Features of potato tuber formation depending on the feeding area and the application of fungicides in the conditions of the Middle Urals

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Abstract. Potato is the most important agricultural crop in the world and in Russia. Currently, in production are used varieties of domestic and foreign selection. Along with the yield, the products obtained are of great importance, according to which the intended purpose of a particular variety is determined. The study of the quality indicators of potato tubers is an integral part of the development of varietal cultivation technology. The purpose of the research is to study the qualitative indicators of potato tubers of the Gala variety at different plant densities and the use of fungicides in the Middle Urals. The research was carried out in 2018-2019 on the experimental field of the educational and experimental farm of the Ural State Agrarian University. The object of research is a medium-early high-yielding potato variety Gala. When conducting biochemical and agrochemical studies, gravimetric, extraction, ebulliostatic, ionometric and photometric methods were used. The electrical conductivity of tubers was determined with a conduct meter in mSm, the concentration of cell juice with a refract meter in %, nitrates in tubers – with a nitrate tester in mg/kg, the acidity (pH) of tubers – with a pH meter. The research results showed that the concentration of potato tubers cell juice decreases from 7.0 to 2.65% with an increase in the feeding area from 1400 to 2800 cm². The use of fungicides shirlan and infinito reduces the electrical conductivity. The specific weight of potato tubers increases with an increase in the feeding area from 0.92 to 1.16 grams. The nitrate content decreased with an increase in the feeding area and the use of fungicides from 340 to 326 mg/kg. During the growing period, the content of carbon dioxide (CO₂) of the potato plant in the control variant was 775, and with the use of shirlan it was 1043, which is an increase of 1.5 times. The scientific novelty lies in the fact that for the first time in the conditions of the Middle Urals, an assessment of tubers was carried out according to physiological, agrophysical and agrochemical indicators with new devices during the periods of storage of tubers (April) and vegetation of potato plants, depending on the feeding area and the use of fungicides.

1. Introduction
Potato is among the most important crops. Potato ranks fourth in world crop production after wheat, rice and corn. Due to the content of starch, high quality protein and vitamins in tubers, it is an extremely important human food product. Potato tubers contain on average 23-27% dry matter, 14-22 – starch, 1.4-3.0 – protein, about 1.0 – fiber, 0.2-0.3 – fat and 0.8-1.0% ash substances. Potato is quite rich in vitamins C, B₁, B₉, B₆, PP. Young tubers are especially rich in vitamins [1]. Potato is also rich in minerals (boron, calcium, iron, magnesium, potassium, sodium and zinc) and phytochemicals [2, 3, 4].
The main minerals and proteins in the tubers are unevenly located, concentrated under the skin or in the immediate vicinity of the surface, so tubers with an intact skin retain all nutritional benefits during storage and, as a rule, are not damaged by diseases. Red, yellow, white and brown tubers provide the human body with a significant amount of vitamins and minerals. For example, one medium potato contains about 620 mg of potassium – more than bananas. Iron, which is found in potato, is involved in the conversion of food into energy, and is also important in the body's resistance to infections [5].

In fact, potatoes contain all nine essential amino acids and are thus a complete protein. Recently, studies on protein and amino acid content have shown that potato protein is superior to other plant proteins and was similar to animal proteins in the content of essential amino acids [6]. Potato protein is characterized by high digestibility and nutritional value: 10 g of potato protein can replace 6-7 g of meat protein [7].

Potato, as the main source of vitamin C, provides protection against scurvy. On average, potato contains 17-35 mg/100 g of vitamin C, much higher compared to corn, wheat, rice, sorghum, and beans. The content of ascorbic acid decreases during storage and during cooking [8]. The chemical composition of potato tubers depends on the variety, size and maturity of tubers, but can change under the influence of the environment (weather and soil-climatic conditions) and agronomic factors [9].

Potato is the main food crop throughout the world [10, 11]. For thousands of years, potato remains the main source of human nutrition and to ensure their health [12]. In many developed countries, potato is consumed as a vegetable and the average consumption ranges from 50 to 150 g per day/person. On the other hand, in some rural areas of Africa and in the highlands of Latin American countries, potatoes are considered a staple crop and are consumed separately in large quantities as a full meal with a consumption of 300 to 800 g per day/person [13].

Potato is used in human nutrition, animal feed and in industry. Potato is a raw material for many industries, where starch, alcohol, artificial rubber, plastics, lactic acid, dextrin, glue, etc. are produced [14, 15]. Diet and nutrition are essential for achieving sustainable development goals, especially good health and well-being. In recent history, potato has remained an integral part of the global food system and can provide global food security and sustainable food energy in the future [16].

Nutrient management is an essential component for successful potato production [17, 18]. Tuber yield depends on a combination of morphological and physiological factors, including photosynthesis, leaf outgrowth, aging at birth, and tuber growth [19].

Potato juice, the liquid fraction of potato tubers, is available in large quantities as a side stream of the starch industry. It should be emphasized that the value of potato juice as an industrial raw material is based not only on its nutritional value but also on its biological activity [20].

In the Middle Urals, a new high-yielding, medium-early variety Gala has recently been spreading, characterized by relative resistance to diseases and good tuber preservation in winter. To determine its intended use, the dependence of quality indicators on weather and soil-climatic conditions, as well as elements used in industrial technologies (feeding area, fungicides, etc.), it is necessary to study the qualitative characteristics of the tubers of the potato varieties used, using classical and modern methods analysis.

The purpose of the research is to study the qualitative indicators of potato tubers of the Gala variety at different plant densities and the use of fungicides in the Middle Urals.

2. Methods
During the years of research, tubers were assessed according to some physiological, agrophysical and agrochemical indicators (concentration of cell juice, electrical conductivity, tuber temperature, acidity or pH and others) with new devices from China during the storage period of tubers (April): Hygrometer VIT-2 (determination of soil moisture), refractometer (determination of the concentration of cell juice of a tuber), pH meter ATC (determination of acidity of a tuber), Thermometer
(measurement of temperature of a potato tuber), Conductivity meter ECTESTER (determination of electrical conductivity of juice), Nitrate tester (express method) for the determination of nitrates, instruments (Digital Professional instruments) for the determination of CO₂, temperature and humidity in storage, Luxmeter for determining the illumination (HS1010A).

During the storage period, the temperature of tubers in the storage depended on the feeding area and the use of fungicides and was different according to variants. In experiments, it ranged from 24.2°C to 26.7°C. During the entire period of storage of tubers in the storage, the optimal air temperature was kept within + 2 ... + 3 (the main storage period), the relative humidity was 90-92%, i.e. storage conditions for potato tubers were favorable.

The research was carried out on the experimental field of the educational and experimental farm "Uralets" of the Ural State Agrarian University (USAU), the village "Studencheskiy", during 2018-2019. The object of the study in the experiment was a medium-early, high-yielding variety of Gala table potato, bred by German breeders, originator Norika (Germany). For research, we chose new fungicides that are currently spreading in the Middle Urals:

Shirlan, 50% CS active ingredient is 500 g/l to fluazinam. Shirlan fungicide contact action is effective in prophylactic use against late blight and early blight potato. Spraying against late blight is carried out during the vegetation period in the phase of closing the rows with a consumption rate of 0.3-0.4 l/ha with an interval of 7-10 days. Water consumption is 200–500 l/ha. The period of protective action varies from 7 to 10 days. The effect of the shirlan fungicide, after applying it to plants, begins immediately. The waiting period is 7 days and the frequency of processing during the vegetation period is 4 [21].

Infinito, 68.7% CS fungicide systemic action, contains 62.5 g/L of fluopicolide and 625 g/L of propamocarb hydrochloride. Fungicide is used on potato plantings with a consumption rate of 1.2-1.6 l/ha, a working fluid of 200–400 l of water/ha. The period of protective action of the fungicide infinito is 7-14 days. The first spraying is carried out for the purpose of prophylaxis during the vegetation period. Infinito preparation penetrates into the plant within 2–4 hours from the moment of treatment. In total, up to 4 treatments are performed per season [22].

The two-factor experiment consists of 15 variants and 4 replicates arranged according to the following scheme: Factor A (feeding area): 1–1400 cm², 2–1750 cm², 3–2100 cm², 4–2450 cm², 5–2800 cm²; Factor B (application of fungicides): – Shirlan: 1–1400 cm², 2–1750 cm², 3–2100 cm², 4–2450 cm², 5–2800 cm²; – Infinito: 1–1400 cm², 2–1750 cm², 3–2100 cm², 4–2450 cm², 5–2800 cm². The area of one plot is 28 m². The total area of the experiment is 1680 m². The placement of variants is systematic. The row spacing is 70 cm, and the distance between plants in a row is from 20 to 40 cm.

The soil of the experimental site is podzolized chernozem, in terms of particle size distribution, heavy loamy with a humus content of up to 4.5% (according to I. Tyurin's method), the reaction of the soil is weakly acidic, close to neutral, the availability of mobile phosphorus is low, exchangeable potassium is medium. Agrochemical indicators of the soil of podzolized chernozem: saline pH according to the Kappen's method – 5.4; nitrogen (N) according to Cornfield – 185.9 mg/kg of soil; mobile phosphorus (P₂O₅) according to Kirsanov – 238.9 mg/kg; exchangeable potassium (K₂O) according to Kirsanov – 268.5 mg/kg.

The determination of the mass fraction of humus in the soil was carried out according to the Tyurin method (GOST 26213-91), the pH value of the salt extract of the soil was determined according to Alyamovsky (GOST 26483-85), the content of mobile phosphorus in the soil according to Kirsanov (GOST 26207-91), the content of exchangeable potassium according to Kirsanov (GOST 26207-91), nitrogen content according to Cornfield (GOST 26207-91).

The quality of the crop was assessed based on the results of biochemical analyzes of tubers. When conducting biochemical and agrochemical analyzes, gravimetric, extraction, ebulliostatic, ionometric and photometric methods were used. The ionometric method of analysis is the simplest and most rapid for the determination of nitrates. The photometric method is more versatile and can be used both in the analysis of nitrates and nitrites in all types of products, including those that have undergone culinary processing and technological processing [23].
The gravimetric method of analysis is based on accurate measurement of the mass of a substance isolated as a compound of a known composition or in an elemental form. The method is based on the law of conservation of mass in chemical reactions [24]. The ebuliostatic method is intended for the determination of reducing sugars in aqueous solutions. The extraction method is the process of distributing a substance between two immiscible liquid phases. One phase is usually water; the second is an organic solvent [25].

The optimal hydrothermal coefficient for potato is 1.4-1.6. During the years of research, the hydrothermal coefficient (HC) changed significantly. The hydrothermal coefficient was 1.4 in 2016, in 2017 it is 1.8, in 2018 – 1.3, and in 2019 it was within 1.6. Thus, the climatic conditions of 2016, 2017 and 2019 were wetter and cooler compared to 2018, which corresponds to slightly arid. This made it possible to study the influence of agrotechnical methods on the yield and quality of potato tubers of the Gala variety.

3. Results

During the storage period of potato (April), the tubers were assessed for some physiological, agrophysical and agrochemical indicators depending on the feeding area and the use of fungicides (Table 1).

Table 1. Change in physiological, agrophysical and agrochemical characteristics of potato tubers depending on the feeding area and the use of fungicides, average for 2018-2019.

| Feeding area, cm² | Cell juice, % | Electrical conductivity, mSm | Weight tuber, g | Tuber volume, cm³ | Specific weight, g | Temperature, °C | Nitrates, mg/kg | Acidity (pH) |
|------------------|--------------|------------------------------|-----------------|-------------------|------------------|-----------------|----------------|-------------|
| 1400             | 7.00         | 8.83                         | 148             | 155               | 0.95             | 25.1            | 340            | 8.92        |
| 1750             | 5.20         | 7.90                         | 99.5            | 100               | 0.99             | 25.0            | 330            | 8.15        |
| 2100 (c)         | 4.90         | 5.03                         | 91.9            | 99.0              | 0.92             | 26.2            | 332            | 8.95        |
| 2450             | 4.00         | 5.57                         | 116             | 100               | 1.16             | 26.6            | 326            | 7.94        |
| 2800             | 2.65         | 4.75                         | 114             | 100               | 1.14             | 26.7            | 326            | 7.65        |
| r=               | -0.97        | -0.90                        | -0.37           | -0.70             | 0.78             | 0.93            | -0.88          | -0.74       |
| Factor B treatment with shirlan | | | | | | | | |
| 1400             | 5.0          | 6.58                         | 113             | 130               | 0.86             | 25.9            | 434            | 7.40        |
| 1750             | 5.0          | 6.85                         | 119             | 140               | 0.85             | 24.2            | 536            | 8.42        |
| 2100 (c)         | 5.1          | 3.11                         | 188             | 200               | 0.94             | 25.4            | 133            | 7.86        |
| 2450             | 5.0          | 5.45                         | 118             | 230               | 0.51             | 26.2            | 162            | 7.96        |
| 2800             | 5.0          | 5.21                         | 104             | 101               | 1.02             | 25.9            | 203            | 7.38        |
| r=               | -0.44        | -0.08                        | 0.09            | -0.01             | 0.39             | -0.73           | -0.18          |             |
| Factor B treatment with infinito | | | | | | | | |
| 1400             | 4.0          | 5.91                         | 102             | 101               | 1.00             | 26.5            | 11.0           | 7.30        |
| 1750             | 4.0          | 6.47                         | 117             | 102               | 1.14             | 26.3            | 19.0           | 7.24        |
| 2100 (c)         | 5.1          | 3.11                         | 133             | 103               | 1.29             | 26.3            | 25.0           | 7.21        |
| 2450             | 5.0          | 5.45                         | 95.8            | 98.0              | 0.97             | 26.3            | 5.00           | 7.25        |
| 2800             | 5.0          | 5.21                         | 117             | 110               | 1.06             | 25.7            | 26.0           | 6.93        |
| r=               | 0.95         | -0.30                        | 0.09            | -0.06             | -0.83            | 0.27            | -0.78          |             |
From the data in Table 1, we observe that the concentration of cell juice in the control variant (factor A) ranges from 2.65 to 5.20%. In this case, the correlation dependence between the concentration of cell juice and the feeding area is negative (\( r = -0.97 \)), i.e., the larger the area of plant nutrition, the lower the concentration of cell juice.

When treated with shirlan (factor B), such a pattern was not established, the concentration of cell juice did not change according to the variants and amounted to 5.0-5.1%. Fungicide infinito increased the concentration of cell juice in tubers from 4.0 to 5.1%, i.e. with an increase in the area of plant nutrition, the concentration of cell sap increases at \( r = 0.95 \), that is, the relationship is positive, strong.

The electrical conductivity of tubers strongly depended on the feeding area in the control variant (factor A) and amounted to 4.75-8.83 mSm, with an increase in the feeding area, the electrical conductivity of tubers decreases at \( r = -0.90 \), the relationship is negative. Application of the fungicide shirlan (factor B), the electrical conductivity decreased from 6.85 to 3.11 mSm at \( r = -0.44 \). When using infinito, the conductivity index ranged from 3.11 to 6.47 mSm and depended on the size of the feed area at \( r = -0.30 \).

The specific mass of grown potato tubers from 0.92 to 1.16 grams in the control variant (factor A) was directly proportional to the feeding area, i.e. with an increase in the feeding area, it increased (\( r = 0.78 \)). With the use of shirlan (factor B), this regularity was preserved, the specific gravity was 0.51-0.72 with the correlation coefficient \( r = -0.01 \). With the use of the fungicide infinito, the specific gravity was in the range of 0.97-1.29 and was weakly dependent on the size of the feeding area at \( r = 0.06 \).

Of interest are the data obtained in the course of measuring the temperature of tubers using laser thermometer. An increase in tuber temperature by 0.1-1.7°C was noted in the control variant (factor A) with an increase in the feeding area by 350 cm
\(^2\). When using the fungicide shirlan (factor B), this pattern is not observed. The temperature of tubers was the highest in the variant with infinito treatment and amounted to 26.2°C, while when using shirlan it was 25.5°C, i.e. close to control 25.9°C. The increased temperature of tubers when using infinito is explained, apparently, by the fact that infinito is a systemic fungicide, and shirlan has a contact action.

Determination of nitrates by the express method in tubers made it possible to establish a tendency for a decrease in nitrates with an increase in the feeding area in the control variant (factor A). The use of fungicides (factor B) reduced nitrates in potato tubers. Thus, the use of infinito led to a decrease in the content of nitrates to 17 mg/kg in comparison with the control (331 mg/kg) or 19.4 times.

An inverse correlation was established between pH and feeding area. In the control variant (factor A) at \( r = -0.74 \), the pH is higher than when using fungicides (factor B) (when using shirlan \( r = -0.18 \), when using infinito \( r = -0.78 \)). Thus, the quality of potato tubers increases with thickened plantings and without the use of fungicides, since it is known that an increase in the alkaline reaction in food is beneficial for the human body. The use of fungicides lowers the pH in the tubers, which affects the quality of the crop.

**Table 2.** Change in physiological, agrophysical and agrochemical characteristics of potato tubers from the use of the fungicide shirlan during the growing season, average for 2018-2019.

| Feeding area, cm
\(^2\) | Number of tubers, pieces | Fresh tuber weight, g | Tuber dry weight, g | Volume weight, cm
\(^3\) | Tuber temperature, °C | Electrical conductivity, mSm | Concentration, % | Nitrates, mg/kg | Acidity (pH) |
|----------------|------------------------|----------------------|-------------------|-----------------|----------------|----------------|----------------|----------------|----------------|
| 2100 (control) | 16 | 18.8 | 3.13 | 10.7 | 19.2 | 5.68 | 6.2 | 73.0 | 6.0 |
| 2450 (shirlan) | 21 | 22.5 | 3.63 | 24.5 | 17.2 | 5.78 | 6.0 | 161 | 7.8 |

From the data in Table 2, it can be seen that with the use of the fungicide shirlan, all physiological, agrophysical and agrochemical characteristics of tubers are higher than in the control, except for the
temperature, which was 2°C higher compared to the control, and the concentration of cell sap of tubers in the control is 2% higher than in the version with the use of shirlan.

**Table 3.** Change in physiological, agrophysical and agrochemical characteristics of potato stems and leaves during the vegetation period, average for 2018-2019.

| Feeding area, cm² | Plant height, cm | Stem diameter, cm | Number of stems, pieces | Temperature, °C | Leaf temperature, °C | Plant cell sap | Electrical conductivity, mSm | Concentration, % | Nitrates, mg/kg | Acidity (pH) |
|------------------|------------------|-------------------|------------------------|----------------|---------------------|----------------|---------------------------|----------------|----------------|-------------|
| 2100 (control)   | 58,0             | 0,50              | 5                      | 18,0           | 17,3                | 14,39          | 4,9                       | 463            | 6,70           |             |
|                  |                  |                   |                        |                |                     |                |                           |                |                |             |
| 2450 (shirlan)   | 65,0             | 0,75              | 6                      | 17,7           | 17,5                | 11,64          | 5,0                       | 472            | 6,08           |             |

From the analysis of the data in Table 3, it follows that the fungicide shirlan had an effect on the biometric parameters of potato plants. Thus, the plant height (49 days after planting) was 65.0 cm in the variant with shirlan, which is 7 cm more than in the control. The number of stems (6 pieces), Leaves (52 pieces), Stem diameter (0.75 cm) were also higher in the variant with the use of shirlan. The stem temperature in the control variant was 18°C, and in the variant with shirlan - 17.7°C. The leaf temperature in the control and in the variant with shirlan was 17°C. In the control, the electrical conductivity of tubers is 14.39 mSm that is 2.75 higher compared to the use of shirlan. The concentration of cell sap in the variant with shirlan was within 5.0%, and in the control – 4.9%. The highest content of nitrates was noted with the use of shirlan – 472 mg/kg, and the highest acidity of tubers was in the control – 6.70.

**Table 4.** Change in physiological, agrophysical and agrochemical characteristics of potato roots during the growing season, average for 2018-2019.

| Feeding area, cm² | Wet weight of the whole plant, g | Dry weight of the whole plant, g | Number of roots, pieces | Raw weight of roots, g | Volumetric mass of roots, cm³ | Dry weight of roots, g | Root length, m | Root temperature, °C | Number of stolons, pieces | CO₂ plants |
|------------------|----------------------------------|----------------------------------|------------------------|-----------------------|-----------------------------|-----------------------|----------------|---------------------|--------------------------|-------------|
| 2100 (control)   | 178,8                            | 18.6                            | 138                    | 25.3                  | 22                          | 3.87                  | 1380           | 18.0                | 30                       | 775         |
| 2450 (shirlan)   | 243,1                            | 27.5                            | 142                    | 32.3                  | 24                          | 4.30                  | 900            | 17.5                | 43                       | 1043        |

From the analysis of the data in Table 4, we observe that all physiological, agrophysical and agrochemical characteristics of potato roots during the growing season are higher in the variant with the use of shirlan (2450 cm²) than in the control (2100 cm²), except for the length and temperature of the roots. The mechanism of the shirlan’s influence on the given indicators is not completely clear; it is to be studied in the future.

### 4. Conclusion and discussion

Research carried out on the physiological, agrophysical and agrochemical characteristics of potato tubers of the Gala variety at different feeding areas in the Middle Urals allow us to draw the following conclusions:

During storage, the concentration of cell sap of tubers in the control variant varied from 2.65 to 7.0% at $r = -0.97$, i.e. the larger the area of plant nutrition, the lower the concentration of cell sap, the relationship is inverse. No such regularity was established when plants were treated with Shirlan. The concentration of cell juice was 5.0-5.1%. Fungicide infinito increased the concentration of cell sap in
tubers grown in large feeding areas. It ranged from 4.0 to 5.1% with a correlation coefficient r = 0.95, i.e. with an increase in the feeding area, the concentration of cell juice increases.

During the vegetative period, the concentration of cell sap of tubers was 6.2% in the control variant with a feeding area of 2100 cm²; when treated with a shirlan with a feeding area of 2450 cm², it was within 6.0%. The concentration of plant cell sap (stem and leaves) was 4.9% in the control variant, and when treated with shirlan it was 5.0%, which is 0.1% more than in the control. The electrical conductivity of tubers depended on the feeding area and the use of fungicides. In the control variant (2100 cm²), the electrical conductivity of tubers was 5.68 mSm, and in the variant with shirlan treatment (2450 cm²), it was 5.78 mSm. The electrical conductivity of the plant (stem and leaves) in the control variant (2100 cm²) was 14.39 mSm when treated with shirlan (2450 cm²) – 11.64 mSm.

Physiological, agrophyysical and agrochemical parameters of potato roots during the vegetative period were different and depended on weather conditions, feeding area and application of fungicides. So the length of the roots in the control variant (2100 cm²) was 1380 m, and when treated with shirlan (2450 cm²) it was within 900 m. The temperature of the roots in the control variant was 18.0°C, when using shirlan it was 17.5°C. The CO₂ content of the whole potato plant in the control variant with a feeding area of 2100 cm² was 775, and with the use of shirlan (2450 cm²) it was 1043, that is 268 more than the control.

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