Sergey V. Zhevora
Boris V. Anisimov *Editors*

Potato Seed Production

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Editors
Sergey V. Zhevora
Russian Potato Research Centre
Moscow Region, Russia

Boris V. Anisimov
Russian Potato Research Centre
Moscow Region, Russia

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Dedicated to the 100th anniversary
of Russian Potato Research Centre

Foreword

This volume examines the present state, problems and opportunities for the innovative development of potato seed production in Russia. Within the presented study, the effectiveness of the integrated use of special agricultural methods is summarized and comprehensively substantiated in order to minimize the risks of the spread of dangerous viral and bacterial diseases in the production of the breeder's potato seed, elite and reproduction seed potatoes.

The text presents the analysis of modern regulatory concerns for the quality of field crops and lots of seed potatoes by the indicators of their varietal purity and maximum tolerances of the standard for various categories of seed material in relation to diseases, pests and defects controlled in potato seed production. There exists a set of standard methods for controlling the commercial quality of seed potatoes, including field surveys and approbation of plantings, tuber analysis of seed potatoes lots, laboratory diagnostics of phytopathogens, and soil control of original and elite seed potato varieties that go into production and trade.

This book is intended for a wide range of specialists in agricultural organizations, agricultural enterprises and farms engaged in the production and sale of seed potatoes.

Moscow Region, Russia Sergey V. Zhevora
Moscow Region, Russia Boris V. Anisimov

Preface

Potato is one of the most important crops with a multitude of applications. Potato is considered the fourth most important food crop in the world, after corn, wheat, and rice, and the first most important non-grain crop. The value of potato as a food product is that it essentially contains all the nutrients necessary for humans (carbohydrates, proteins, vitamins, organic acids, mineral substances).

In modern food industry, various types of potato products (French fries, potato chips, mashed potatoes), as well as ready-to-eat products (pasteurized potato) and processed foods (peeled potato in vacuum packaging, etc.), are popular and widely consumed by populations of many countries.

Further development in the production of commercial potato for various intended uses in the current context is impossible without a streamlined system for providing potato-growing agricultural enterprises, private farms, and individual entrepreneurs with pedigree seeds of the highest quality categories.

The systemic improvement of the sequential production process of original, elite, and reproduction potato seed based on the application of innovative technologies developed by science and proven in practice, as well as the wide use of the best international practices in this area, is particularly important in solving this problem.

Moscow Region, Russia — Sergey V. Zhevora
Moscow Region, Russia — Boris V. Anisimov
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We would like also to thank the number of colleagues who have worked to develop potato knowledge, technologies, and innovations over the years during of their work experience at Russian Potato Research Centre for the benefit of potato producers and consumers.

Introduction

Potato is an important crop globally. The average potato yield is 17–18 t/ha, but many potato-producing countries are above the world average. In the Russian Federation, the total demand of potato planting material is evaluated at 4 million tones for the total planted area above 1.2 million hectares in 2019. The Russian Federation has created a system for growing high-quality seed potatoes, which is in demand by both Russian and foreign agricultural enterprises. This book presents the experience of forming a potato seed system in Russia.

The book is organized into four main themes.

In the first part, the authors consider the history of potato cultivation in Russia and the general trends in the development of selection and seed production. The pattern of potato consumption, planting area, gross harvest, and potato yield are analyzed and the level of provision of the population with domestically produced potatoes is determined.

The results of monitoring the quality of seed potatoes for 2011–2019 have been analyzed. Technologies for obtaining and clonal propagation of healthy (infection-free) source material in tissue culture as well as traditional and alternative technologies for growing mini-tubers using tunnel shelters, hydroponic, aeroponic, and aerohydroponic systems are considered. Prospects for improving technologies for growing mini-tubers in order to increase their attractiveness for seed potato producers are outlined. The production of primary and subsequent field generations and classes of original, elite, and reproductive seed potatoes as well as the propagation of potatoes using true potato seed (TPS) technology are considered.

In the second part of the book, the authors present the Russian experience of phytosanitary and technological regulations in growing seed potatoes of the highest quality categories. This takes into account the increasing role of the selection of special territories (zones) with favorable climatic and phytosanitary conditions, as well as the complex of basic agrotechnical and protective methods used in potato seed production.

In the third part of the book, the main objects of seed potato quality control in Russia are observed by authors. Varietal identity and varietal purity are considered. The authors describe are the most harmful diseases caused by viral, viroid and bacterial pathogens, controlled on plantings during vegetative growth, as well as dry and wet rot of tubers caused by fungal and bacterial pathogens. The defeat of tubers by scab and rhizoctonia is considered. It has been shown that defects caused by physiological disorders under the influence of abnormal conditions, damage, and injuries from the effects of machinery mechanisms and chemicals as well as damage by nematodes, wireworms, and larvae of insect pests are becoming increasingly important in the quality control system of seed potatoes.

Finally, the fourth part focuses on main aspects that affect seed potato specifications and methods of determining the quality. It is noted that in accordance with the standard, all seed potatoes must be inspected during crop growth (field inspection) and during post-harvest control (lot inspection). Inspection results will normally be based on a visual assessment of the crop. The identification of faults may be supported by appropriate tests when required. Unification and harmonization with international requirements of the Russian system of seed potato quality control and certification of seed material as well as the transfer of modern potato technology are essential for the development of potato production in Russia.

Sergey V. Zhevora and Boris V. Anisimov (Editors)
Russian Potato Research Centre.

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About the Editors

Boris V. Anisimov Head of laboratory of variety identification and soil control of the original potato seed of Russian Potato Research Centre, PhD in Biology, Academician of the Russian Academy of Natural Sciences (RANS), Honorary Worker in the agricultural sector of Russia, Distinguished Worker in the agricultural sector of the Republic of North Ossetia-Alania.

Sergey V. Zhevora Director of Russian Potato Research Centre, Doctor of Agriculture

Evgenii A. Simakov Head of plant breeding center, head of department of experimental gene pool of Russian Potato Research Centre, Doctor of Agriculture, Professor

Elena V. Oves Head of department of meristem tissue technologies and the bank of healthy potato varieties of Russian Potato Research Centre, PhD in Agriculture

Sergey N. Zebrin Senior Research Scientist of laboratory of variety identification and soil control of the original potato seed of Russian Potato Research Centre, PhD in Agriculture

Part I
Potato Cultivation in Russia. Potato Seed Classification and Production System. Modern Technologies Used in Potato Seed Production Process

Chapter 1
Potato-Growing History in Russia. Categories and Classes/Generations of Potato Seed and the System of Its Production Stages

Boris Vasil'evich Anisimov, Evgeny Alekseevich Simakov, and Sergey Valentinovich Zhevora

Contents

The region of origin of potato is South and Central America, where its wild and primitive species still grow. It is in this area that potato was first introduced as a crop by the Indian tribes about 8000 years ago.

The first lot of potato arrived in Russia 100 years after its appearance in Western Europe, while the main delivery of potatoes was in the mid-eighteenth century.

Unlike with Western Europe, potato in Russia was immediately introduced as a food crop, not a medicinal plant, although doctors in the seventeenth century recommended its juice, rich in vitamin C, as a drug [17].

The spontaneous invasion of potato into Russia started from Poland and Latvia, where it was cultivated since 1676–1678. It is assumed that it was brought to western Ukraine, Belarus, Lithuania, and subsequently to Kiev Governorate from the royal estates under Warsaw. It follows from the archival materials (the report of the Kiev Prosecutor to the Senate) that potato was cultivated on the vegetable gardens of Kievans since 1764, though village people were not aware of potato by that time.

According to Free Economic Society, Peter the Great supposedly in 1697–1698 sent from Holland a sack of potatoes personally to Field Marshal B. P. Sheremetyev. In 1736, potato was grown on a pharmacist's vegetable garden in Petersburg. In

B. V. Anisimov · E. A. Simakov · S. V. Zhevora (✉)
Russian Potato Research Centre, Moscow Region, Russia

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1741, it was served at court banquets as an exotic dish. According to the academic journal, in 1758, potato was reproduced on vegetable gardens of Petersburg.

The Russian army got acquainted with potato in Prussia during the Seven Years' War (1756–1763). Tubers of different varieties arrived in Russia together with troops returning home. Therefore, potato penetrated in Arkhangelsk, Olonets, Kargopol, Kiev, Irkutsk, Nerchinsk, Novgorod Governorate, and vicinities of Moscow.

The Senate Decree of January 19, 1765, issued at the initiative of the Medical Board, which, in order to prevent the recurrence of famine in the Vyborg Governorate due to corn failures, recommended breeding "earth apples," marked the beginning of smooth advance of potato on vegetable gardens and fields of peasants. The Senate Decree, which prescribed the purchase of potatoes from private individuals for distribution throughout the country, was sent to all governors.

The Senate appropriated 500 rubles for this purpose, having charged the Medical Board with the procurement and distribution of potato. Potato seed was purchased in various places – in Petersburg, on an English ship in Kronstadt, Prussia. In the spring of 1765, it was brought to Vyborg, Novgorod, Petersburg, and Arkhangelsk governorates.

In the same year, two "Guides" were published: the first concerning potato breeding (a relatively competent agricultural instruction on the growing of a new crop plant) and the second on potato storage and transportation. These first printed works on potato played a significant role in potato breeding in Russia.

In the fall of 1765, new lots of potato seed were purchased, but the lots arrived in Petersburg as late as in November. Potato that was packed in barrels and covered with hay was sent to Moscow, Smolensk, and other populated localities. It was winter, so most seed tubers froze.

In 1766, the Senate again appropriated 500 rubles for potato seed purchasing. This time, purchased potato seed lots were sent out in the spring of 1767. The Medical Board sent out 101 barrels of potato seed to remote areas – Irkutsk, Yakutsk, Okhotsk, and Kamchatka. They also had potato seeds sown in Siberia and Kamchatka, making it possible to create varieties better adapted to local conditions in the future.

Potato seed, which was distributed in the spring of 1765, was successfully reproduced in many areas. Thus, in Novgorod, a vegetable grower planted about 45 kg of tubers and produced a record harvest of 3740 kg. It is assumed that he cut seed tubers into pieces and thus increased the rate of propagation. Peterburgskie Vedomosti wrote about this achievement on February 10, 1766.

By the end of the eighteenth century, potato was gradually moving to fields from vegetable gardens, but still occupied relatively small areas (1–2 hectares). It won the competition against the turnip back then. People already had time to appreciate the advantages of a new crop plant and gave it a decided preference.

Considerable progress in potato expansion was made under Nicholas I. In the late 1830s and early 1840s, due to frequent corn failures, the government paid special attention to potato, whose widespread cultivation would prevent famine in the future. Three resolutions were issued: (1) on the organization of potato seed plantings on the lands of state peasants for their extensive use in Russia; (2) on the publication of a manual on growing potato; and (3) on issuing awards as an incentive to those owners who succeeded in cultivating this crop. The first resolution caused peasant disturbances that spread to more than 15 Russian governorates. They were mistakenly called "potato disturbances." State peasants revolted not against potato as such – they decided that potato growing on a voluntary basis meant their transition to serfhood. To subdue the peasants, the authorities even had to call in troops. Anyway, by 1843, potato production in the country reached 20 kg per year per capita, which was a lot for the time. The Decree of 1844 abolished mandatory potato growing on state-owned lands and bonus awards. Incentive rewards were preserved only in the southern and eastern parts of the empire, where the expansion of potato production was slow.

As potato blight spreads further, makeshift selective breeding with the use of imported nonresistant varieties became ineffective, so they started to import, breed, and distribute more foreign novelties in Russia. Domestic companies engaged in breeding new varieties appeared in Russia by the mid-nineteenth century [17].

The famous Petersburg vegetable grower E. A. Grachev (1826–1874) played an outstanding role in the development of Russian potato production. First, he introduced and tested new foreign varieties on the experimental field of Grachev's family in Petersburg and then became interested in breeding. Grachev introduced the then famous varieties such as Early Rose and Richter the Emperor. He produced catalogs with full varietal characteristics (indicating strengths and weaknesses). In addition, they contained information on where, when, by what company, and by which expert a particular potato variety was created. Thanks largely to Grachev, this crop plant acquired numerous fans. By choosing the right varieties and seed stock and using agricultural practices, amateur gardeners developed potato growing in the country. Grachev constantly participated in various international agricultural exhibitions – in Vienna, Philadelphia, Brussels, Cologne, Paris, Saint Petersburg – and was awarded 60 medals, which include 10 gold, 40 silver, and 10 bronze.

At the 1890 All-Russian Exhibition, 250 "Grachev's" potato varieties were presented by Grachev's widow – V. E. Gracheva. This was the last powerful success of the Grachev family's Petersburg experimental field. Potato seed that was produced there was sold all over Russia until World War I.

In the following years, potato breeding was continued by N. Y. Nikitinskiy. He obtained from Grachev's daughter all available potato varieties and began to breed them in the Kostino estate that was purchased in the Ryazan guberniya for this purpose.

Nikitinskiy received many varieties from abroad, actively corresponded with customers, and sent them catalogs and seed stock on request. He devoted much of his time to the development work – crossing, selection, and breeding of the best hybrids to create new varieties. The potato collection of Nikitinskiy was increased to 400 varieties, including cross-bred varieties. The Kostino estate was the only major source of potato seed in the country at the time. In 1912, Nikitinskiy died, and his wife continued his work of breeding and maintenance of varieties. The Kostino estate went into decline after the revolution of 1917, since it did not receive state support. In 1919, on the initiative of the Bureau of Applied Botany of the Agricultural Scientific Committee, work was started on the creation of a collection of nuclear seed stock and the regular collection of samples (domestic and foreign) for breeding potato domestic varieties.

In 1920, when the Korenevskaya Experimental Station (at present the All-Russian Potato Research Institute) was established in Moscow, its founder and director A. G. Lorch exported from Kostino the collection of varieties of Nikitinskiy. In the same period, mass surveys and selections of varieties (domestic and foreign) on peasant crops of potatoes in the Moscow governorate were carried out [5, 6, 14, 15]. A collection of foreign varieties was also released and replenished. By using this nuclear seed stock, the employees of the Korenevskaya Experimental Station in 1921 launched their breeding efforts aimed at creating domestic potato varieties. By 1930, Lorch and Korenevskiy varieties were developed and regionalized, the first of which is grown in Russia to this day.

From 1925 to 1958, a large amount of valuable nuclear seed stock for selective breeding was given by expeditions conducted by S. M. Bukasov, S. V. Yuzepchuk, N. I. Vavilov, P. M. Zhukovsky, and other researchers of plant resources of South America [7–9, 14]. The work that was carried out in subsequent years at the Vavilov Crop Production Research Institute aimed at preservation, study, and use of genetic diversity of potato in selective breeding programs [12, 17, 18, 21, 22] largely contributed to the development of selective breeding programs and primary seed production (supportive breeding) of original potato varieties based on regional agricultural research institutes located in different environmental and geographical conditions, including central [3, 4, 17], north-west [16], north-east [19], Ural [10, 20], and Siberian [11, 13] regions.

The variety assortment of potato developed in Russia in the second half of the twentieth century has no longer met the new market requirements, especially with regard to the characteristics of commercial potato quality which enters trade turnover, as early as in the early 1990s. Thus, in the category of major potato producers, which includes agricultural organizations and peasant (private) farms (peasant farm enterprises), the issue of scarcity of good table varieties and processable varieties became particularly topical, and for small individual farms there was a need to expand the range, primarily, of the early phytophthora rot-resistant and nematode-resistant varieties.

Under these conditions, the methodological and technological bases of creation of potato varieties of popular areas were dramatically improved in a short time by Russian scientists and breeders. Main efforts were focused on the study of the nature of inheritance and the correlation relationship of the main features that determine the projected intended use of varieties, assessment of the combining ability of parental forms, identification of specific cross-breeding combinations for certain directions of practical selective breeding, and development of variety models of different intended use, taking into account the level of expression of the main economically significant characters.

Using new methodological approaches in practical selective breeding allowed creating more than 70 varieties between 1991 and 2010, which successfully passed state tests and were placed on the National Register of selection achievements released for implementation [1, 2].

According to environmental-geographical and state tests, the varieties which were placed on the National Register provided yields of 40–45 tons per hectare, which was implemented under production conditions with the corresponding technological level of potato growing.

Significant progress was made in the selective breeding of new varieties that meet the requirements of agricultural industry in the breeding center of the All-Russian Potato Research Institute as a result of the implementation of the long-term (since 1986) program for parallel elaboration of identical hybrid flocks in various environmental and geographic conditions [17]. Many regional scientific institutions of the country, involved in selective breeding of potato, participated in this program every year. All of them were given the opportunity to receive and use a genetically diverse seed stock from the breeding center of the All-Russian Potato Research Institute, which was pre-selected at the pre-breeding stage according to the presence of valuable dominant genes and polygenes responsible for many agronomic characters, primarily for its resistance to diseases and pests, and heterozygosity determining the high yield of potato.

The implementation of a program to use identical populations for selection in different environmental-geographical conditions has led to a significant increase in the number of bred varieties with a wide adaptability to the conditions of the main regions of potato growing. A joint program to test identical hybrid flocks allowed all participants to save money for breeding new varieties.

The most important areas for the period until 2020 were identified within the scope of the strategy of further development of practical selective breeding [18]. Creation of table varieties whose tubers are used for fresh food. The main (competitive) parameters for them are as follows: attractive appearance of tubers, high tasting rates, and pulp which does not become dark in raw and boiled form. The degree of cooking property of table varieties may vary from soapy potatoes (salad type) to more fluffy types. Tuber shape and peel and pulp color are also important for a modern consumer.

The range of table varieties also envisaged enhancing the development of short-season varieties for obtaining early harvest, including very early varieties with the vegetational season of up to 80 days and early varieties with vegetational season of 80–90 days.

One of the new areas that has been developed in selective breeding of potato is also an increase in the content of antioxidants in tubers and creation of varieties with intense (bright) anthocyanic colors of tuber pulp, which is of high nutritional value for use in the modern balanced healthy diet.

Creation of varieties for processing into potato products (potato chips, French fries, dry mashed potatoes). These varieties must have distinctive properties, of which the dry matter content (20–25%) and reductive sugar content in tubers (optimally 0.2%) are particularly important, since they determine the quality and color of the final finished product. Tubers intended for processing into a specific product must have their own parameters in terms of form (potato chips – rounded, French fries – elongated), eye depth, resistance to damage, pulp spotting, and yield of commercial grade of the standard size.

Creation of industrial varieties with starch content of at least 18%. This area also takes into account the possibility of improving qualitative characteristics of starch (starch grain size, amylose-to-amylopectin ratio, and other indicators). The combination of high starch with resistance to potato blight and potato nematode is also important for this group of varieties.

Improvement in the resistance of varieties to various diseases has been the key condition in the development of selective breeding of potato of various intended use. This criterion is especially relevant in the current context of ever-increasing injuriousness of most pathogenic agents, emergence of new races and strains, and formation of forms resistant to fungicides. Against this background, selective breeding programs provided for the combination of various types of resistance in created varieties – immune resistance, hypersensitivity, tolerance, field resistance depending on the disease, utilized genetic sources of resistance, and possible use of chemical and biological plant protection products.

A substantial contribution in the development of selective breeding programs was made by research institutions involved in selective breeding of potato in various regions of the Russian Federation (central region, north-west region, Volga region, Ural region, Siberian region, Primorsky Krai, and Far Eastern Federal District). This allowed the creation of varieties with various ripening times, combining high productivity and quality of products with high resistance to common diseases, pests, and a wide range of adaptivity to environmental conditions.

For the last 10 years (2010–2019), more than 50 new promising varieties with various intended use have been created by Russian breeders, including table varieties for the early ripening and for long storage, varieties for a healthy diet, and varieties for processing into potato products (French fries, potato chips, dry mashed potatoes), as well as industrial varieties for starch production.

Depending on the breeding stage, quality of plantings, and quality of tubers, potato seed is subdivided into three categories:

1. The category of nuclear and original potato seed includes nuclear seed stock (microplants, microtubers, minitubers), the first field generation seed from minitubers and super-superelite potato seed (second field generation), produced by the variety originator or a person duly authorized by the variety originator and intended for production of elite potato seed.
2. Elite potato seed: potato seed (superelite, elite) obtained from sequential propagation of original potato seed.
3. Reproduction potato seed: potato seed (first and second breeding generations) obtained from sequential propagation of elite potato seed.

Based on the comparison of classification systems adopted in Russia and EU countries, the category of nuclear and original potato seed may be conditionally made equivalent to the category of prebase (PB) potato seed. Accordingly, the category of elite potato seed is equivalent to the category of base potato seed (classes

SE and E), and the category of reproduction potato seed is equivalent to the category of certified potato seed (classes A 1–2) [3, 4].

The comparison of similar categories by the number of field generations of potato seed in the Russian Federation and EU countries is presented in Table 1.1.

In Russia, according to GOST 33996–2016, the maximum number of field generations should not exceed 6, including for the OS category – 2, ES category – 2, and RS category – 2 generations. In the EU countries, as recommended by the European Seed Association (ESA), up to a maximum of 9 generations are allowed, including in the category of prebase seeds – 4, base seeds – 3, and certified seeds – 2 field generations. The modern potato seed production process is presented by the three main blocks, which include production of original, elite, and reproduction seed [3, 4].

Original potato seed production includes maintaining the bank of healthy potato varieties (BHPV), producing healthy (free from viral and other infections) nuclear seed stock in vitro (microplants, microtubers), as well as growing minitubers, the first field generation seed from minitubers, and super-superelite potato varieties.

Elite seed production includes production of classes of superelite and elite potato varieties by sequential propagation of original potato seed while preserving and maintaining its high purity of a variety, productivity, and sowing qualities.

Lots of elite potato varieties which comply with standards in terms of their sowing and varietal properties enter trade turnover and are sold to agro-enterprises producing commercial potato, private farms, as well as farms of individual entrepreneurs and individual farms for variety renovation and variety changing.

Production of reproduction seed includes seed production of the first and second breeding generations intended for sale to farms producing commercial potato, farmers, and common people. The third breeding generation is the last stage in potato seed propagation and yield is fully used for food, technical, and feed purposes.

The flow chart of successive stages of production of original, elite, and reproduction potato seed is presented in its general view in Fig. 1.1.

Table 1.1 Comparison of similar categories of potato seed by the number of field generations in the Russian Federation and EU countries

Potato seed	Number of generations	Designations
Russian classification system		
Original (OS)	2	ПП-1 и ССЭ
Elite (ES)	2	СЭ и Э
Reproduction (RS)	2	$РС_{1–2}$
Total number of generations	6	
EU classification		
Prebase	4	PB–PB 4
Base	3	S, SE, E
Certified	2	A1–A2
Total number of generations	9	

Source: compiled by the authors

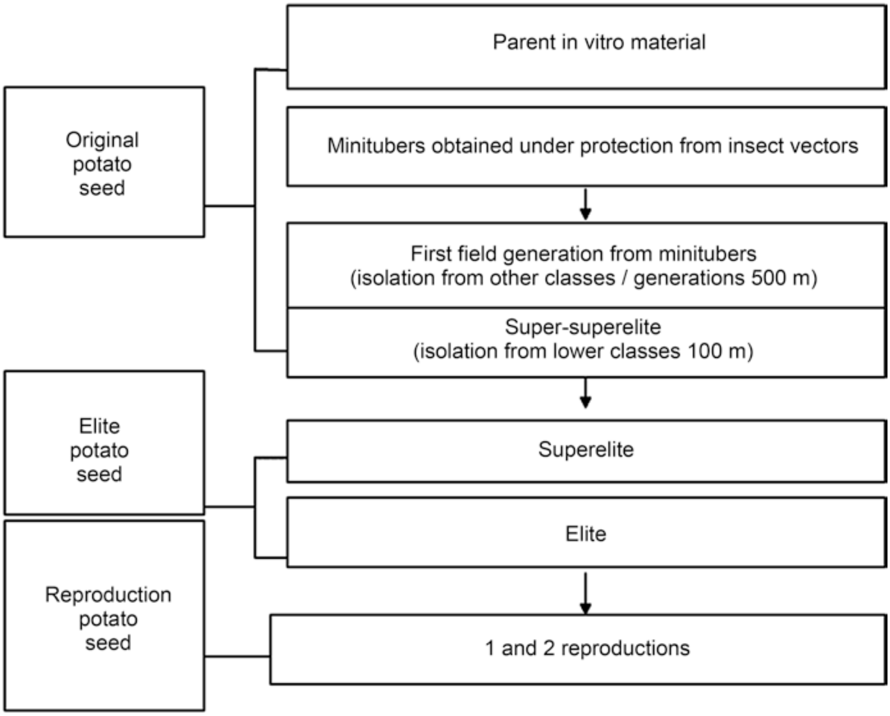

Fig. 1.1 The flow chart of successive stages of production of original, elite, and reproduction potato seed. (Source: compiled by the authors)

Hence, sequential potato seed production process includes the following structural elements:

- Maintaining the bank of healthy potato varieties (BHPV) and selecting basic clones for the introduction into in vitro crop plant
- Clonal micropropagation of in vitro stock
- Production of in vitro microtubers
- Growing minitubers protected against insects-vectors of viral infections
- Growing the first field generation seed from minitubers
- Growing super-superelite potato varieties
- Seed fields of superelite and elite potato varieties
- Seed plots of reproduction potato seed (first and second breeding generations after the elites)

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Chapter 2
Potato Consumption Pattern, Crop Acreage, Bulk Yields, Yielding Capacity, and Priority Lines of Innovative Development

Sergey Valentinovich Zhevora

Contents

FAO [1] estimates that the global consumption of potato and potato products per capita is about 35 kg a year, while the average for the European region is 85 kg per capita and that for Russia is 90 kg per capita.

The average annual amount of potato consumed for food purposes in the Russian Federation is estimated at 13–14 million tons. In order to achieve advanced processing into potato products (French fries, potato chips, dry mashed potatoes), about one million tons are needed. The need for potato seed for categories of agricultural organizations (AO), peasant (private) farms (PPF), and individual entrepreneurs (IE) with a total planting area exceeding 300,000 hectares is about one million tons [2, 3]. It is extremely difficult to assess the real volumes of potato used for seed and fodder in the category of small individual farms, although the estimate indicator here may be five to six million tons. Average annual storage losses in farms of all categories can be estimated at 1.5 million tons, while export shipments can be estimated at 150,000–200,000 tons.

Thus, the level of domestic production of potato in Russia should not be less than 22 million tons. Lowering this level may result in a deficit of commercial potato in the overall balance and, therefore, an increase in the share of imports. The estimated import ratio in total potato consumption is 300,000 to 350,000 tons. It is mainly an early "new" potato, which is characterized by growth in demand and volume of

S. V. Zhevora (✉)
Russian Potato Research Centre, Moscow Region, Russia

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sales on the retail networks during the off-season when last year's crop stocks are almost out in May and consumers are at least 2 months away from the beginning of supply of commercial potato of a new crop.

According to official statistics at year-end 2019, the area under potato in Russia in farms of all categories was 1,256,000 hectares, including in the category of agricultural organizations – 170,000 hectares; peasant (private) farms and individual entrepreneurs – 135,000 hectares; and small individual farms – 951,000 hectares (Table 2.1).

The bulk yield of potato in farms of all categories in 2019 was 22.0 million tons; in particular, 7.5 million tons were produced by agricultural organizations and peasant farm enterprises. The analysis showed that for the period from 2013, the share of individual farms in potato production has decreased from 77.7% to 65.8% with a simultaneous increase in the share of agricultural organizations from 13.8% to 21.0% and peasant (private) farms and individual entrepreneurs from 8.6% to 13.3% (Fig. 2.1) [4–6].

Most likely, further decrease in the share of individual farms in the total volume of potato production can be expected in the following years, and their dominance in the market of commercial potato will be further decreased. A possible increase in gross output of commercial potato in agricultural organizations, peasant farm enterprises, and individual entrepreneurs can be achieved in part by expanding the areas and especially by increasing yields.

The index of average potato yielding capacity in 2019 in the category of agricultural organizations was 28.4 tons per hectare, while in the category of peasant (private) farms it was 22.7 tons per hectare, at an average yielding capacity in farms of all categories of 15.3 tons per hectare (Table 2.2).

Table 2.1 Planting area, bulk yield, and yielding capacity of potato in farms of all categories in 2018[a]

	Farms of all categories	Including: agricultural organizations	Peasant (private) farms and self-employed entrepreneurs	Individual farms	Was in farms of all categories in 2018	2019 as a percentage of 2018
Area, thousand hectares	1256	170	135	951	1325	94.8
Bulk yield, thousand tons	22,080	4630	2924	14,525	22,395	98.6
Yielding capacity, tons per hectare	17.8	26.4	22.7	15.3	17.04	104.5

Source: compiled by the authors

[a]According to ROSSTAT, with due account for the returns of the 2016 All-Russian Agricultural Census

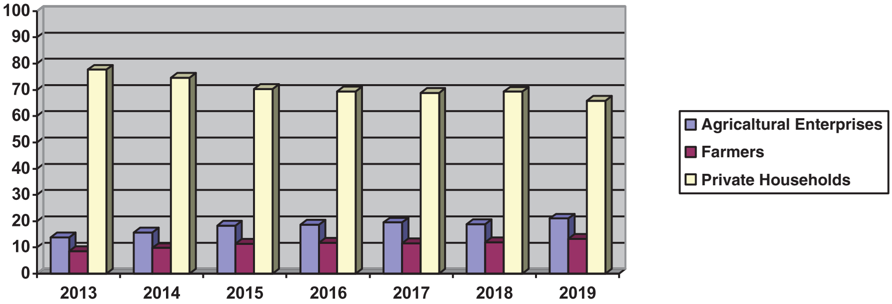

Fig. 2.1 The bulk yield structure of potato by categories of farms (% of the total volume of production). (Source: compiled by the authors)

Table 2.2 Potato-yielding capacity by categories of farms of the Russian Federation, tons per hectare

Farm categories	2013	2014	2015	2016	2017	2018	2019
All farm categories	14.7	15.3	16.4	15.8	16.3	17.0	17.8
Agricultural organizations	19.8	20.7	23.4	22.6	25.8	25.6	28.4
Peasant (private) farms and self-employed entrepreneurs	17.6	18.5	19.6	18.6	20.6	21.4	22.7
Individual farms	13.8	14.1	14.8	14.2	14.2	15.0	15.3

Source: compiled by the authors

[a]According to ROSSTAT, with due account for the returns of the 2016 All-Russian Agricultural Census

In the near term, projected indicators of average potato-yielding capacity in agricultural organizations applying modern technologies can stabilize at 26–28 tons per hectare. Peasant farm enterprises will likely remain at a lower yield level of 21–23 tons per hectare, largely due to the more backward material and technical base of most peasant farm enterprises as compared to that of agricultural organizations, as well as the farmers' still more difficult access to leasing equipment, bank loans, fertilizer subsidies, fuel, and other resources.

For most agro-enterprises, which have the necessary material and technical base and established distribution channels, the volume of potato production will most likely continue to be stable. However, a significant potential for real growth in the volume of potato production can be employed in the category of peasant (private) farms and individual entrepreneurs. To increase the efficiency of potato production in this category of farms, development of cooperation between farms in the production and sales of commercial potato and potato seed may be especially important. The accumulated experience of domestic and best foreign practices shows that within the framework of interfarm associations, farmers, becoming members of the cooperative and complying with its charter, do not lose economic and commercial independence, but relieve themselves of problems related to sales of products, delivery of seed stock necessary for its production, or obtainment of other services. At the same time, all available resources and capabilities of each member of the cooperative are employed in a rational manner with a view to reducing the cost of production, improving the quality of the final product, and making a profit [7].

High efficiency of cooperation between farms in the area of production and trade of potato seed and commercial potato is confirmed by long experience of best international practices of countries with high level of potato industry development (France, Netherlands, United States, etc.). Taking this into account, cooperation between farms based on voluntary association of potato-growing peasant (private) farms, as well as economically strong individual entrepreneurs could become one of the most efficient and promising areas in the development of the potato-growing industry in Russia. Otherwise, small enterprises alone will find it increasingly difficult to stay on the market due to their higher costs of production and hence lower profitability. Creating the most favorable conditions for the development of cooperation between farms could significantly affect the increase in potato production efficiency in the category of private farms and would allow them not only to increase their sale volumes using their existing traditional distribution channels, but also to adjust supplies of high-quality farm products to modern large retail networks.

In the present context, further development of large-scale commercial potato production is impossible without a streamlined system for providing potato-growing agricultural enterprises, peasant (private) farms, and individual entrepreneurs with seeds of elite classes and top-breeding generations [8, 9]. In this regard, increasing the production volume and dramatically improving the quality of original and elite potato seed becomes one of the key priorities of stable and profitable maintenance of the potato-growing industry [10–14].

According to the results of the monitoring held by FSBI “Rosselkhoztsentr,” 788,800 tons of potato seed were planted in agricultural organizations and peasant (private) farms in 2018 (Table 2.3).

The analysis for the period 2011–2018 shows that a considerable proportion of potato seed, which fails to conform with applicable regulatory requirements of stan-

Table 2.3 Results of quality monitoring of potato seed produced by FSBI “Rosselkhoztsentr” for 2011–2018

Years	Planted, thousand tons	Checked		Complies with applicable regulatory requirements of standard	
		Thousand tons	%	Thousand tons	%
2011	889.3	706.9	79.5	460.4	65.1
2012	1064.8	1028.8	96.6	798.1	77.6
2013	794.6	599.0	75.4	504.0	84.1
2014	826.6	597.1	72.1	515.3	86.3
2015	884.4	653.1	73.8	563.7	86.2
2016	828.5	637.1	76.9	564.6	88.6
2017	743.1	568.1	76.5	490.3	86.3
2018	788.8	594.4	75.4	507.2	85.3
2019	777.3	601.2	77.3	537.7	89.4

Source: compiled by the authors

dards and varies in various years within the range 12–35%, is planted annually in agricultural organizations and peasant (private) farms.

The situation with the use of the available potential of domestic potato varieties also requires serious improvement. In 2018, 442 potato varieties were presented in the National Register of selection achievements allowed for use, of which 235 varieties (53.4%) were created by domestic originators and 207 varieties (46.6%) were created by foreign originators. That said, the share of varieties created by domestic originators in the total amount of planted seeds following the results of the 2018 monitoring was only about 20%. Leading positions in terms of potato seed volumes were held by varieties such as Gala (81,600 tons), Red Scarlett (78,800 tons), Lady Claire (25,500 tons), Nevsky (24,000 tons), Rosara (21,400 tons), Udacha (15,400 tons), Queen Anne (13,900 tons), Innovator (10,900 tons), Colomba (10,700 tons), and Labelle (9700 tons). Of ten leading varieties in terms of potato seed volumes, eight varieties were created by foreign originators, and only two varieties were created by Russian originators (Udacha and Nevsky).

A similar analysis conducted more than 10 years ago showed that four domestic varieties were in the top five of the leaders – Nevsky, Udacha, Elizabeth, Lugovskoy – with only one foreign variety – Romano [15]. Based on the expert assessment, the share of varieties of foreign selective breeding programs in the total potato seed volume in large agro-enterprises can be estimated at 80–85%, in peasant (private) farms –at 60%, and in individual farms at the level of 40–50%, although exact statistics for these indicators are not available. Although Russian breeders have created many new promising varieties with higher yields and resistance to diseases and pests over the last years, apparently, for a considerable part of major producers it is still profitable to import seed stock of varieties of foreign selective breeding rather than spend years reproducing Russian varieties. In any case, a large proportion of varieties created by foreign originators, especially in the sector of large-scale commercial potato production, could pose a real threat of further substitution of Russian varieties.

One of the main reasons for the low level of potato-yielding capacity in many regions has been the high rate of infection of seed stock with contagious phytopathogens. This fact is pointed out by many agricultural enterprises, as well as private farms, and especially, individual farms, where multiyear breeding generations of potato are often used for planting, which are severely affected by viral, bacterial, or fungal infection. The biological features of potato as a clonal crop plant contribute to rapid accumulation of infections in the case of reproduction of seed stock. The situation is further aggravated by the fact that many potato producers do not observe spatial isolation of seed plantings from plantings of commercial potato; phytosanitary and variety rogueings and protective measures are not always carried out in an efficient and timely manner.

The deterioration of the situation with the correlation between potato seed volumes of Russian and foreign varieties is also mainly due to the fact that the technological level of domestic original seed production and the technological infrastructure of most institutions – originators of Russian varieties – are simply not comparable to the level of modern Western European breeding and seed production centers and companies. In this regard, taking effective measures aimed at modernizing the material and technical base of selective breeding and seed production of potato and creating modern breeding and seed production centers are becoming one of the most crucial tasks in potato-growing industry development in Russia. The implementation of investment projects aimed at establishing and (or) modernizing agro-industrial facilities under the sub-program "Development of Selective Breeding and Seed Production of Potato" of the Federal Scientific and Technical Program for the Development of Agriculture for 2017–2025 will be important in this case [8, 9].

The situation in the area of scientific support and innovative development of potato-growing industry also needs fundamental improvement. The wide application of innovative technologies of selective breeding and seed production, increasing the competitiveness of domestic selective breeding and their accelerated promotion of production, should become the top priorities. This, in turn, requires a significant increase in the methodological level and in the volume of work by scientific institutions in the most important areas of fundamental and exploratory applied research, including:

- Creation of new promising potato varieties with predefined agronomic characters based on traditional selective breeding and modern methods of marker-assisted and genome-selective breeding.
- Conservation, maintenance, and development of bio-resource genetic collections for the selective breeding of new domestic varieties for various purposes and the establishment of shared use centers for breeders on this basis.
- Creation and expansion of a DNA marker base and the search and development of new DNA markers necessary for the mass and effective application of marker-based breeding.
- Development of new high-efficiency methods and technologies for the direct editing of the potato genome in order to produce genotypes with predefined agronomic characters for subsequent selective elaboration.
- Development of methods for the diagnosis of phytopathogens and creation of highly sensitive test systems based on PCR technologies, enzyme-immunoassay, and immunochromatographic assay to identify potato viruses and bacteria.
- Application of modern biotechnological techniques and meristem tissue technologies for the production and clonal micropropagation of in vitro stock and creation of a competitive pool of new promising varieties of original potato seed.
- Development of efficient technologies of potato growing, harvesting, storage, and protection from pathogenic agents affecting potato and abiotic stresses.

FSBSI "All-Russian Lorch Potato Research Institute," being one of the leading research centers in Russia for selective breeding and seed production of potato, currently coordinates scientific research within the framework of the implementation of the subprogram "Development of Selective Breeding and Seed Production of Potato in the Russian Federation" (Federal Scientific and Technical Program for the Development of Agriculture for 2017–2025).

One of the largest nuclear stocks of potatoes, comprising more than 800 specimens of wild and cultural species, complex interspecific hybrids, and varieties of different geographic origin, has been formed in the breeding center of the All-Russian Lorch Potato Research Institute. This nuclear stock is constantly replenished due to receipts from the world collection of the All-Russian Institute of Plant Genetic Resources named after N. Vavilov, the International Potato Center (CIP, Peru), and other breeding centers.

Practical result of the selective breeding activities of the institute in recent years consists of the creation of new original potato varieties of various ripening periods and various intended use.

Table varieties for early production:
Meteor, Gulliver, Krepysh, Zhukovsky Early, Udacha
Long-storage table varieties:
Velikan, Kolobok, Fregat, Babushka, Il'inskiy
Table varieties for diet food (health food):
Vasilek, Fioletovyi, Severnoe Siyanie, Siurpriz
Varieties intended for processing into French fries:
Favorit, Fritella, Nadezhda, Vostorg, Navigator, Ekstra
Varieties intended for processing into crisps potato:
Vympel, Grand, Barin, Debiut, Krasa Meshchery, Iziuminka
Varieties intended for processing into mashed potatoes:
Krasavchik, Noktiurn, Signal, Brianskiy Delikates
Industrial varieties for starch production:
Divo, Malinovka, Nakra, Nikulinskiy.
Varieties for amateur gardeners:
Sineglazka 2016, Golubizna, Lorch

For all of these varieties, the laboratory of meristem tissue technologies has centralized in vitro production of certified nuclear seed stock for the original potato seed production, as well as the production of minitubers and super-superelite potato varieties from the potato-breeding center of the All-Russian Lorch Potato Research Institute, based on requests from interested agricultural organizations and agro-enterprises on a contractual basis.

In the coming years, innovative development of the potato-growing industry will largely depend on the efficient implementation of high-priority measures, which include:

- Creating conditions for obtaining stable indicators of potato-yielding capacity in the commodity sector (agricultural organizations and peasant farm enterprises) at a level of 25–26 tons per hectare, which will allow achieving stable bulk yield of commercial potato in farms of these categories at a level not lower than seven to eight million tons.
- Increasing the level of average potato yielding capacity in the category of individual farms up to 17–18 tons per hectare, which even with the expected decrease in areas in this category of farms allows achieving the bulk of yield at least 14–15 million tons and to satisfy real demand in the light of the long tradition of domestic production of potatoes for a considerable part of the population.

- Increasing the efficiency of the use of varietal resources, especially the best domestic selection achievements, and creating conditions for a more rapid increase in production volumes and increasing the quality of potato seed, as well as market promotion of new promising varieties of domestic selective breeding.
- Development and strict compliance with modern standard standards, specifications, flow charts, and scientifically based specifications of production of original, elite, and reproduction potato seed.
- Increasing the level of potato marketability through the use of high-quality domestic seed stock, efficient plant protection products, and introduction of innovative farming techniques.
- Development of potato-processing industry and promotion of the implementation of efficient capital investment project for the creation of modern hi-tech processing companies able to produce a large amount of various types of potato products which have a general run (French fries, potato chips, dry mashed potatoes), as well as ready-to-eat products (pasteurized potato) and processed foods (peeled potato in vacuum packaging, etc.).
- Infrastructure development of the potato and potato products market and creation of regional and interregional logistic centers for the sale of commercial potato and potato seed as well as potato products.
- Development and support of cooperation between farms and improvement of investment opportunities for the creation of modern technical base of potato production in this category of farms.

Successful implementation of the abovementioned high-priority measures and key priority decisions in the near future will largely contribute to the innovative development of the industry, provision of the stable output of potato, creation of modern logistical systems of market promotion of domestic potato and potato products of guaranteed quality, and reduction of import dependence.

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Chapter 3
Technologies for Obtaining and Clonal Propagation of Healthy (Free from Infection) Parent In Vitro Material and In Vitro Growing of Microtubers

Elena Vasil'evna Oves

Contents

3.1 Technologies for Obtaining and Clonal Propagation of Healthy (Free from Infection) Nuclear Seed Stock In Vitro

Sequential potato seed production process in Russia is represented by three structure blocks, which include production of original, elite, and reproduction seed [1–7]. The original potato seed production block includes the production of virus-free seed in a sterile in vitro crop plant (microplants and microtubers), growing minitubers in a controlled environment protected against vectors of infection, as well as growing the first field generation seed from minitubers and super-superelite potato varieties under the conditions of pure phyto-hygiene and spatial isolation from lower classes/generations of potato seed and commercial potato.

The general view of the innovative flow chart of the original potato seed production process developed based on research of the All-Russian Lorch Potato Research Institute [8] is presented in Fig. 3.1.

Real-life experience gained over the last years has shown that the use of the innovative flow chart of the original seed production opens the potential for the

E. V. Oves (✉)
Russian Potato Research Centre, Moscow Region, Russia

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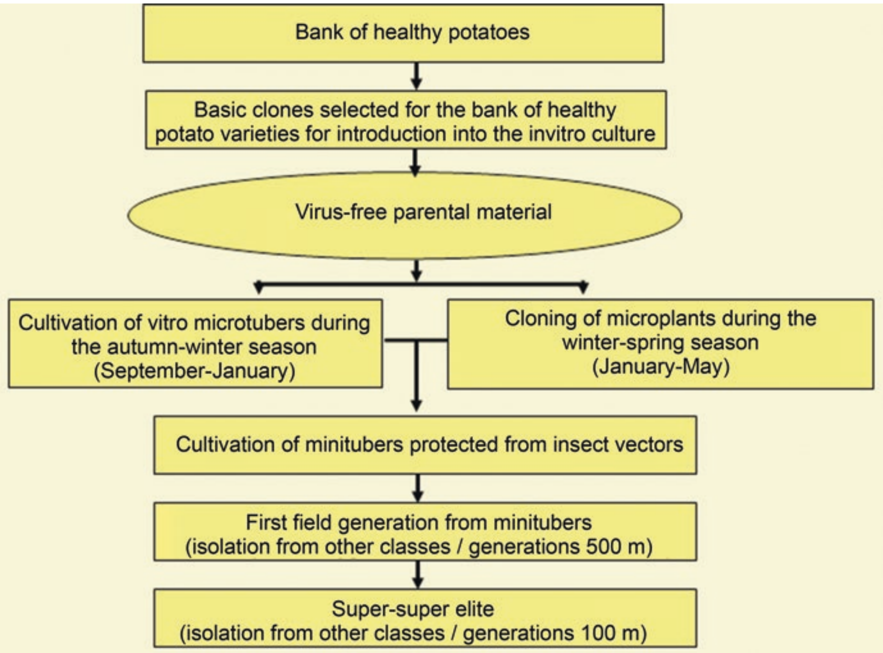

Fig. 3.1 Innovative flow chart of the original potato seed production process. (Source: compiled by Anisimov et al. [3])

expansion of time frames and more productive use of growing houses and production equipment in the process of growing microtubers in in vitro crop plant during the fall–winter season (September–January) and clonal propagation of microplants to the necessary size during the winter–spring season (January–May). This makes it possible to substantially increase the volume of growing minitubers and the total quantitative yield of seed stock when growing the first field generation seed from minitubers and super-superelite potato varieties, which ensures 25–30% increase in profitability of production [8].

3.2 Technologies for Production of Nuclear Seed Stock in In Vitro Crop Plant

The well-known methods of production of healthy (infection-free) nuclear seed stock in virus-free potato seed production are based on the application of meristem tissue technologies in in vitro crop plant. The practical application of the method of apical meristem in order to free clonal crop plants from viral diseases was started with the work of French researchers J. Morel and S. Mart, dating back to 1948. Results of their studies showed that embryonic tissues of apical meristem contain much less virus and often do not contain it at all. This allowed using isolated meristems to produce healthy (infection-free) plants. In 1955, potato plants free of X, Y, and A viruses from the area of 100–200 μm apical meristem were produced for the first time.

In the following years, the meristem tissue culture method has been widely used in many countries of the world for freeing (cleaning) potato varieties from viruses and research toward optimization of the composition of nutrient solutions, conditions, and regimes of plant growth from meristems, as well as from cuttings of microplants in the case of clonal micropropagation in in vitro crop plant. These works have been successfully developed in Russia since the second half of the 1960s [9–12].

In practice, during the meristem tissue procedures, it is often necessary to distinguish a large number of meristems in order to select a pure (infection-free) line in in vitro crop plant. Usually meristems are extremely small, isolated from sprouted tubers, tend to poorly regenerate, and the selection of larger meristems does not guarantee their complete viral purity. The higher is the virus concentration in tubers, the more difficult it is to obtain healthy meristem lines.

Pre-seasoning of tubers at a temperature of +36.0–37.0 °C (thermal therapy) allows for more efficient elimination of most viruses of potato varieties and obtaining pure meristem lines for subsequent clonal micropropagation.

More successful results can be obtained with the use of heat treatment of microplants. Special growth chambers are used for these purposes, allowing for the control of temperature and photoperiod (14 h – day, 10 h – night) during the entire period of thermal therapy. The use of thermal therapy of microplants allows creating conditions for the growth of the apical portion at a temperature of +37.5–38.0 °C, which contributes to the inhibition of virus replication in the apical area of microplants and provides more opportunities for the extraction of shoot apex free from infection [13–15]. With tuber heat treatment, these possibilities are more limited, since the temperature range is 1.0–1.5 °C lower.

3.3 Technologies of Clonal Micropropagation of In Vitro Stock

The microplant grafting method is the most widely used method in clonal propagation of pure (infection-free) meristem lines. For this purpose, under sterile conditions, microplants that have formed five to six internodes are extracted from test tubes and cut into pieces (Fig. 3.2).

The cuttings are placed in test tubes on the nutrient solution at the internode depth. Shoots are formed from the lateral buds of the microcuttings. Microcuttings are cultivated at a temperature of 23–25 °C during the day and 19–20 °C during the night, light conditions of 5–6 klux, and duration of photoperiod of 16 hours. Stem and root growth begin 3–4 days after planting on the nutrient solution. Each

Fig. 3.2 Micropropagation of in vitro stock. (Source: compiled by the authors)

successive grafting should be performed after 21–30 days. One plant can produce four to five cuttings. In mass reproduction, the number of cuttings starting from nuclear seed stock in vitro should not exceed four to five passages.

A prerequisite for working with a culture of isolated tissues is strict sterility, because isolated explants which are placed on the nutrient solution can easily be affected by microorganisms, so the sterilization of explants and the nutrient solution is necessary. All procedures with isolated tissues should be carried out in an aseptic room using sterile tools. Microplants propagated in in vitro crop plant to the necessary size are used for in vitro microtuber production and/or for planting on the growing medium and growing minitubers under controlled environment conditions.

3.4 In Vitro Microtuber Production Technologies

In the majority of cases, seed stock in vitro in original seed production programs in laboratories of various agro-enterprises is usually produced in the form of microplants, more rarely in the form of microtubers. Microtubers, or in vitro tubers, are produced under laboratory conditions on intact plants or explants by changing the nutrient solution or external conditions. Usually, the resultant in vitro tubers are mostly very small (0.02–0.7 g or 3–10 mm in diameter), although on-going developments have shown that with proper environmental management and a long period of time, it is possible to grow fairly large microtubers (more than 10 g) if special methods of in vitro tuberization are used [16].

In the technologies used to produce in vitro microtubers, there are several distinctive features and different modifications with respect to the composition of nutrient solutions, temperature conditions, and lighting regimes.

For in vitro microtuber production technologies, test tubes or flasks of different diameters, as well as vessels or containers of different design and capacity, are used. Liquid and agar media of various composition are used [17].

One tuber is usually formed in applicable systems of growing microtubers in in vitro crop plant from one plant or explant. Nevertheless, the possibility exists of increasing the number of tubers per explant, but this can be achieved only when the explant is able to maintain the formation and growth of the second tuber and provides an opportunity to both tubers to reach the acceptable size (more than 9 mm in diameter) (Fig. 3.3).

Although the microtuber production reports that are used by various laboratories present a number of distinctive features, approaches, and different modifications, the main elements of existing microtuber production systems consist of the use of the micrografting technology to produce plants with subsequent induction of tuberization.

Microtubers should be grown as follows:

- The initial stage of microtuber production is based on the use of the well-known micrografting technology. This stage may be repeated many times until the necessary amount of seed stock is produced.
- After the removal of roots and the top of the stems, the microplants are placed in flasks, in a medium conducive to the formation of lateral buds and shoots. After some time, lateral buds begin to develop on the stems and several shoots develop in one flask.
- Tuberization stimulation is a prerequisite. The medium for tuberization stimulation changes with the addition of special hormones (cytokinins and chloroquinchloride), required amounts of sugars, or stimulant fertilizers. Small amounts of a highly concentrated hormone (chlorocholine chloride [CCC]) and sucrose solution are usually added to the existing medium.

Fig. 3.3 Producing microtubers in in vitro crop plant. (Source: compiled by the authors)

Critical factors at the tuberization stage are as follows:

(a) Sugar (saccharose) concentration in the medium (optimally – 8%). Saccharose is important as a source of energy, since it impacts the osmotic potential of the medium (optimal level positively influences tuberization) and since it makes tuberization independent of other impacts.
(b) The presence of growth-regulating chemicals. Cytokinin and chlorocholine chloride (CCC) are often added. Nevertheless, other hormones are active as well.
(c) Preferable growing temperature 18–20 °C.
(d) Plants must be grown in the dark or with low lighting intensity (100–500 lux) with photoperiod lasting 8 hours. Many varieties may produce better results with a short light day (8 h) than in total darkness. Some papers note that microtubers grown in the dark may have somewhat reduced properties as compared to microtubers grown in the light. The difference may be due to the large number of eyes in microtubers that are cultivated in the light and their shortened state of rest, or due to their higher resistance to diseases.

After a few months, microtubers are usually ready for harvesting. These tubers are characterized by a fairly low concentration of dry matter, and generally speaking, they are in the dormant state. This means that tubers will not germinate until they lie dormant long enough in the storage. Chemical interruption of the state of rest with incisions on the peel is dangerous, since small tubers can easily start to rot after such damage.

Within the framework of research conducted in 2006–2009 by the All-Russian Lorch Potato Research Institute and at the premises of the meristem laboratory of LLC Litvinovskoe, the technology of growing revitalized microtubers was tried and tested, and the possibility of their use as nuclear seed stock during original potato seed production [18] was assessed.

The overall view of the system of cloning microplants and production in vitro microtubers developed in the All-Russian Lorch Potato Research Institute is presented in Fig. 3.4.

Based on the research results, the terms for producing in vitro microtubers for original potato seed production were optimized. It was shown that mass grafting of microplants in September–November allows for microtuberization in December–January and passing through the rest period of in vitro microtubers until their planting. Following the rest period, it is recommended that microtubers are usually planted on the growing medium in indoor structures (in covered tunnels) in the first half of May. Dimensions of microtubers should also be taken into account when using them during original seed production.

Based on the comparative assessment of productivity and the quantitative yield of seed using different sizes of microtubers, the highest indicators were achieved when 0.8–0.1 cm microtubers were planted. In this option, depending on the variety, productivity indicators were higher than those in options with the use of microtubers less than 0.8 cm in size (Table 3.1).

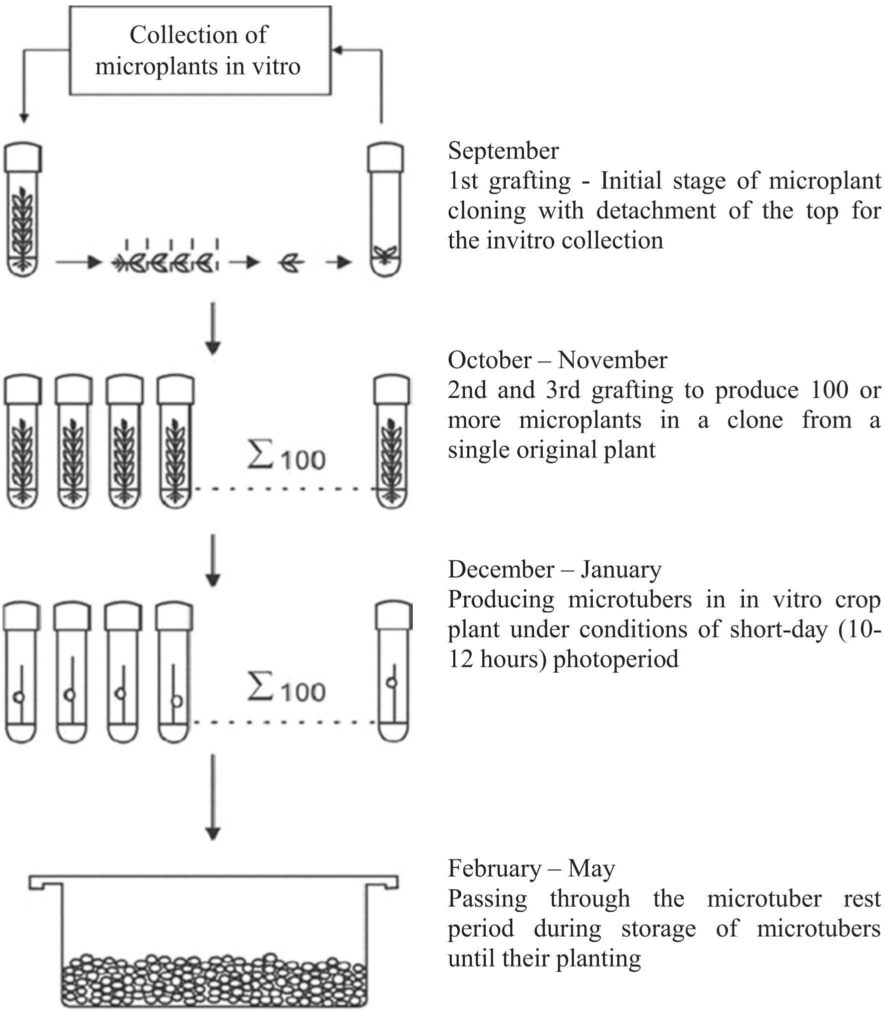

Fig. 3.4 The system of cloning microplants and production in vitro microtubers. (Source: compiled by Anisimov et al. [18])

The best productivity indicators from 238.2 to 600.9 g per bush and the quantitative yield of minitubers from 9.5 to 19.8 pieces per bush were achieved in options with 70 × 30 cm, 70 × 25 cm, and 70 × 20 cm planting system. In options with the use of 70 × 5 cm, 70 × 10 cm, and 70 × 15 cm planting systems depending on the variety, productivity was 134.8–548.3 g per bush, and the quantitative yield was 8.0–16.5 pieces per bush (Table 3.2).

In addition, it was found that plant productivity with the use of microtubers was 1.4–2.3 times higher as compared to the ordinary way of growing minitubers from microplants. The quantitative yield of minitubers when using microtubers was also

Table 3.1 Plant productivity depending on dimensions of microtubers

Size of microtubers, cm	Weight, g per bush		Number of tubers, pcs per bush	
	Udacha	Lugovskoy	Udacha	Lugovskoy
>0.5	348.0	313.7	5.0	12.6
0.5–0.8	484.5	325.5	9.3	14.9
0.8–1.0	600.9	429.1	10.2	14.1
1.0–1.5	–	433.1	–	14.2
<1.5	–	352.3	–	13.9
HCP05	103.4	50.9	5.0	12.6

Source: compiled by the authors

Table 3.2 Plant productivity under various microtuber planting systems

Microtuber planting system, cm	Weight, g per bush		Number of tubers, pcs per bush	
	Udacha	Lugovskoy	Udacha	Lugovskoy
70 × 5	364.6	172.3	8.0	8.4
70 × 10	436.6	233.1	10.1	10.4
70 × 15	548.3	325.5	10.9	15.7
70 × 20	600.9	429.1	10.2	14.1
70 × 25	402.2	310.3	9.5	12.7
70 × 30	548.7	442.9	9.7	16.5
HCP05	86.8	97.0		

Source: compiled by the authors

higher (1.1–1.7 times) as compared to the crop plant grown from microplants. Differences in indicators of plant productivity and the quantitative yield of minitubers may largely be determined not only by dimensions of microtubers but also by their higher ability to adapt to growing conditions after their planting.

Along with producing microtubers in in vitro crop plant, more productive in vitro technologies of microtuber growing are used as well. Research conducted in the laboratory of meristem tissue technologies of the All-Russian Lorch Potato Research Institute in 2014–2016 with the use of in vitro technologies [17] showed that in the case of stage-by-stage control of environment and creation of optimum conditions for in vitro tuberization, the possibility exists of significantly increasing the quantitative yield of microtubers of more than 10 mm in diameter.

For more productive in vitro microtuber production technologies, they use special sterile plastic vessels (containers) of various capacity. Their design provides for special nozzles that allow changing liquid nutrient medium without breach of sterility of in vitro crop plant. This allows for step-by-step regulation of nutrition regimens in various phases of plant growth and development, and initiating the stolon and tuber formation. In order to create optimal temperature and light conditions, containers are placed in special incubator chambers.

At the initial stage, for regeneration, the cuttings are placed in containers on the Murashige and Skoog nutrient medium, which contains 3% sucrose. Regeneration of explants in containers in a growth chamber usually occurs during 16-hour photoperiod with lighting intensity of 5–6 kilolux at a temperature of +20 to 22 °C. Following vegetative growth period, the nutrient solution is replaced by a solution of the same composition, but by increasing the concentration of saccharose to 8%. Short day mode (8/16 hours day/night) at a temperature of 18–20 °C during the day and 10–12 °C during the night is set in a growth chamber. Under such conditions, stolon and tuber formation is induced, after which, if necessary, an additional replacement of nutrient solution can be made, facilitating the formation of tubers of acceptable size (Fig. 3.5).

The period of producing microtubers from the moment of grafting of plants until their harvesting usually lasts 16–20 weeks. The rate of propagation depends on varietal features and is equal to 1–2 microtubers per containerized plant. Microtubers are stored at a temperature of +4 °C in a cold room no longer than 1 year.

Fig. 3.5 Production of in vitro microtubers in containerized crop plant. (Source: compiled by the authors)

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Chapter 4
Technologies for Growing Minitubers

Boris Vasil'evich Anisimov and Sergey Nikolaevich Zebrin

Contents

4.1 Importance of Growing Minitubers

Over the last years, minitubers have become in fact an independent commodity group in the world market of prebase (original) potato seed. This, in turn, led to the need for development of standardized procedures for minituber production process and the use of minitubers in potato seed production.

For a long time, the development of traditional (basic) minituber-growing technologies has been focused on the use of heated wintertime ground hothouses. However, due to the dramatic increase in energy costs associated with heating, lighting, and soil replacement, many producers gradually started using less cost-intensive technologies of growing minitubers in spring–summer farming rotation under conditions of nonheated framed tunnel shelters with the use of light synthetic cover materials [1, 2].

According to expert estimates, "tunnel technologies" serve as the basis for producing a total of 80% minitubers during spring–summer farming rotation, whereas the volume of growing minitubers based on alternative technologies with the use of hydroponic (water) and aeroponic (air) crop plant is about 20%.

Experience has shown that the use of vegetation structures of this type given the strict observance of controlled environment conditions and measures of protection

B. V. Anisimov (✉) · S. N. Zebrin
Russian Potato Research Centre, Moscow Region, Russia
e-mail: anisimov@vniikh.com

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from insects as vectors of infection allows for achieving fairly high quantitative yield of minitubers and their quality level, which conforms with enforceable regulatory requirements of the standard [3].

4.2 Specifics of Growing Minitubers in Tunnels

Real-life experience gained over the last years has shown that growing minitubers with the use of tunnel technologies without strict observance of proper controlled environment conditions does not exclude the risks of possible transfer of phytopathons from the outside (viruses, viroids, phytoplasms). This can lead to severe problems in terms of seed quality even actually in the direct breed from minitubers (first field generation) or in its subsequent propagation during original seed production in future. In the end, such lots have to be literally taken out of trade due to their failure to conform with applicable regulatory requirements of the standard, resulting in severe economic losses.

To minimize risks of negative implications related to seed quality, it is necessary to primarily ensure strict observance of the standardized procedure of the minituber-growing process under controlled environment conditions and measures of protection from insects as vectors of infection, especially migrant aphid species.

Placement of tunnels in an area with the lowest number of vectors and sources of viral and other infections is one of the most important features of tunnel technologies of growing minitubers. Furthermore, of fundamental importance is the presence of double entrance doors, disinfecting carpets for shoes, places for changing clothes, special protective robes, headgears, gloves, washing, and hand disinfection at the entrance in each tunnel (Fig. 4.1).

The growing media that are used for minitubers must be isolated by the protective film from the soil of tunnels. Disinfection of the growing media with the use of fumigation, steam disinfection, or yearly change is a mandatory process requirement as well.

In the initial period for acclimatization of planted plants, spraying with water mist is of fundamental importance. After that, it is particularly important to ensure the creation of the most optimal conditions of temperature, lighting, air circulation, and humidity control during the vegetational season. Only purified or artesian water should be used for irrigation, with regular inspection for potato-harmful organisms.

After harvesting from each lot of minitubers, samples are taken for laboratory testing to identify phytopathons that are controlled in compliance with the requirements of applicable standards.

Lots of minitubers should be packed and placed in storage under conditions preventing contamination by pests. Small tubers are sorted, packaged, and stored only in specially designated premises. Experience has shown that sorting grown minitubers into grades by size is one of the most important process requirements in the case of their use in production and trade turnover. In this regard, of prime impor-

Fig. 4.1 Growing minitubers protected against insects – vectors of viral infection (LLC "FAT-AGRO," RSO-Alaniya, 2016). (Source: compiled by Anisimov et al.)

tance is to ensure the obtainment of the optimal quantitative yield of standard-size minitubers according to their dimensions.

In accordance with specifications of a new interstate standard GOST 33996-2016, minitubers with a diameter of 9–60 mm (approximately weighing 5 to 90–100 g) are allowed to be used in production.

Results of research conducted in 2014–2016 at the premises of the LLC Fat–Agro [3] showed that growing minitubers in tunnels allows achieving fairly high figures of quantitative yield of standard-size seed tubers within the range 75–89%. Small-sized tubers (less than 9 mm) for the Zhukovsky Early variety accounted for 17% in the yield structure of minitubers and 8–10% for the Udacha variety. The maximum number of large-sized minitubers (more than 60 mm) in the yield structure for the Zhukovsky Variety early did not exceed 6% and for the Udacha variety, 17% (Table 4.1).

Special tests of different grades of minitubers planted in highland conditions (2500 m above sea level) [3] that were carried out in 2017 detected fairly significant differences in plant growth and development, as well as indicators of productivity

Table 4.1 Yield of tunnel-grown minitubers differing in size (LLC "FAT–AGRO," 2014–2016)

Size of minitubers, mm	Quantitative yield of minitubers, %			
	2014	2015	2016	The average of 2014–2016
Zhukovsky Early variety				
<9	17	17	17	17
10–20	41	35	31	36
21–40	23	24	32	26
41–60	19	22	14	18
>60	0	2	6	3
9–60 mm (standard)	83	81	77	80
Udacha variety				
<9	10	8	10	9
10–20	25	20	32	26
21–40	23	29	30	27
41–60	41	26	18	28
>60	2	17	10	10
9–60 mm (standard)	89	75	80	81

Source: compiled by Anisimov et al.

Table 4.2 Productivity and the quantitative yield of seed depending on the size of planted minitubers in highland conditions, 2017

Size of planted minitubers, mm	Productivity and the quantitative yield of seed		
	Weight of tubers, g per bush	Number of tubers, pieces per bush	Quantitative yield of tubers, 1000 pcs per hectare
Zhukovsky Early variety			
<9	87	2, 5	217
10–20	172	4, 8	398
21–40	290	7, 3	562
41–60	359	9, 1	637
Udacha variety			
<9	108	3, 0	261
10–20	203	5, 8	481
21–40	373	10, 1	777
41–60	494	12, 4	868

Source: compiled by the authors

and the quantitative yield of seed produced in the seed field of the first field generation seed from minitubers (Table 4.2).

The findings showed that the plants of the smallest size of minitubers <9 mm were lagging far behind the plants of all other options in terms of the development of tops, leaf area, and other indicators. The most significant reduction of plant productivity and the quantitative yield of seed was also noted in the option with the use of smallest minitubers [3].

In actual practice, when the small size of minitubers is used up to 9 mm in diameter, usually a lot of problems arise due to the high sparseness of seedlings, large number of rejects, delay in plant growth and development, and low plant productivity. For these reasons, small-sized tubers are often simply rejected and not used for transplanting in the field. However, small-sized tubers can be a valuable seed stock for replanting in protected soil in regulated growing conditions, where their productivity may be quite comparable to the productivity of, for example, microtubers produced with the use of nutrient solutions in in vitro crop plant.

The size of minitubers 10–20 mm in diameter turned out to be well suited for direct transplanting in the field, although it also had lower indicators of productivity and the quantitative yield of seed compared to larger minitubers – 21–40 mm and 41–60 mm.

In order to improve plant productivity with the use of 10–20 mm minitubers, a significant positive effect can be achieved with the use of the technique of preplant coating with a special nutrient mixture prepared on the turfy substrate and containing all necessary macro- and microelements. Research conducted by N. S. Shakurov in conditions of the Middle Volga (Samara Region, 1995–1997) showed that preplant treatment of minitubers 10–20 mm in size contributed to the formation of the shell (capsule) from nutrient mixture on their surface and upon planting in the field significantly increased the germinating power, plant productivity, and quantitative yield of seed per unit area (Table 4.3).

In an average of 3 years, the increase in yielding capacity due to the use of dressed 10–20 mm minitubers of Volzhanin variety for planting was 7.3 tons per hectare, Nevsky variety 10.5 tons per hectare, Lugovskoy variety 10.9 tons per hectare as compared to the control without preplant treatment of minitubers with a nutrient solution.

Based on the results of the research carried out in practical work for planting of the first seed fields, it is usually recommended to use three types of minitubers that differ in dimensions – 10–20 mm, 21–40 mm, and 41–60 mm in diameter. Separate planting of tubers of every size is required, allowing for more uniform plantings, which would make it more convenient to identify and reject plants with varietal characters that deviate from the official description of a variety, as well as plants with possible manifestation of other visual defects during the vegetational season. This makes it possible to ensure a fairly high quality of original potato seed conforming with applicable regulatory requirements of the standard.

Table 4.3 The impact of the technique of preplant coating of minitubers (10–20 mm in size) with a nutrient solution on yielding capacity of the direct breed from minitubers (mean value for 1995–1997)

Variety	Yielding capacity, tons per hectare		Quantitative yield of tubers, 1000 pcs per hectare	
	Undressed minitubers	Dressed minitubers	Undressed minitubers	Dressed minitubers
Volzhanin	15.3	22.6	133.9	174.9
Nevsky	8.7	19.2	131.2	150.3
Lugovskoy	14.8	25.7	98.4	164.0

Source: compiled by the authors

Conformity with applicable regulatory requirements of the standard in terms of identity of a variety, purity of a variety, and other quality indicators is particularly important for lots of minitubers that are intended for sale. For these purposes, the soil control of varieties from lots of minitubers is carried out on the test plot of the All-Russian Lorch Potato Research Institute starting from 2016 for the verification of their conformity with applicable regulatory requirements of standards in terms of identity of a variety (authenticity of a variety), purity of a variety, and damage caused by viral and bacterial diseases [4].

4.3 Specifics of the Hydroponic Method of Growing Minitubers

For growing minitubers with the use of modern hydroponic technologies, it is usually recommended to breed microplants to produce adapted transplant seedlings with well-developed leaves, stems, and root system to be subsequently planted into hydroponic modules of different types and designs, where the solution of various macro- and microelements, concentration of which may vary depending on phases and time of plant vegetation, maintaining pH value of nutrient solution at the level of 5.9–6.3, was used as nutritive base. The supply of nutrient solution and lighting of plants in hydroponic installations are regulated by means of timers that are set to corresponding modes. Relative air humidity indoors must be maintained at the level of 50–55%. Minitubers are harvested according to their ripening and achieving optimal standard size. Collected tuber yield should be stored at a temperature of +3 + 4°C.

One of the major advantages of the hydroponic method is that it makes it possible to fairly efficiently grow minitubers all year round and virtually eliminates the possible risk of viral infection of plants from the outside in the process of accelerated propagation of potato varieties [5].

However, research results showed a number of distinctive features of tubers should be taken into account in the case of the use of hydroponic minitubers produced in hydroponic installations [1].

Minitubers grown in hydroponic modules should be used in a strictly differentiated manner depending on the time of their harvesting. The highest indicators of germination ability and productivity were achieved during the December and January time of harvesting minitubers from plants of Lugovskoy variety, vegetating in hydroponic modules during 52–84 days. Minitubers of later harvest time from the same plants had lower indicators of field germination ability and productivity (Table 4.4).

Table 4.4 Germination ability and productivity of hydroponic minitubers depending on the time of their harvesting and duration of the storage period (Lugovskoy variety, 1996)

Date of harvesting minitubers	Period of storage, months	Ground germination capacity, %	Weight of tubers, g per bush	Average number of tubers, pieces per bush
18.12.95	5.0	100	536	6.4
03.01.96	4.5	97	437	5.7
19.01.96	4.0	97	184	3.7
05.02.96	3.5	67	125	3.4
22.02.96	3.0	59	75	2.4
11.03.96	2.0	38	55	1.8
29.03.96	1.0	0	–	–

Source: compiled by Anisimov et al. [1]

It is common knowledge that in Russia the plant-growing method based on cultivation and introduction was put forward by K. Tsiolkovskiy, who substantiated the idea of the possible use of hydroponics in spaceships. His ideas gained momentum in hydroponics research, but they were mainly focused on the creation of the most appropriate mineral nutrient solutions for vegetative growth and development of plants. In the last 20 years of the last century, the interest in the hydroponic crop plant significantly increased along with the creation of drip irrigation systems and the development of new technological solutions, which made it possible to monitor and efficiently control the composition and concentration of nutrient solution, its electrical conductivity, pH, concentration of dissolved oxygen, stability of maintenance of the optimal temperature regime, and other factors.

The minitubers of February and March harvest time of most varieties usually do not have time to pass through the rest period before starting transplanting in the field. Therefore, they cannot be planted without special additional measures that ensure their withdrawal from the state of rest. If this is impossible, such minitubers should be better placed in storage in cold rooms until the next planting season.

It is interesting to point out that technologies for producing virus-free minitubers from hydroponic crop plants were developed in the early 1990s in the Kurchatov Atomic Energy Institute and JSC Doka (Zelenograd), which made it possible at the time to produce more than 1000 minitubers per 1 square meter using aerohydroponic installations and maintain year-round production. Considering the high efficiency of the developed technology, the Government of the Russian Federation adopted Special Resolution No. 415 of April 30, 1993, "On Production of Virus-Free Potato Minitubers," and the Ministry of Agriculture of the Russian Federation issued Order No. 192 of June 16, 1993, which established relevant measures aimed at developing industrial production of virus-free minitubers for the original potato seed production.

4.4 Specifics of Aeroponic Technologies of Growing Minitubers

Aeroponics is the plant-growing method in which mechanically supported plant roots must be permanently or periodically present in an environment saturated with a nutrient solution in the form of mist or spray. The basic principle of aeroponics is plant growing in a closed or semi-closed environment by means of spraying their roots with a solution rich in nutrients. Ideally, the room equipped with aeroponic installations should be isolated from external environment to maintain a high level of phyto-hygiene and pest and disease prevention. This makes it possible to ensure healthier plants and their faster growth as compared to, for example, with soil culture conditions in greenhouses.

Different types of installations are used for the aeroponic method of producing minitubers, where the plants are fed by supplying nutrient solution to the roots in the form of an oxygenated spray. Since roots are in air space, it is important to maintain high air humidity, protecting them from drying.

The efficiency of any plant-growing technology is determined by the possible regulation of each phase of their growth and development. Control of metabolism in case of the aeroponic plant-growing method allows regulating conditions of abiotic environment more efficiently than when using traditional methods and technologies. The possibility of rapid regulation of environment for the operation of the root system is one of the most important advantages of aeroponic technologies. With the help of optimally selected mineral food formulations, as well as spectral composition of light and the temperature around the leaf area and in the root zone of plants, it is possible to control the metabolism of plants, to accelerate the outflow of macronutrients to tubers. As a result, the tuberization process significantly accelerates, and the quantitative yield of minitubers increases.

According to research conducted by Y. T. Martirosian with employees of the All-Russian Research Institute of Agricultural Biotechnology [6], it is necessary to distinguish five main periods of potato growth and development under aeroponics conditions.

The first period is the transplant of adapted in vitro plants into the installation and their further growth until the appearance of three to four new leaves. Fresh branched root hair emerges in the root zone. This period usually lasts 7–8 days.

In the second period, there is active formation of stems, leaves, and the root system. Usually, for 18–22 days the roots are interwoven with each other and form a solid cover.

The third period is the emergence of flower buds in plants and the formation of stolons; it takes 5–7 days. Meanwhile, the tuberization process is induced. Having reached a certain size, the last internode of the stolon is thickened and a young tuber is formed. Intense growth of tops continues in this period; plants require the maximum amount of moisture and fertilizer elements. The weight of the tops increases, but the tuber growth rate is low. Intense tuberization begins 2–3 weeks after induction, and massive thickening occurs on the stolons (tuber buds). Usually one stolon forms five to eight tubers, and their weight varies between 5 and 50 g, so even with only one stem in the bush, at least 20–30 minitubers can be obtained from one plant.

The number of main stems in a bush depends on the technology of transplanting adapted in vitro plants, the number of sprouts, physiological condition of the planting material, and the formation of the bush itself in the planting hole on the installation, as well as the growing technology. Usually three to four stems form in the bush. The optimal stem density is 75–90 stems per m^2.

The fourth period covers flowering and continues until the end of the growth of tops, almost until it starts wilting. At this time the most intense tuber growth rate occurs, and up to 65–75% of the final yield is formed. The micro-climate parameters maintained during this period influence the final harvest. Under optimal conditions of plant growth and development, average daily increments in tuber yield are up to 250–300 g per m^2.

The fifth period lasts from the end of the period of growth of tops and start of its necrosis until full physiological ripening of tubers. The tuber growth rate still continues, but less actively as compared to the fourth period. A considerable part of nutrients goes from the wilting tops to tubers. Accumulation of dry matter in tubers comes to an end, and tubers reach physiological ripeness and enter the state of rest.

As a result, 50–120 minitubers weighing 5–30 g each depending on the variety can be collected from each bush if all conditions of technology are observed. In some experiments, results were obtained that suggest that natural plant potential is in fact higher and varies from 250 to 300 minitubers per bush. It all depends on the duration of the growing season, growing conditions, and potato varieties [6].

Plant growing in closed growing houses under artificial light has many advantages, but it requires creating optimum conditions for plant growth and development. The parameters of a growing house should contribute to maximizing the development of natural, genetic potential of plants.

For example, it has been shown that the influence of light, its spectral composition, on the growth and morphogenesis of plants is made through changes in photosynthesis and its products, as well as through photoregulatory and hormonal systems. Along with the light factor, temperature factor is important in the potato minituber production technology under aeroponics conditions. Temperature is one of the main conditions that determine the plant development rate. Rapid ontogenesis of plants is important both in the natural environment, where the rate of development allows plants to avoid adverse vegetation conditions, and when growing them in indoor structures, where one of the important tasks is the production of high-quality seed.

According to the available observation data, there is a range of temperatures at which the vegetation duration is extended and which corresponds to either the lower or upper limits that are favorable for plant development [6]. Thus, for the first three stages of potato growth under aeroponics conditions, the optimal temperature regime is 22–24/16–18 °C day/night. During the second half of the vegetational season (the fourth and fifth periods), it is necessary to reduce the plant-growing temperature to 18–20 °C during the day and 14–16 °C during the night.

In practice, the use of aeroponic technologies with strict observance of all growing parameters allowed to obtain positive results under production conditions. For example, based on aeroponic complex in Pavlovsky Posad of the Moscow region, more than 1 million minitubers were produced during 1 year at the 1200 m^2 planting area. Economic calculations also confirm the efficiency and expediency of a wider use of aeroponic technologies in potato seed production [5, 6].

4.5 Aerohydroponic Minituber Growing Systems

In modern practice, combined aerohydroponic technologies have been increasingly developed and applied, in which active aeration of the root system (aeroponics) is combined with either continuous or periodic immersion of it in nutrient solution (hydroponics). This makes it possible to optimize conditions for growth of vegetative mass, development of the root system, and tuberization. These technologies are increasingly in demand, especially for accelerated propagation of new and scarce varieties.

In the course of research conducted in the All-Russian Lorch Potato Research Institute, the method of growing minitubers using the aerohydroponic module was developed and tested [7].

The minituber production process on the aerohydroponic module is characterized by the following distinctive features:

- Plants are grown on differentiated media in the biotechnological installation with active-passive feed system.
- The plant arrangement scheme is on the 190 × 190 mm module with a total of 60 slots. The total area of the module intended for planting is 3000 × 760 mm (2.28 m^2).
- This arrangement makes it possible to increase the density of plant placement on the unit area and to increase significantly the quantitative yield of minitubers per square meter.

- The technology allows for well-targeted activities for the initiation and promotion of reproductive processes in certain phases of plant growth and development, and the use of the differentiated method of stage-by-stage harvesting during the visual inspection of tuber development.
- The module is equipped with a plant-retaining device in order to keep plants in a vertical position during their ontogenesis.
- The module is compact, versatile, and mobile and is designed for operation in any environment, in natural or artificial light. Any number of modules can be bundled with each other into one complex unit.
- The design of a module provides for equipping it with a light source for indoor growing.
- The engineering solution of the design of a module provides for equipping it with its own source of energy (solar batteries) to implement this method in a standalone mode in any conditions.

For testing, the experimental prototype of the aerohydroponic module was equipped with active and passive power supply systems, with a single 100 W high-pressure water pump with a voltage of 12/24 V, capable of generating the water pressure of up to 0.7 MPa. The module was placed on the test site of the All-Russian Lorch Potato Research Institute in an unprotected environment. Figures 4.2, 4.3, and 4.4 show the overall view of the module during vegetation and fragments of root development of plants with tuberization and the size of harvested minitubers.

The growing process was maintained in natural light conditions, and a differentiated scheme of supply of balanced nutrient solution was used. A fairly large volume of radical space provided full visual monitoring and easy access to the root system and careful treatment of roots in the case of repeated harvesting of minitubers. Limited access of light to the root system prevents undesired illumination of roots.

Fig. 4.2 General view of aerohydroponic installation, All-Russian Lorch Potato Research Institute, 2015. (Source: compiled by Khutinaev et al. [7])

Fig. 4.3 Tuber formation on the aerohydroponic installation, Zhukovsky Early variety, All-Russian Lorch Potato Research Institute, 2015. (Source: compiled by Khutinaev et al. [7])

Fig. 4.4 Harvest of minitubers produced on the aerohydroponic installation. (Source: compiled by Khutinaev et al. [7])

The operation cycle on the aerohydroponic installation was started from planting of in vitro plants directly into the module without their prior breeding. Before transplanting, plants were carefully and thoroughly washed to remove residues of agar medium and prevent residues of agar-agar from entering the active feed system.

Formulations of macro- and microsalts, which, according to the results of earlier studies, most fully met the requirements of the minituber production process, were used in the growing process [7]. For the first phase of plant growth and development, a nutrient solution was used with the following content of macrosalts in the solution (mg/l): N (85), P (45), K (180), Ca (60), Mg (35), pH (5.8–6.0), EC (0.8); for the second phase N (45), P (30), K (90), Ca (35), Mg (20), pH (5.8–6.0), EC (0.7); for the third phase N (70), P (45), K (200), Ca (60), Mg (35), pH (5.8–6.0), EC (1.2). The content of microsalts in the solution (mg/l) is presented in the following formulation: Fe-EDTA (8), B (0.5), Mn (0.5), Zn (0.1), Cu (0.05), I (0.63), Co (0.006), and Mo (0.1). EC of the medium varied according to the vegetation phases and terms, and was generally maintained within the range 0.7–1.3. The pH was controlled and adjusted once every 2–3 days, and the solution was replaced once every month. During the operation, the volume of nutrient solution was replenished due to the removal of mineral elements and due to transpiration losses.

The technological mode of supply of the nutrient solution in the daytime and in the nighttime depending on the growing period was as follows. First mode: 60 days from 6 am to 10 pm; cycle: 1-minute operation and 9-minute break; during the night from 10 pm till 6 am; cycle: 1-minute operation and 29-minute break. For 30 days, the pump operates 3360 minutes or 56 hours (56 hours × 100 W = 5.6 kW). Second mode: 30 days from 6 am to 10 pm; cycle: 1-minute operation and 19-minute break; during the night – from 10 pm to 6 am; cycle: 1-minute operation and 29-minute break. For 30 days, the pump operates 1980 minutes or 33 hours (33 hours × 100 kW = 3.3 kW). Third mode: 30 days till the end of vegetation period from 6 am to 10 pm; cycle: 1-minute operation and 29-minute break; during the night – from 10 pm till 6 am; cycle: 1-minute operation and 59-minute break. For 30 days, the pump operates 1080 minutes or 18 hours (18 h × 100 kW = 1.8 kW).

The first solution was used in the first 2 months. After that, the solution was replaced with a second solution, stimulating solution, which was preserved for 2 weeks. Subsequently, the plants were converted to a third solution until the end of the growing season. The required amount of water was added at all stages as the liquid was consumed. The concentration of macro-, meso-, and microelements was adjusted once a week.

The tubers were removed after reaching 20–30 mm in diameter every 7 days. After harvesting, tubers were treated with a 0.1% bleach followed by rinsing in water for prophylactic purposes to avoid bacterial contamination. The collected minitubers were drying for a week at a high relative air humidity, after which they were kept at room temperature for 3–5 days and were placed in storage at a temperature of 3–4 °C.

As a result of recordings and observations when growing minitubers in the aero-hydroponic crop plant on the Zhukovsky Early variety, it was found that the square meter of useful area can yield more than 1500 minitubers. The 60 plants that were planted in an area of 2.28 m^2 yielded 3467 minitubers.

The quantitative yield of minitubers per plant averaged 57 pcs. Tubers with a size of at least 10 mm were taken into account. Due to the forced termination of vegetation, small tubers less than 10 mm in size were not harvested or taken into account, although they could theoretically give a significant increase in the number of adequate minitubers.

The analysis of the tuber yield structure revealed that the quantitative yield of optimum-sized minitubers of 20–30 mm in diameter exceeded 75%. The number of larger-sized tubers (>30 mm) was about 7% and that of tubers 15–20 mm was about 9%. Small-sized tubers (10–15 mm) accounted for no more than 7% (Table 4.5).

Table 4.5 The quantitative yield of minitubers of the Zhukovsky Early variety of various size in the aerohydroponic crop plant, 2015

Total amount of minitubers harvested	Size, mm	Average weight of 1 tuber, g	Number of tubers, pcs	% of tubers
3467	10–15	1.3–3	248	7.15
	15–20	3–7.5	334	9.63
	20–25	7.5–12	1543	44.50
	25–28	12–14	724	20.88
	28–30	14–25	354	10.21
	30–35	25–30	197	5.68
	>35	>30	67	1.94

Source: compiled by Khutinaev et al. [7]

For 90 days of operation of the installation, the consumption of electricity in the production of 3467 minitubers was 10.7 kW, and the consumption of water was 2600 liters. With an average number of 57 minitubers per plant, more than 82% accounted for optimum-sized tubers for planting in open ground and 18% accounted for smaller-sized tubers that can be planted in protected ground.

In monetary terms, material expenses for the production of the experimental lot of minitubers were 200 rubles, including 56 rubles for electricity supply, 73 rubles for water supply, and 71 rubles for agrichemicals.

The energy expenditure required to produce one minituber was 3.08 W. The comparison of results of growing minitubers under artificial conditions with combined light with high-pressure sodium arc lamps DNAT-400 and light-emitting diode lamps showed that in production cost of one mini-tuber produced in artificial light the cost of electricity was between 6 and 9 rubles, and in natural light conditions using the AHM module, it was less than 1 ruble.

Thus, the aerohydroponic method of growing minitubers in natural light conditions on the aerohydroponic module showed undeniable advantages in comparison with other alternative ways of producing minitubers.

Selection of optimal nutrient media, depending on phenological phases of plant growth and development, and optimization of light conditions for the indoor use of installations, also seems to be a highly relevant and promising area of further research in order to ensure the ability to regulate the process of tuberization and creation of the most favorable conditions for growing minitubers.

The use of the aerohydroponic method in natural conditions from spring to early fall avoids high energy costs and other resources that are required in the case of artificial lighting in closed rooms or fall–winter crop rotation in greenhouses.

Recent research conducted at the premises of the Ural Agricultural Research Institute [8] showed that when minitubers are grown with the use of the aerohydroponic method, the time of the onset of phenological phases of plant growth and development significantly differed in varieties of various ripeness groups, which eventually also impacted the quantitative yield of tubers. The composition of nutrient solution also had an impact on indicators of plant growth and development. The results clearly confirm the need to make a selection of optimal nutrient media depending on phenological phases of plant growth and development and to take into account varietal features of the tuberization process.

From a practical standpoint, the opportunity to reduce costs and cheapen minitubers in the near term can contribute to the wider use of aerohydroponic technologies and make them more attractive to original potato seed producers.

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Chapter 5
Production of First and Subsequent Field Generations/Classes of Original, Elite, and Reproduction Potato Seed: Potato Breeding Using True (Botanic) Seeds

Boris Vasil'evich Anisimov, Evgeny Alekseevich Simakov, Sergey Valentinovich Zhevora, and Sergey Nikolaevich Zebrin

Contents

5.1 Production of First and Subsequent Field Generations/Classes of Original and Elite Potato Seeds

When growing healthy (infection-free) potato seed, of fundamental importance is strict compliance with the established process procedure [1]. Lots of minitubers produced with the use of tunnel technologies on the growing media or in an aerohydroponic environment should be planted separately according to their size in the seed field of the first field generation.

Seed tubers that were produced in the seed field of the first field generation seed from minitubers are used next year for growing super-superelite potato varieties.

When the first field generation seeds are grown from minitubers and super-superelite potato varieties, thorough phytosanitary and variety rogueings are especially important. First, rogueing should be carried out shortly after the emergence of full-blown seedlings, when plants reach a height of 15–20 cm. At this time, it is particularly important to identify and remove bushes in case of emergence of

B. V. Anisimov · E. A. Simakov · S. V. Zhevora (✉) · S. N. Zebrin
Russian Potato Research Centre, Moscow Region, Russia

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symptoms of black stem and viral diseases. Usually the total number of removed plants is low, but the earlier they are removed, the less sources of spread of possible infection remain in the field. Varietal differences in this period can hardly be noticed, and therefore, it is almost impossible to completely get rid of varietal impurities during the first rogueing. The second rogueing is the main rogueing. It should be carried out during flowering, when external varietal characters are manifested most clearly not only in the color, but also in the shape of bushes and leaves, the presence of pigments on the stem, and other characters. When establishing the variety of the plant, only young flowers should be examined, since the pigment that colors them may be destroyed due to the effect of sunlight, and the 3–4 days old corolla becomes white. In addition to varietal impurities, during the second rogueing, bushes showing symptoms of bacterial and viral diseases, as well as plants that are lagging in terms of growth, should be removed.

Before the destruction of tops while they are still green, the third rogueing should be carried out, which makes it possible to remove impurities and bushes with signs of ring rot that were unnoticed earlier. Special attention should be paid to plants with signs of wilt. Removing such plants allows eliminating bacterial diseases of potato plantings.

After phytosanitary and variety rogueings, the quality of plantings and the quality of lots of tubers produced in the seed field of the first field generation and super-superelite potato varieties must conform with applicable regulatory requirements of the standard.

Tubers of the super-superelite class are used for planting in the seed fields of superelite potato varieties. Soil preparation, planting, interrow cultivations, spraying, tops removal, and harvesting should be carried out with the use of modern machine technologies. During the growing season, they implement a complete package of seed production and protective measures, including phytosanitary and variety rogueings at least twice during the vegetational season. The quality of plantings of superelite potato seed is determined based on approbation. Superelite potato, in terms of planting quality and tuber quality, must conform with applicable regulatory requirements of the standard. Harvesting should be carried out as early as possible with reasonably preliminary removal of tops while forming the maximum seed marketability of tubers.

Lots of superelite tubers are used for planting on elite potato seed fields. All technological operations related to soil preparation, planting, interrow cultivations, spraying of plants during the vegetational season, preharvesting removal of tops, and harvesting are carried out with the use of modern machine technologies. In this case, however, it is strictly required to implement a set of special agricultural practices that limit the spread of diseases and pests in the field and ensure the optimum yield level, at least 70% of quantitative yield of standard-size seed tubers, and seed quality in accordance with applicable regulatory requirements of standards.

Elite potato plantings are subject to approbation. Elite potato tubers that comply with the standard are sold to seed production enterprises and farms producing commercial potato for variety renovation and variety changing.

In the present context, accelerated promotion of the production of new promising potato varieties from Russian variety originators is particularly important. Various organizational forms of cooperation and models of interaction between variety originators and interested enterprises in the production of potato seed of the highest quality categories and creation of high-quality, competitive bank of original and elite potato seed can be used for this purpose (Fig. 5.1) [2–4].

Within the scope of cooperation, any agricultural enterprise or a private farm seeking the production of new varieties may select any suitable model of production of elite potato seed presented below – model 1 (Table 5.1), model 2 (Table 5.2), or model 3 (Table 5.3), depending on its capabilities and conditions.

Cooperation in the process of production of elite potato seed based on presented models necessitates further investment of financial and material resources in infrastructure development, renewal of means of production, modernization of the storage base, etc. At the same time, enterprises must focus primarily on the use of their own capacities, as well as attraction of additional investments (funds from enterprises, interested investors, business entities, etc.). In this case, it is important to use the most efficient financing schemes on a contractual basis, which are in line with the principles of market relations and ensure a balance between the internal financial abilities of enterprises and all the sources of financing attracted, as well as the state support means that are allocated for these goals.

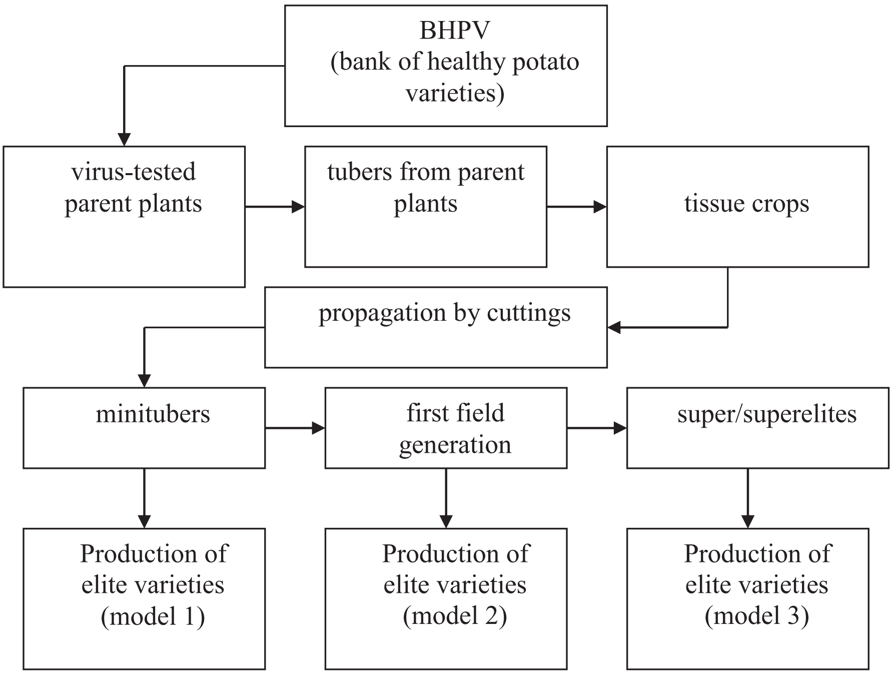

Fig. 5.1 The flowchart of sequential stages and possible models of interaction in the process of original and elite potato seed production. (Source: compiled by the authors)

Table 5.1 Delivery of 10,000 minitubers[a] from the originator on a contractual basis

Year	Class (generation)	Area, hectares	Amount, tons
1	First field generation seed from minitubers	0.2	3
2	Super-superelite varieties	1	20
3	Superelite varieties	5	100
4	Elite varieties	25	500

Source: compiled by the authors
[a]Estimated base price of one minituber starts from 20 rubles per piece

Table 5.2 Delivery of 3 tons of the first field generation seed from minitubers from the originator on a contractual basis[a]

Year	Class (generation)	Area, hectares	Amount, tons
1	Super-superelite varieties	1	20
2	Superelite varieties	5	100
3	Elite varieties	25	500

Source: compiled by the authors
[a]Estimated base price of the first field generation seed from minitubers starts from 60 rubles per kilogram

Table 5.3 Delivery of 15 tons of super-superelite potato seed from the originator on a contractual basis[a]

Year	Class (generation)	Area, hectares	Amount, tons
1	Superelite varieties	5	100
2	Elite varieties	25	500

Source: compiled by the authors
[a]Estimated base price of super-superelite potato seed starts from 30 rubles per kilogram

5.2 Production of Reproduction Potato Seed

Seed stocks of elite class, as well as the first and second breeding generations after the elites, are used for seed plots. The process of growing reproduction potato seed on seed plots includes the same key elements that are used in the seed fields of elite potato seed production. Multiple applications of agricultural practices that limit the spread of viral and other diseases and ensure an optimal yield level, quantitative yield of standard-seed tubers size (70%), and quality of reproduction potato seed lots in compliance with the requirements of applicable standards are mandatory as well. Plantings of the first and second breeding generations, the yield of which is planned to be used for seed goals, are subject to approbation.

The system of provision of potato-growing agricultural enterprises with high-yielding certified seed stock for variety renovation and variety changing in many regions is not smooth running so far and is still one of the topical issues in potato seed production. Common practice of the last years has shown that most agricultural potato production enterprises and private farms regularly purchase lots of certified elite or reproduction (not lower than first and second breeding generations) potato seed for variety renovation and variety changing.

While reproducing certified lots of elite and reproduction potato seed in the field, especially in regions with a high level of infection load, a rapid increase in the development of viral infection with every next breeding generation due to new infections can be observed, which results in reduced productivity and degeneration of potato seed properties [5, 6].

The rate of development of viral infection is largely determined by the susceptibility of varieties to certain viruses and their sets, as well as by the level of infection load in potato seed–growing areas, namely, the presence of viral hotbeds (infected plants), the activity of migrant aphid species – vectors of viral infection, and other factors. Also important are agroclimatic conditions, which in the main regions of potato growing are characterized by great variety in terms of soil composition and fertility, amount and uniformity of distribution of precipitation during the vegetational season, amount of efficient temperatures, frostless season, and other factors.

Following the research of the All-Russian Lorch Potato Research Institute aimed at assessing qualitative and productive indicators in the process of reproduction of elite potato varieties under the conditions of the Moscow region, it was found that the incidence of viral diseases among plants significantly exceeded the regulatory tolerance limits of the standard starting from the third breeding generation and reached 45–52% in the susceptible variety Zhukovsky Early in the fourth and fifth breeding generations and 22–25% in relatively resistant Udacha variety. Reduction in potato productivity in breeding generations as compared to the elites was up to 22.6–39.8% (Fig. 5.2).

Considering the research results, two options of schemes of variety renovation of potato seed in the context of different types of agricultural organizations and peasant (private) farms were recommended (Tables 5.4 and 5.5) [7].

Recommended options of variety renovation schemes are designed for farms with a volume of production of commercial potato of 500 tons. The estimated quantitative yield of standard-size seed tubers (28–60 mm) on seed plots is 20 tons per hectare. Yield of the third breeding generation (scheme 1) and the second breeding generation (scheme 2) is used as commercial potato.

5.3 Potato Breeding Using True (Botanic) Seeds

The possibility of potato breeding using true botanic seeds (generatively) has been attracting the attention of potato researchers and practitioners for many years. Much effort in this area has been devoted to studying the feasibility of the use of true potato seeds as an alternative to seed tubers. During the tests conducted in different countries, seeds produced as a result of open pollination, as well as hybrid flocks produced on different genetic basis (tetraploid-diploid hybrids), were used.

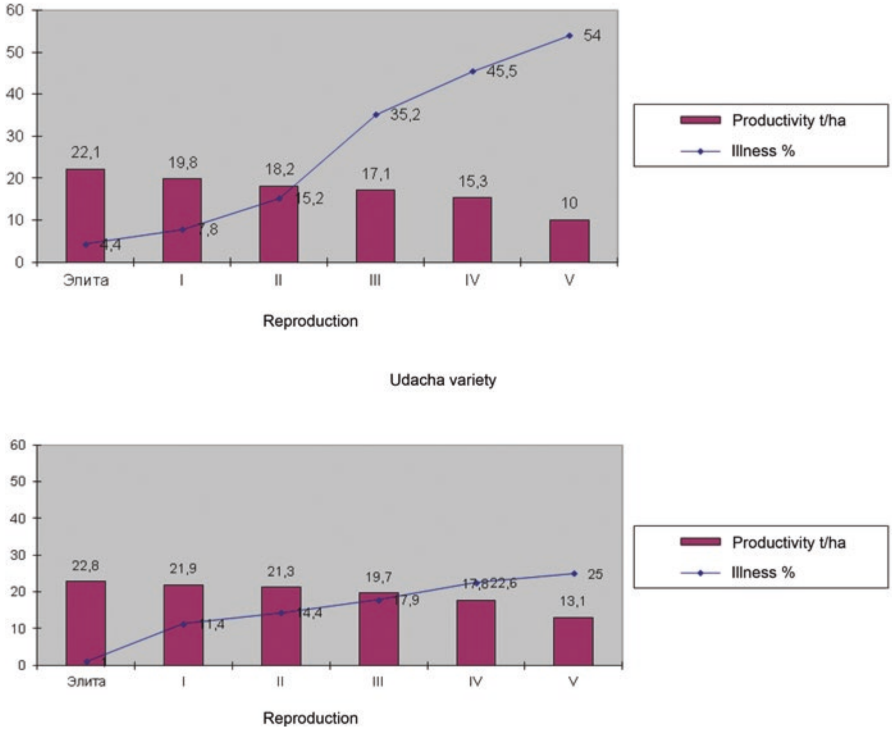

Fig. 5.2 Incidence of viral diseases among plants and yielding capacity of reproduction seeds of elite potato varieties (average value for 2003–2005). (Source: compiled by the authors)

Table 5.4 Scheme 1: A farm purchases 3 tons of elite potato each year

Reproduction potato	Area, hectares	Amount, tons
Seed plot (first breeding generation)	1	20
Seed plot (second breeding generation)	5	100
Commercial potato (third breeding generation)	25	500

Source: compiled by the authors

Table 5.5 Scheme 2: A farm purchases 15 tons of elite potato each year

Reproduction potato	Area, hectares	Amount, tons
Seed plot (first breeding generation)	5	100
Commercial potato (second breeding generation)	25	500

Source: compiled by the authors

In Russia, potato breeding using true seeds also has a long history. Back in the early 19th century, the Free Economic Society, and in the 1930s, the People's Commissariat for Agriculture of the USSR, issued the resolution on mass experimental and economic sowing of potato seed. Seeds produced as a result of open pollination of existing varieties [8] were mainly used in practice during this period, although there were attempts of production and use of hybrid flocks [9].

Major efforts were undertaken toward potato growing from true seed in the Moscow Timiryazev Agricultural Academy at the vegeculture department. A two-year system of production of commercial potato with the use of a bottom set that was first put forward by V. A. Kharchenko in the 1930s was elaborated here [10].

In order to avoid the effect of depression when using seeds from self-fertility, the method of dynamic population breeding was proposed [11]. The hybrids with necessary characters were introduced in genetic heredity by hybridization. As a result, multispecies hybrids were created, self-fertility of which yielded the seeds. Up to 15 species produced due to self-fertility were present in the breeding record of certain breeding generations.

Since 1981, specialists of the Tuber Division of the All-Union Research Institute of Plant Breeding have been working to obtain, by meiotic polyploidization, heterotic self-fertile potato hybrids that were expected to produce homogeneous, highly productive generative offspring [12].

The global program for the advancement of potato production based on true seeds was initiated in the mid-1970s by the International Potato Center (Peru, Lima – CTP). The program focused on the widespread use of this technique in developing countries located in areas with hot climate. As part of this program, comprehensive research was started on a contractual basis in different countries, which included: direct field seeding, transplanting method, production of bottom set on seed fields, annual crop (the yield of plants grown from true seeds is used for consumption), biannual crop (the yield of plants grown from bottom set is used for consumption) [13, 14], storage of the bottom set, and extended systems of potato production designed to last 4–6 years. The study also covered the rest period, germinating ability and durability of seeds, the value of populations produced as a result of open pollination, and flocks hybrid according to economic traits.

In 1983, persistent efforts focused on the commercial use of true seeds were started. Thus, for 1984–1989, in the implementation of the joint project of CIP and the Academy of Agricultural Sciences, 65 kg of hybrid potato seeds were produced in Chile [15]. Ambitious hybrid potato seed production programs were launched in India and Bangladesh. Based on hybrid flocks that have been created and selected in Peru since 1985, international tests were organized covering about 40 countries, including developed countries: Italy, Greece, Finland, and the United States [16].

Since 1992, the scope of research efforts focused on true seeds in CIP has been gradually decreasing due to limited funding, as well as low efficiency in the real-life management of potato production based on true seeds in several countries. A detailed analysis of this situation was presented at the meeting on true potato seeds, which was held in 1994 in Egypt. It was noted that failures were largely due to excessive populism and the use of underclassified populations in agricultural practices with low investment [17]. However, countries such as India, Bangladesh, Egypt, Italy, and the United States continued their study and practical use of true potato seeds. In the United States, "Potato Products International Ltd," a member of the group "Beiosseds" since November 1997, proposed six population varieties for commercial use that were bred from true seeds: Catalina, Mindy, Gilroy, Cinderella, Evelyn, and Atlas. The seeds of these populations were produced by four companies and sold to many countries where they were in demand, especially by amateur vegetable growers [18].

In India, three population varieties were officially registered (HPS 1/13, TPS C3, and 92RT 24), propagated based on true potato seeds. The International Potato Conference that was held there in 1999 offered a massive program for the use of true hybrid seeds in the production of commercial potato.

In China, efforts on growing potato from true seed produced due to open pollination (Kuannae variety) were undertaken as early as at the beginning of the 1950s. In 1975, 1000 kg of true potato seeds were produced, which made it possible to plant 335 hectares with transplant seedlings and 27,000 hectares of commercial plantings in 1976 [11]. In subsequent years, tests of hybrid flocks that were produced both in China and elsewhere were mostly conducted.

At the end of the 1970s, in Russia, at the premises of the potato breeding center of the All-Russian Lorch Potato Research Institute, the work on potato breeding using true seeds was started. Based on nuclear seed stock of interspecific origin from Laptev, original parental forms were selected, which had characteristics and properties that are necessary for seed hybrid production and selective breeding of hybrid varieties – flocks. At the same time, the optimum scheme and technology of the production of commercial potato using true hybrid seed were tested [19].

During the period 1978–2007, work focused on the development of potato population varieties propagated with the use of true hybrid seeds, and nuclear seed stock was generally used for hybridization, which was based on interspecific hybrids by Y. P. Laptev, Y. G. Trinkler, as well as seed stock of the All-Union Research Institute of Plant Breeding and other scientific institutions. Some forms were derived from CIP. A total of 1614 forms passed integrated assessment and were used in the work as nuclear seed stock [19] (Fig. 5.3).

Fig. 5.3 Berries on potato plants. (photographed by A. A. Meleshin) (Source: compiled by the authors)

Berries on potato plants are formed 15–20 days after the beginning of flowering. Inside the berries there are flat light yellow to light-brown seeds, measuring 0.5–1 mm. On average, one berry can contain 150–300 seeds and 1 g of air-dried seeds contains 1200–1800 pcs.

The vast majority of populations was produced based on hybrids in which other species, besides *S. tuberosum*, are involved. The average yielding capacity of the seedling populations selected for further work was 18 tons per hectare, and the average yielding capacity of the best seeds was 24 tons per hectare. The average yielding capacity of selected populations in tuber generations was 28 tons per hectare, which was quite comparable to the yielding capacity of standard varieties. The average yielding capacity of the best populations reached 31 tons per hectare. The recognized varieties of different ripeness groups, as well as the best population during testing, were taken as the standards.

In 1998, a potato variety propagated with the use of true hybrid seeds, entitled Gibridny VK 1, was placed on the National Register. It was allowed for use in individual farms in the North Caucasus and West Siberian regions. In 2005, a mid-season population variety called Gibridny VK 3 was still being prepared for transmission to the State Variety Testing, but it was not accepted for testing because it had about 7% of genotypes not resistant to potato wart disease. According to these efforts, 2.7 kg of hybrid seeds were produced in 1986, and a total of more than 8 kg of hybrid potato seeds were produced for the period from 1986 till 2007.

The flowchart of potato production based on true seeds that was developed in the All-Russian Lorch Potato Research Institute is presented in Table 5.6.

It was assumed that depending on the area of cultivation and phytosanitary condition of seed stock, this scheme could be shortened or extended [19]. The scheme was tested in 1991 on the basis of production facilities of the Tula region and the Krasnodar Krai on the total area of 5 hectares. That said, seed stock that in terms of quality corresponded to the first breeding generation in traditional potato seed production was used for commercial plantings. For this purpose, phytosanitary rogueings with removal of underdeveloped and diseased plants were recommended at all breeding stages.

Table 5.6 Flowchart of potato production based on true seeds

Names of work stages	Seeding, planting rate (per 1 hectare)	Estimate indicators		
		Yielding capacity[a] (tons per hectare)	Rate of propagation	Rot (%)
Hybrid seed production	Originator institution			
Growing bottom set from transplant seedlings (by sowing seeds)	70–100 g	12–15	–	0
Bottom set propagation[b]	0.8–1.2 t	30–35	1:12–15	0
Seed propagation	2.3–2.8 t	25–30	1:6–10	0.1–0.2
Commercial plantings	2.5–3.0 t	20–25	1:5–6	0.3–0.5

Source: compiled by the authors based on information from reference [10]

[a]Range of fluctuations depending on the growing conditions and the level of farming techniques

[b]Tubers weighing 10–30 g

Plants that were grown directly from true potato seeds are usually called seedlings. Seedlings can be produced by directly sowing dry seeds in the field at a yield rate of 100–150 g per hectare. Since potato seeds are very small (1 g may contain more than 1000 seeds), it is recommended to mix them with the filler in a ratio of 1:10 for ease of sowing. The method of hydrosowing the sprouted seeds proved to be more efficient. Furthermore, the seeds that were previously sprouted (5–10% of the total mass) were sown together with the water flow to a depth of 2–3 cm and carefully buried. This increased field emergence, and seedlings appeared after 7–10 days, which simplified weed control and reduced their vegetation period [19].

Many problems that arise during potato growing via direct sowing of true seed can be avoided using the transplanting method, which makes it possible to significantly reduce the seed consumption. With this method, transplant seedlings are grown in a plastic greenhouse or a hot frame. Seed is usually sown in 2–3 weeks before potato planting is started. Seeds are planted in boxes 7–10 cm high and sizes convenient for work. The seeding depth is 0.8–1.5 cm. The seeding is gutter, with a distance between rows of 5 cm. It is then amply irrigated and covered with polyethylene film until the seedlings appear. Nearly 1.5–2.0 g of seeds are sown per square meter, which allows to grow 1000–1500 seedlings. 50–70 g of potato seeds are required to plant transplant seedlings on an area of 1 hectare. Usually in 30–45 days after seed sowing, transplant seedlings reach a height of 12–15 cm, have 5–6 real leaflets, and are ready to be transplanted in the field. It is transplanted without irrigation after rain before the night. When transplant seedlings become 20 and 25 cm high, interrow cultivations are started at a decreased rate. After 2 months, the plants become big and the techniques of their care are no different from the conventional techniques used in growing potato planted in tubers. Harvesting should be carried out in proportion to the formation of bottom set yield (tubers weighing 10–30 g).

Tubers from plants grown on the basis of true hybrid seeds are distinguished by enhanced seed properties. Besides, in areas where the vegetational season is insufficiently long, it may sometimes be difficult to achieve potential crop yields from true seeds even if transplanting method is used. Potato growing is more preferable from true seeds as a biannual crop, which was first proposed by V. A. Kharchenko in the 1930s and more thoroughly elaborated by V. I. Edelshtein in the 1950s. In the first year, in order to produce as many 10–30 g tubers from the bottom set as possible per unit area with transplanting method, the planting rate is increased to 170–280 thousand plants per hectare. The planting scheme is 70 × 25cm, 3–5 transplant seedlings per hole. Harvesting should be carried out in proportion to the development of natural necrosis of tops or in the case of damage of tops due to frost. During harvesting, tubers weighing more than 10 g are selected for storage in winter in a potato warehouse. In the spring of the following year, the tubers of the produced set are graded into three sizes: 10–20, 21–40, and 41–60 g, which are planted in the field manually or using the plant setter – 70 × 25 cm planting system. The planting depth is 5–6 cm. Farming techniques of potato growing from bottom set are similar to the generally accepted technique when growing potato in tubers [19].

In the early 1990s in Russia, more than 20 varieties were presented by different suppliers (Assol, Ausonia, Ballada, Velina, Deva, Ilona, F Carmen, Krasa, Revansh, Farmer, etc.) that are proposed for breeding potato using true seeds, which had a demand from some owners of household plots and plots near summer cottages. These varieties did not pass the state testing and were not officially placed on the National Register of Selection Achievements allowed for use in the Russian Federation, and it seems that the practical result of using these varieties failed to fully meet the expectations of their originators and suppliers.

Gratifying results in the creation and testing of new hybrid varieties for the generative propagation of potato have been recently obtained by Solynta (the Netherlands). In Russia, in the 2019 season, under a cooperation agreement between the All-Russian Lorch Potato Research Institute and Solynta, joint preliminary tests of hybrid varieties with the use of true (botanic) seeds supplied by Solynta were started. It is expected that results that were obtained during preliminary tests under the jointly agreed protocol will reveal the most promising hybrid varieties for their subsequent transmission for governmental tests and official registration with the National Register of Selection Achievements allowed for use in the Russian Federation. This will ensure the protection of rights of originators of hybrid potato varieties in accordance with the Convention of the Union for the Protection of New Plant Varieties (UPOV-91 Convention).

During preliminary tests, a comparative assessment of hybrid potato-growing systems using a traditional seed multiplication system and the economic efficiency of an alternative method of potato breeding using true (botanic) seeds are envisaged.

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Part II
Specifics of Phytosanitary and Process Regulations When Growing Potato Seed of Top-Quality Categories

Chapter 6
Selection of Special Protected Territories (Areas) with Favorable Natural, Climatic, and Phytosanitary Conditions

Boris Vasil'evich Anisimov, Elena Vasil'evna Oves, and Sergey Valentinovich Zhevora

Contents

Infectious diseases caused by pathogenic viruses and bacteria may result in sharp reduction in the quality of potato seed. There is a generally recognized consistent pattern – the higher is the level of infection load in potato seed–growing areas, the greater is the likelihood of the spread of infection through seed and soil, and the more severe is the harm that may be caused by these diseases [1, 2].

In modern global practice, this problem is most successfully solved by creating special protected territories (areas) with favorable natural, climatic, and phytosanitary conditions for growing healthy (free of phytopathogens) potato seed. Creation of such areas, in fact, becomes an integral part of modern potato seed production systems [3–6].

The High-Grade Seed Potato Region in Finland, where stricter standards have been introduced for phytosanitary requirements within protected territory, is well known for its success in creating and operating a special area for growing potato seed of the highest quality category.

Located in Finland, on the coast of the Gulf of Bothnia, the lands of province Tyrnävä, Liminka, and Temmes form the High-Grade Seed Potato Region, which is northernmost in the European Union. The area is located 25 km south of Oulu and is particularly favorable for growing high-quality potato seed due to its soil and climatic conditions. The long light day of the north in the summer period contrib-

B. V. Anisimov · E. V. Oves · S. V. Zhevora (✉)
Russian Potato Research Centre, Moscow Region, Russia

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utes to fair growth and development of potato. Deep freezing of soil in winter protects it from diseases and pests, which is important when growing potato seed.

In the High-Grade area, the purity and quality requirements of the EU are exceptionally high at all stages of potato production, so the seed production of this area is of high quality. It is the main center of potato seed growing in Finland. A key factor in high quality is the production of nuclear seed stock based on meristem growing and micropropagation technologies. Farmers working in this area have high professional skills of growing potato seed of the highest quality.

Great Britain, where on the lands of Scotland and Northern Ireland the most favorable phytosanitary areas are located, which have been granted special status of the EU “High-Grade Seed Potato Region,” also offers great experience in this regard.

Over the last years, persistent efforts have also been taken in certain regions of the Russian Federation toward the creation of areas that are favorable for potato seed production, where more strict state phytosanitary control is exercised, and special attention is paid to the minimization of possible risks of the spread of infection through seed and soil.

The first area of virus-free potato seed production in Russia was officially declared by the special Resolution of the Government of the Republic of North Ossetia-Alania of December 13, 2013. In accordance with the abovementioned resolution, special district for the production of seeds of agricultural plants with a total area of 430 hectares was created in the highlands in the territory of Alagirsky District, which allows placing seed fields for the original potato seed production under the conditions of a clean phytosanitary area, virtually eliminating the possible risk of viral infection of plants from the outside (Fig. 6.1) [7, 8].

In modern execution of phytosanitary control within the boundaries of allocated seed production areas, four groups of pathogenic agents are controlled especially strictly:

- Diseases and pests of quarantine importance (potato wart disease, brown bacterial rot, cyst-forming potato nematode);
- Phytopathogenic viruses transmitted by migrant species of aphids (Y-potato virus (YPV-various strains), A-potato virus (APV), M-potato virus (MPV), and potato leafroll virus (PLRV);
- Viruses transmitted by burrowing nematodes and fungi (potato mop top virus (“Mop-Top”) and tobacco rattle virus;
- Pathogenic bacteria (“black stem” and ring rot of tubers).

Potato diseases and pests of quarantine importance are considered particularly dangerous, so the possibility of their spread through seed and soil in potato seed–growing areas should be completely ruled out.

Phytosanitary requirements with regard to viral and bacterial diseases are strictly regulated by the introduced regulatory tolerance limits within the scope of current national quality standards for potato seed and UNECE International Standard, which is a legal framework for international trade in potato seed.

The degree of potential risks of viral infection of potato largely depends on natural and environmental characteristics in potato seed–growing areas.

Fig. 6.1 Growing first field generations of original potato seed in the highlands of the Republic of North Ossetia-Alania (Russian Federation). (Source: compiled by the authors)

Potato can be successfully grown within an immense territory of Russia, but high-quality seed can only be produced in conditions with the most favorable climate and minimal risk of infection load, especially when it comes to pathogens of virulent (severe) forms of viral diseases. Areas with a cool climate, coastal areas near the seas and large bodies of water, and arable land plots located in the highlands are usually best suited for this.

Given the wide variety of natural and climatic conditions, as well as factors having the strongest influence on the quality of potato seed in places of its production in the Russian Federation, three territories that have significant differences in the level of contamination and total vector activity (migrant aphid species) can be globally distinguished.

Northern and northwestern territories are considered as the most favorable for growing high-quality potato seed. The cool weather during the vegetational season, as well as the relatively low background of insects as vectors of infection, minimizes the spread of the most harmful viruses. The vegetational season in these regions is very short – from late May to mid-September (100–110 days). However, the day length that is characteristic of northern latitudes creates good conditions for rapid growth and development of plants, especially during the initial vegetational season, which is also important for the production of high-quality seed.

Central Russia, including Central Region, Central Black Earth Region, Middle Volga, as well as Urals, Siberia, Far East, despite wide variety of composition and fertility of soil, amount and uniformity of precipitation, accumulated active temperatures, duration of the frost-free period, and other factors, is generally characterized by a relatively moderate background of infection load and can be considered as a reasonably prosperous region for the organization of own production of high-quality potato seed in terms of phytosanitary control.

The South and Southeast regions are less favorable for the organization of own production of high-quality seed. Due to the hot and dry vegetational season and the generally consistently high level of infection load (except in the mountainous and foothill areas of the North Caucasus), the rate of development of viral infections with every next generation is much higher here, than in the areas located in more northern latitudes. High infection rates reduce productivity and degrade seed properties of potato as early as after two to three vegetations and in susceptible varieties – even after the first vegetation.

Spatial isolation In special potato seed production areas, introduction and strict compliance with special process procedure is of fundamental importance. One of the fundamental principles of the creation of special seed production areas is the isolation of the location of land plots with the observance of necessary spatial isolation of healthy seed stock, especially from plantings of commercial potato, vegetable gardens, plots near summer cottages, etc.

For this reason, it is necessary to ensure strict compliance with minimum spatial isolation standards for relevant categories and classes of original and elite potato seed within the boundaries of special seed production areas. Based on modern understanding of the ways and features of transmission and distribution of phytopathogenic viruses, as well as migration of their vectors on potato, spatial isolation of 500 m from possible sources of infection for seed stock of first breeding stages and 100 m for subsequent generations is recommended (Table 6.1).

Generally, well-ventilated coastal areas located near the seas and large bodies of water, as well as cultivated arable land, located in the highlands, are the most favorable environmental factors within the boundaries of seed production areas. It is

Table 6.1 Spatial isolation standards recommended for growing original and elite potato seed

Category	Class	Isolation
Nuclear seed stock	Growing minitubers protected against vectors of infection	Framed summertime greenhouses covered by polycarbonate sheets; tunnels made from lightweight cover materials
Original potato seed	Field breeding (1–2 generations)	500 m distance from any other classes of potato seed
Elite potato seed	Seed fields with superelite and elite varieties	100 m distance from lower classes of potato seed plantings and commercial plantings

Source: compiled by the authors

important that the lands that are allocated for the seed fields are as far away as possible from the potato fields of production facilities and from the private plots of the population. Within the boundaries of an isolated seed production area, there should be no spontaneous potato planting, especially in local vegetable gardens of the population and garden plots near summer cottages.

From a practical standpoint, for the creation of the most favorable environment in a special seed production area, especially when growing first field generations, a reasonably affordable and effective technique is "microisolation" with the use of protective shielding crops of cereals or grasses at the edges of the field (Fig. 6.2).

In order to guarantee quality seed quality in special seed production areas, multiple applications of the most efficient agricultural practices that limit the spread of viral infection in the field are mandatory [9–12].

The set includes:

- Compliance with established spatial isolation standards of original and elite potato seed from plantings of lower breeding generations;
- Creating the most optimal conditions for rapid growth and development of plants, especially during the initial vegetational season;
- Regular phytosanitary rogueings with possibly earlier rejection and removal of infected plants from plantings as potential sources of infection;
- Application of efficient insecticides, as well as agents based on mineral and vegetable oils against aphids that transmit viral infection;
- Determining optimally early time for removal of tops when the maximum seed marketability of tubers is reached, taking into account the monitoring results of virus-transmitting insects (migrant aphid species) in the conditions of each specific farm;
- Disinfection of storages, equipment, machinery, and packages before placement of seed lots in storage.

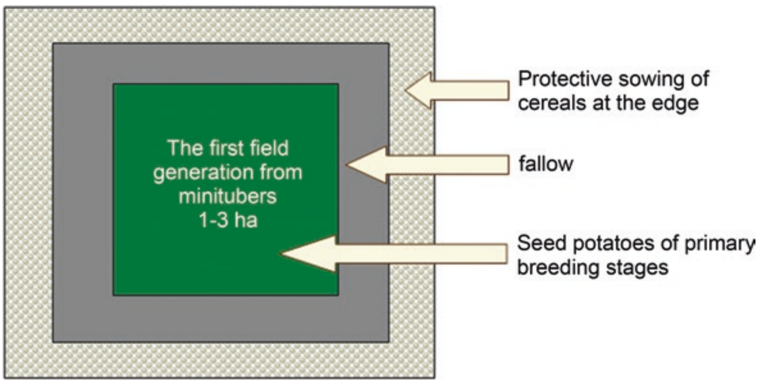

Fig. 6.2 The system of microisolation of first-generation field plantings by sowing grain crops or grass as a protective shield along the field perimeter. (Source: compiled by the authors)

Within allocated seed production areas, seed stock should be produced in strict compliance with formal quality criteria for produced categories and classes of potato seed.

The sources of supply of nuclear seed stock within the allocated areas should only be limited to those that meet standard quality criteria. Nuclear seed stock from several sources may be used, but only if it meets the established quality criteria. Healthy nuclear seed stock must be produced in laboratories and greenhouses that may be located beyond the allocated area.

In future, following the land invasion, only that seed stock should be used within its area that is produced within its boundaries. The planting of seed stock produced outside the territory is generally not permitted. In this regard, it is especially important to ensure adequate control over the vegetable gardens of citizens and, if necessary, organize deliveries of high-quality potato seed for the needs of local vegetable growers and summer visitors. In practice, this is possible only on the basis of the voluntary participation of the local population and the interest of citizens in implementing a phased replacement of their old local seed stock, which is usually represented by multiyear breeding generations, with a new one that is made within the boundaries of a controlled seed production area.

One of the key elements of a special processing method for production within the territory under control is the introduction of a special system of checks, which should combine regular phytosanitary surveys of fields and laboratory testing of seed stock by sheet and tuber samples. It is necessary to ensure strict compliance with regular standards and laboratory testing methods for the relevant classes/generations of potato seed.

The introduction of a check system that combines phytosanitary field surveys and mandatory postharvest monitoring of potato seed lots produced within the boundaries of special seed production areas must become an integral part of the process procedure of production of original and elite potato seed.

In solving the problem of special potato seed production areas, certification of agriculturally used areas by means of surveys with a view to detecting pests, diseases, and weeds with subsequent issue of phytosanitary certificates of hygiene for fields is of fundamental importance as well. The presence of such field certificates is one of the requirements for the voluntary certification of individuals and legal entities producing (cultivating), refining (preparing), packing, and selling plant seeds of higher categories.

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Chapter 7
A Set of Basic Agronomical and Protective Techniques Used in Potato Seed Production

Boris Vasil'evich Anisimov and Sergey Valentinovich Zhevora

Contents

When growing healthy (infection-free) potato seed, of fundamental importance is the use of special agricultural and protective agricultural practices, aimed at acceleration of vegetative growth and tuberization, reduction of infection background, elimination of transmitting agents of viral infection, and removal of tops as early as reasonably possible. Agricultural practices must primarily contribute to acceleration of ripening of plants and early harvesting.

Preparing tubers for planting starts from their picking. In this process, diseased and imperfect tubers are rejected, and flawless tubers are sorted according to their size. One of the primary goals of preparing tubers for planting is to ensure correct preplant sprouting of seed tubers, contributing to the germination of as many eyes as possible, and the subsequent formation of full stems from each underground seedling. The simplest and most massive technique of germination until eye sprouting is heating at a temperature of 8–10 °C 15–20 days before planting. It can be carried out in a storage with active ventilation under cover or in an open area under the film for protection of tubers from rain and damage by frost.

It is more efficient to sprout tubers in a well-lit heated room at a temperature of 12–14 °C. For this purpose, tubers are laid in 2–3 layers in racks or crates 30 days before planting. Two weeks after the start of sprouting, it is advisable to swap tubers around: top tubers should be moved down and bottom tubers should be moved up. In these conditions, all rotten tubers, as well as tubers that tillered out no stalks or have thready sprouts are rejected.

B. V. Anisimov · S. V. Zhevora (✉)
Russian Potato Research Centre, Moscow Region, Russia

S. V. Zhevora, B. V. Anisimov (eds.), *Potato Seed Production*,
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Even more effect can be achieved from tuber sprouting at variable temperature for 50–60 days. Tubers are sprouted in boxes or plastic bags, in a room that is well lit with luminescent lamps for 15–16 hours a day. In the first week, the temperature of 20 °C should be maintained, while for the rest of the time it should be 8–9 °C. The tubers should be laid out on shelves or in boxes; after 2–4 weeks, they should be shifted, changing their position so that they received more light.

In this mode of germination, the high temperature maintained in the first week increases the germination energy and increases the number of eyes sprouted by at least 20%. The following temperature drop reduces respiration intensity and carbohydrate consumption. Short, well-seated sprouts with a large number of root buttons are formed (Fig. 7.1).

The plants grow faster and produce significantly better yield in terms of weight and the number of tubers.

The comparative assessment of various methods of preplant treatment of seed tubers showed that greensprouting at variable temperatures did not only increase the yield [1], but also increased the quantitative yield of tubers of Priekulsky Early variety by 46% and tubers of Lorch variety by 33% as compared to the control (planting non-sprouted tubers) (Table 7.1) [1, 2].

Preplant sprouting of tubers is a mandatory technique in potato seed production process. The method for sprouting at a variable temperature regime removes apical domination of tubers and they germinate with almost all eyes. This, in turn, allows obtaining the predefined number of stems and accordingly regulate seed tuber yield per hectare. Tubers with sprouts up to 1 cm long should be planted into a sufficiently dry soil when the temperature reaches 8–10 °C. Typically, experienced farmers adhere to the principle according to which it is better to plant tubers 1 week later than 1 day earlier, meaning the readiness (ripeness) of soil.

Fig. 7.1 Tubers sprouted at variable temperatures. (Source: compiled by the authors)

Table 7.1 The influence of germination on yield and the number of tubers

Germination method	Variety			
	Priekulsky Early		Lorch	
	Yield, centner per hectare	Number of tubers per bush	Yield, centner per hectare	Number of tubers per bush
Without germination	345	11.6	394	9.0
Regular	412	14.1	447	10.4
At variable temperatures	446	17.0	470	12.0

Source: Compiled by the authors [2]

The preplant tuber treatment technology described above allows ensuring early removal of tops and growing high-quality seed in 2.5 months (from planting up to removal of tops), which significantly mitigates the risks of virus attack.

The density of planting is also important when growing potato seed. On thick plantings the possibility of the spread of contact viruses increases. At the same time, a decrease in the degree of virus infection transmitted by migrant aphid species can be observed. This may be less favorable environment for aphids on such plantings. In addition, the number of aphids per plant on average in the case of thick planting is smaller considering that it is the same per unit area with thick planting and with spaced planting. After all, it is not the number of tubers planted that matters, but the stem density and development of tops, which, in turn, depend on the number of seed tubers, their preplant treatment, nutritive conditions and water supply conditions, varietal features, etc.

In potato seed growing, the recommended density of planting should be at least 60,000–70,000 tubers per hectare with row spacing of 75 or 90 cm [3].

When planting potatoes, it is important to take into account the interrelation between the size of seed tubers, the average number of sprouts per tuber, and the planting weight per hectare.

Potato lots with standard-size seed tubers (28–60 mm) intended for planting should be sorted by tuber size (mm): 28–35, 35–45, and 45–60. That said, seed tubers of different sizes should be planted separately.

Within 2–3 weeks before the start of planting, the average number of sprouts per tuber (number of potential stems) is estimated. In order to do that, one should take 100 tubers of every size of seed tubers and season them for 2 weeks at a temperature of 14–15° before sprouting. Usually 28–35 mm seed tubers form an average of 2–3 stems. Larger-size tubers (35–45 mm and 45–60 mm, respectively) are able to form up to 4–5 stems (Table 7.2) [4].

Small and medium standard-size seed tubers are usually more expensive as compared to larger-sized tubers, since 1 ton of large seed tubers makes it possible to plant a lower number of stems than one 1 of small-sized tubers. For this reason, the number of tubers planted per unit area and the planting weight rate are determined depending on the size and weight, as well as the predefined stem density of a tuber (the number of stems per hectare) [4].

Table 7.2 Estimated planting weight rate depending on the size of seed tubers and the average number of sprouts per tuber

Tuber size, mm	Tuber weight, g	Average number of sprouts per tuber	Number of tubers planted, 1000 pcs per hectare	Planting weight rate, kg per hectare	Distance between tubers in a row, cm
28–35	25	2–3	60	1500	22
35–45	50	4	38	1900	35
45–60	90	5	27	2700	44

Source: Compiled by the authors [4]

The stem density affects both the yielding capacity and the yield structure depending on the size of tubers. When the planting density increases to a certain extent, total tuber yield usually increases, and the average tuber size usually decreases. If there is a need to produce small tubers in the yield structure (for seed purposes), the stem density must be at least 20–25 stems per square meter. If it is advisable to produce larger tubers in the yield structure, then the stem density must be within 15–20 stems per square meter.

Potato seed is usually planted with row spacing of 75–90 cm. If small-sized seed tubers (28–35 mm) are used for planting, the density of planting with row spacing of 75 cm should be at least 60,000 tubers per hectare, and the distance between tubers in a row should be 22 cm. That said, seed consumption will be 1.5 tons per hectare. Medium-sized seed tubers can be planted with a row spacing of up to 35 cm and the density of planting of 38,000 pcs per hectare (1.9 tons per hectare). When larger-sized tubers are used (45–60 mm), even more spaced planting can be used with the distance between tubers in a row of 44 cm and density of planting of 27,000 pieces per hectare. In this case, the planting weight rate will be 2.7 tons per hectare.

During the research conducted in the All-Russian Lorch Potato Research Institute (1979–1987) on various soil types, the impact of wide-row planting systems (140 cm) on the productivity and the quantitative yield of seed on fields of primary seed breeding of potato was studied [5]. Experiments were conducted on coherent sandy soils and on medium loamy soils with common varieties during that period by Domodedovsky and Ramensky.

Seed tubers were let to germinate in plastic greenhouses before planting. The tubers were planted with the use of a plant setter in pre-cut mounds with different plant spacing (35, 70, and 100 cm).

The results of these surveys and inspections showed that the beginning of phenophases does not depend on the tuber planting system, plant height changes, slightly like the number of main stems, but the leaf area in case of 140 × 100 planting system increases substantially. Moreover, it was noted that the bush radius increases significantly with wide-row spacing. For example, in case of 140 × 100 planting system, bush diameter was 150 cm and in case of 70 × 35 planting system it was only 93 cm. The tubers in the bunch were placed along the length of the mound, but along its width, mainly 60 cm in diameter from mother tuber.

In all years of research, yields and the number of tubers per plant were much higher in the option with the wide-row (140 cm) planting system (Table 7.3).

Table 7.3 Productivity of potato plants under various planting systems in loamy sands

Planting system, cm	Average tuber yield per plant		Yield structure, %		
	kg	pcs	Less than 25 g	26–125 g	More than 125 g
Domodedovsky variety					
70 × 35 (control)	0.75	17.2	14.2	83.0	2.8
70 × 70	1.35	25.1	8.5	86.6	4.8
140 × 70	3.66	44.2	7.0	78.8	14.2
140 × 105	4.25	51.0	7.3	70.2	22.5
Ramensky variety					
70 × 35 (control)	1.05	19.4	18.5	76.9	4.6
70 × 70	1.86	28.5	12.2	78.4	9.4
140 × 70	2.85	39.4	10.1	75.4	14.5
140 × 105	3.46	45.2	9.5	69.6	20.9

Source: Compiled by the authors

Table 7.4 Productivity of potato plants under various planting systems in loamy soils

Options	Density of planting, 1000 pcs per hectare	Domodedovsky variety		Ramensky variety	
		number of tubers, pieces per bush	weight of tubers, kg per bush	number of tubers, pieces per bush	weight of tubers, kg per bush
70 × 35 (control)	40.1	15.1	0.58	17.3	0.84
70 × 70	20.5	23.9	0.87	25.0	1.28
70 × 100	14.3	25.4	0.95	29.3	1.56
140 × 70	10.2	25.8	1.45	32.1	1.93
140 × 100	7.0	28.4	1.69	38.2	2.38

Source: Compiled by the authors

Thus, for example, the rate of propagation for Domodedovsky variety varied from 1:25 to 1:51; for Ramensky variety it varied from 1:32 to 1:45. Yielding capacity per bush with row spacing of 140 cm varied depending on the year from 1450 to 4250 g for Domodedovsky variety and from 1930 to 3460 g for Ramensky variety.

In the no-treatment option (70 × 35 cm planting system), yielding capacity per bush for the Domodedovsky variety did not exceed 750 g, for Ramensky variety – 1050 g. Hence, the 140 × 70–100 cm planting system ensures the maximum number of tubers in the yield per every planted tuber as compared to the no-treatment option (70××35 cm) (Table 7.4).

It should also be noted that in the usual 70 × 35 cm scheme (Ramensky variety) during harvesting there were 45% of bushes where the number of tubers was up to 10 pieces per bush, 55% of bushes yielded 11–20 tubers per bush, and only 8% of bushes yielded 21–30 tubers per bush.

When the 140 × 100 planting system was used, only 11% yielded less than 10 tubers per bush. All other 89% of bushes had much higher number of tubers, including 47% – up to 20 tubers per bush, 24% – 21 to 30 tubers per bush, and 18% – 31 to 50 tubers per bush.

The use of wide-row spacing (140 cm) in the seed fields of primary seed production made it possible to increase the quantitative yield of seed by 5–8 times, depending on specifics of studied varieties.

It is important to note that planting with the use of wide-row spacing creates the most favorable conditions for plant growth and development and improves the conditions for all seed production and protective measures in the first seed fields, as well as assessment and rejection of plants at the earliest stages of cultivation, which contributes to improvement of seed quality.

The planting depth of tubers and their arrangement in the mound are important as well (Fig. 7.2). Planted tuber must be 2–3 cm lower than the soil surface, but in no case higher than the leveled surface of soil or at the apex of the mound.

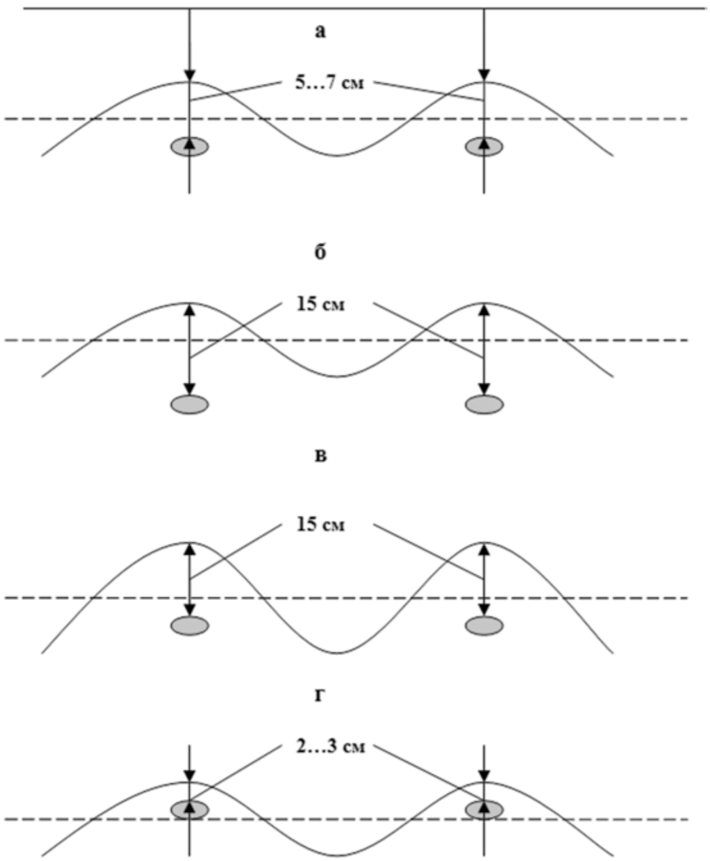

Fig. 7.2 Placement of tubers in mound. (**a**) Correct (shallow planting and low mound). (**b**) Incorrect (deep planting and low mound). (**c**) Incorrect (shallow planting and high mound). (**d**) Incorrect (planted tuber is too close to the top of mound). (Source: Compiled by the authors)

When the traditional planting system with 75 cm row spacing is used, the optimally formed mound must have a base of 75 cm, a height of 25 cm, and a rounded apex of 15–20 cm consisting of loose soil. The presence of lumps in the mound may have a negative impact on the yield and also causes many problems in case of combine harvesting of potato.

The management system should ensure the looseness of soil in the mound due to preplant soil preparation and pre-emergence management. For weed control in pre-emergence care, herbicides recommended for potato may be applied to seed crops.

The level of infection background on potato seed plantings strongly depends on the number of diseased plants as potential sources of infection. Such plants present the greatest danger during the mass summer flight of aphids [6]. Phytosanitary rogueings (removal of diseased plants) are usually carried out 2–3 times during the vegetational season. It is recommended that the first, most important rogueing, is carried out as early as possible when plants are 15–20 cm high. By this time, signs of the most viral diseases (potato rugose mosaic and potato streak mosaic, leaf rolling and curling) and bacterial disease – black stem – have emerged. Late first rogueing drastically reduces its efficiency. The second rogueing should be carried out during mass flowering of plants. Varietal impurities, plants affected by viral diseases, black stem, and ring rot are removed. The third rogueing should be carried out before harvesting when wilt of plants affected by ring rot is most pronounced. Diseased plants are removed together with tubers and taken off the field immediately.

Application of chemical treatments. System aphicides are usually applied for destruction of virus-transmitting aphids on potato seed. Treatment should be started in 10–15 days after the emergence of full-blown seedlings and repeated every 10–14 days.

Information on the efficiency of aphicides in the fight against viruses is quite contradictory. Positive results can be obtained from their application against unwinged populations of aphids before rogueing. This treatment helps to prevent the spread of viruses by wingless aphids, which are transmitted from diseased plants to healthy plants during handling. The effectiveness of the application of aphicides in the fight against persistent viruses (PLRV), transmitted by migrant aphid species within a field, is beyond question. In this case, the aphids die before the virus can be transmitted to a healthy plant. In most cases, there is no effect in the fight against nonpersistent viruses (Y, A, M), since aphids do not die immediately, but 3 hours after spraying, and during this time are able to transmit the virus at the tip of the lancet immediately after feeding on a diseased plant. Moreover, at this time, the aphids are actively fed and fly from one plant to another. However, since it takes about 2 months in most regions from planting to the beginning of the mass flight of summer aphids, and during this period plants cannot accumulate enough of seed tubers, it is necessary to apply aphicides on potato seed plantings [7, 8].

In the research of the All-Russian Lorch Potato Research Institute, good results in the fight against viral and other diseases were achieved in case of three-stage spraying with 1% emulsion of agents based on mineral oils with the addition of insecticide (trichlorol-5) and fungicide (oleocuprite) at 20-day intervals (the first one – when plants are 10–15 cm high) [9]. Unfortunately, this technique did not receive wide practical application in that period for various reasons [9, 10].

In modern foreign practices, the application of agents based on mineral and vegetable oils is one of the most important elements in the system of protective measures when growing potato seed. Thus, based on field tests conducted in Spain, it was found that treatment of potato plantings with mineral oil reduced the number of PVYn-infected plants by 60%, with rapeseed oil – by 40% compared to plantings that were only treated with insecticide imidacloprid (analogue to Confidor, Cruiser, etc.) [11].

Results of 3-year tests demonstrated a significant positive effect of limitation of the spread of PVY with the use of oil Sunspray 11E. The maximum efficiency was achieved after systematic sprayings every week throughout the vegetational season since the emergence of 50% of the seedlings. It was pointed out that the use of an oil-based chemical Sunspray 11E can be particularly effective in production of potato seed varieties with increased susceptibility to PVY (Turska, Wrobel, 1999).

It has also been noted that the use of oils to treat vegetative plants allows creating a mechanical barrier against bites of virus-transmitting aphids. The main way of impact of sprayed oils on insects is asphixy: they suffocate after they are covered with a thin oil film. For example, mineral oil made it possible to achieve the rate of aphid death of over 80%, and some residual toxicity of oils was observed. It was shown that the use of oil chemicals in the fight against PVY is more effective than plant treatment with insecticides. Moreover, it was noted that mineral oil is more effective than plant oil and allows reducing the number of occurrences of PVY to 50%.

However, there are also indications that oil can impede plant growth, especially if used in hot and dry weather, and can also be phytotoxic when used together with agrichemicals, causing necroses on plants.

Results of research conducted in the All-Russian Lorch Potato Research Institute [12] showed that the most effective protection of potato seed plantings against new viral infections can be achieved by spraying plants with mineral and vegetable oils during the vegetational season combined with ½ dose of insecticide (Table 7.5).

The use of oil-based preparations makes it possible to significantly reduce the risk of new infections of plants with phytopathogenic viruses transmitted by migrant

Table 7.5 The effectiveness of the use of mineral and vegetable oils when growing original potato seed

Plant treatment option	Degree of virus infection,%			
	Udacha variety		Meteor variety	
	YBK	MBK	YBK	MBK
Decis Profi insecticide (full dose)	0.5	1.0	0	1.0
1% mineral oil emulsion +½ dose of Decis Profi	0.5	1.0	0	1.0
1% rape oil emulsion +½ dose of Decis Profi	0.5	0	0	0
Control (without treatment)	3.0	2.0	0	3.0

Source: Compiled by the authors [12]

aphid species, and to limit the possibility of transmission of infection to new crop tubers in the seed field of super-superelite potato varieties to the level of applicable regulatory requirements of the standard [12].

New combined system-contact agrichemicals have been increasingly often used over the last years on potato seed. For example, a new system-contact combined insecticide Proteus contains two active ingredients with different modes of action. It has the newest unique form of the chemical – oil dispersion, which is characterized by a perfect content of chemical on layered surface, resistance to washing-off due to rain and active penetration inside the leaf. The combination of the two active ingredients with different mode of action and the form of the chemical – oil dispersion – allows for the control of a wide range of pests, provides long-term action and precludes the emergence of resistance to the chemical. During spraying, oil droplets containing active ingredient are evenly distributed in water. Once it is on the leaves, the water evaporates, and the oil film with an active ingredient remains on the surface. It is the oil film that ensures the strong retention of the drug on the plant, resistance to washing-off due to rain and easier penetration of the system component of the chemical into the leaf tissue.

If there is a threat of potato blight development and Alternaria blight, a set of medium-powered or powerful chemical and biological preparations should be used for spraying of plants during the vegetational season. These techniques make it possible to significantly minimize crop losses due to rots during potato storage period in future.

Preharvesting removal of tops is an important technique preventing tuber infection during harvesting and reducing the risks of development of tuber rots during storage [13]. It is performed on plantings of original and elite potato seed in 14, and on reproductive plantings – at least 7 days before harvesting. In case of removal of tops immediately before harvesting, tuber peel doesn't have enough time to firm become and is severely damaged by harvesting machines, which may result in mass infection of potato with dry and soft rots. Thus, for example, if the degree of potato blight development on plants reached 50% and the mass of the crop is no longer increased, the tops should be immediately destroyed so that tubers are not infected in the soil. In this case, however, the interval between destruction of tops and harvesting should be maintained.

Tops can be destroyed by mechanical mowing, with mandatory removal of vegetational matter from the field, as affected tops are a serious source of potato blight and bacterial diseases of tubers before and during harvesting. Chemical desiccation of seed fields is recommended as well. For this purpose, potatoes are sprayed with Reglon Super, Basta, or Tongara. The working liquid consumption must not be less than 300 liters per hectare.

During harvesting, transportation of potato as well as its placement in storage, it is recommended to perform regular disinfection of packing, means of transport, sizing machines, etc., with a 2–3% copper spray. All potato residues after sortings and pickings should be disposed of, and equipment should be disinfected with a 5% copper spray.

All techniques to prevent mechanical injury to tubers during potato harvesting, picking, transportation, and placement for storage are effective in controlling rots. This requires proper regulation of combine harvesters, potato diggers, grading equipment, careful handling of tubers to avoid their falling from a high height. The acceptable height of tubers falling on a wooden solid surface is 25–50 cm, wooden slatted floor – 15–25 cm, rubberized surface – 50–75 cm, soil – 200 cm, potato pile – 100–125 cm.

Fertilizer application features. The fertilizer system is highly important for growing healthy potato seed. The fertilizer effect on potato plants is multifaceted. They affect the manifestation (or concealment) of viral infection, the nature of the interaction between the virus and the plant, plant resistance to viruses in general, and the timing of the onset of age resistance in particular. Many research papers deal with these issues. Their results are often quite controversial. This may be due to the fact that research was conducted in different soil and climatic conditions, with various varieties in terms of their resistance to viruses, often in seed stock that isn't checked for virus infection, without strict virological control. However, based on the consolidated literature data, the following observations on the effects of individual fertilizers are made.

Large doses of nitrogenous fertilizers with their unilateral or unbalanced application result in the increase in the number of diseased plants in the generation. This is mainly due to the nature of action of a nitrogenous fertilizer on potato plant growth and development. It is known that the ripening of plants slows down in the case of application of large doses of nitrogenous fertilizers, the growth of the above-ground mass increases, and thus the most favorable conditions are created for the spread of contact viruses. High nitrogen doses contribute to the weakening of cuticular cover of leaves, which improves feeding conditions for aphids. A nitrogenous fertilizer also impacts the degree of manifestation of viral diseases. Diseased plants on a high nitrogen background often conceal external symptoms of a disease and reduce yields to a lesser extent. A number of studies suggested that concealing symptoms shows that there is curative action of a nitrogenous fertilizer, which yields a positive effect when growing commercial potato. At the same time, it is more difficult to remove diseased plants during potato seed growing. Finally, it is clear that increased protein and nucleic exchange with increased nitrogen supply to plants contributes to increased viral particle synthesis and increase in their concentration in the plant.

According to many studies, phosphorous nutrition contributes to the decrease in the number of diseased plants in the generation. This may be due to accelerated ripening of plants and earlier beginning of their age resistance. All techniques that focus on accelerated ripening, reduce the number of diseased plants in the generation.

The positive role of potassium is noted in increasing overall resistance of potato to viruses. In some cases, this may be due to a decrease in the number of aphids on plants on a potassium background, which is obviously due to a decrease in sugar content in plant tissues. There is evidence for the number of diseased plants in case of application of chlorine-containing potassium fertilizers, which can be explained by the increase in dispersibility of colloidal materials of a plant cell, contributing to more rapid transmission of viruses.

The research in the All-Russian Lorch Potato Research Institute, under conditions of the stationary experiment on sod-podzol medium loamy soils, the long-term application of potassium fertilizer increased plant resistance to viruses. The lowest concentration of X- and M-viruses was against the nutrient status of potassium sulfate both with regular (60 kg of active ingredient per hectare), and with double (120 kg per hectare) doses. In the first year of growing with sulfuric acid and potassium chloride, no distinctions in concentration of viruses were observed, while next year concentration against the same nutrient statuses was much higher in the option with potash chloride. During potato seed growing, it is recommended to use moderate nutrient status with some increase in phosphorus and potassium doses (by 25–30%) compared to nitrogen. If potassium fertilizers are used, chlorinated forms are preferred [14].

The use of techniques for the reduction of storage losses is highly significant [15]. No later than 1 month before placement of potato in storage, the storage facilities should be cleaned of soil, old tubers, disinfected with lime with addition of a 2–3% copper spray, after which the walls and ceiling of the storage, as well as the walls and boards should be painted white with lime. Besides, fumigation with Vist chemical (bulk blocks 150–200 g per 1000 m^3 of potato storage area) should be carried out.

In order to reduce crop losses of potato seed due to rots in the fields where severe potato blight development can be observed, Phoma rot, bacterial blights, and tubers suffered mechanical damage, during placement in storage and initial storage period, decontamination using Maxim (0.2 l/t) or Fitosporin (1 kg/t) agrichemicals is mandatory. Tuber decontamination is carried out with the aid of aerosol generators of different types, which are mounted on store loaders and/or dressing stations. The working liquid consumption must be 3–5 liters per ton. This water consumption does not require additional drying of potatoes. In addition, fumigation with Vist chemical (bulk blocks 5–10 g/t) is used.

Agrichemicals are the most efficient if they are applied no later than 3 days after potato harvesting, better yet immediately after harvesting during placement in storage according to direct-flow technology. In this regard, it is necessary to comply with safety procedures when handling pesticides.

The efficiency of disinfection of seed stock before placement in storage is quite high. The number of tubers affected by rots of different origin decreases by 10–15%, and natural loss decreases by 3–5% depending on variety.

During the first 20–25 days of temporary or permanent storage (treatment period), the temperature of 14–16 °C and relative air humidity of 90–95% should be maintained. This contributes to faster healing of injuries on tubers. The height of the tuber mound depends on the type of storage and it being equipped with active ventilation and "climate control" systems.

Following the treatment period, the temperature in potato pile should be gradually reduced, but not more than 0.5–1 °C per day for 25 to 30 days, and should be maintained during the main storage period within 2–5 °C, varying slightly depending on the biological characteristics of varieties.

Optimum storage conditions are achieved by ventilation, cooling by outside air, or outside air mixed with air in the storage. In all cases, the temperature of supplied must be positive. In spring, optimum conditions are maintained by ventilation at night and in the morning longer than in winter.

The temperature of the air or air mixture supplied to potato pile must be positive, but 2–5 °C lower than the temperature in potato pile. Storage temperature must be equal to or higher than the temperature in potato pile, but not more than 1 °C.

Practice has shown that recommended potato storage conditions substantially slow down the development of tuber rots and significantly decrease losses during storage.

Potato sorting in winter is unwelcome, since it may contribute to reinfection of tubers with dry rot and, consequently, an increase in harmfulness of a disease. Tubers affected by dry rot should be collected and removed from the upper layer of pile. Detected sites of damage with soft rot should be also carefully removed together with adjacent layer of healthy tubers.

Potato should be completely sorted if more than 10% of tubers are affected by fungal and bacterial diseases.

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Part III
Main Monitoring Items of Potato Seed Quality: Purity of a Variety, Diseases, Pests, Defects

Chapter 8
Varietal Identity and Varietal Purity. Viral and Viroid Pathogens Controlled in Potato Seed Production

Evgeny Alekseevich Simakov, Elena Vasil'evna Oves, Sergey Nikolaevich Zebrin, and Boris Vasil'evich Anisimov

Contents

8.1 Identity of a Variety (Authenticity of a Variety) and Purity of a Variety

Real-life experience has shown that the use of even most state-of-the-art technologies in the process of potato seed production of the highest quality categories does not always rule out the possible emergence of plants with deviating varietal characters. In the context of vegetative potato breeding method, we cannot rule out, for example, the emergence of spontaneous somatic (vegetative) mutations and modifications of varietal characters that subsequently consolidate and accumulate in the following generations and may lead to severe contamination of a variety. The most common types of vegetative mutations and modifications of varietal characters usually include changes in bush habitus, form and shape of leaves and their lobes, stem pigmentation, flower color and form, tuber shape and dimensions, eye color, and peel and pulp color.

The emergence of various types of modifications of varietal characters may also be caused by the use of nutrient solutions that are non-standardized and unbalanced

E. A. Simakov · E. V. Oves (✉) · S. N. Zebrin · B. V. Anisimov
Russian Potato Research Centre, Moscow Region, Russia

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in terms of their composition in the process of maintenance of in vitro collections and clonal micropropagation of nuclear seed stock in vitro for the original potato seed production. The use of different hormonal growth-regulating agents, especially in high concentrations, is also capable of contributing to the emergence of modifications of varietal characters and their further consolidation in the generation (displacement of phenophases and ripening time, the change in biometric and morphological characteristics of plants and tubers, productivity, and other indicators).

In addition, in the process of potato seed production of several varieties of different categories and classes/generations due to errors of technical staff, there may be cases of mechanical contamination of lots of the same variety with impurities of other varieties, especially harvesting, transportation, postharvest processing, sorting, and presale preparation of seed lots.

From this point of view, one of the most important tasks in modern potato seed production is to assess the commercial quality of seed lots and to confirm their conformity with the regulatory tolerance limits of standards in terms of identity of a variety (authenticity of a variety), purity of a variety, and other quality indicators for different classes/generations included in the category of original seeds (OS), elite seeds (ES), and reproduction seeds (RS1-2), which enter production and trade turnover [1–3].

Identity of a variety (authenticity of a variety) may not be determined based on any single feature only; it must be determined according to the totality of morphological characteristics of a plant (bush), its stem, leaf, flower, and tuber (Fig. 8.1).

Two basic methods are usually used in practical work for the identification of potato varieties by morphological characters. The first method is based on the visual assessment of the totality of signs, and the second method is based on the more detailed analysis of certain signs. In this case, it should be considered that certain characters are not identical in their systematic value, which may vary for different varieties.

Plants with varietal characters that deviate from the official description of a variety, as well as impurities of other varieties, are usually identified during field surveys of plantings during the vegetational season and in the process of postharvest quality control of potato seed lots. Since many varietal characters can manifest themselves in different phases of plant growth and development, observations and record-keeping for each variety should be carried out starting from the emergence of full-blown seedlings and further in the process of vegetative growth, including budding, flowering, tuberization, and ripening phenophases (Fig. 8.2).

Field surveys and consideration of various phenophases make it possible to identify plants with deviations from typical varietal characters and impurities of other varieties according to appearance of the bush, shape and color of leaves, stem pigmentation, flower color, as well as the shape of the formed tubers and color of their peel and pulp, in the most efficient way. This is also important in cases where the atypical characteristic is unstable, for example, accelerated (outrunning) height growth during the initial vegetational season or differences in the coloration of flowers can be observed.

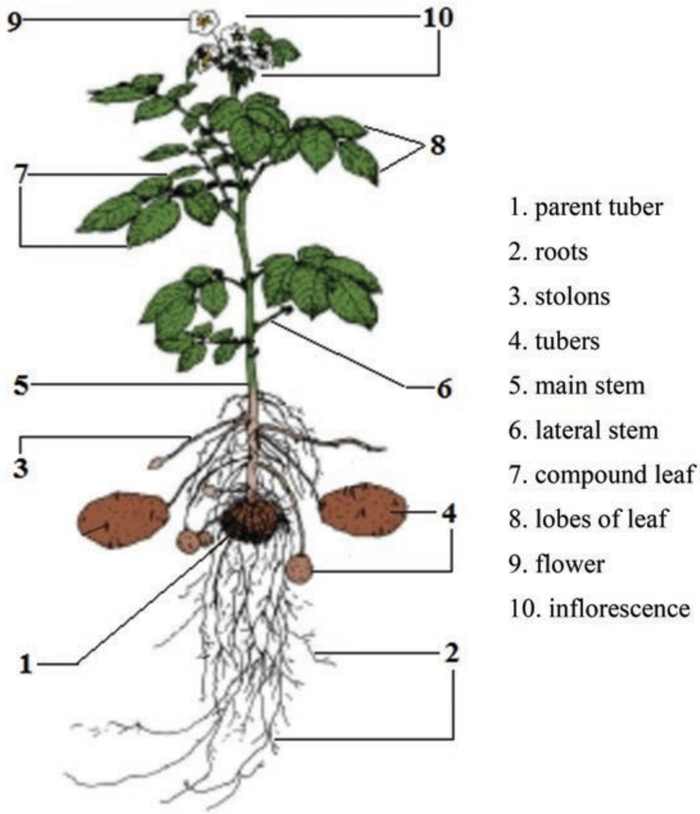

Fig. 8.1 Morphological structures of potato. (1) Parent tuber, (2) roots, (3) stolons, (4) tubers, (5) main stem, (6) lateral stem, (7) compound leaf, (8) lobes of leaf, (9) flower, (10) inflorescence. (Source: compiled by the authors)

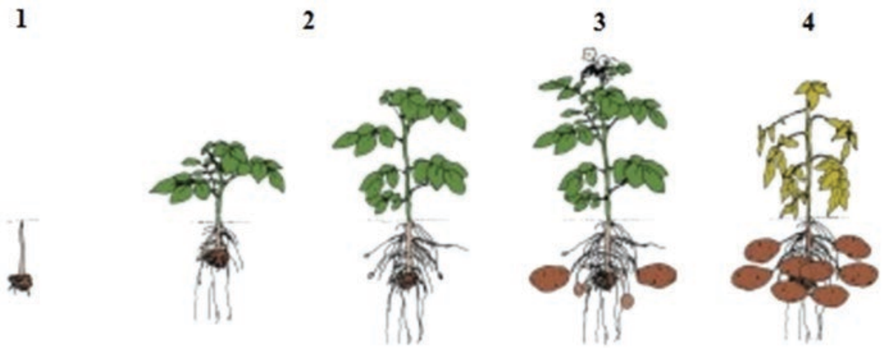

Fig. 8.2 Phases of potato plant growth and development: (1) sprouting, (2) vegetative growth, (3) tuberization, (4) ripening. (Source: compiled by the authors)

In any case, the results of the phenotypic identification of varietal characters must be based on thorough visual assessments in different phases of plant growth and development. The most elaborate study of identified plants with deviant varietal characters can be most conveniently conducted using the method of soil control of varieties on special testing plots on the basis of internationally agreed UPOV character scale, which includes identification of the most important indicators of the degree of manifestation of characters for purposes of variety identification of potato [4].

8.2 Viral and Viroid Pathogens Controlled in Potato Seed Production

According to generalized modern data, significant economic losses in potato production process may be caused by more than 30 types of viruses, 11 types of bacteria, 3 types of phytoplasma, 19 types of nematodes, and more than 50 types of phytopathogenic fungi [1, 2]. Recent years have been characterized by the apparent change in the biodiversity of several agents of diseases, which are dangerous for potato and have an adverse effect on the quality of potato seed:

- New strains of virus appear, causing more severe forms of damage of plants and tubers. Among them, along with the already widespread PVYn (normal strain of Y potato virus), particularly harmful is PVY (ntn), which causes necrotic ring spot on potato tubers (PotatoTuberNecroticRingspot);
- There are increasing problems with bacterioses due to the emergence of new types of pathogens of "black stem" (*Pectobacterium*/*Dickeya* spp.) and more intense spread of ring rot (*Clavibacter michiganensis*) and brown bacterial rot (*Ralstonia solancearum*);
- Researchers registered earlier time of emergence of potato blight on plants and formation of more aggressive natural populations of this pathogen, which, in fact, can become resistant to systemic action fungicides that are used for the treatment of potato plantings during the vegetational season;
- The spread of Alternaria blight is increasing, especially considering that many common varieties are characterized by increased susceptibility to this disease.

Observable changes in the biological diversity of disease agents call for the optimization of relevant statutory indicators and ultimate levels of limitation of phytopathogens that pose the highest danger for potato seed [5–7].

8.3 Phytopathogenic Viruses Transmitted by Migrant Aphid Species and by Contact

1. Potato leafroll virus (PLRV). Primary symptoms: Rolling of the youngest top leaves, starting from the leaf base, sometimes accompanied by change of color into violet; these symptoms can only be observed at early infection stages, especially in hot climate.

Secondary symptoms (from infected tubers): The leaves roll inward and become dry, brittle, and sometimes brown. Leaf rolling is initially manifested on lower leaves and then moves up the plant. Plant growth is slowing down, and the plants may be eventually covered under nearby healthy plants.

Sources and vectors of infection: The source of infection is infected seed. The main vector of PLRV on potatoes is the green peach aphid (Myzuspercicae). Infected aphids remain PLRV carriers throughout their lives.

Diagnosis: Visual inspection of plants. EIA laboratory test or PCR analysis of leaf and tuber samplings.

Control: Minimization of sources of infection, isolation from infected plantings, early rogueings with removal of diseased plants from the field.

The use of aphicides, agrichemicals of mineral, and vegetable oils for spraying of plants during the vegetational season. Early removal of tops.

2. Viruses that cause severe and mild mosaic forms (YPVn – (normal strain), ABK, MBK, XBK и SBK).

Symptoms: Severe mosaic (potato rugose mosaic) is caused as a result of infection with YPV (especially YPVn), as well as in combination with ABK, MBK, XBK, and SBK viruses. However, on some varieties these viruses may cause milder forms of disease in the form of the common mosaic. On plants affected by the common mosaic, there is a spotting of different degrees (light-green mosaic pattern on leaves). In some varieties only the paleness of the leaves (no mosaic) appears, making diagnosis difficult. Infection may occur without symptoms in some varieties. Severe mosaic symptoms are associated with deformation of leaves and/or wilt of a plant. In particularly severe cases, there may be necrosis (potato streak mosaic) and leaf shedding.

Sources and vectors of infection: Infected tubers and plants. The infection is transmitted by migrant aphid species, which may become infected with virus in a split second, but lose infectivity within several hours.

Diagnosis: Visual inspection of plants. EIA laboratory test or PCR analysis.

Control: Minimization of sources and vectors of infection, isolation of seed production plantings from plantings of commercial potato, early rogueings, and removal of diseased plants. The use of insecticides and agents based on mineral and vegetable oils against aphids. Destruction of tops as early as reasonably possible with due account of control data of dynamics in flight of aphids in potato seed–growing areas.

3. Necrotic ring spot on potato tubers (PVY ntn). Symptoms: The degree of manifestation of symptoms differs depending on the variety. YBK strain (ntn) sometimes causes symptoms of mild mosaic on infected plants; some varieties do not show symptoms on the foliage when infected.

Development of symptoms on tubers is contributed by high temperatures at the end of the vegetational season and after harvesting. These symptoms become more evident during storage: originally smooth pink or reddish-brown necrotic rings or arcs begin to appear on the tuber surface before falling in the form of dark-brown craters.

Sources and vectors of infection: Infected tubers and plants. It is transmitted by migrant aphid species.

Diagnosis: Visual inspection of tubers. The laboratory test of tubers with external symptoms to confirm the presence of a virus.

Control: Rejection of affected tubers during picking.

8.4 Viruses Transmitted by Burrowing Nematodes and Fungi

1. Potato mop top virus (PMTV) ("Mop-Top" potato virus). Symptoms: Symptoms on plants are manifested next year after infection and can vary depending on the potato variety. The most acute manifestation is the shortening internodes of the top of the stalk, which results in the formation of a panicular (brush-like) top.

A less acute symptom is yellow chevron-shaped patterns or spots on the leaves, which have little to no effect on the growth of the plant. The symptoms usually appear on 1–2 stems only. Therefore, only some part of tubers is usually affected on the infected plant.

Browning, red-brown circles, or lines on the surface continuing as arcs of red-brown necrotic tissue on the pulp can also be observed on tubers.

Sources and vectors of infection: Inoculum of the PMTV in soil is transmitted through the terricolous fungus *Spongospora subterranea* (powdery scab).

Diagnosis: Visual inspection of plants. EIA laboratory test.

Control: Minimization of sources and vectors of infection in soil. In the absence of a vector, the virus eliminates (self-destructs).

2. Tobacco rattle virus (TRV). Symptoms: The plant shows spotting, leaf deformation, scragginess of some or all stems. The leaves may exhibit deformation with purple red or yellow edges at the tip of the leaf.

Browning of tubers can be observed; in addition, there are brown suberose arcs and spots on the tuber pulp, which are sometimes visible on the peel surface. They somewhat differ from PMTV, but differences on potato varieties make differentiation more difficult judging from visual symptoms.

Sources and vectors of infection: Tobacco rattle virus on potato is transmitted by nematodes *Trichodorus* and *Paratrichodorus* living free in soil.

Diagnosis: Tuber inspection and PCR test. EIA test is unable to detect certain isolates.

Control: The use of cereals in crop rotation. Excessive waterlogging of soil during tuberization period should be avoided whenever possible.

3. Potato spindle tuber viroid (PSTV). Symptoms: Symptoms of lesions of plants and tubers vary depending on the variety, viroid strain, and external conditions. Plants may look stunt and standing atypically straight; their leaves are corrugated.

Tubers may become more oblong than usual or have spindle shapes and unusually large number of eyes. The tissue around the eyes is slightly or strongly swollen and looks like protruding eyebrows. In the case of severe damage, tubers may deform with formation of deep cracks.

Sources of infection: Unlike with many other potato pathogens, PSTV may be transmitted via true (botanic) potato seeds. The disease can also spread mechanically, in particular when infected seed tubers are cut.

Diagnosis: Visual inspection of plants and tubers. PCR test.

Control: To use seed stock that corresponds to the zero-tolerance limit of the standard for all categories of potato seed. To avoid cutting potato tubers with external signs of PSTV.

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Chapter 9
Potato Bacterioses, Monitored on Plantings During Vegetative Growth Period: Tuber Rots Caused by Fungal and Bacterial Pathogens

Boris Vasil'evich Anisimov, Sergey Valentinovich Zhevora, and Elena Vasil'evna Oves

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9.1 Potato Bacterioses, Monitored on Plantings During Vegetative Growth Period

1. Black stem (*Dickeya*/*Pectobacterium* spp.). Symptoms: The symptoms of both pathogenic agents may be very similar in plants, which makes it very difficult to diagnose the pathogen bacterium.

Dickeya spp. initially causes mild (sometimes asymmetrical) wilt of plants. As the disease develops, stem rots can occur, which usually spreads from the axil film of a leaf.

Pectobacterium spp. can cause leaf wilting and rolling toward the interior in the upper portion. Near the stem base, as the disease develops, black mucous rot usually appears. Affected stems are easily removed. Brownish-white rot on tubers usually spreads from the lower portion of the tuber or from the eyes. The affected area is bounded by a dark edge. Distinct fish-like odor can be sensed.

B. V. Anisimov · S. V. Zhevora (✉) · E. V. Oves
Russian Potato Research Centre, Moscow Region, Russia

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Sources of infection: Infected seed tubers. In the field, the disease spreads from infected plants to healthy plants through water drops (raindrops, aerosols) by bacteria and insects, as well as via equipment and packaging.

Diagnosis: Inspection of plants and tubers. Laboratory testing.

Control: The use of certified potato seed. Observance of phyto-hygiene at all sequential stages of potato seed production process.

2. Ring rot (*Clavibacter michiganensis* spp. *sepedonicus*). Symptoms: At the end of the season, the plant usually exhibits typical symptoms of vascular wilting on the leaves in the lower portion, which in some cases are accompanied by leaf rolling. The areas between the leaf veins become chlorotic, and the leaf edges become affected by necrosis.

Vascular ring and surrounding tissue on tubers become pale yellow or vitrified, becoming darker in the course of disease development. The rot may subsequently spread up to the tuber core. As rot spreads in the vascular ring, the peel becomes discolored and deep cracks emerge.

Sources of infection: Infected seed. Bacteria can be spread by equipment (especially cutting movable operating elements).

Diagnosis: Inspection of plants and tubers. Laboratory testing using the immunofluorescence (IF) method and PCR analysis.

Control: Withdrawal from sale of lots of original and elite seed material of potatoes in case of infected tubers detection.

9.2 Tuber Rots Caused by Fungal and Bacterial Pathogens

In the established practice of quality control and potato seed certification, tuber rots are usually divided into two main types – dry and soft rots [1, 2].

The most common dry tuber rots include dry Fusarium blight and Phoma rot. In addition, superficial dry rot may often develop on tubers if they are affected by Alternaria blight.

Development of soft tuber rots most often occurs as a result of transmission of infection from plants infected by potato blight or black stem to new crop tubers. When potato is grown on highly waterlogged lands, rubber rot may develop on tubers during harvesting or immediately after harvesting. High soil humidity during the vegetational season also contributes to development of pink tuber rot, while hot weather during tuberization period can contribute to development of watery wound tuber rot shortly after harvesting.

In some cases, "mixed rots" can be very harmful: potato blight rot and bacterial rot, Fusarium blight-bacterial rot, Phoma-bacterial rot. Entry of fungal and bacterial infection into tubers and development of rots is facilitated by damage and injuries that are caused by machinery and equipment, as well as damage caused by nematodes, wireworms, and larvae of insect pests. In adverse conditions of potato harvesting and storage, possible causes of development of tuber rots may be hypothermia and slight freezing of tubers [3–5].

In any case, it is virtually impossible to separately identify the above diseases and pathogens, contributing to the development of tuber rots, by visual inspection during tuber analyses of potato seed lots. Therefore, according to specifications prescribed in the standard, the above pathogens are controlled by regulatory tolerance limits provided for by various categories of potato seed for dry and soft rots [6, 7].

Below you will find the most characteristic distinctive features of tuber rots, causes contributing to their development, as well as recommended methods of diagnosis and the most efficient methods of their control, which make it possible to minimize losses caused by tuber rots in potato seed production.

9.3 Dry Tuber Rots Caused by Fungal Phytopathogens

1. Fusarium blight (Fusarium spp.). Symptoms: There are several Fusarium species that cause slightly different symptoms. Dry tuber rots usually develop around lesions and lead to dehydration of the tuber. There are grayish-brown foveate spots on the tuber surface; the peel is wrinkled and covered with convex pads of spores of gray-white, yellow, or pink fungi. The pulp at the cut under the stains is loose, dry, and brown. At the final stage of development, affected tissue becomes black, completely destroyed, the tuber turns into a mummy, being covered with wrinkled peel. Mucus is always absent. Planting of tubers affected by dry rot may result in weak plants or nonemergence.

Source of infection: Infected seed and soil. Tuber infection and development of rots is facilitated by damage, for example, that caused in transportation, further contributed by high temperature.

Diagnosis: Visual inspection of tubers and identification of fungi in a special environment.

Control: Avoid damage, apply fungicides and long farming rotation.

2. Phoma rot (Phoma spp.). Symptoms: Tuber rotting occurs during storage. It is manifested on the tuber surface in the form of small roundish dark foveate spots (ulcers), which as the damage develops become black and hollow with uneven wavy edges. Black pycnidia may develop on the surface. Rotten tissue usually becomes brown or black with a distinct border between healthy and affected tissue. The cavities are usually covered with purple, yellow, or white mycelium fungi. Tubers become wrinkled, very dry, hard, and lightweight.

Source of infection: Mainly seed stock; infection may be spread with rain. Tubers may become infected during harvesting, but Phoma rot usually develops after harvesting and postharvest picking and/or at low storage temperatures.

Diagnosis: Visual inspection of tubers and identification of pathogens in a special environment.

Control: Early harvesting with subsequent healing drying. Treatment with fungicides immediately after harvesting. The use of resistant varieties.

3. Alternaria blight (Alternaria spp.). Symptoms: Two types of pathogenic agents are most common: *Alternaria solani* and *Alternaria alternata*. It is almost impossible to distinguish the symptoms of these two pathogens. Unlike with potato blight during the vegetational season of potato in humid conditions, spore-forming fungus of milky-white color does not emerge on the back of the leaf. Superficial dry rot may develop on affected tubers.

Source of infection: The fungus survives on potatoes or other organic residues in the field or directly in the soil as spores.

Diagnosis: Visual inspection of leaves and tubers.

Control: The use of fungicides, especially those containing mancozeb. Susceptible varieties may require spraying with special agrichemicals.

9.4 Soft Rots Caused by Pathogenic Fungi and Bacteria

1. Phytophthora rot of tubers (*Phitofhthara infestans*). Symptoms: Dark brown, sometimes pinkish area usually appears on the surface of infected tubers. Internal rot is reddish brown, grainy; it either may occur next to the tuber surface or develop deep into its core. Rot develops nonuniformly, without any distinct line of travel; it may be thready in shape. Affected tubers are often characterized by a hard tissue with brown necroses; disease development may lead to a wet decomposition of the tuber pulp.

Source of infection: Plant spores infect tubers in soil. Phytophthora rot of tubers can be observed during harvesting and continue its development during storage. This is often contributed by tuber damage during postharvest processing.

Diagnosis: Visual inspection of plants and tubers.

Control: Prevention of potato blight of tubers by disease control in the field.

2. Pink rot (*Phitophora erythroseptica*). Symptoms: Tubers with rubber texture are usually affected in the lower portion. When exposed to the air, affected tissue becomes pink in an hour. Rot develops in lenticels and eyes shortly after harvesting, especially if the weather on the day before harvesting was humid and warm. Tubers may have a distinctive odor and produce a colorless transparent liquid when squeezed hard.

Source of infection: Soil. Infection development is contributed by high soil humidity and temperatures. Rot develops during harvesting or shortly after harvesting.

Diagnosis: Visual inspection of tubers and identification of pathogens in a special environment.

Control: Adequate farming rotation and drainage. Rejection of affected tubers.

3. Rubber rot (*Geotrichum candidum*). Symptoms: Rot develops during harvesting or immediately after harvesting in tubers grown on waterlogged soils. The tuber surface, which is colorless and wet by touch, is covered with white mycelia spots. Watery gray rot quickly spreads from the peel toward the interior. The cut tuber bleeds with an acetic smell.

Source of infection: Soil; is associated with waterlogged soils, warm conditions and forthcoming harvesting period.

Diagnosis: Visual inspection of tubers and identification of fungi in a special environment.

Control: Proper drainage of soil. Storage of tubers harvested from the flooded areas of the field separately from the rest of the harvest may reduce the rate of rot spread.

4. Watery wound rot (Pythium spp.). Symptoms: Tuber rot develops on small wounds shortly after harvesting, especially when plants were growing under hot weather conditions. Tubers become discolored and mucous by touch. Rot develops in tuber tissue with a distinct dark border between healthy and spongy light brown affected tissue, which becomes dark in the air. Rotten tissue usually smells like alcohol first; then it smells like fish.

Source of infection: Soil-borne. Tuber infection occurs through small lesions. Rot quickly spreads on freshly dug tubers, the peel of which has not yet coarsened. The spread of rots is contributed by warm weather during harvesting.

Diagnosis: Visual inspection of tubers and identification of fungi in a special environment.

Control: Do not use the fields where the disease was observed. Ensure formation of a strong tuber peel. Avoid damage during harvesting and postharvest processing. Perform healing drying with ventilation if necessary.

5. Tuber rot due to infection with "black stem" (*Dickeya*/*Pectobacterium* spp.). Symptoms: Disease development in the field usually leads to the emergence of black mucous rot near the stem base, sometimes from spreading the axil film of a leaf. Soft brownish white rot on tubers spreads from the lower portion of the tuber or from the eyes. The affected area is bounded by a dark line. Rot has a distinct fish-like odor. The symptoms caused by both pathogenic agents may be very similar in plants, which makes it very difficult to diagnose the pathogen bacterium.

Source of infection: Infected seed tubers, but infection may be transmitted in the field from infected plants to healthy plants with water drops, with bacteria (raindrops/aerosols), as well as with insects. Contact contamination may occur from infected equipment or containers. Humid growing conditions contribute to infection with both pathogens and disease development, but cool and humid weather conditions are more favorable for *Pectobacterium*, while warm and wet weather conditions are more favorable for *Dickeya*.

Diagnosis: Visual inspection of plants and tubers. EIA laboratory test.

Control: Use healthy certified potato seed for planting. Special attention should be paid to phyto-hygiene at all stages of potato growing, harvesting, and storage.

6. Ring rot (*Clavibacter michiganensis* spp. *sepedonicus*). Symptoms: Rotting of the vascular ring can be observed on tubers, and surrounding tissue becomes pale yellow or vitrified, becoming darker in the course of disease development. When pressing on the tissue, light yellow mucous mass is released from the ring vessels. The rot of a cheese-like or crumbly structure usually has no odor and

may reach the tuber core. As rot spreads in the vascular ring, the peel is discolored to white, and deep cracks appear.

Source of infection: Seed stock. Tubers of some varieties may be asymptomatically infected. Bacteria may also spread by infected equipment, especially cutting machines.

Diagnosis: Visual inspection of plants and tubers, testing using the immunofluorescence method (EIA) and PCR.

Control: In most countries, it is considered a quarantine disease, and in the event of its outbreak, infected seed stock should be removed from circulation and disposed of.

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Chapter 10
Damage to Tubers Caused by Scab and Crater Rot, Defects Caused by Physiological Disorders Under the Influence of Abnormal Conditions, and Damages, Injuries, Diseases, and Pests of Quarantine Significance

Boris Vasil'evich Anisimov, Sergey Valentinovich Zhevora, and Elena Vasil'evna Oves

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10.1 Damage to Tubers Caused by Scab and Rhizoctonia

The damage to seed tubers caused by various types of scab and rhizoctonia largely determines commercial qualities of potato seed and is regulated by the tolerance limits of the standard [1–3].

1. Common and netted scab (Streptomyces spp.). Symptoms: They vary from superficial corked damage to the formation of brown ulcers of various size and to extensive protruding plaques appearing alone or in a group. Netted scab causes surface corked browning of the peel.

B. V. Anisimov · S. V. Zhevora (✉) · E. V. Oves
Russian Potato Research Centre, Moscow Region, Russia

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A tuber is considered to be affected if the area of the affected surface exceeds 33.3% or more than 1/3 of the total surface area.

Sources of infection: Common scab is caused by *Streptomyces scabiei* and other spp., for example, *S. turopaeiscabiei* and *S. Stelliscabiei*. Netted scab is caused by *S. turopaeiscabiei* and *S. reticuliscabiei*.

The infection persists in soil and on seed tubers. Dry and hot weather contributes to the spread of the disease, especially during and after tuberization, growing on light, well-drained soils. Symptoms do not progress during storage.

Diagnostic technique: Visual inspection of tubers during the tuber analysis of potato seed lots.

Control: Use resistant varieties. Water during tuberization, but excessive irrigation increases the risk of occurrence of powdery scab. Avoid alkaline or lime-treated soils.

2. Powdery scab (*Spongospora subterranea*). Symptoms: During harvesting, there are scattered, round, slightly elevated pustules that, when opened, release a powdery spore mass of brown color, leaving ragged edges of the peel. Infection during eye development may cause nodules (gallnuts) of different sizes on the apical portion of tubers. Root galls may also form on stolons and roots.

A tuber is considered to be affected if the area of the affected surface exceeds 10%.

Sources of infection: Infected tubers and soil. Infection contamination is contributed by damp and cold weather during the tuberization period, especially on heavy soils.

Diagnosis: Visual inspection of tubers, detection of ball-shaped spores under the microscope.

Control: Resistant varieties and long farming rotation are the most efficient methods of fighting against the disease on land-infected plots. Proper irrigation, especially during tuberization period, contributes to minimizing infection.

3. Silver scab (*Helminthosporium solani*). Symptoms: Disease development starts from the emergence of small round silver portions on the tuber peel. During storage, as individual spots expand and merge, large silver portions of the affected surface are formed. Tubers may become dehydrated, leading to shriveling.

Sources of infection: The source of infection may be seed tubers, infected soil, or spores, surviving in dry soil in the storage. Symptoms are usually not visible during harvesting, but the disease can develop rapidly in a reservoir under wet and warm (>3 °C) conditions.

Diagnosis: Visual inspection of tubers and identification of fungi in a special environment.

Control: Treating tubers with a fungicide before transplanting or in the storage after harvesting may slow down the spread of infection and disease development, but this does not suppress the already present infection completely. Storage at low temperatures allows controlling the disease to some extent. Conformity with regulatory tolerance limits in terms of the number of wrinkled tubers.

4. Black speck/black scab (*Rhizoctonia solani*). Symptoms in plants: Non-field-uniform emergence, low height, and wilt. At the base of the stem, brown, somewhat hollow ulcers with sharp edges develop immediately above the ground; stem may be covered by a taint of fungus mold. The development of fungal lesions leads to dry and brittle tissue.

In tubers: Damage is caused by dark brown or black sclerotia formed on the tuber surface; the area of damage is difficult to estimate on unwashed tubers. Symptoms can occur in the form of tuber cracking, forming a star-mesh pattern with an elephant hide texture and the formation of funnel-shaped cavities.

Source of infection: The infection is spread via seed stock and soil. Contamination typically occurs in loose soil in dry and cold weather.

Diagnostic technique: Visual inspection of tubers during tuber analyses of potato seed lots. A tuber is considered to be affected if the area of the affected surface exceeds the tolerance limits of the standard.

Control: Use well-sprouted seed tubers. Avoid premature and deep planting in cold weather. Long farming rotation. Treat with fungicides before planting.

10.2 Defects Caused by Physiological Disorders Under the Influence of Abnormal Conditions

Recent years have been characterized by the apparent impact of high temperatures on potato during the vegetational season due to increasingly frequent short-term and long-term summer droughts and increased level of CO_2 in the atmosphere. Observed effects from these factors can also significantly reduce the indicators of external appearance of tubers and other commercial qualities of potato seed, in particular [4]:

- The probability of slowing down and even stopping the growth processes during the vegetational season increases, followed by the emergence of defects of the so-called secondary growth in the form of tuber deformation, vitrification of the pulp, formation of growth cracks on tubers, cavities in the tuber core, and other defects.
- Researchers point out an increase in the average tuber size and the number of large-sized tubers that are inadequate in terms of potato seed dimensions.
- Development of rots increases due to defects in tubers during storage due to humid conditions in winter.

Below you can find a description of the most frequent defects caused by physiological disorders under the influence of abnormal conditions.

1. Tuber deformation and vitrification. Symptoms: Tubers are considered to be misshapen when they differ from the normal shape characteristic of a particular variety. These include pear-shaped tubers, dumbbell-shaped tubers, and tubers of other shapes, as well as tubers with various nodules. There is also frequent

rotting of the stem end of the tuber due to the lack of starch granules in the pulp, which leads to transparent vitrification.

Causes: Observed defects are usually caused by changes in growth conditions, especially when precipitation follows a hot period. Changing conditions lead to uneven growth and deformation of a tuber after its formation and elongation. Tuber deformation usually occurs during the second phase of tuberization. Vitrification occurs in tubers formed earlier than others, when after necrosis of tops due to uneven influx of macronutrients, younger tubers take their energy from older ones who are forced to convert their starch.

Control: Such growing technology should be used that prevents nonuniform growth. Early desiccation of tops should be carried out, or the time between desiccation and harvesting should be shortened to reduce vitrification.

2. Growth cracks. Symptoms and causes: Emergence of cracks may be caused by several factors (physiological disorders, viruses, herbicides) or their combination.

Physiological growth cracks are formed as a result of fast growth of tubers, often caused by the increase in soil humidity after a dry period in the second half of the vegetational season.

Virus cracks: They may be caused by viral infection (mosaic viruses and PMTV); symptoms are usually difficult to distinguish from physiological cracking.

Cracks caused by the application of herbicides: some herbicides, for example, glyphosate or its counterparts, may lead to deformation and formation of deep cracks on plant tubers on which the agrichemical was accidentally applied.

Control: Strict compliance with the rules for application of herbicides. Soil humidity control.

3. Internal cavities/hollow heart. Symptoms: cavities of various configuration and size are formed inside the tuber. The cavity is covered with a thin creamy or light-brown peel. If the cavity does not break the tuber surface, no rotting of tissues and various taints can be observed.

Causes: Hollow heart occurs as a result of delayed growth of internal tissues as compared to external tissues. This can be facilitated by the increase in soil humidity after a dry period, as well as excess nitrogen during tuberization. Cavities can be more often observed in the core of large tubers.

Control: Conformity with the tolerance limits of the standard in terms of the availability of internal defects in tubers.

4. Wrinkled tubers. Symptoms: Tubers that lost turgor become wrinkled and pithy.

Causes: Dehydration and loss of tuber turgor can be attributed to a variety of causes, including excessive ventilation, loss of moisture due to damage caused by diseases and physiological disorders, damage caused by silver scab, as well as strong germination during prolonged storage.

Control: Careful monitoring of tubers during postharvest processing and healing. Tuber storage under conditions that are the most favorable for a particular variety, including the duration of the storage period. Minimization of disease emergence risks.

5. Hypothermia and slight freezing of tubers. Symptoms: Hypothermia causes color change of tuber tissue from reddish brown to black. Symptoms on the tuber surface in the form of dark-brown spots. Internal symptoms may occur as well.

The pulp of frozen tubers bleeds, and the edges of affected areas become black. One can often see a distinct border between healthy and affected tissue.

Causes: Low temperature (below 1 °C) before harvesting or in the storage. Tuber damage may also be caused by a rapid temperature change (not necessarily below the freezing point).

Control: Visual inspection of tubers. Harvesting before frost. Maintaining optimum storage conditions.

10.3 Damage and Injuries from the Effects of Machinery and Chemicals

1. Mechanical damage. Symptoms: Cuts, tears, cracks, dents on tuber tissue. Cracks and cuts deeper than 5 mm and longer than 10 mm in the tuber can lead to secondary contamination by rot-causing pathogens.

Causes: Mechanical damage may be caused to tubers due to the operation of machinery, starting from harvesting and ending with delivery to end consumers. Damage may vary from small superficial cracks to deep cuts, cracks, and tears in pulp. The extent of damage depends on many factors. Bruises may be caused by blows or compression.

The main cause of mechanical damage is the use of faulty machinery and equipment and negligent handling of tubers at all stages of work with them.

Control: Use properly functioning machinery and equipment operating at optimum speed. Potato should be placed in storage carefully. Harvesting should be carried out with special care in dry weather; avoid transloading of cold tubers.

2. Chemical damage. Symptoms in plants: Depend on the chemicals being used and may include deformation of the bush and yellowing of leaf edges as well as their rolling and curling. The seedlings can be weak, uneven, and a larger number of rejects.

In tubers: Are manifested in the form of growth cracks and grid pattern on the peel. Affected tubers can germinate to form many weak stems.

Causes: Spraying of plants from unwiped containers or wind deflection of the sprayed preparation during treatment of other crops. Problems usually arise in the case of application of herbicides, such as glyphosate and/or growth-regulating agents.

10.4 Damage Caused by Nematodes, Wireworms, and Larvae of Insect Pests

1. Potato stem nematode – Ditylenchus destructor. Nematodes are mainly transferred together with infected seed tubers. Healthy certified potato seed should be used; fields, with previously reported outbreaks, should be excluded. It is difficult to get rid of nematodes, since they live on a large number of plants. The use of cereals in farming rotation together with efficient weed control in crop rotation can reduce their number.
2. Wireworms (*Agriotes*/*Tandonia*/*Arion* spp.). Larvae eat out small superficial or deeper passages in the tuber. The passages are always narrow (as opposed to damage caused by slugs), but can be highly branched. Damage caused by wireworms allows other pathogens to penetrate the tuber, which may cause different types of rots.

In addition to wireworms, tuber rotting due to dry or soft rot tubers (depending on storage conditions) often results from damage caused by chafers, cotton leafworms, slugs, and potato tuber moth.

3. Chafers (larvae) eat out cavities in the tubers. Unlike cotton leafworms, they do not leave peel leftovers along the edges of the cavities.
4. Cotton leafworms (caterpillars) eat out cavities of different sizes in the tubers. Peel leftovers in the form of a fringe on the edges of tubers can be observed after their activity.
5. Slugs eat out cavities of different sizes in the tuber pulp; as a result, it may facilitate the entry of phytopathogens into tubers causing different types of rots.

10.5 Diseases and Pests of Quarantine Importance

There should not be any infectious diseases and pests of quarantine importance in potato seed. If they are detected, such potato seed lots must be withdrawn from commerce, and infected seed stock must be destroyed under the control of quarantine service representatives [5].

1. Potato wart disease (*Synchytrium endobioticum*). Symptoms: Nodules that resemble cauliflower are formed near the stem base, as well as on stolons and stems. These nodules are green above the ground and milky below the ground. With the necrosis of the plant, these nodules wilt and become black.

Source of infection: Infected tubers or fungi spores contained in soil.

Diagnosis: Visual inspection of tubers and stem base. Microscopical investigation of spores.

Control: In the case of case finding, supervisory phytosanitary authorities must be informed.

Potato growing on infested fields must be prohibited.

2. Brown rot (*Ralstonia solanacearum*). Symptoms: Wilt of the youngest small leaves can be observed on the plant, especially during the hottest time of the day; one may get the impression that plants recover during the night. Wilt is not often the case in areas with cool climate.

Disease development results in plant growth retardation, overall wilt, leaf yellowing, and necrosis of the plant. Bacterial gum may sip from the vascular tissue of cut stems.

Initial symptoms on tubers emerge in the form of brown spots on the vascular ring, starting from the stolon end. As the disease develops, complete rotting of the vascular tissue occurs, along with emergence of pale sticky excreta resulting in adhesion of soil to these areas, in the area of eyes and/or stolon end of tuber.

Source of infection: Infected tubers or infected plant residues in the fields.

Infection can spread via equipment or water in the irrigation scheme.

Diagnosis: Inspection of plants and tubers. Laboratory testing using the immunofluorescence (IF) method and PCR analysis.

Control: In most countries, quarantine is used, that is, elimination from production of infected seed stock and its destruction in case of case finding.

3. Cyst-forming potato nematode (*Globodera* spp.). Symptoms: Potato is affected by two varieties of cyst-forming nematodes: *G. rostochiensis* and *G. pallida*. Contamination is manifested in the field in the form of the presence of pockets of weakened or scraggy plants prone to wilt, or plants with dark or discolored leaves. On the roots one can distinguish (with the naked eye or with the aid of a handglass) white or golden-yellow cysts with a size of less than a pin head.

Source of infection: Infected tubers and soil. The spread of infection can occur by the transfer of infected soil on movable operating elements of machinery or by floodwater.

Diagnosis: Soil testing (before planting) using a microscopic examination or a PCR analysis. Visual inspection of plants at the grassroots.

Control: The use of resistant varieties, long farming rotation, use of nematocides. Application of trap crops (traps) may contribute to nematode population decline.

4. Potato tuber moth. Symptoms: Larvae of potato tuber moth feed both on growing plants and on potato tubers.

In plants: Larvae mine the leaves, eating out the inner tissue, especially along the main leaf veins; such damage (“mines”) is usually negligible.

In tubers: The emergence of potato tuber moth in tubers may go unnoticed during harvesting, but they may contain eggs or young larvae. Feeding on the tuber, larvae eat out increasingly long passages under the peel or inside the tuber. Affected tubers may lose excessive moisture and shrivel. Secondary fungal infection that enters through the holes can cause tuber rotting.

Source of infection: Infection can spread via infected tubers in storages; butterflies of potato tuber moth may enter storages and lay their eggs there.

Diagnosis: Visual inspection of leaves and tubers.

Control: Certified seed should be used. Delivery of potatoes from regions where potato tuber moth may be widespread should be avoided.

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Part IV
Potato Seed Quality Control and Certification

Chapter 11
Quality Standards for Various Categories of Potato Seed: Crop Surveys and Appraisement of Plantings and Tuber Analysis

Boris Vasil'evich Anisimov

Contents

11.1 Quality Standards for Various Categories of Potato Seed

In the last two decades in the Russian Federation, much attention was given to the improvement of the certification system and quality control of potato seed toward unification with the fundamental principles and rules of modern international systems in this area. At the same time, standard indicators of commercial quality of various categories of potato seed were optimized and brought into proximity with generally accepted internationally agreed normative indicators [1–8].

In 2016, employees and specialists of the FSBSI All-Russian Lorch Potato Research Institute, FSBI "Rosselkhoztsentr," and Potato Union of Russia developed a new interstate draft standard for potato seed that was widely discussed and was put into effect since 2018 as the national standard in the seed certification system GOST 33996-2016: "Potato Seed. Specifications and Quality Assessment Methods." The standard specifies differentiated standard indicators of commercial quality for the three categories of potato seed – original (OS), elite (ES), and reproduction (RS) (Table **1**) [9, 10].

B. V. Anisimov (✉)
Russian Potato Research Centre, Moscow Region, Russia
e-mail: anisimov@vniikh.com

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The tolerance limits specified in the standard take into account the possible reduction of individual quality indicators with the increase in the number of generations in the process of potato seed production (Table 11.1).

The tolerance limits are brought in line, to the extent possible, with generally accepted internationally agreed regulatory requirements of the UNECE International Standard in terms of the most important quality indicators [11, 12].

For potato seed lots intended for planting and destined for trade turnover, the standard also provides for fairly heavy restrictions for availability of tubers:

- which fail to conform requirements for size – 3%;
- which are affected by stem nematode – 0.5% (for RS category only);
- which are affected by rust spot and pulp spotting (when more than 1/4 of the lengthwise cut of a tuber is affected) – 5%;
- damaged by agricultural machinery (cuts, tears, cracks, dents on tuber tissue more than 5 mm deep and more than 10 mm long) – 5%;
- damaged by agricultural pests (wireworm – more than three passages, rodents, chafers, and cotton leafworms), but with unaffected eyes – 2%.

There should be no infectious agents and pests of quarantine importance on potato seed (potato wart disease, brown bacterial rot, golden cyst-forming potato nematode, potato tuber moth). In the category of original and elite potato seed, there should be no tubers affected by ring rot.

Table 11.1 The regulatory tolerance limits for potato seed plantings and lots in terms of varietal purity and manifestation of physical signs of the most dangerous diseases on plants and tubers[a]

Indicator name	*Nuclear seed stock* in vitro	Minitubers	OS	ES	RS_{1-2}
For plantings during approbatory inspection (percentage of plants), not more than					
Other varieties	0	0	0	0	0,5
Viral diseases[b]	0	0	0,4	1	2
Black stem Dickeya/Pectobacterium spp.	0	0	0	0	1
For lots (percentage of tubers), not more than					
Soft rot (unless caused by *Synchytrium, Clavibacter, Ralstonias)*	0	0	0	1	1
Dry rot	0	0	0,5	1	1
Scab (common and netted)[c]	0	0,5	5	5	5
Powdery scab[c]	0	0	1	3	3
Black speck (Rhizoctonia blight)[c]	0	0	1	3	5
Wrinkled tubers, including due to development of silver scab	0	0	1	1	1

Source: Compiled by the authors based on information from the standard GOST 33996-2016
aThere should not be any infectious diseases and pests of quarantine importance in seed stock of all categories and in soil
bOnly symptoms of severe mosaic forms (YPV) and potato leafroll virus (PLRV) are taken into account
cA tuber is considered to be affected by a disease if the area of the surface affected by common and netted scab exceeds 33.3%, if the area of the surface affected by powdery scab exceeds 10%, and if the area of the surface affected by black speck exceeds 10%

Complex standardized procedure of the quality inspection of plantings and potato seed lots includes:

- Traceability of the origin of seed lots intended for certification
- Field surveys and inspection of plantings
- Tuber analyses of potato seed lots
- Postharvest collection of tuber samples for check-up laboratory tests
- Soil control of varieties for lots of original potato seed, which are destined for trade turnover
- Making a decision on the conformity with the regulatory tolerance limits of the standard
- Determining the conformity of potato seed lots to the regulatory tolerance limits of the standard

The general view of a flow chart of quality inspections of potato seed intended for certification is shown in Fig. 11.1.

In the course of pendency of an application that was filed to the seed certification authority from the potato seed producer, documents that confirm the origin of the potato seed lot are checked. The application to the certification authority must be filed not later than 1 month before planting. The application must be accompanied by copies of documents certifying varietal affiliation, quantity, and quality of the declared category (class/generation) of seed stock and confirming its origin.

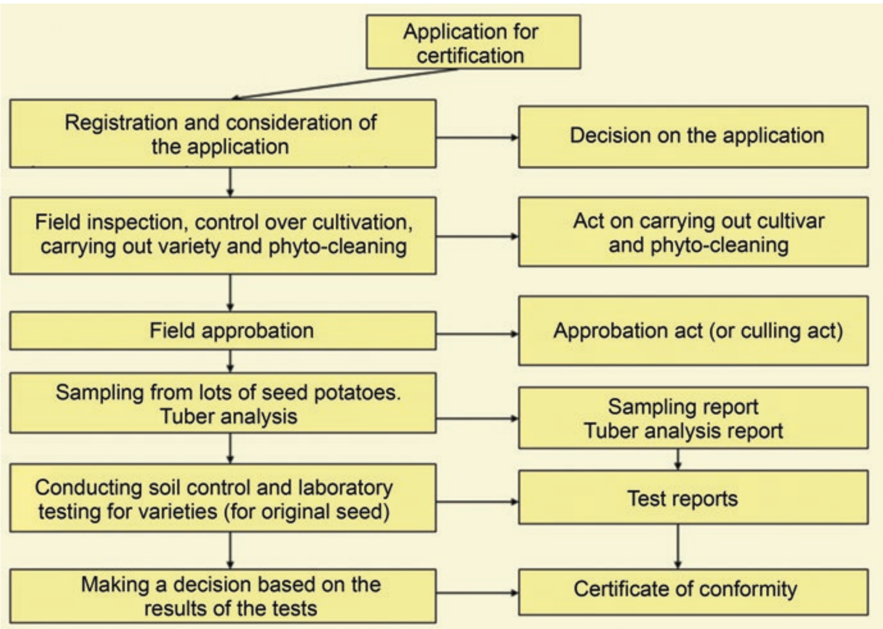

Fig. 11.1 Flowchart of quality inspections of potato seed intended for certification. (Source: Compiled by the authors)

Patentable varieties must be certified by a license contract. The application is registered in the register. Certification authority, on the basis of the results of the pendency of the application and the verification of the submitted documents, makes its decision within 10 days from the time of submission of the application. If the documents do not meet applicable requirements, are incomplete, or are missing, a negative decision will be made. If the decision is positive, the applicant is informed who performs field inspection, cultivation control, field approbation, sampling, and tuber analysis.

11.2 Field Surveys and Inspection of Plantings

When minitubers are grown in summertime greenhouses and tunnels, as well as on seed fields of the first field generation seed from minitubers, three inspections are carried out with a visual assessment of every plant.

Plantings of super-superelite, superelite, elite, and reproduction potato varieties are assessed using the field approbation method during the vegetational season.

Three surveys of plantings are usually carried out: the first survey is carried out when plants are 15–20 cm high, the second survey is carried out during flowering time, and the third survey is carried out before preharvesting removal of tops. During the visual inspection of plants, it is established whether they belong to the leading variety or impurity, and the availability of symptoms of viral and bacterial potato diseases is checked.

The leading variety or impurity is determined according to the totality of varietal characters in line with the official description of morphological characteristics of a variety. Viral diseases are taken into account according to the appearance of mild symptoms (common mosaic, mosaic leaf curling) and severe forms (potato rugose mosaic, potato streak mosaic, leaf rolling). Black stem and ring rot can be identified by external signs of their manifestation on plants, an underground portion of stems and formed tubers.

Based on the survey results, percentages of varietal impurities and plants damaged due to diseases are calculated relative to the total number of examined plants, and conformity of the quality of plantings with applicable regulatory requirements of the standard is defined. An inspection report is drawn up for nuclear seed stock and the first field generation, and an approbation report is drawn up for super-superelite potato varieties, superelite, elite, and reproductive plantings.

The control over rogueings with removal of diseased plants – sources of infection and impurities of other varieties during field surveys – is especially important. Since disease symptoms on plants are manifested in different times, the maximum effect can usually be achieved in the case of three-stage rogueing.

First rogueing should be carried out shortly after the emergence of full-blown seedlings, when plants have grown to a height of 15–20 cm. At this time, it is particularly necessary to remove bushes that are affected by black stem and viruses. The sooner diseased plants are removed from plantings, the less sources of possible spread of infection remain in the field.

Second rogueing should be carried out during flowering before approbation. During this period, varietal impurities as well as stunted plants and plants damaged due to bacterial and viral diseases are usually removed. After the second rogueing, field approbation is made, and conformity of plantings with applicable regulatory requirements of the standard set for various categories and classes of potato seed is ascertained.

Before removal of tops, the third rogueing is usually recommended. During this period, remaining impurities, as well as plants showing signs of bacterial (ring rot) and viral diseases, may be removed (Fig. 11.2).

Rogueings must be carried out by well-instructed workers in the presence of a seasoned professional who is specially trained and has practical skills of identification of varietal impurities and symptoms of diseases in potato plantings. Usually two people walk along the furrow and carefully examine the plants in two rows to the right and to the left of the furrow along which the passage is made (Fig. 11.3).

Fig. 11.2 Field surveys and rogueings of potato seed plantings. (Source: compiled by the authors)

Fig. 11.3 Training of approbators on test plots of the All-Russian Lorch Potato Research Institute. (Source: compiled by the authors)

Detected varietal impurities or diseased plants are dug out using a shovel together with tubers, including parent tubers, and removed from the field. It is not recommended to pull out plants, since in this case parent tubers may be left in the soil, germinate one more time in the same year, and give rise to diseased plants again. Tops and tubers that were removed during rogueings must be completely destroyed.

11.3 Tuber Analysis of Potato Seed Lots

Tuber analysis of potato seed should be carried out as follows:

- Determining the availability of land and impurities
- Determining the tuber size
- Determining the availability of tubers of other botanical varieties
- Determining the availability of tubers with external and internal signs of morbid affection, damage, and defects

The sampling procedure for the tuber analysis and applicable regulatory requirements for the quality of seed stock is defined by the standard GOST 33996-2016: "Potato Seed. Specifications and Quality Assessment Methods."

It is recommended that tubers are stored at a temperature of 10–20 °C for 20 days before the analysis of selected tuber samples to activate phytopathogenic fungi, bacteria, and stem nematodes in tubers.

First the sample is weighed; then the loose soil and other impurities are removed from it. The amount of soil and impurities is determined by weight as a percentage of the total weight of tubers of this sample. Once the soil and impurities have been removed, each tuber is washed in water and examined. Nonstandard and defective

Fig. 11.4 Procedure of tuber analysis of potato seed lots. (Source: compiled by the authors)

tubers are separated and grouped according to diseases, damage, and defects. The number of tubers that do not conform to the tolerance limits of the standard in terms of diseases, damage, and defects is expressed as a percentage of their total number in the analyzed sample. Based on the data of the tuber analysis, potato seed lots are included with the relevant categories of seed stock (Fig. 11.4).

To detect internal defects and damage caused by diseases (black stem, ring rot, potato blight, Phoma rot, pulp spotting, rust spot, hollow heart, Ditylenchus destructor), 100 tubers in each sample are cut longitudinally. If diseases or defects are detected, other tubers of the analyzed sample are cut as well.

In the case of multiple diseases on one tuber, consideration should be given to one most harmful disease with the following priority: ring rot, black stem, potato blight, Phoma rot, Ditylenchus destructor, common scab, black speck, powdery scab and silver scab, frostbite, and mechanical damage.

Tubers that are to any extent affected by dry and/or soft rots, caused by fungal and bacterial pathogens, are considered to be diseased. Subsequent to the results of the tuber analysis, a tuber analysis report is drawn up, in which the number and the percentage of diseased tubers are specified.

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Chapter 12
Ground Control of Varieties, Laboratory Diagnosis of Phytopathogens, and Commercial Potato Seed Marking

Boris Vasil'evich Anisimov, Evgeny Alekseevich Simakov, Elena Vasil'evna Oves, and Sergey Nikolaevich Zebrin

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12.1 Soil Control of Varieties

The main goal of soil control of varieties is to hold a detailed inspection of potato seed lots intended for sale, with a view to determining their conformity with the regulatory tolerance limits in terms of identity of a variety (authenticity of a variety), purity of a variety, and the degree of infection with viral and bacterial diseases transmitted via seed stock.

The main task is to determine the amount of impurities of other varieties and/or atypical plants in the tested varieties, as well as to identify plants with external symptoms of diseases controlled by tolerance limits of the standard during vegetative growth period on potato seed plantings [1, 2].

For soil control, samples are selected from potato seed lots which are intended for sale and for planting. Sampling is carried out in accordance with the effective standard for potato seed GOST 33996 – 2016. An average sample of at least 120 tubers is taken from collected samples for soil control. Varieties intended for testing using the soil control method must be delivered to an organization that is authorized to carry out soil control no later than 1 month before the start of potato planting in

B. V. Anisimov · E. A. Simakov · E. V. Oves (✉) · S. N. Zebrin
Russian Potato Research Centre, Moscow Region, Russia

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this area. Soil control is carried out by legal entities that were duly accredited for this activity within the scope of certification system of seeds of agricultural plants.

All samples that were submitted for proof tests for each variety are grouped together and placed on the test plot of soil control in sequential order according to categories and classes (generations) of seed stock, starting from samples of minitubers (MK) Followed by the first field generation (FF-1), the super-superelites (ESS), the superelites (SE), the elites (E) and the first breeding generation after the elites (RS1).

The plots with samples of one generation within each variety are arranged side by side, so that samples with the presence of atypical characters or with external symptoms of diseases were clearly visible during the observation process and enabled their convenient detailed comparison with samples, received from the variety originator (Fig. 12.1).

Soil treatment and planting management on the test plot of soil control should be made in accordance with standard potato seed production process with due account for peculiarities of regional natural and climatic conditions.

Throughout the vegetational season, the samples on the plots are examined for the detection of impurities of other varieties and characters deviating from the official description of the variety, as well as external symptoms of diseases transmitted via seed stock and controlled the tolerance limits of the standard. Since many varietal characters can manifest themselves in different phases of plant growth and development, the observation for each variety is carried out during the period of the emergence of full-blown seedlings and in the following during the beginning of phenophases of budding, flowering, tuberization, ripening and natural necrosis of tops. At the first detection of impurities of other varieties or plants with atypical

Fig. 12.1 Soil control of varieties of original potato seed on the test plot of the All-Russian Lorch Potato Research Institute. (Source: compiled by the authors)

characters, they are marked with color paint or another label so that they are easier to find for the subsequent more thorough study and analysis. This is especially important in cases where the atypical characteristic is unstable, for example, accelerated (outrunning) growth height during the initial vegetational season or differences in coloration of flowers can be observed. Plants with deviations from typical varietal characters and impurities of other varieties are identified in different phenophases, by appearance of the bush, stem pigmentation, shape and color of leaves and their lobes, color of flowers, and by the shape of the tubers formed, color of their peel and pulp. More thorough study of plants with deviant varietal characters detected in the course of inspections is performed on the basis of UPOV character scale, which includes identification of the most important indicators of the degree of manifestation of characters for purposes of variety identification of potato.

Viral diseases that are controlled by the tolerance limits of the standard are defined by the external manifestation of symptoms of medium and severe (potato rugose) mosaic (YVC) and potato leaf roll virus (PLRV) with an additional check using the method of immunodiagnosis of leaf samples collected from plants with external symptoms in order to confirm availability of viral infection.

"Black stem" is determined by the manifestation of characteristic external symptoms on plants, underground part of stems and formed tubers.

In order to acquire necessary practical skills in the identification of varietal characters and symptoms of diseases taking into account the characteristics of the season, it is recommended to allocate special training plots for employees and specialists carrying out soil control, with selection of varietal mixtures which are distinguished for their most distinctive morphological characters of a bush, stem, leaf, flower and tuber.

During flowering of plants on the test plot of soil control, it is also recommended to carry out joint final inspection of varieties and discuss results of observations with the participation of variety originators and representatives of companies which presented their varieties for comparative testing.

During the growing season in 2018, soil control method was used on the test plot of the All-Russian Lorch Potato Research Institute for the assessment of 93 varieties of potato seed from various originators in terms of identity of a variety, purity of a variety (impurities of other varieties), and manifestation of external symptoms of diseases controlled by the regulatory tolerance limits of the standard (Table 12.1).

Based on the assessment of the totality of varietal characters of a plant, stem, leaf, and inflorescence, plants with deviations from typical varietal characters by plant height (Fioletovyi variety) and tuber shape (Gulliver variety) were found. In specimens of other varieties, there were no deviations in terms of varietal uniformity, and all characteristics of varieties studied matched their author's descriptions.

Exceedance of the tolerance limits of the standard in terms of the number of viral diseases (YVC) was found in 2 minituber samples (Lukyanovskiy and Red Scarlett varieties), 13 samples of the first field generation (Vasilek, Zhukovsky Early, Udacha, Brianskiy Delikates, Il'inskiy, Vympel, Zhigulevskiy, Kupets, Lukyanovskiy, Fritella, Fitoolevyi, Red Scar), and 7 samples of super-superelite potato varieties (Vasilek, Udacha, Zhigulevskiy, Nadezhda, Favorit, Fioletovyi).

Table 12.1 Results of proof tests of varieties of original potato seed by soil control

	Total	Including:		
		Minitubers	FF-1	SSE
Number of varieties assessed, pcs	93	26	36	31
Number of varieties that conformed to the regulatory tolerance limits of the standard:				
In terms of variety typicality	90	26	35	29
In terms of viral diseases (YBK)	71	24	23	24
In terms of bacterioses (blackleg)	92	26	36	30
Number of varieties that exceeded the regulatory tolerance limits of the standard:				
In terms of variety typicality	3	0	1	2
In terms of viral diseases (YBK)	22	2	13	7
In terms of bacterioses (blackleg)	1	0	0	1

Source: compiled by the authors Anisimov et al. [1]

Plants with external signs of damage caused by bacteriosis (black stem) were found in only one variety (Red Scarlett) that was taken as a comparative variant as the most wide-spread variety of foreign selective breeding programs.

Plant productivity and yield structure indicators varied depending on season conditions, ripening periods of varieties, and generally corresponded to their varietal characters.

12.2 Laboratory Diagnosis of Phytopathogens

For laboratory testing with the use of PCR diagnosis, enzyme-immunoassay (EIA) and immunochromatographic assay (ICA), the standard specifies varied sampling rates depending on lots of seed stock of various breeding stages (Table 12.2).

PCR diagnosis is used for determining potato spindle tuber viroid (PSTV), YPV and PLRV viruses, and pathogens of bacterial diseases (black stem and ring rot) in nuclear seed stock before its propagation and at subsequent breeding stages. Analysis specificity is more than 99%, and detection threshold (minimum detectable concentration) is 10 pathogen units/cm^3.

Enzyme-immunoassay (EIA) is used to determine the rate of infection of plants and tubers with viral (SBK, MBK, YPV, PLRV) and bacterial (black stem) infections via laboratory testing of postharvest tuber samples collected from lots of minitubers of the first field generation, super-superelite potato varieties, superelite and elite varieties. Detection threshold (minimum detectable concentration) for viruses is 10 ng/cm^3, for bacteria – 104 cells/cm^3.

Postharvest tuber testing for the detection of viral infection is carried out in the fall-winter period on plants that were grown from indices (tuber eye with adjacent tissue). Potato is tested for the presence of bacteria on segments cut from the top of a funicular portion of tuber.

Table 12.2 Sampling rates for laboratory testing

Name of seed stock	Class/generation	Sampling rate
Basic clones for the introduction into in vitro crop plant	Nuclear seed stock (NSS)	100% of plants
Nuclear seed stock of microplants for clonal propagation in in vitro crop plant		100% of plants
Plants grown in greenhouses or covered tunnels for the production of minitubers		250 plants
OS category	First field generation seed from minitubers (FF-1)	200 tubers (in a postharvest sample)
	Super Superelite (SSE)	200 tubers from the lot
ES category[a]	Superelite (SE)	100 tubers from the lot
	Elite (E)	

Source: compiled by the authors based on information from the standard GOST 33996-2016
[a]Tuber samples are collected from lots which are intended for sale, upon a mutual agreement of the parties, based on potato seed supply contracts

Immunochromatographic assay (ICA) is used for instant diagnosis of phytopathogens on potato plants with the use of dip sticks both in laboratory environment and in the field.

The standard established special rates for the control of phytopathogenic viruses based on laboratory testing of leaf and tuber samples depending on the breeding stage of original potato seed, including nuclear seed stock in vitro, minitubers, the first field generation seed from minitubers and super-superelite potato varieties.

For all classes (generations) included in the category of original potato seed, there are fairly strict regulatory tolerance limits for viruses which cause severe forms of potato rugose mosaic and potato streak mosaic (YPV), potato leafroll virus (PLRV) and potato spindle tuber viroid (PSTV). The presence of YPV and PLRV in nuclear seed stock in vitro and minitubers is not allowed. The maximum allowable rate in the first field generation seed from minitubers must not exceed 0.5%, and 1% in super-superelite potato varieties. Zero tolerance limit is set for PSTV of all generations.

For lots of superelite, elite and reproduction potato seed which are destined for trade turnover, the maximum allowable rates of limitation of viral and/or bacterial infection on completion of laboratory testing of tuber samples can be specified in potato seed supply agreements (contracts). However, for lots of superelite and elite varieties, the YPV limit should not exceed 10% on completion of laboratory testing.

As mentioned above, the fundamental principles of the standard for regulatory tolerance limits and methods of determining the quality of nuclear seed stock, original and elite potato seed are close to the level adopted in the EU [3–5]. However, there are still significant distinctions from with the UNECE International Standard in terms of the less stringent standards based on results of laboratory testing for the rate of infection of plants and tubers with viral infection for categories of elite and reproduction (certified) potato seed. The introduction of stricter tolerance limits in the long term is only possible with the introduction of standardized procedures of sequential process, including production of nuclear seed stock in vitro, minitubers, super-superelite potato varieties and elite potato varieties, as well as taking additional measures for creation of special territories (areas) for production of potato seed of the highest quality categories.

Modern world practices are mainly focused on the use of the most favorable agro-climatic and pure phytosanitary conditions for growing potato seed of the highest quality categories. Real-life experience has shown that any attempts to grow potato seed in adverse environmental and climatic conditions with a high level of infective load always resulted in irreparable loss of quality.

12.3 Marking Potato Seed Intended for Sale

Potato seed should be packed in accordance with regulations on seed sale with additions as per GOST R 33996-2016.

Potato seed that was grown in a greenhouse and in the field is packed in crates as per GOST 11354-2008, pallet boxes as per GOST 21133-87, cloth bags as per GOST 30090-93 and mesh bags (mesh width should be smaller than the minimum size of tubers in a lot) as per document in accordance with which they were produced.

Potato seed of the category of original and elite seed should only be sold packed. Potato seed of the category of reproduction potato seed may be sold in bulk subject to agreement with the customer.

The packing must be clean, undamaged, free from previous goods, pests and disease excitants.

Potato seed should be marked in accordance with the seed sale and transportation regulations adopted in accordance with the established procedure with additions as per standards GOST R 53136-2008 and GOST R 55329-2012.

A label should with following information should be attached to each packing unit:

- Name and address of a farm (supplier)
- Name of plant
- Designation of the category of potato seed, class/generation
- Name of botanic variety
- Tuber size
- Harvest year
- Lot number
- Net weight of the packing unit or net weight of the lot
- Designation of the standard

In case of the use of products for chemical protection of plants from potato diseases and pests, the label should indicate the name of the dresser and the legend “Dressed!” as well as the date of dressing.

Shipping labels should be applied as per GOST 14192-96. The transportation packing should have internal and external stickers (labels) as per GOST R 53136-2008.

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