Methodology and Results of the Study of Seed Potato Tuber Parameters Using Digital Tools

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Research Article

Keywords: potato tubers, physical assessment, machine vision, image analysis, food quality, non-destructive evaluation

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METHODOLOGY AND RESULTS OF THE STUDY OF SEED POTATO TUBER PARAMETERS USING DIGITAL TOOLS

Abstract

The article presents a methodology for the quantitative assessment of seed potato tuber and mini-tuber parameters, comparing traditional manual measurements with an automated digital method using a machine vision system based on OpenCV in Python. Five major Kazakh potato varieties—Astana, Alliance, Janaysan, Narly, and Eden—were analyzed. Each tuber's mass and linear dimensions (length, width, thickness) were measured manually and digitally. The automated setup uses two cameras to capture images from perpendicular planes, allowing calculation of mass, dimensions, area, and perimeter from images. An algorithm was developed to convert image data from pixels to millimeters and ensure accurate physical measurements. Results showed close agreement between manual and digital methods, with a relative error not exceeding 1.6% for mass and 3.0% for dimensions. Shape descriptors such as index and form coefficient were also calculated. Regression models for mass prediction were developed, offering high accuracy and potential for refinement. The digital method increased measurement productivity by seven times compared to manual approaches. The findings and regression equations will contribute to the development of machine learning algorithms for automated varietal classification of potato tubers based on their physical traits.

Keywords: potato tubers, physical assessment, machine vision, image analysis, food quality, non-destructive evaluation

Introduction

Potato is the third most important food crop in the world, consumed by billions of people. It makes a significant contribution to global food security. At the 11th World Potato Congress held in Dublin in 2022, FAO Director-General Qu Dongyu remarked that worldwide potato production has the potential to double within the next decade. In Kazakhstan, potatoes represent a key food staple, grown across an area exceeding 200,000 hectares. In Kazakhstan, potatoes are one of the main food products, cultivated on an area of more than 200,000 hectares. The average yield is about 18 tons per hectare, with total tuber harvests reaching approximately 3.6 million tons, fully covering the needs of the population. Among the activities aimed at increasing potato yield, seed production plays a leading role. In the hot and arid climate of most regions of Kazakhstan, and with the spread of viral diseases, many high-yielding varieties of domestic and foreign breeding begin to decrease in yield, seed quality, and degeneration by the second or third year of reproduction. Consequently, the primary and most pertinent avenues of scientific inquiry include: enhancing productivity through breeding, developing heat tolerance and drought resistance, improving resistance to prevalent diseases within the country, and a novel focus on producing varieties that are suitable for industrial processing into high-quality food products and starch.[1-2]

Depending on the reproduction stage, planting quality, and tuber quality, seed potatoes are classified into categories.

Original material: potatoes free from viral and other infections, obtained through biotechnological methods or clonal selection (microplants, microtubers, basic clones), intended for the production of original seed potatoes. The maintenance of a healthy potato variety bank (HPVB) under sanitary conditions relies on the continuous and repeated improvement selection of basic clones based on variety typicality, health, and productivity indicators[1];

Original seed potatoes: seed potatoes of the primary stages of seed production (minitubers, 1st field generation from minitubers, super-super elite), obtained from the propagation of decontaminated original material, produced by the variety originator or an authorized person, and intended for the production of elite seed potatoes. During the cultivation of minitubers in a controlled environment, protected from insect vectors of infections, various types and designs of vegetative structures are used. In most cases, microplants are used for growing minitubers, and less frequently – microtubers, obtained through in vitro culture.

Reproductive seed potatoes: seed potatoes (1-2 generations of reproduction), obtained from the sequential propagation of elite seed potatoes. The modern technological process of seed potato production includes the following structural elements:

- maintenance of the healthy potato variety bank (HPVB). The maintenance of the healthy potato variety bank (HPVB) under sanitary conditions is based on the continuous and repeated improvement selection of basic clones based on indicators of variety typicality, health, and productivity[1];
- field selection of basic clones for introduction into in vitro culture;
- clonal propagation of in vitro material;
- production of in vitro microtubers;
- cultivation of minitubers under protection from insect vectors of viral infections;
- cultivation of the first field generation from minitubers;
- cultivation of super-super elite potatoes;
- field nurseries of super-elite and elite potatoes;
- seed plots of reproductive seed potatoes (first and second generations after elite).

When describing the distinguishing morphological characteristics of tubers, particularly their size and shape in hybrids and varieties in breeding and seed production work, manual measurements of tuber length, width, and thickness are performed. The mechanical measuring instruments presently employed fall short in delivering adequate productivity for the tuber analysis process, necessitating extra time for the interpretation of measurement results. Measurements and recording of tuber sizes are carried out by operators using calipers. The labor productivity in tuber analysis is about 600 tubers per hour. Therefore, the development of a digital method for determining the morphological indicators of potato tubers using a technical vision system and modern algorithms and computer programs for data processing is highly relevant and timely. This is in accordance with the requirements of the standard "GOST 33996 – 2016 Seed Potato. Technical Conditions and Methods for Determining Quality," adopted by the Interstate Council for Standardization, Metrology, and Certification. The main drawbacks of the existing technology are the subjectivity in determining the shape and the high labor costs for size measurements. To increase the efficiency of seed potato production and improve the productivity of tuber analysis, it is necessary to conduct research based on digital technologies and image processing. A possible direction for solving the problem of increasing the accuracy and productivity of determining potato tuber parameters is the application of advancements in image processing. Computer vision is used to solve practical tasks in many fields to free humans from monotonous, low-productivity labor.

The objects of the study are mini and regular seed potato tubers, as well as the algorithm and program for determining tuber parameters.

The subject of the research is the technical implementation of a digital method for image acquisition and processing, along with the computer program for determining tuber parameters.

This article aims to establish a methodology for assessing the quality indicators of seed potato tubers through a digital approach and to design an algorithm for the functioning of an automated system intended for conducting experimental research. To achieve this goal, the following tasks are addressed and solved in the article:

1. An analysis of the potato standard requirements was conducted, and five varieties of seed potatoes of Kazakhstani selection were chosen for experimental research on tubers and minitubers;
2. The algorithm was justified, and a computer program was developed for determining the parameters of potato tubers on the automated digital system;
3. Based on the results of the experimental research, regression models of the dependencies between the weight and size of potato tubers were created to further justify the machine learning algorithm for determining the conformity of the tuber to the varietal characteristic of a specific potato variety.

Methods and Materials.

According to the standard, seed potatoes are categorized based on tuber and planting quality, depending on the generation of seed material:

IM – The category of original and base seed potatoes includes the original material (microplants, microtubers, minitubers), the first field generation from minitubers, and super-super elite seed potatoes;

ES – The category of elite seed potatoes includes super-elite and elite seed potatoes;

RS – The category of reproductive seed potatoes includes the first and second generations after elite for seed production purposes, as well as subsequent generations, after the second generation, for use by the producers for their own needs or in accordance with the procedures and regulations set by the standardization documents of the countries that have adopted the standard.

To determine the compliance of seed material with the standard requirements, tuber analysis is performed.

Seed potato tubers should be healthy and intact, exhibiting a firm skin, with a shape and color that are characteristic of the specific botanical variety. They must be dry and free from sprouting, although for spring sales, tubers with sprouts not exceeding 5 mm in length are permissible. The tuber size by the largest transverse diameter should be 28-60 mm, and for minitubers, it should be 9-60 mm.[1] Most of the indicators are assessed by the agronomist using the organoleptic method, which is characterized by subjectivity and low productivity. The size of the tuber is determined using a caliper by measuring the largest transverse diameter. Another important characteristic of the variety is the shape of the potato tubers as an indicator of varietal conformity. When Goryachkin and Efremov[2, 3] described the shape of tubers, they used the ratio of the length to the largest diameter of the tuber as an indicator of shape:

$$I_f = \frac{\text{a}}{\text{в}}, \tag{1}$$

In this context, "a" represents the length of the tuber, while "b" denotes its width.

The research conducted has demonstrated that a more objective evaluation of the shape of potato tubers is achieved through the shape coefficient, defined as the ratio of the square of the perimeter to the area of the longitudinal cross-section of the tuber[4]:

$$\text{К}_f = \frac{L^2}{S}, \tag{2}$$

where **L** is the perimeter of the section of the object; **S** is the area of this section.

The main drawbacks of the existing technology are the subjectivity in determining the shape and the high labor costs for measuring sizes.[18] To increase the efficiency of seed potato production and improve the productivity of tuber analysis, research based on digital technologies and image processing is required. A promising direction for the development of seed production is the implementation of innovative methods and the creation of a modern industry for quality control of potato crops and tubers. The study of the influence and interconnection of innovations with labor productivity is one of the research problems for both foreign and domestic scientists. [5-6] Research is underway in Kazakhstan to enhance the conditions that influence the growth and development of potato plants in vitro within a bioreactor. [7-8] A possible solution to the problem of increasing the accuracy and productivity of determining potato tuber parameters is the application of advancements in image processing. Computer vision is applied to solve practical tasks in many fields, freeing humans from monotonous, low-productivity labor. [9-12]

In recent decades, image processing systems for determining quantitative indicators of various objects have gained widespread use, especially for fruits and vegetables. Optical methods for determining the quality indicators of potatoes are being studied by scientists in the Russian Federation.[13-14] At the Kazakh National Agrarian Research University, in collaboration with the Ruse University of A. Kănchev, research is being conducted on determining the quality indicators of potato tubers using a technical vision system and automatic sorting by categories.[15] To improve the methods for determining the parameters of seed potato tubers, additional research is being conducted at the Almaty University of Energy and Communications, together with the Kazakh National Agrarian Research University, under a project funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan.

For the comparative evaluation of the compliance of tuber quality indicators with the requirements of the standard, following the recommendations of breeders from the Kazakh Scientific Research Institute of Horticulture, tubers from five varieties of Kazakhstan selection were selected. A total of 500 tubers were selected, with 50 minitubers and 50 seed tubers from each variety. Figure 1 shows photographs of the seed and minitubers selected for the study.

Figure 1. Photographs of seed and minitubers selected for the study.

The mid-season table variety "Zhanaysan." The skin color is white, and the flesh color is white. The tubers have a round-oval shape. The depth of the eyes is average. The variety has good storability and drought resistance. It is resistant to potato cancer and shows field resistance to viral diseases. It is recommended for cultivation in the Zhambyl and Kyzylorda regions.

The mid-early universal variety "Astana." The tubers have a round-oval shape, and the depth of the eyes is average. The potential yield is 500 c/ha. The variety demonstrates resistance to diseases and climatic conditions. It is heat-resistant and drought-resistant. It is resistant to potato cancer and has good storability.

The table variety "Nerli." The growing season is 80-100 days. The tuber shape is round-oval. The skin color is white, and the flesh color is white. The depth of the eyes is average. The potential yield is 500-550 c/ha. The variety shows resistance to diseases and climatic conditions. It is resistant to viral diseases, macroporiosis, and alternariosis, and is not affected by potato flesh rust. The average tuber weight is 120 g, and the starch content is 18%. The taste quality is good, and it has good storability.

The early-maturing variety "Eden." The growing season is 85 days. The tubers are yellow, round-oval in shape, with smooth skin and white flesh. The eyes are superficial. The average yield was 227 c/ha. Quality indicators: the average starch content is 19.6%. It is resistant to diseases. It is recommended for cultivation (with irrigation) in the Almaty region.

The early variety "Alliance" shows stable yield, heat and drought resistance. The tubers are round and white with smooth skin. The eyes are numerous and small. The flesh is white and does not darken when cut, making it suitable for making French fries, chips, and salads.

For each tuber, the weight (m) and linear dimensions: length (a), width (b), and thickness (c) were determined using electronic scales and a manual digital caliper. On the automated digital installation, the weight and linear dimensions were determined, along with the area (S1) and perimeter (L1) of the longitudinal section formed by length and width based on images captured by the cameras. To quantitatively assess the shape of the tubers, the shape index and shape coefficient were calculated using formulas (1) and (2).

The general view of the automated installation is shown in Figure 2.

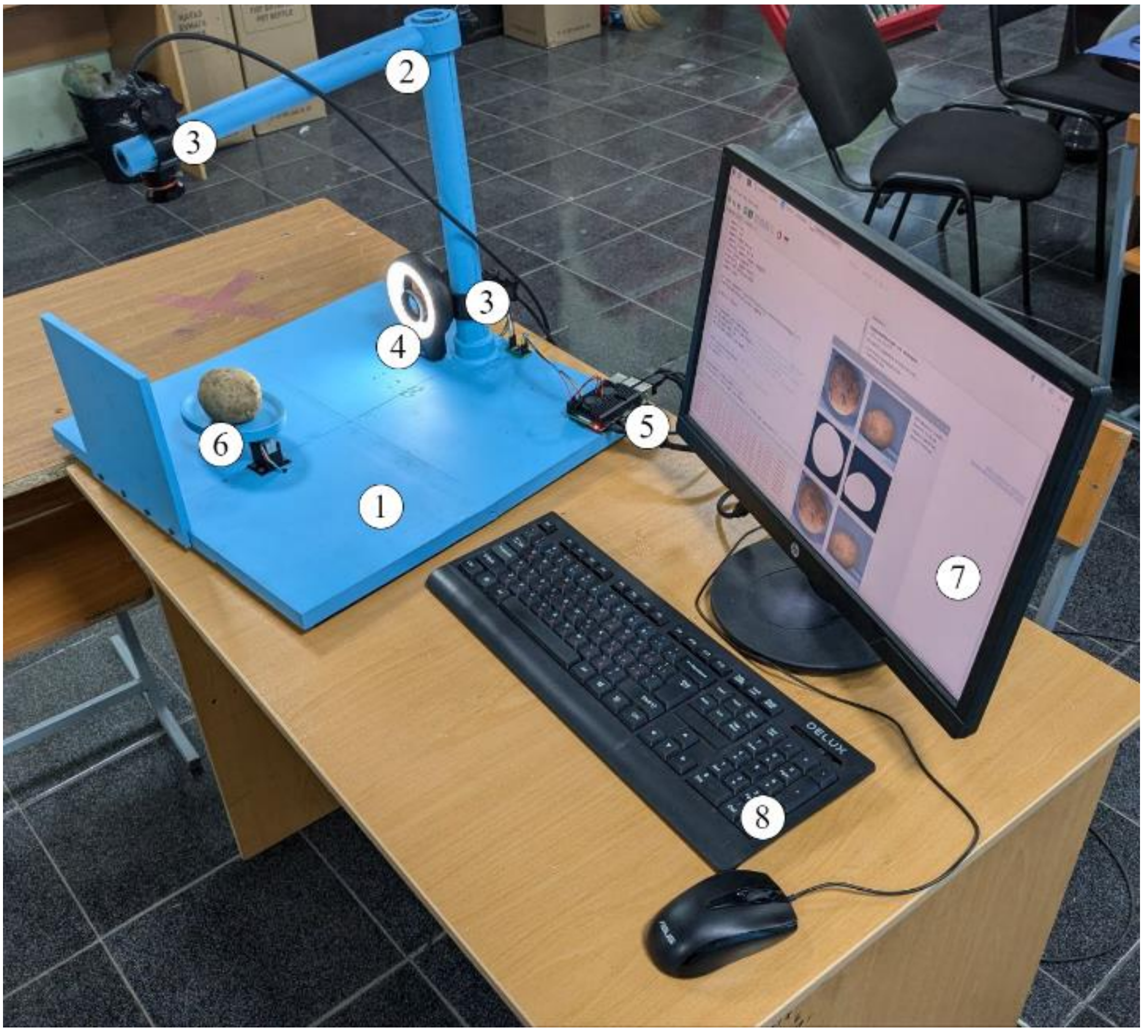


Figure 2. Automated installation for determining the parameters of potato tubers.
1 – Working platform, 2 – Stand for mounting cameras, 3 – Digital cameras, 4 – Ring-shaped LED lamp, 5 – Single-board computer, 6 – Strain gauge sensor with installed carriage, 7 – Monitor with program interface, 8 – Keyboard, mouse.

The algorithm for the potato tuber quality indicators program has been developed, which includes camera initialization, image capture, image filtering, segmentation and binarization of the image with the object. This process is succeeded by the assessment of both quantitative and qualitative quality indicators of potato tubers. This includes measuring the dimensions of the potatoes—specifically their length, width, and thickness—along with calculating the area and perimeter of the longitudinal section. Following these measurements, the values for the shape index and shape coefficient are then computed. The operation algorithm of the automated installation for evaluating the quality of potato tubers is shown in Figure 3.

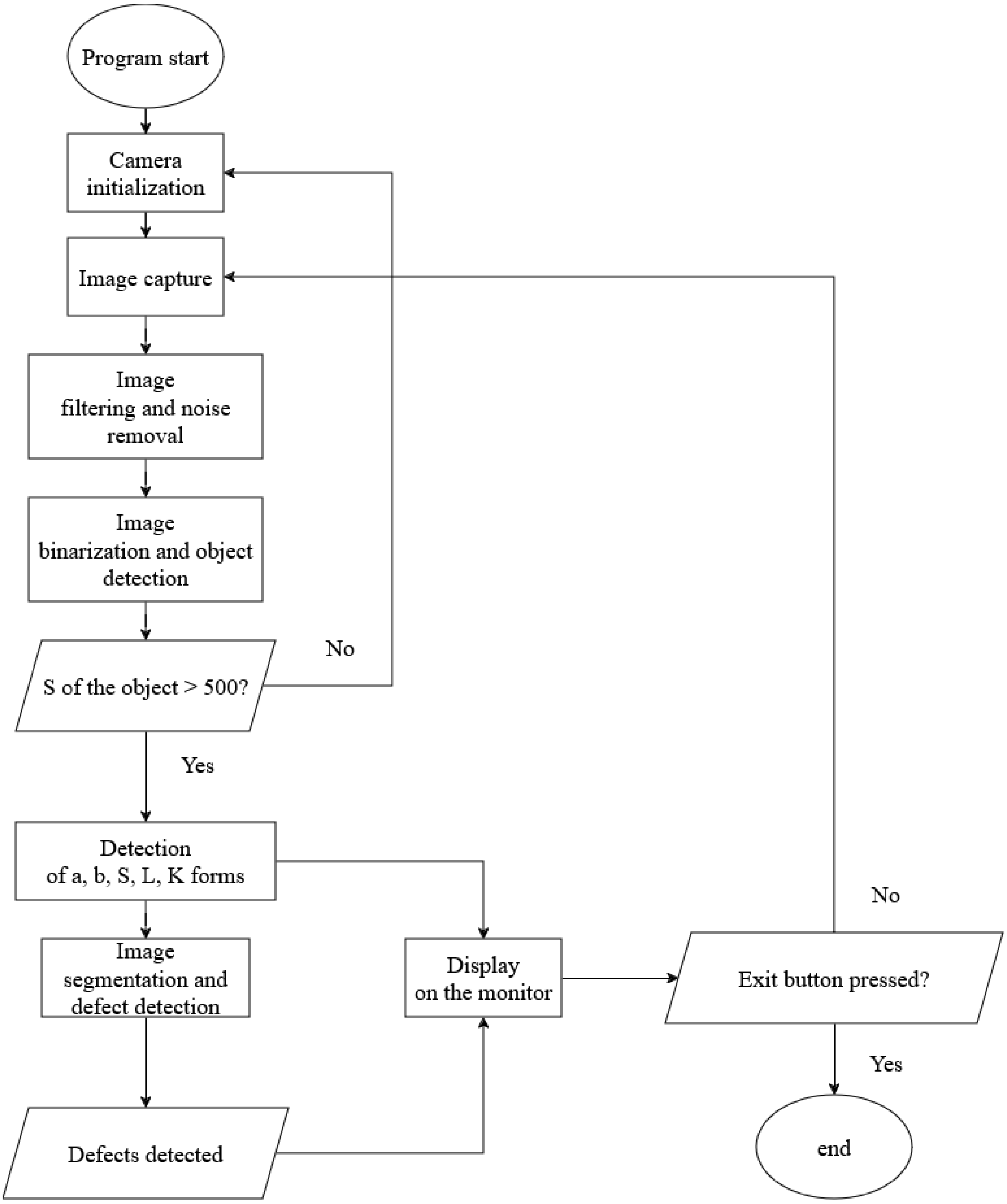


Figure 3. Algorithm of the automated installation for evaluating the quality of potato tubers.

Experimental studies have been conducted to verify the algorithm and program for determining the parameters of potato tubers using machine vision. Functions for calculating geometric parameters, such as length, width, thickness, area, and perimeter of the longitudinal section of the tuber, have been implemented, which allowed for classifying tubers by size. The program is implemented using Python and OpenCV libraries for image processing, as well as NumPy for data processing.

To test the developed program and conduct experimental studies, a prototype of the automated installation was manufactured. The experimental studies were carried out in two stages:

1. Measurement of mass (m), length (a), width (b), and height (c) of mini tubers and standard seed potato tubers using a manual method with electronic scales and a digital caliper.

2. Determination of mass (m), length (a), width (b), and height (c), as well as the area and perimeter of the longitudinal section of the tuber (S1, L1) for mini tubers and standard potato tubers on the experimental automated installation using the developed program.

To determine the mass of the tubers, electronic scales DX1200 with an accuracy of up to 0.01 g were used, and the size of the tubers was measured with a digital caliper. The time measurement for determining the mass and linear dimensions showed that manual measurements for 50 tubers take approximately 25 minutes, or 30 seconds per tuber.

Principle of operation of the automated installation. The operator places the potato tuber on the working surface. Under the working surface, a strain gauge sensor is installed to measure the mass of the tuber. Above the working surface, two digital cameras are positioned to capture images of the working area with the tuber in mutually perpendicular planes. The program then extracts the images of the tuber from the two planes, processes them, and determines the geometric parameters of the tuber. The total time for determining the parameters of 50 tubers was on average about 210 seconds. Therefore, the digital method and automated installation allow increasing the productivity of the tuber parameter determination process by approximately seven times.

Results and Discussion.

There are minor discrepancies between the mass and linear dimensions (a, b, c) measured by the manual method and those determined using the automated system. The automated digital method provides high accuracy in determining the tuber mass and linear dimensions, with the relative error in mass determination not exceeding 1.6%, and for linear dimensions, the average error is no more than 3.0%. Therefore, the data presented in the table were obtained using the automated system.

The results of the research and statistical processing of the experimental studies of potato tubers on the automated installation are presented in Table 1.

Table 1. Results of statistical processing of experimental studies of tubers

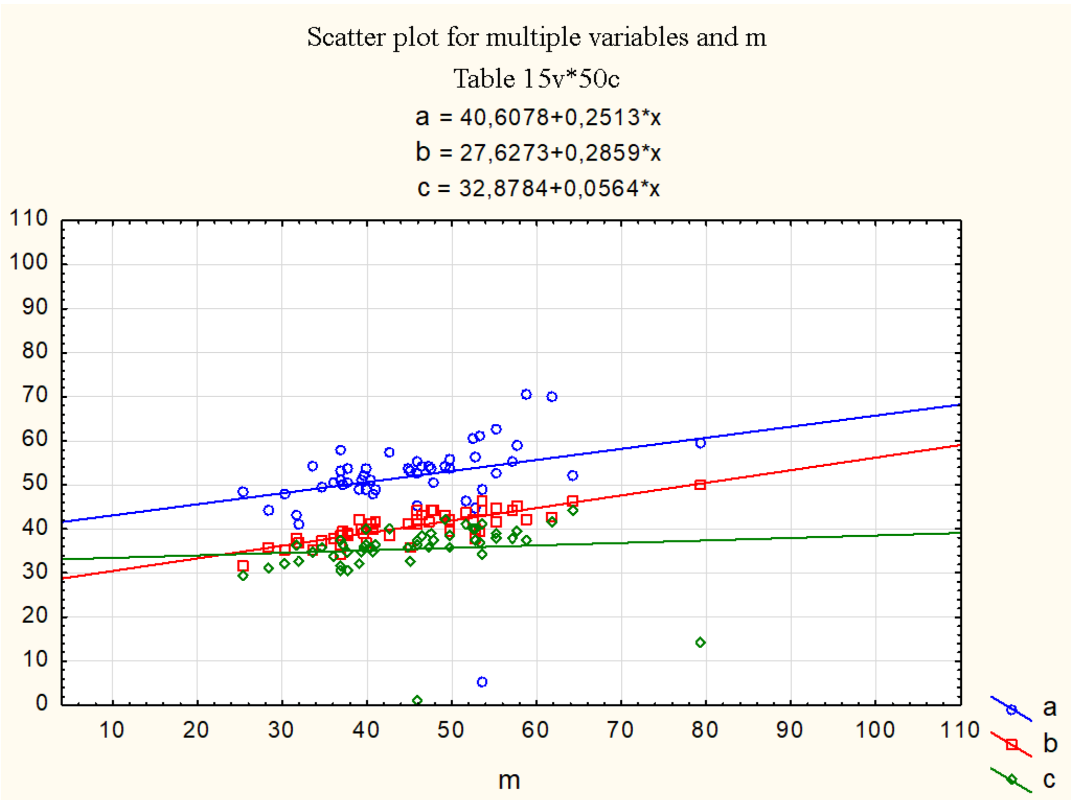
Name	m, mass, g	A, length, mm	b, width, mm	c, thickness, mm	L1, mm	S1, mm2	Kf, %	If
Alliance								
Medium	45,3	52,0	40,6	35,4	164,9	1790,7	15,2	1,3
Standard error	1,5	1,3	0,5	0,9	2,1	41,6	0,1	0,0
Standard deviation	10,3	8,8	3,6	6,7	14,9	293,9	0,9	0,1
Minimum	25,3	5,6	31,4	1,4	139,0	1180,0	13,7	1,1
Maximum	79,4	70,5	50,1	44,3	206,0	2687,0	17,8	1,6
Alliance Mini Tubers								
Medium	18,5	37,5	29,1	28,2	115,4	923,1	14,6	1,3
Standard error	0,8	0,9	0,5	0,9	2,0	28,8	0,1	0,0
Standard deviation	5,4	6,0	3,8	6,7	13,9	203,7	0,7	0,2
Minimum	9,4	28,2	12,5	20,5	95,0	620,0	13,3	1,0
Maximum	32,6	49,8	37,0	71,1	151,0	1430,0	16,5	1,8
Zhanaysan								
Medium	50,3	49,4	42,9	39,7	158,9	1768,5	14,4	1,1
Standard error	1,4	0,7	0,5	0,5	1,7	35,7	0,1	0,0
Standard deviation	9,6	5,1	3,3	3,4	11,7	252,4	0,5	0,1
Minimum	34,8	39,0	34,3	34,3	134,0	1298,0	13,4	1,0
Maximum	78,2	61,2	50,2	51,6	185,0	2283,0	15,7	1,3
Zhanaysan mini tubers								
Medium	16,9	33,3	29,0	27,1	107,0	816,7	14,2	1,1
Standard error	0,7	0,7	0,4	0,4	1,8	25,3	0,1	0,0
Standard deviation	4,8	5,1	3,2	3,0	12,8	178,7	0,6	0,1
Minimum	8,6	23,5	22,5	21,1	78,0	468,0	13,1	1,0
Maximum	26,1	45,2	35,4	33,7	131,0	1185,0	16,7	1,6
Astana								
Medium	65,0	57,3	45,5	40,1	181,8	2130,4	15,4	1,3
Standard error	1,4	0,8	0,4	0,4	1,7	34,0	0,1	0,0
Standard deviation	9,6	5,4	2,5	3,0	12,2	240,6	0,8	0,1
Minimum	43,2	42,5	41,0	34,4	159,0	1536,0	14,2	1,0
Maximum	82,4	65,2	51,9	47,4	205,0	2584,0	17,4	1,5
Astana mini tubers								
Medium	24,8	39,1	32,3	29,6	121,8	1007,2	14,6	1,2
Standard error	0,8	0,6	0,4	0,5	1,7	32,0	0,1	0,0
Standard deviation	5,4	4,5	3,1	3,6	12,1	226,5	0,6	0,1
Minimum	14,4	29,0	25,9	22,5	93,0	197,0	13,8	1,0
Maximum	38,9	47,5	39,8	38,9	150,0	1535,0	16,3	1,5
Nerli								
Medium	58,6	52,3	45,2	41,4	168,4	1942,9	14,7	1,2
Standard error	1,9	0,9	0,5	0,8	2,1	44,6	0,1	0,0
Standard deviation	13,5	6,1	3,9	5,5	14,7	315,5	0,6	0,1
Minimum	37,5	41,4	40,3	29,0	143,0	1422,0	13,8	1,0
Maximum	106,7	66,1	58,5	57,5	209,0	2990,0	16,4	1,5
Nerli Mini Tubers								
Medium	15,4	33,4	28,1	26,0	105,6	779,3	14,5	1,2
Standard error	0,8	0,9	0,6	0,5	1,7	25,7	0,1	0,0
Standard deviation	5,7	6,1	4,1	3,7	11,7	181,8	0,5	0,1
Minimum	32,2	45,0	37,0	34,3	135,0	1290,0	15,9	1,5
Maximum	769,9	1669,9	1405,2	1298,8	5278,0	38967,0	722,7	60,3
Eden								
Medium	46,9	46,5	41,2	38,1	151,8	1576,9	14,8	1,1
Standard error	1,2	0,8	0,5	0,4	1,7	32,4	0,1	0,0
Standard deviation	8,4	5,5	3,3	2,7	11,9	229,0	0,8	0,1
Minimum	31,0	38,9	33,5	31,5	130,0	1220,0	13,5	1,0
Maximum	71,6	67,4	47,1	47,0	183,0	2266,0	16,4	1,4
Eden mini tubers								
Medium	16,8	30,9	28,0	28,1	103,8	741,1	14,1	1,1
Standard error	0,6	0,5	0,4	0,5	1,5	28,8	0,0	0,0
Standard deviation	4,3	3,4	3,1	3,2	10,4	203,9	0,4	0,1
Minimum	8,8	25,1	20,9	22,2	87,0	80,0	13,6	1,0
Maximum	27,2	40,1	36,3	40,3	129,0	1181,0	15,5	1,3

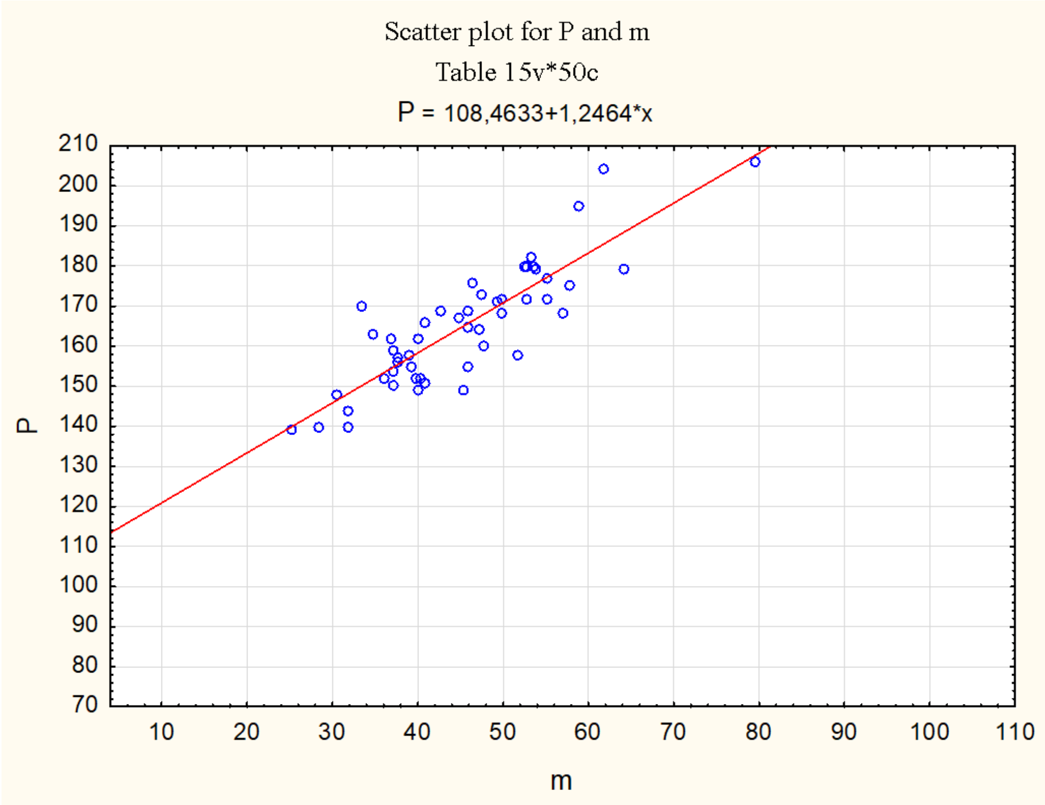
In Table 1, the values of the parameters of the tubers for all investigated varieties are presented: mass (m), length (a), width (b), thickness (c), area (S1), and perimeter (L1) of the tuber image in the plane formed by the length and width, determined on the automated system. To verify the accuracy of linear dimensions determined by the automated system, linear measurements were also taken manually using a caliper.

From the data presented in Table 1, it can be observed that there is a positive correlation between the mass and linear dimensions, as well as between the area and perimeter. This relationship can be used to indirectly determine the mass based on the size of the tuber. The values of the form index and form coefficient for seed tubers and mini tubers of the investigated varieties differ insignificantly. Therefore, based on the shape, mini tubers correspond to the seed tubers of the respective variety.

Considering the ratio between the width and thickness of the tubers, the stable position of the tuber is the one where the thickness is perpendicular to the plane of the tuber placement.

Based on the results of experimental studies, scatter diagrams were constructed showing the relationships between length (a), width (b), thickness (c), perimeter (L), area (S), and mass for all the studied potato varieties. Regression equations were compiled to express the dependence of the geometric parameters of the tubers on their mass. The scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Alyans" variety are shown in Figure 4.





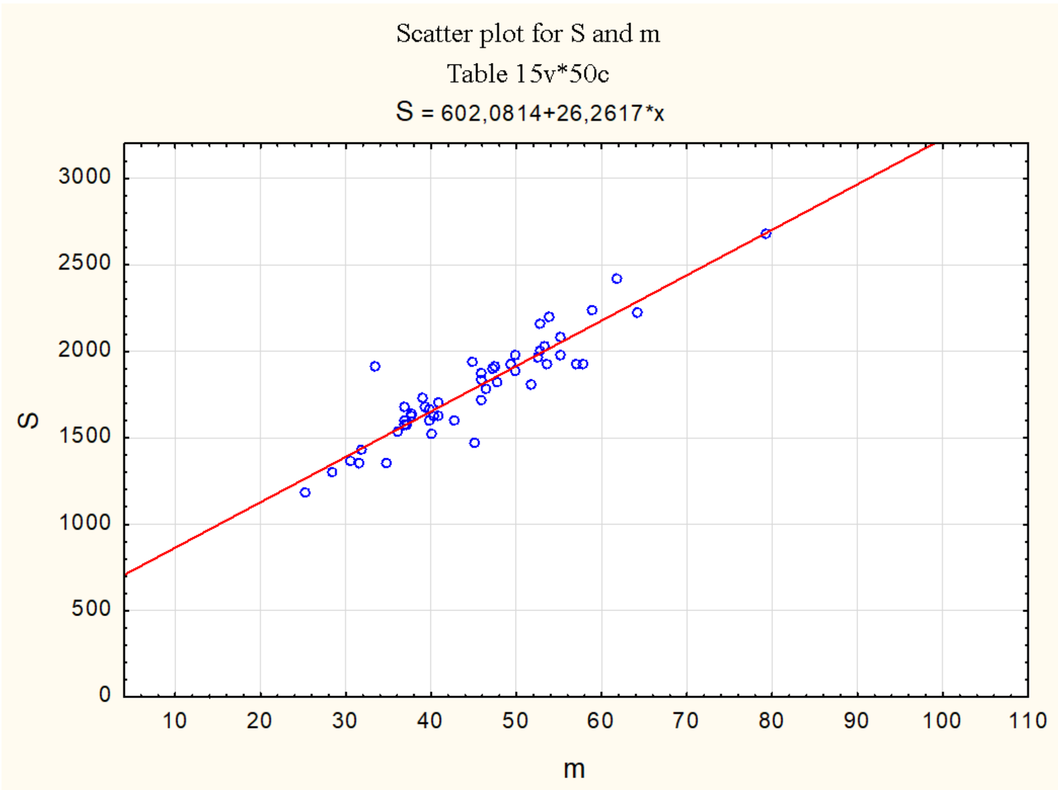
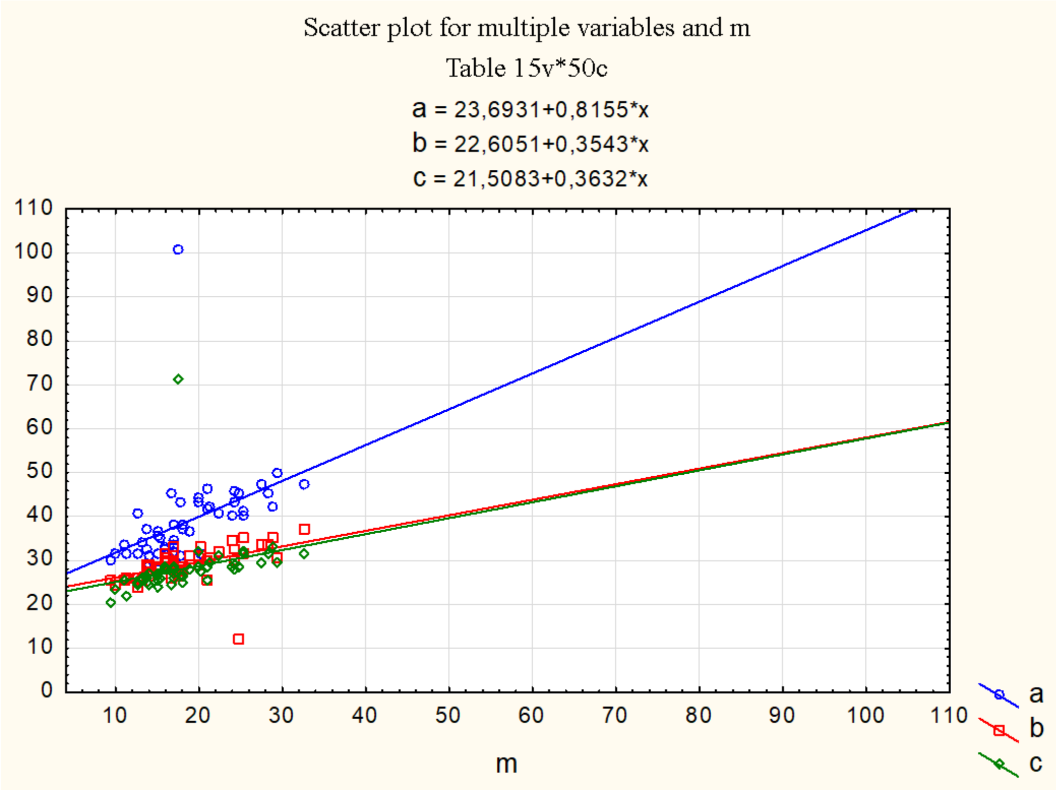
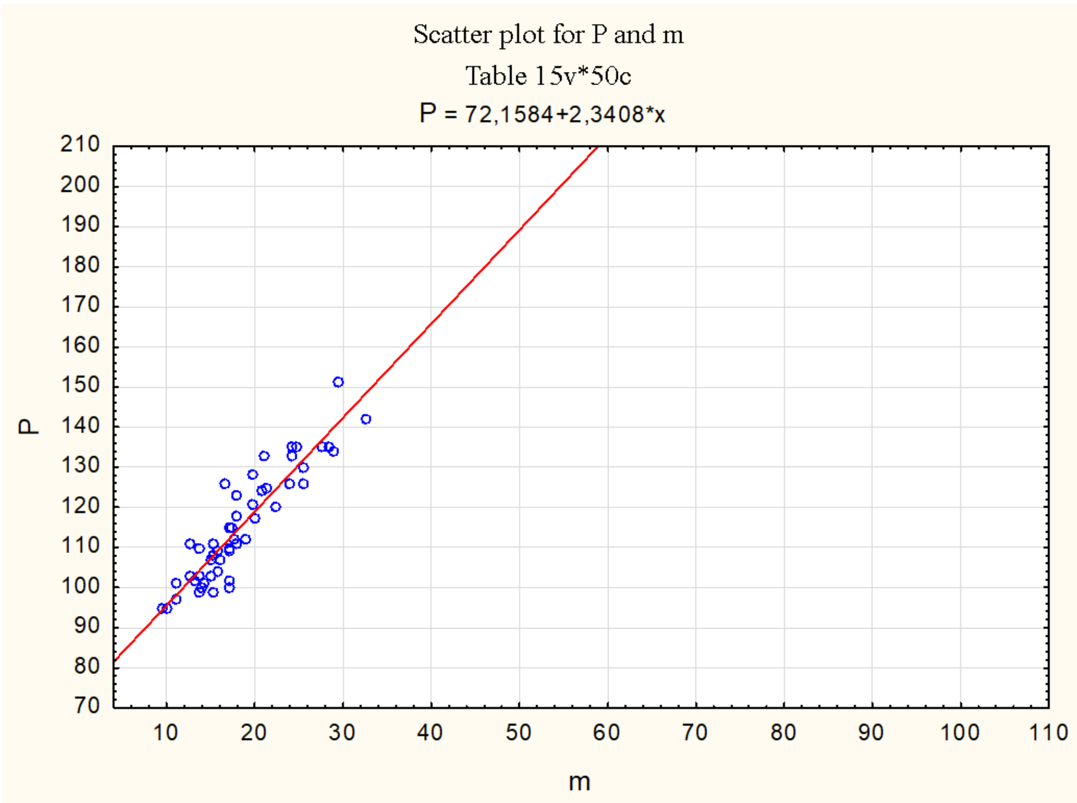


Figure 4. Scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Alyans" variety.

The scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Alyans" variety are shown in Figure 5.


Scatter plot for multiple variables and m
Table 15v*50c
a = 23,6931+0,8155*x
b = 22,6051+0,3543*x
c = 21,5083+0,3632*x
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
m
a
b
c


Scatter plot for P and m
Table 15v*50c
P = 72,1584+2,3408*x
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
P
10
20
30
40
50
60
70
80
90
100
110
m

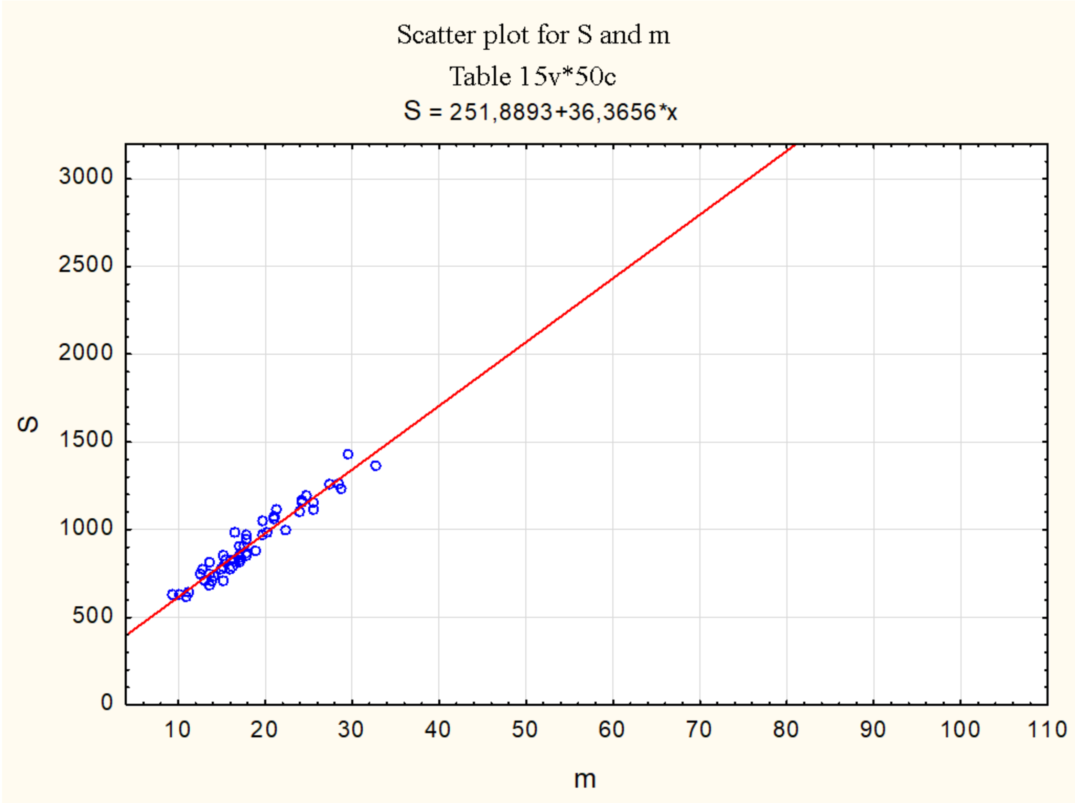
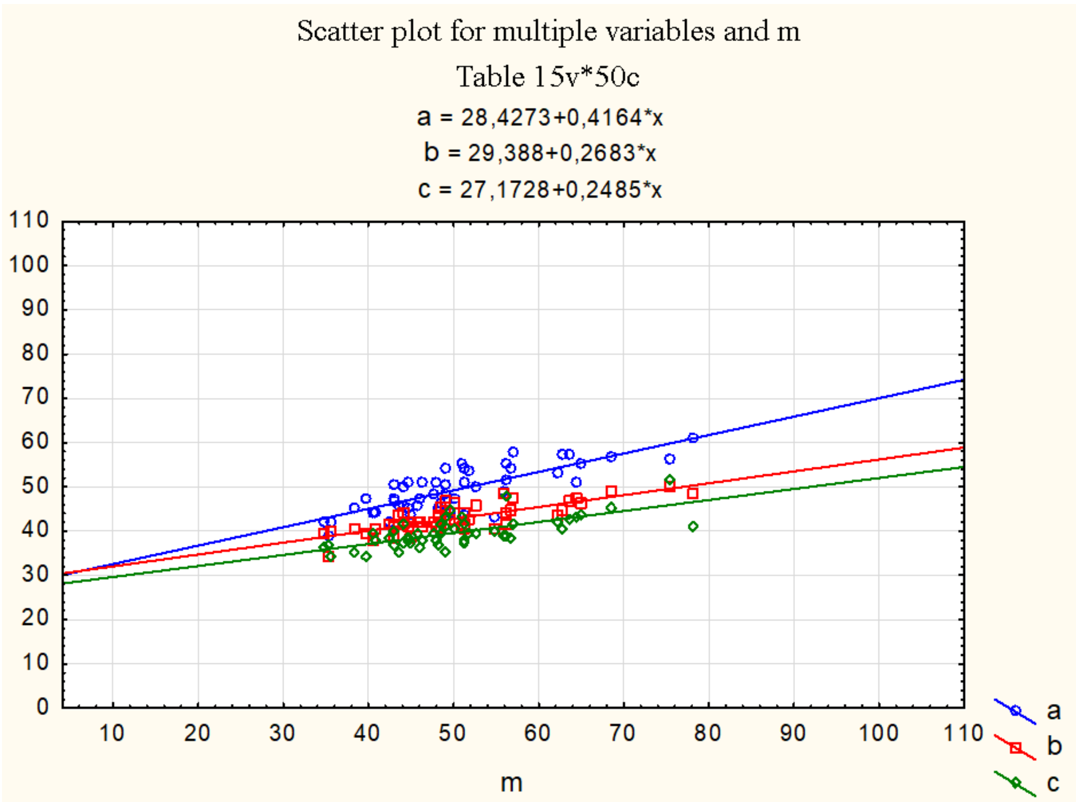
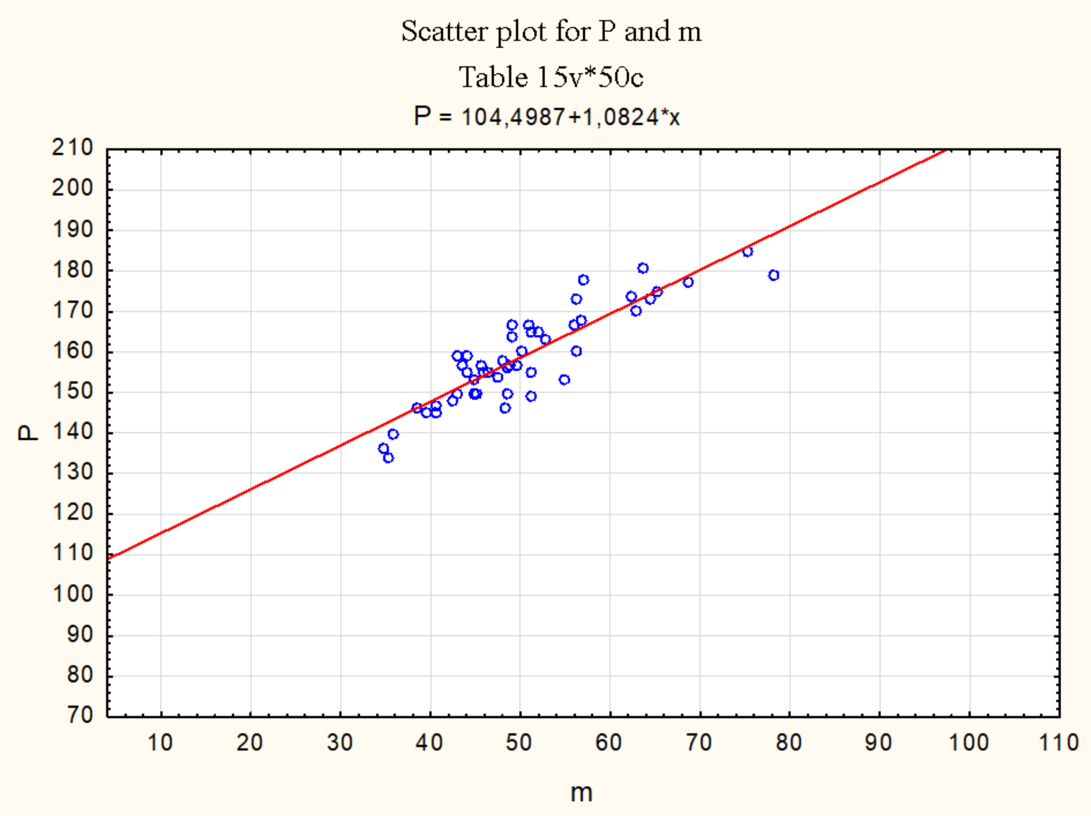


Figure 5. Scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Alyans" variety.

The scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Zhanaysan" variety are shown in Figure 6.





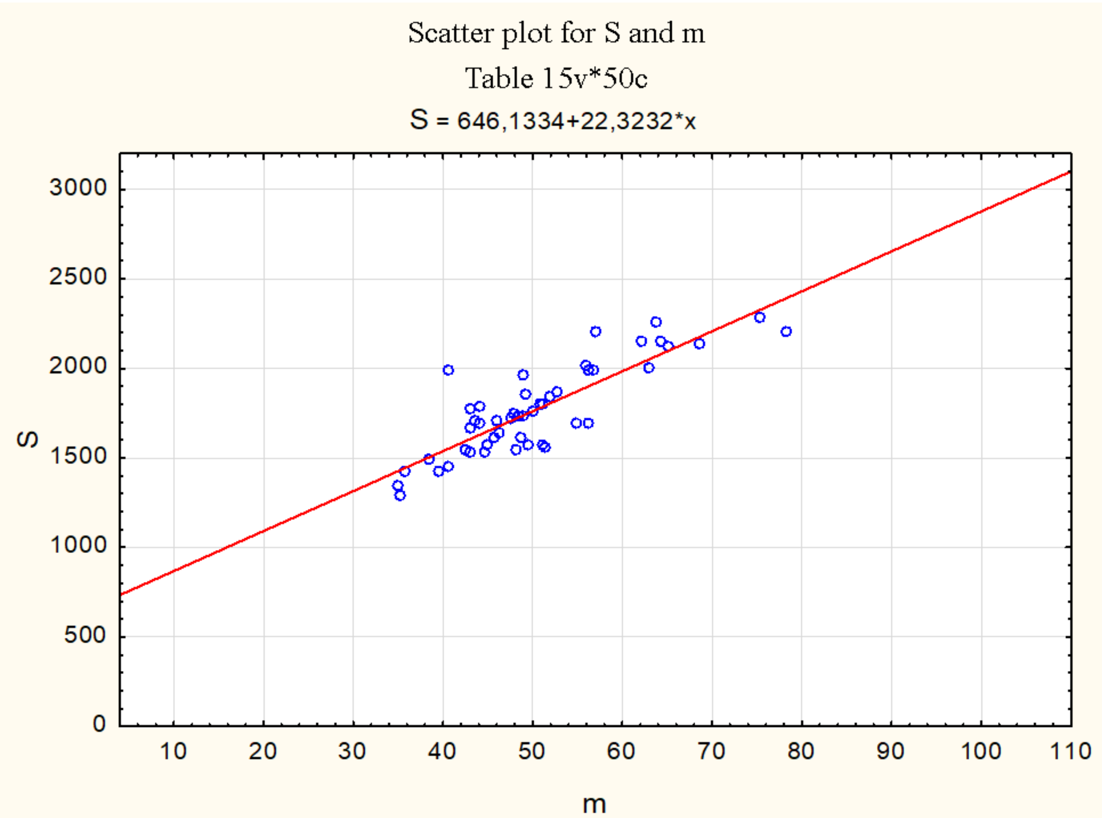


Figure 6. Scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Zhanaysan" variety.

The scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Zhanaysan" variety are shown in Figure 7.

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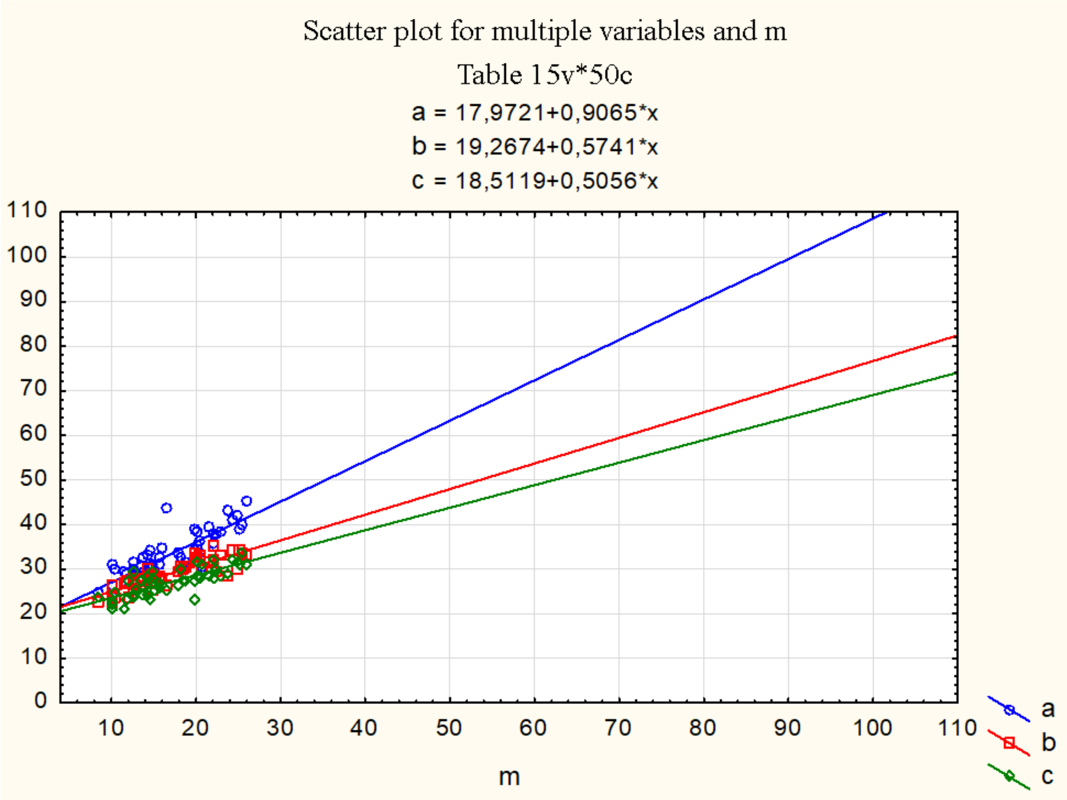
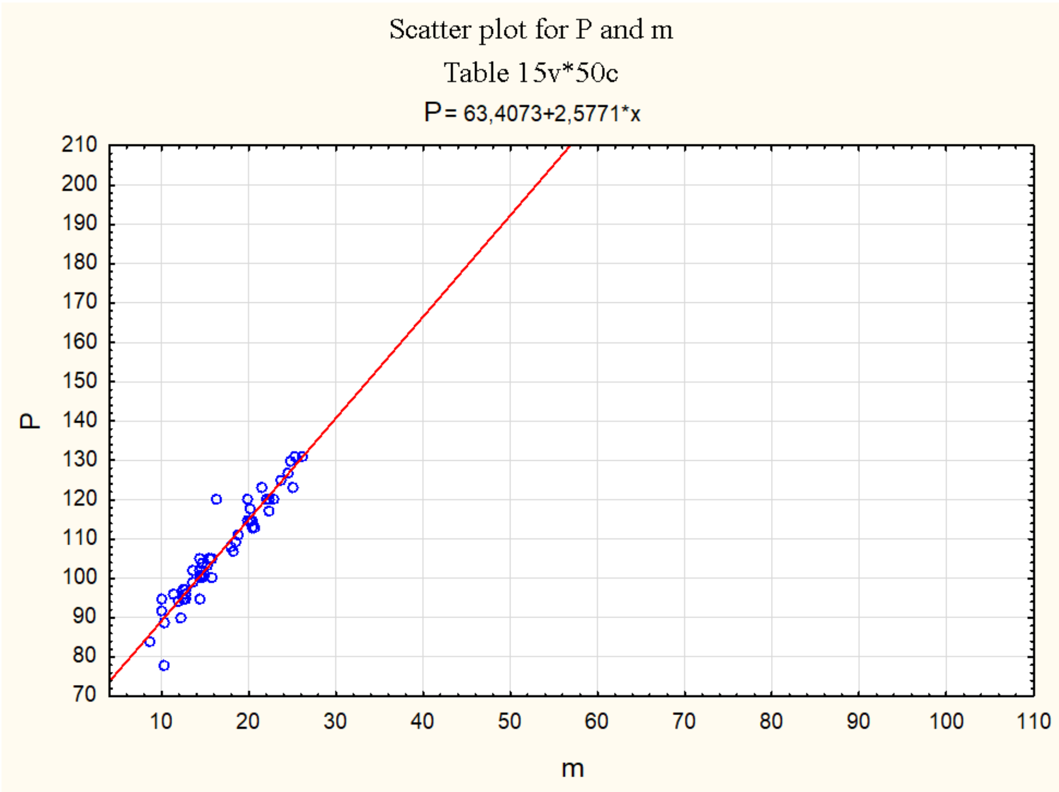

Scatter plot for multiple variables and m
Table 15v*50c
a = 17,9721+0,9065*x
b = 19,2674+0,5741*x
c = 18,5119+0,5056*x
m
a
b
c


Scatter plot for P and m
Table 15v*50c
P= 63,4073+2,5771*x
P
m

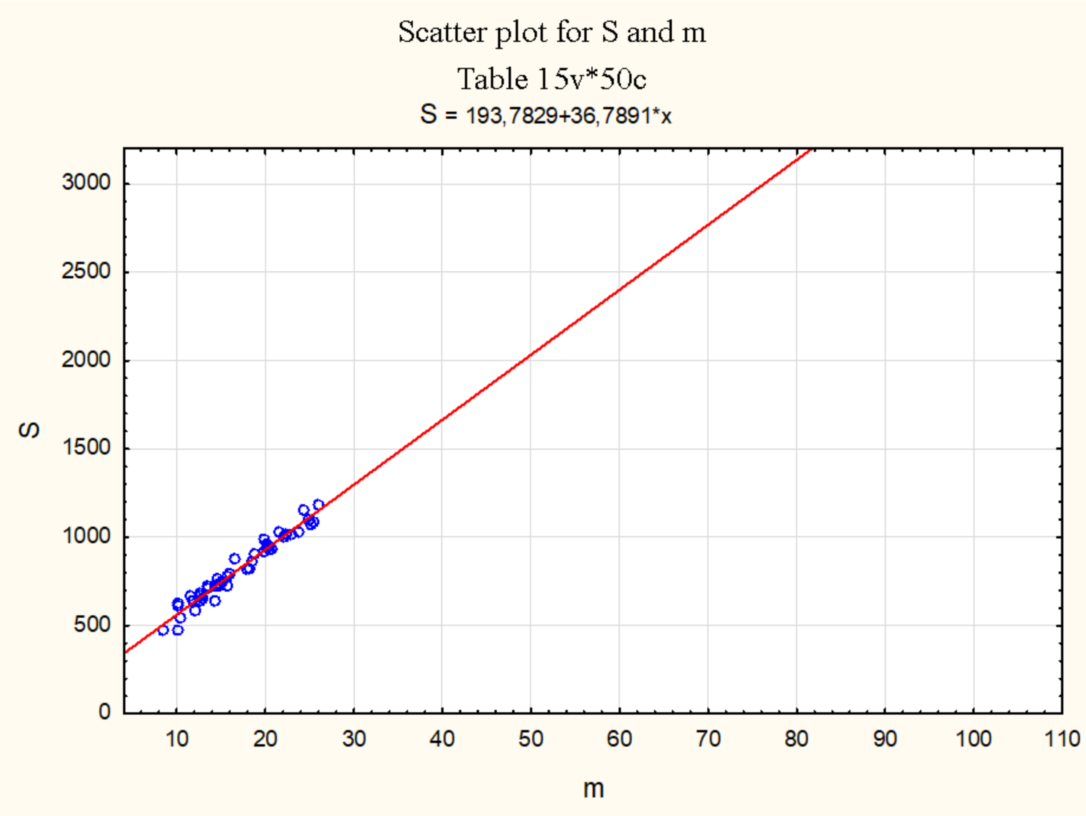
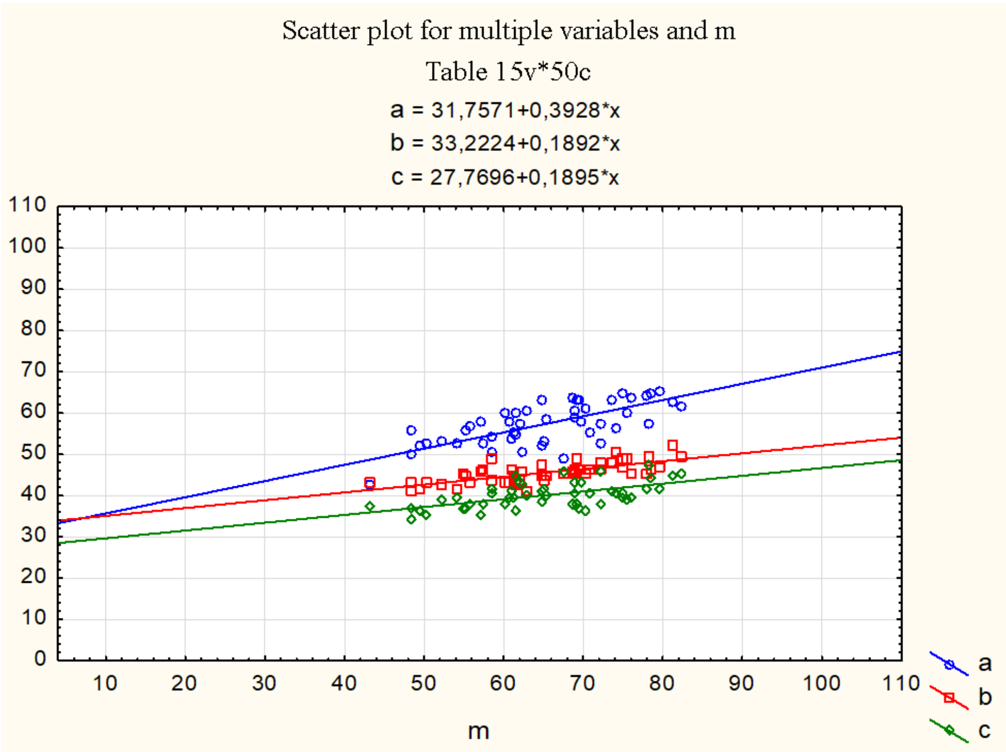


Figure 7. Scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Zhanaysan" variety.

The scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Astana" variety are shown in Figure 8.



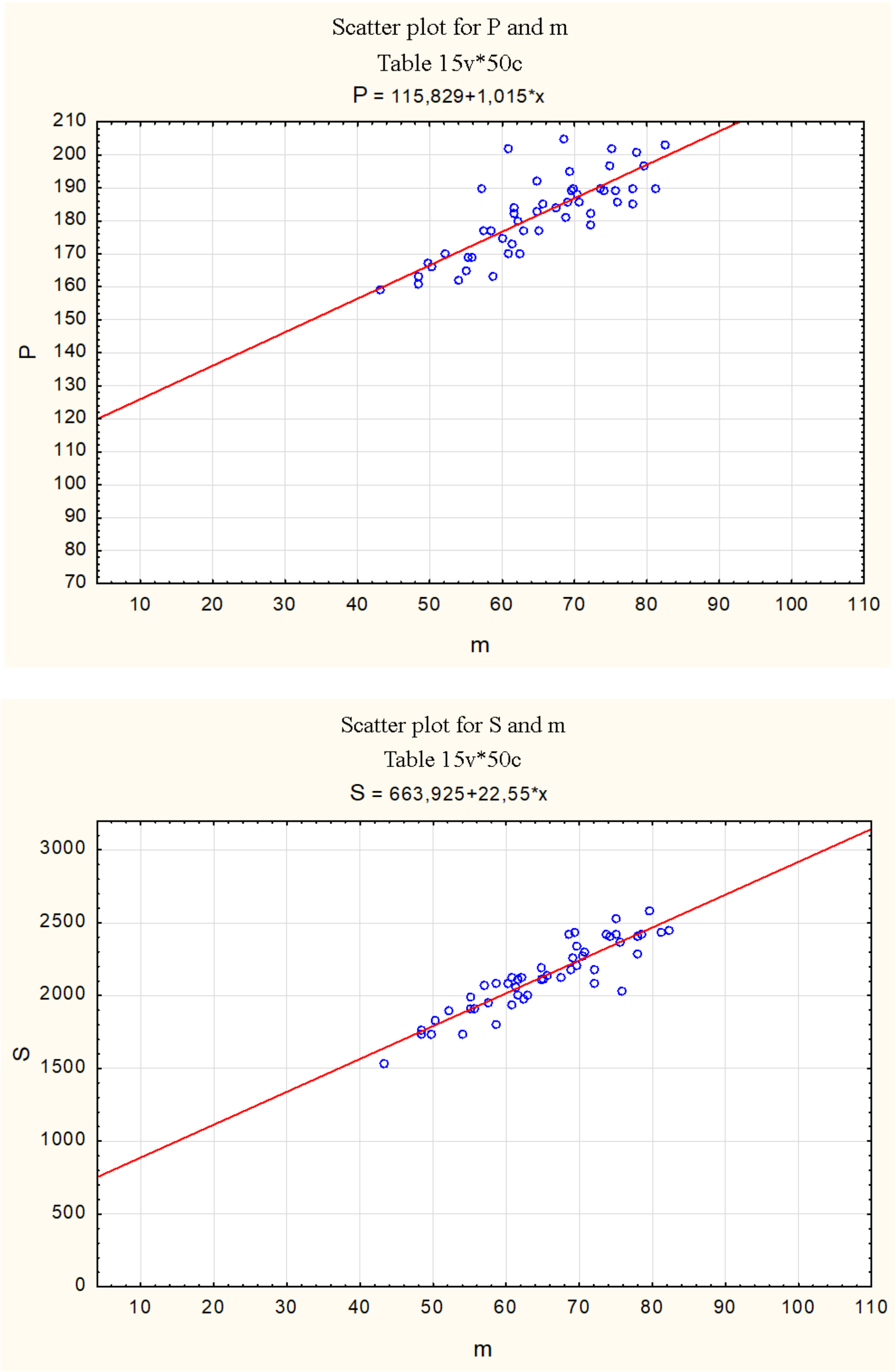
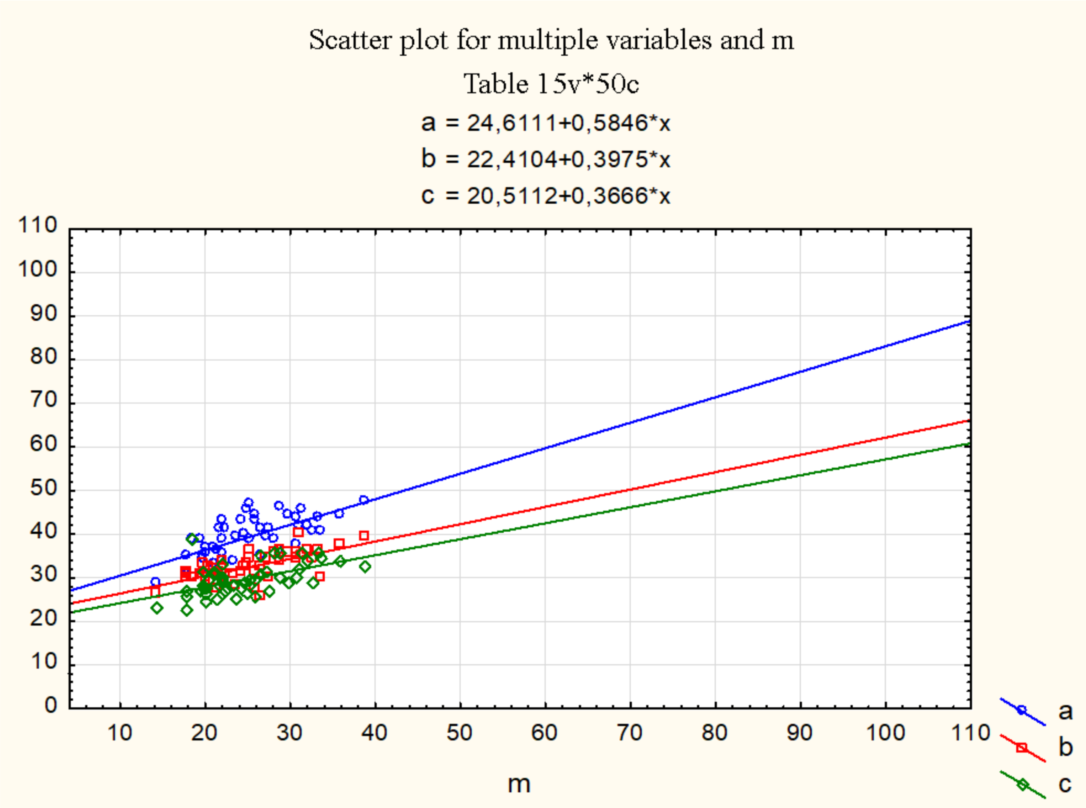
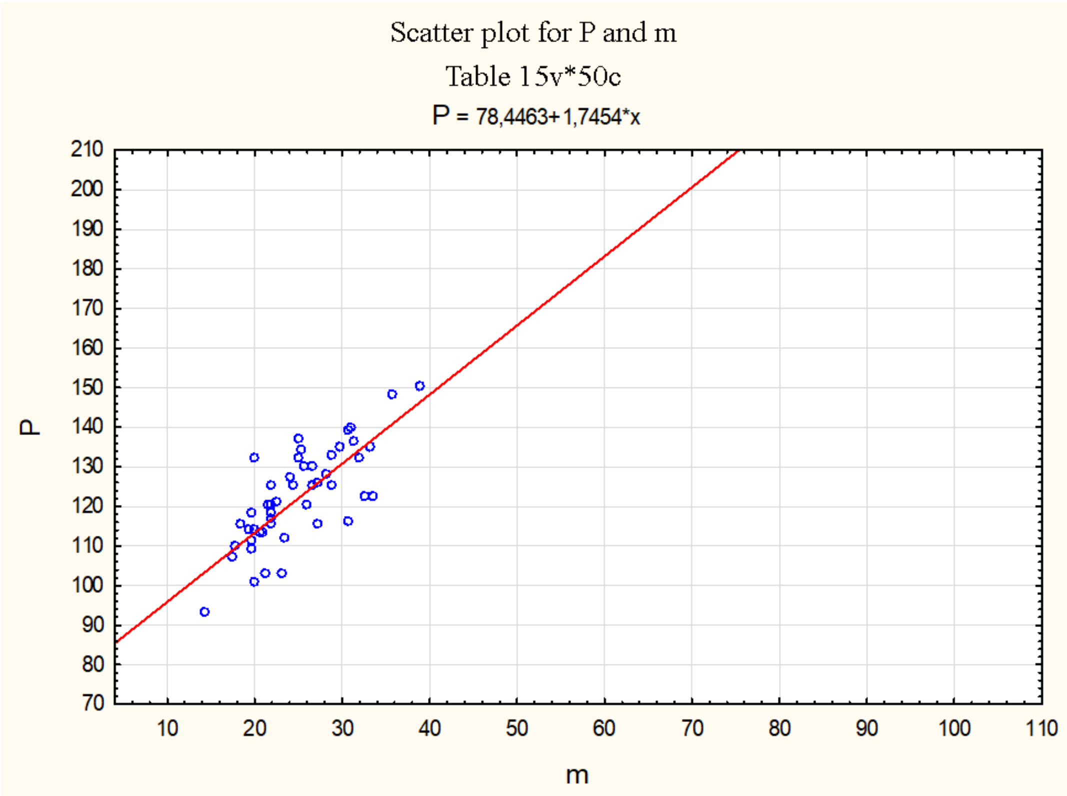


Figure 8. Scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Astana" variety.

The scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Astana" variety are shown in Figure 9.


Scatter plot for multiple variables and m
Table 15v*50c
a = 24,6111+0,5846*x
b = 22,4104+0,3975*x
c = 20,5112+0,3666*x
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
m
a
b
c


Scatter plot for P and m
Table 15v*50c
P = 78,4463+1,7454*x
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
P
10
20
30
40
50
60
70
80
90
100
110
m

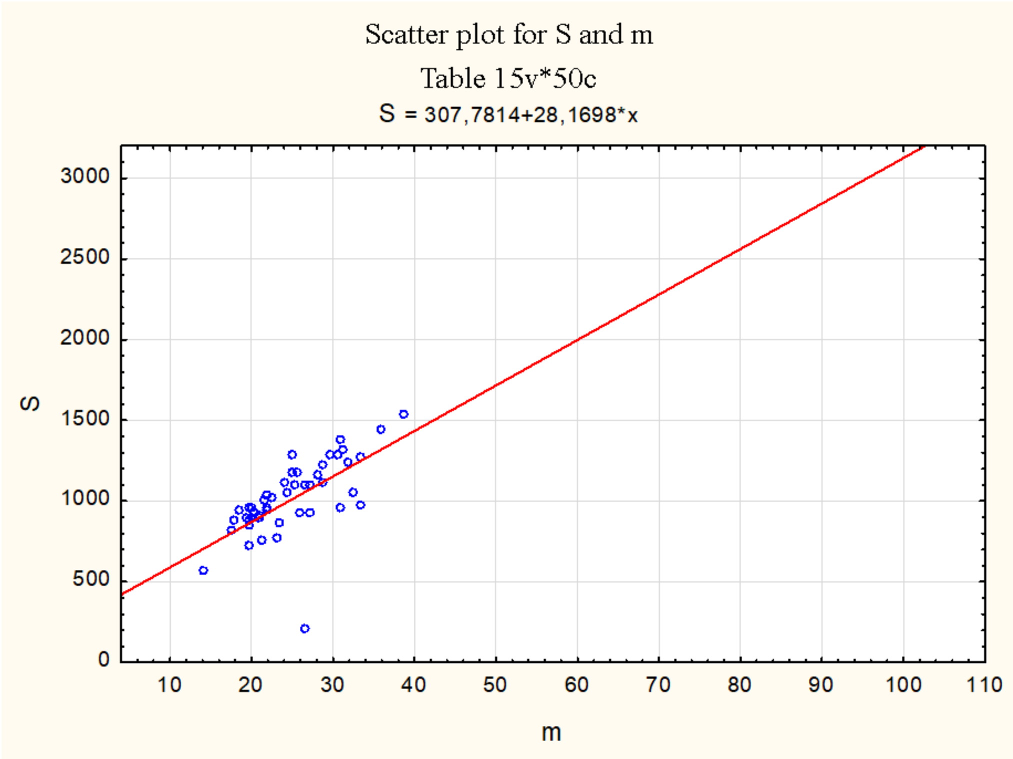
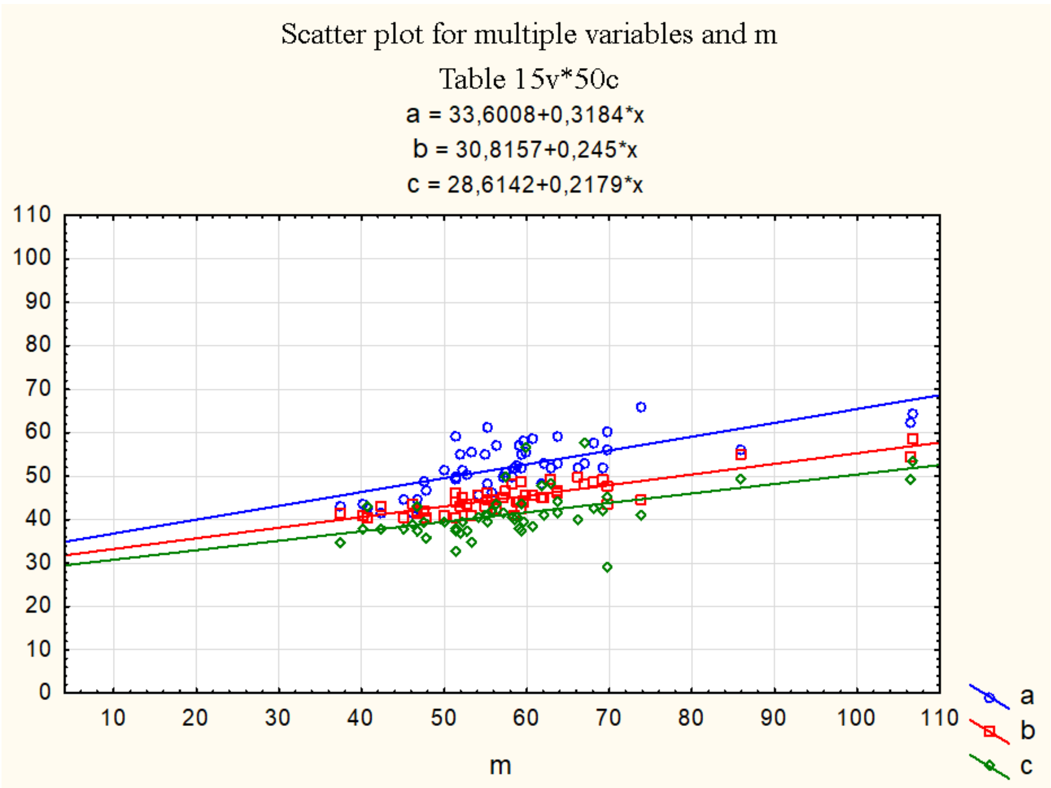
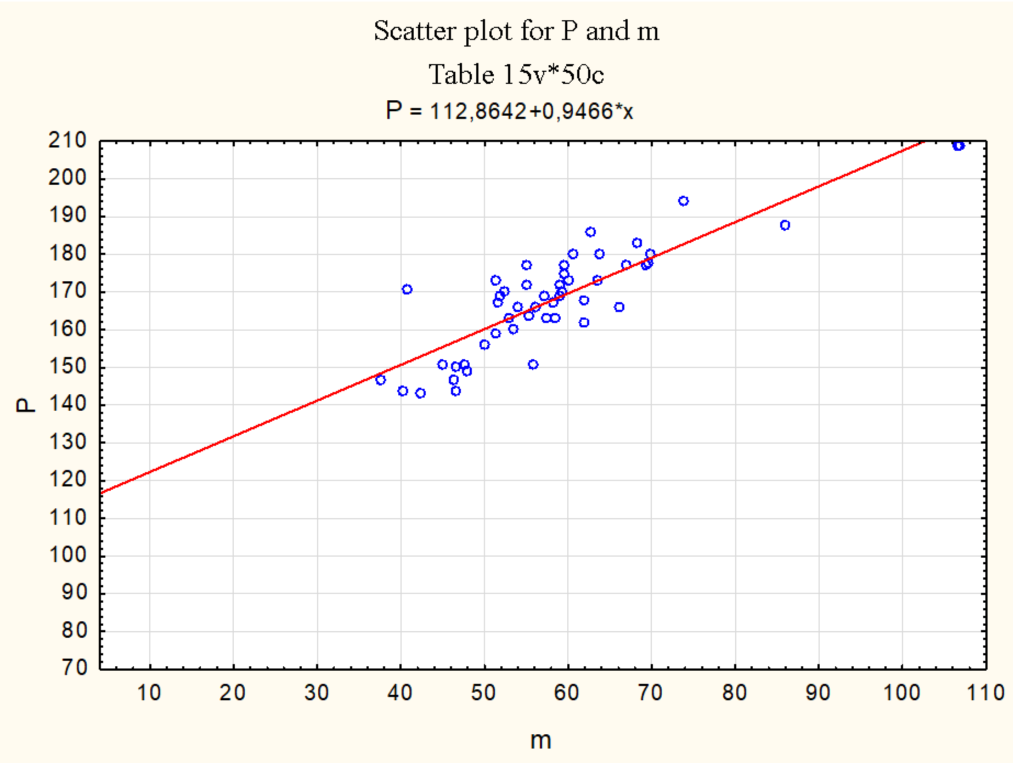


Figure 9. Scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Astana" variety.

The scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Nerli" variety are shown in Figure 10.





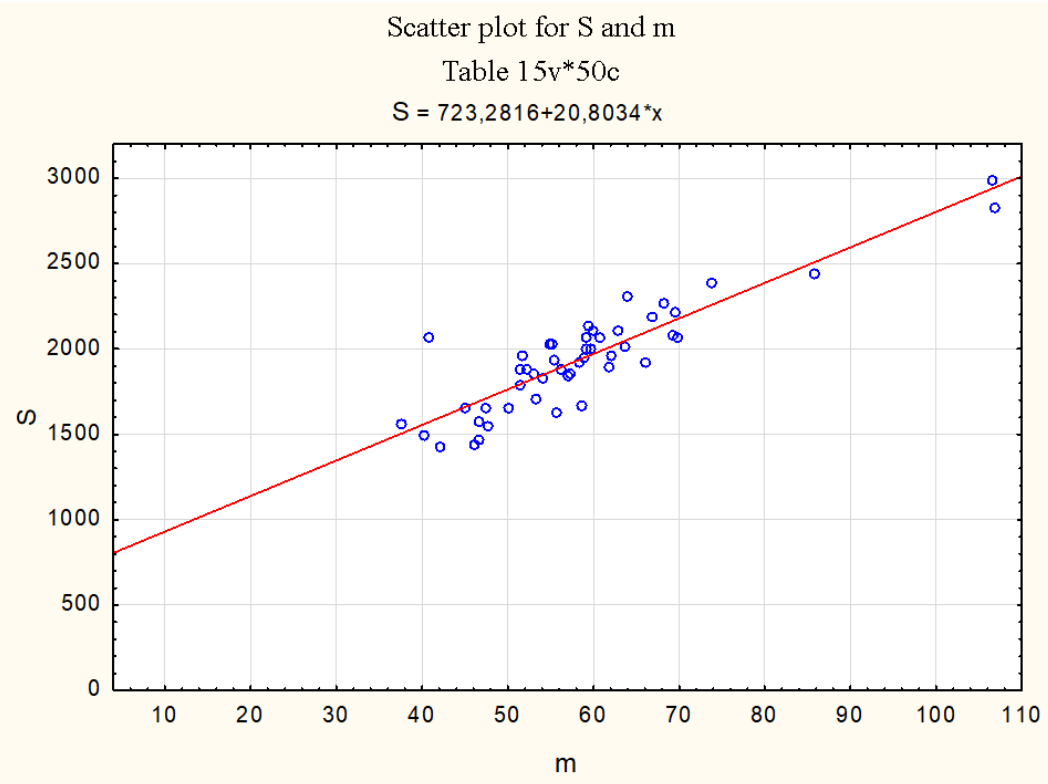
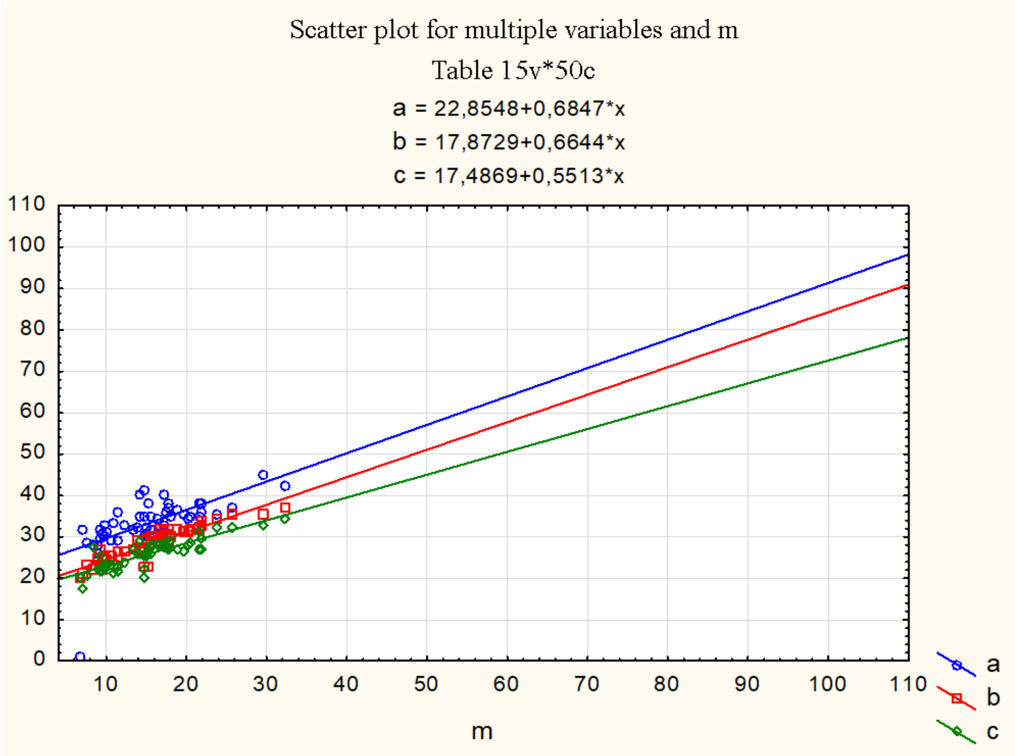
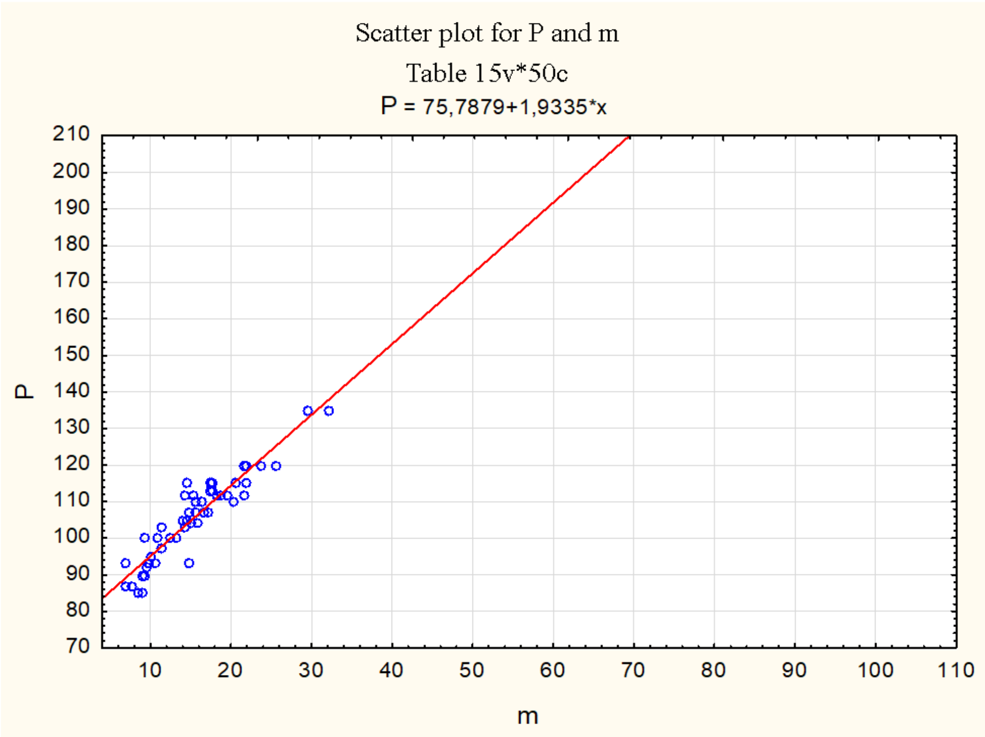


Figure 10. Scatter diagrams of the geometric parameters of seed potato tubers and mass for the "Nerli" variety.

The scatter diagrams of the geometric parameters of seed potato mini tubers and mass for the "Nerli" variety are shown in Figure 11.


Scatter plot for multiple variables and m
Table 15v*50c
a = 22,8548+0,6847*x
b = 17,8729+0,6644*x
c = 17,4869+0,5513*x
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
m
a
b
c


Scatter plot for P and m
Table 15v*50c
P = 75,7879+1,9335*x
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
P
10
20
30
40
50
60
70
80
90
100
110
m

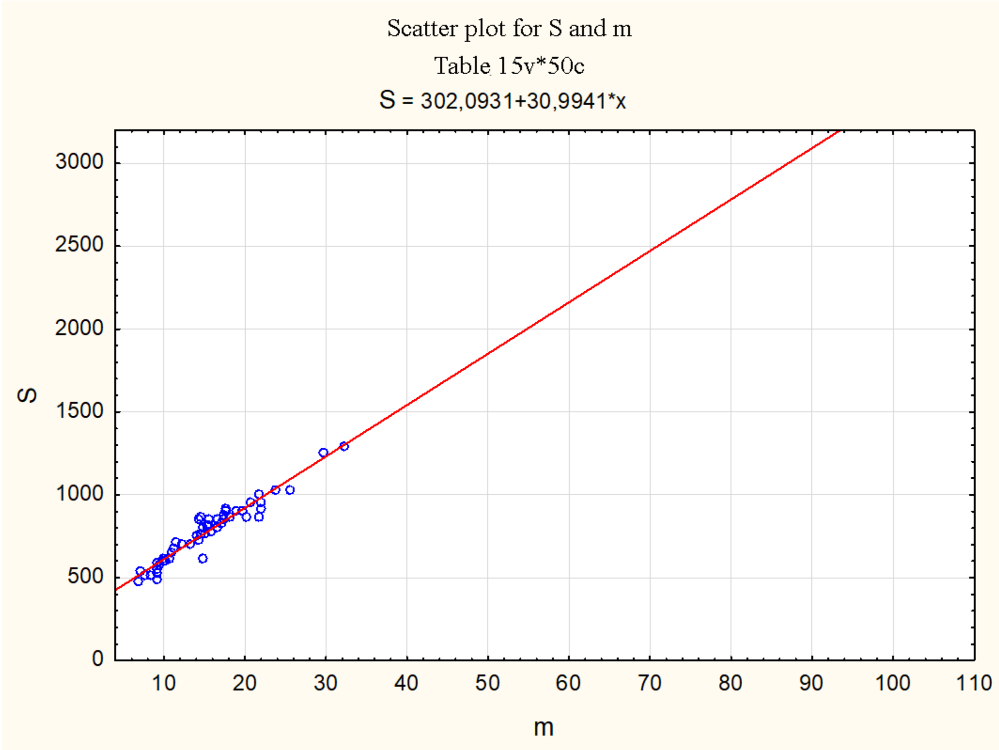
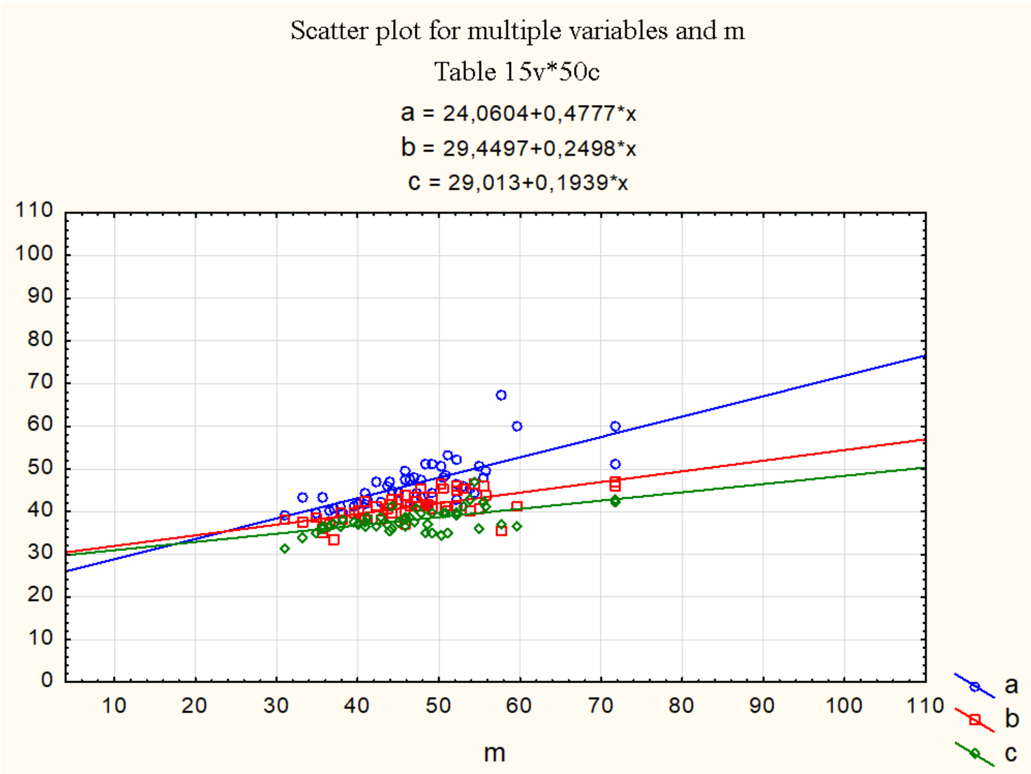
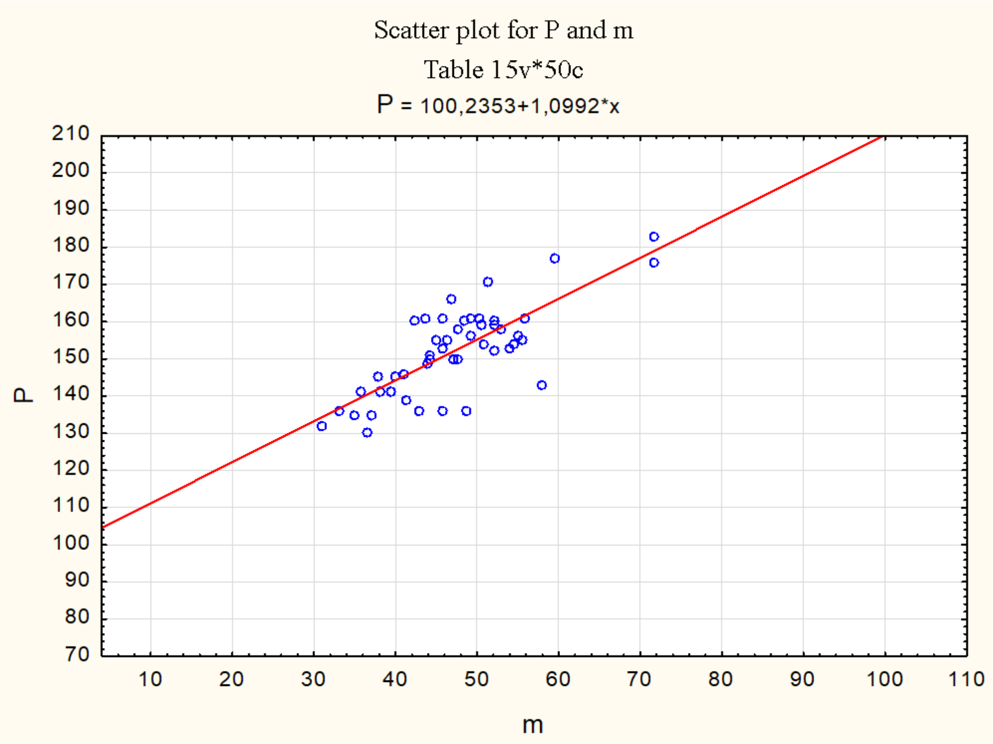


Figure 11. Scatter plots of geometric parameters of seed mini tubers and their mass for the Nerli variety.

Scatter plots of geometric parameters of seed tubers and their mass for the Edem variety are shown in Figure 12.





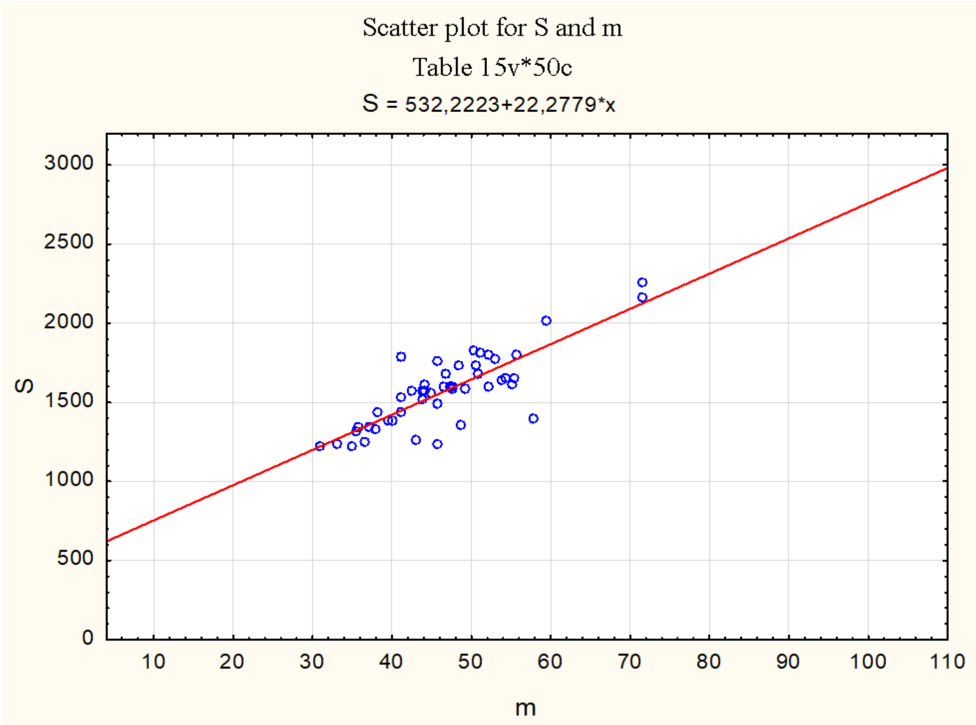
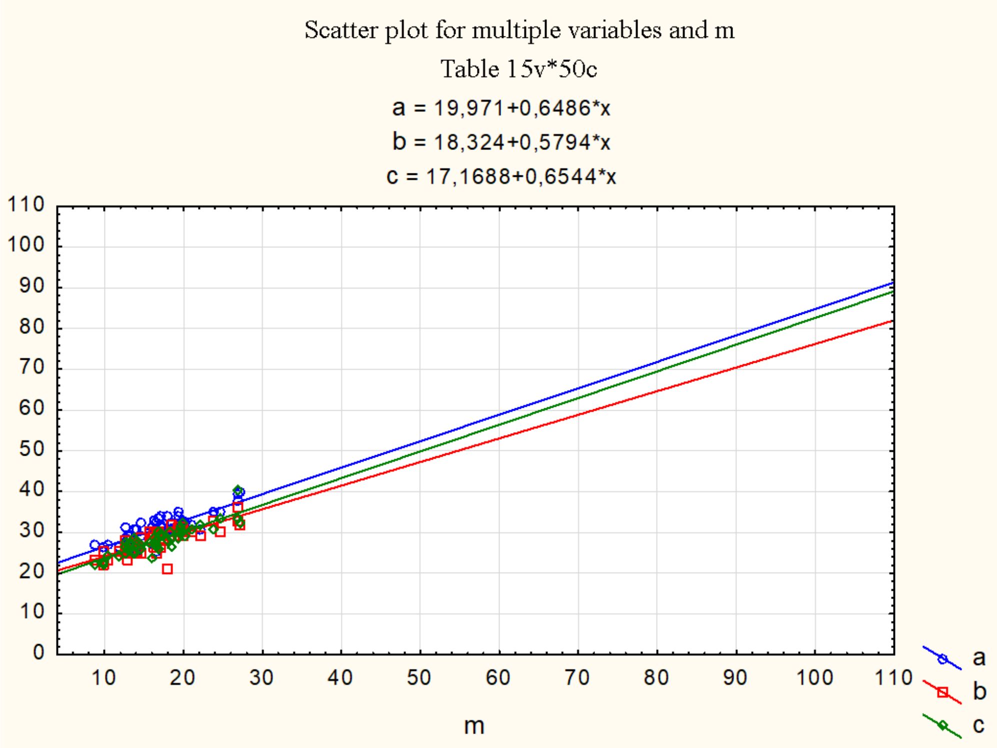
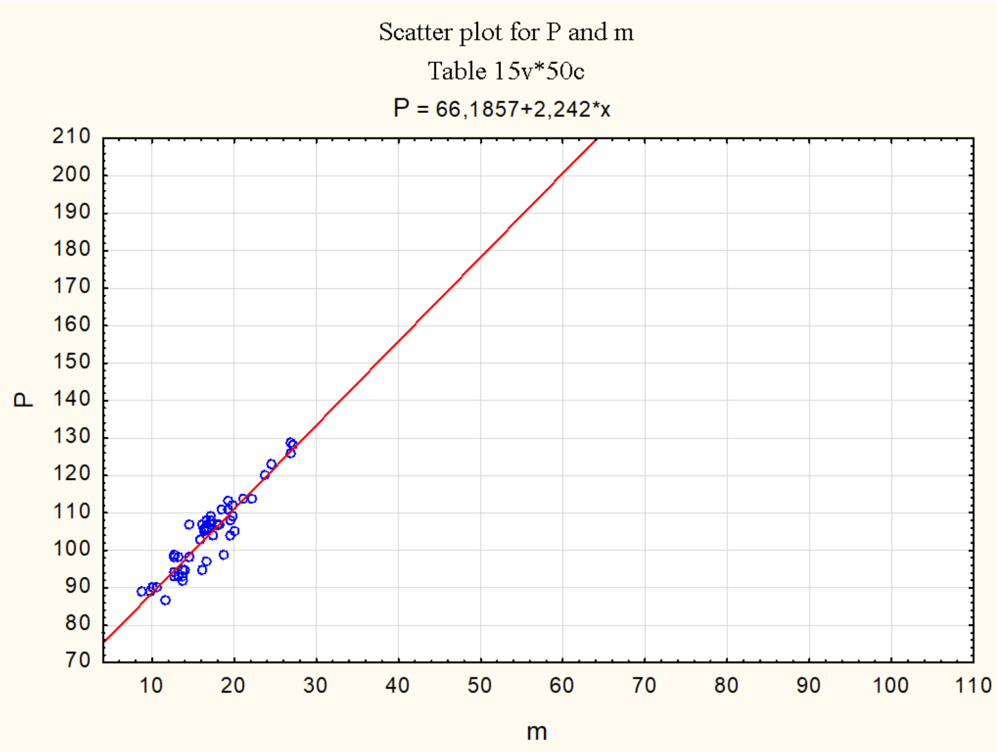


Figure 12. Scatter plots of geometric parameters of seed tubers and their mass for the Edem variety.

Scatter plots of geometric parameters of seed mini tubers and their mass for the Edem variety are shown in Figure 13.



Scatter plot for multiple variables and m
Table 15v*50c
a = 19,971+0,6486*x
b = 18,324+0,5794*x
c = 17,1688+0,6544*x
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
m
a
b
c



Scatter plot for P and m
Table 15v*50c
P = 66,1857+2,242*x
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
P
10
20
30
40
50
60
70
80
90
100
110
m

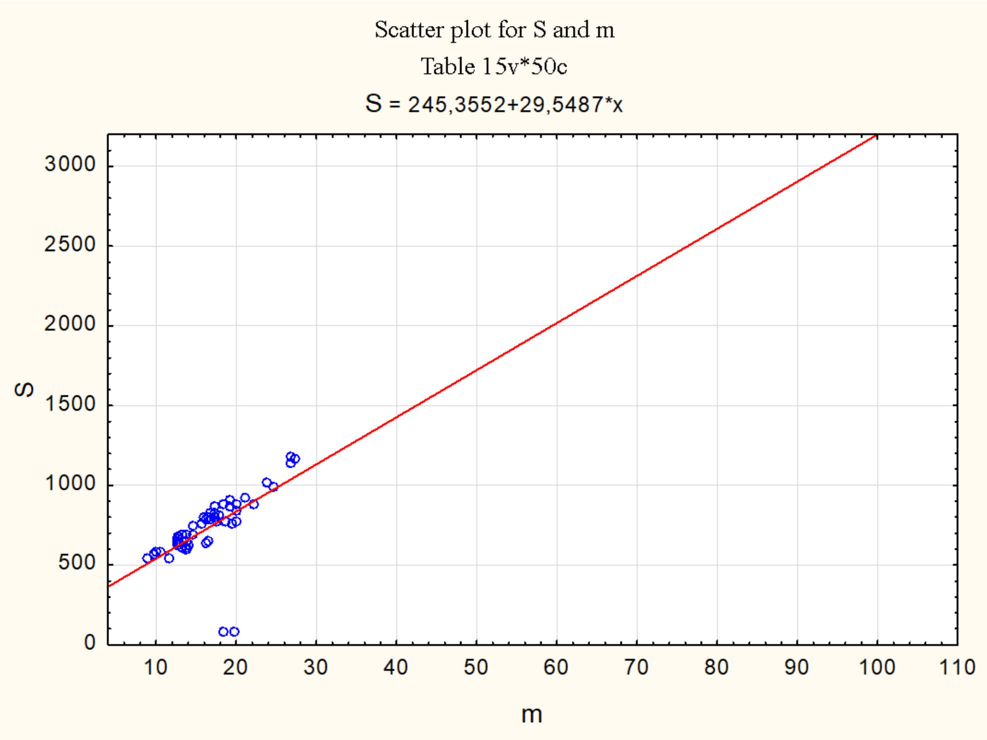


Figure 13. Scatter plots of geometric parameters of seed mini tubers and their mass for the Edem variety.

Based on the dependencies shown in Figures 4–13, it follows that for indirect mass estimation, it is preferable to use the perimeter and the area of the longitudinal section of the tuber. The correlation coefficients between mass and length (a) for all the studied varieties are high and range from 0.7 to 0.8. The correlation coefficients between mass and width (b), as well as between mass and height (c), are lower and range from 0.55 to 0.65. A strong correlation was found between mass and the area of the longitudinal section (S), with coefficient values for the studied varieties ranging from 0.85 to 0.93. A high correlation was also established between mass and the perimeter of the longitudinal section (L) of the tuber, with coefficients for the studied varieties ranging from 0.8 to 0.9. To confirm the obtained dependencies, further studies are needed on a large sample of seed tubers from different varieties, taking into account their shape and maturation periods.

Conclusions:

1. Based on a systematic analysis of the standard requirements for potatoes, five varieties of seed potatoes from Kazakhstani selection were selected for experimental research on tubers and mini-tubers. An analysis of the achievements published in scientific journals in the field of methods for determining product quality indicators showed that image processing systems and machine learning are widely implemented for determining the parameters of vegetables and fruits.

2. The developed digital method for determining potato tuber parameters has been implemented in an automated system that ensures high accuracy in determining the mass and geometric parameters of seed potatoes and mini-tubers. The algorithm has been justified, and a computer program for determining potato tuber parameters has been developed for the automated digital system.

3. The experimental studies of the size and mass characteristics of mini-tubers and standard seed potato tubers, conducted using manual tools and an automated system with the developed program, confirmed the possibility of determining the linear dimensions seven times faster compared to the manual method. The automated digital method ensures high accuracy in determining the mass of the tuber and linear dimensions, with the relative error in mass determination not exceeding 1.6% and the average error in linear dimensions not exceeding 3.0%.

Therefore, the developed digital method, algorithm, and computer program can be used in tuber analysis in seed farms and research institutions.

4. Based on the results of the experimental research, regression dependencies between the mass and dimensions of potato tubers were developed for further justification of the machine learning algorithm for determining the conformity of the tuber to the varietal traits of a specific potato variety. The accuracy of the procedures for determining potato tuber parameters can be improved by optimizing the models and parameters of the system, as well as increasing the number of varieties.

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The authors report there are no competing interests to declare.

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