet dirtiness amounted to 20.8%. Reduced dirtiness fell on the third harvest period. High sugar beet dirtiness at a later harvest time was primarily due to the amount of precipitation during that period, which affected the soil moisture in the arable layer. Sugar beet frost-damage in 2013 was recorded during the sixth harvest period – 2.4%, and at further harvest periods, it ranged from 2.4 to 3.7%. In 2014 the frost-damage from the fifth to the eighth harvest periods varied from 4.3 to 53.4%. The surge was recorded during the eighth harvest period. In 2015 the frost-damage was already observed during the fourth harvest period – 3.1%, and by the sixth period, it increased to 67.8%. The percentage increase of frost-damaged root crops was primarily due to air temperature decrease.

Losses due to beetroot dirtiness and frost-damage increased in November harvest time. From the first to the fourth harvest periods, the number of losses was not that great, unlike the further ones. The maximum loss rate (89.9%) was observed in the eighth harvest period in 2015. On average, over three years, the lowest losses fell on the third harvest period.

On average, over three years of the research, the maximum gross yield of purified sugar, including losses, was revealed at the fifth harvest period (6.66 t/ha). The minimum value of this indicator was at the seventh harvest period (2.93 t/ha) as a result of significant losses due to beetroot dirtiness and frost-damage (Figure 7).

The gross sugar harvest and the gross refined sugar harvest increased from the first to the seventh harvest period. In contrast to the previous indicators, the gross yield of purified sugar, including losses, increased from the first to the fifth harvest periods. There is a slight decrease during the sixth harvest period and a sharp decline during the seventh and eighth periods, which was due to high losses. Fig. 4 shows the possibility of choosing the most optimal harvest time to obtain the maximum yield with high technological qualities. To obtain the highest gross yield of purified sugar, the optimal harvest time is October 10–25.

The accumulation of sugar in the root

crops of sugar hybrids (Akhat, Christella) is more intense than in hybrids of yielding (HM-1820, Dominica) and normal (Geracl) types. The sugar content of the control hybrid (RMC-70) was higher than that of other hybrids of the same type. With an increased dose of nitrogen fertilizer, the sugar content of the root crops naturally decreased. As the crop density increased, the sugar content also increased. By the end of the growing season, a crop density of 95,000 and 110,000 plants/ha revealed the highest sugar content in root crops. In the fourth experiment, the sugar content of sugar beet roots increased until November 10, although there was some decrease in its intensity in early November.

The hybrids producing high yield (HM-1820) and normal yield (Dominica) formed the maximum crop productivity. With an increase in the dose of nitrogen fertilizer, the sugar beet yields also increased. The maximum yield was found in the variant with a density of 95,000 plants/ha. Thinned out (50,000 plants/ha) and thick planting (110,000 plants/ha) formed a lower yield of root crops. In the variant with a density of 110,000 plants / ha, the increase in plant number per unit area did not compensate for the decrease in an individual mass of plant. The yield of sugar beet root crops increased (by 41.6%) to the seventh harvesting period (10.11). In the eighth term (20.11), there was some decrease. The sugar beet yield within the period studied largely depended on the harvest time.

The hybrid types differ significantly in the content of molasses-forming substances in root crops. There is a significant intercultivar variability in potassium, sodium, and α -amino nitrogen content. Hybrids of sugary (Akhat) and normal-sugary (Christella) types contained less molasses-forming substances than hybrids producing high yield (HM-1820) and normal yield (Dominica). Hybrid control RMS-70 had a high content of alpha-aminatta. With an increase in the dose of nitrogen fertilizer, the content of molasses-forming substances in sugar beet roots naturally increases. The increase in the area of plant nutrition led to an increase in the content of molasses-forming substances in the root crops of sugar beet. A significant increase in α -amino nitrogen content occurred in the roots from the first (10.09) to the seventh (10.11) harvest time. Potassium content in root crops also increased from the first to the seventh harvest periods. Sodium content, on the contrary, decreased from the first to the eighth harvest periods (20.11).

Due to the high content of molasses-forming substances, standard sugar losses in

molasses formation were higher in hybrids producing high yield (HM-1820) and normal yield (Dominica) than that of sugary (Akhat) and normal-sugary (Christella) types. The purified sugar content in the root crops of hybrids producing high yield (HM-1820) and normal yield (Dominica) was less than that of sugary (Akhat) and normal-sugary (Christella) types. With an increased dose of nitrogen fertilizer, the standard sugar loss in molasses increased due to the increase of molasses-forming substances such as α -amino nitrogen and potassium. With an increase in nitrogen fertilizer dosage, the purified sugar content decreased. Standard losses of sugar decreased with increasing density of plantings. The highest content of refined sugar was at a density of 95,000 plants/ha.

Further increase in crop density led to a decrease in the purified sugar content in root crops. At a later harvest time (10.11–20.11), sugar losses increased sharply, and from the third to the sixth harvest periods (01.10–30.10), losses were minimal. There was an increase in the purified sugar content from the first (10.09) to the seventh (10.11) harvest periods, and by the eighth period (20.11), there was some decrease in the content of purified sugar.

In yielding hybrids (HM-1820, Dominica), the gross sugar yield was higher than that of sugary ones (Akhat, Christella). With an increase in the dose of nitrogen fertilizer, the gross sugar yield increased and reached the maximum value when applying N_{240} . Gross sugar yield depended on the crop density. The maximum gross sugar harvest provided sowing for the final density of 95,000 plants per 1 ha. The highest gross sugar yield was detected at the late harvest time (10.11).

The gross sugar yield of Dominica hybrid was more than that of Geracl hybrid, and the gross sugar yield of Christella hybrid was less than that of Dominica and Geracl hybrids. Evaluation of the productivity of the gross collection of refined sugar showed that Geracl hybrid is not inferior in productivity to the hybrid of Dominic, and Christella is superior in sugar collection both hybrids.

The most substantial gross sugar yield was obtained in the variant with a dose of nitrogen fertilizer of N_{240} . At the same time, the gross yield of purified sugar, including molasses losses, was higher in the N_{160} variant. The crop density of 95,000 plants/ha provided the highest gross yield of purified sugar in comparison with other variants. Further increase in crop density

(up to 110,000 plants/ha) and reduction (up to 50,000 plants/ha) resulted in a decrease in the gross yield of purified sugar. The natural increase in the gross yield of purified sugar occurred from the first (10.09) to the seventh (10.11) harvest periods. During the eighth period (20.11), there was a slight decrease.

The sugar beet dirtiness and frost-damage are important indicators in determining the optimal harvest time. Starting from the fifth harvest period (20.10), due to the increase in soil moisture, the sugar beet dirtiness increased and amounted to 89.9% during the eighth harvest period (20.11). Beetroot frost-damage occurred from October 10. The maximum frost-damage was during the eighth harvest period. Due to the dirtiness and frost-damage, the beetroot losses increased dramatically, starting from the sixth harvest period (30.10). The highest beet root yield and gross yield of purified sugar, including losses, were revealed in the fifth harvest period (20.10).

According to the suite of metrics, the optimum sugar beet harvest time in the natural conditions of the middle CIS-Ural region when using modern beet harvesters is October 10–25.

4. CONCLUSIONS:

To obtain the highest gross yield of purified sugar in sugar beet cultivation on the leached chernozem of the middle CIS-Ural region, it is recommended:

- for early harvesting – cultivate a sugar beet hybrid of normal-sugary type (Christella), for late harvesting – a hybrid of yielding type (HM-1820);
- apply nitrogen fertilizer at a dose of 160 kg of active agent/ha;
- cultivate sugar beet with a density of 95,000 plants per hectare;
- remove sugar beetroots with modern beet harvesters on October 10–25.

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$$\text{SSL} = 0,12 \times (\text{K} + \text{Na}) + 0,24 \times \alpha\text{-amino N} + 0,48 \quad (\text{Eq. 1})$$

where

SSL – Standard Sugar Loss, %;

K – potassium content, mmol/100 g wet weight;

Na – sodium content, mmol/100 g wet weight;

α -amino N – α -amino nitrogen, mmol/100 g wet weight

Figure 4. Hybrid sugar yield (Karmaskaly, 2007-2009)

Figure 5. Sugar yield under different doses of nitrogen fertilizer treatment (2008-2010)

Figure 6. Sugar collection at different plant density (2008-2010)

Figure 7. Changes in sugar yield by harvest time (2013-2015): GSY – Gross sugar yield, t/ha; GYPS – Gross yield of purified sugar, t/ha; GYPS including losses – Gross yield of refined sugar including losses, t/ha