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EFFICIENCY OF ETHYLENE APPLICATION ON SEED POTATO TUBERS

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Abstract

Potato (*Solanum tuberosum* L.) is one of the most important agricultural crops in Russia. Potato tubers contain protein of high biological value, starch and vitamins necessary for humans. There are various ways to increase the yield of the crop, currently, it is mainly due to application of mineral fertilizers. However, this method has limitations, since an increase in doses of fertilizers is associated with deterioration of consumer quality and culinary indicators of tubers. One possible alternative is the gassing of seed tubers with ethylene. This phytohormone is widely used on various crops, but its effect on potatoes has not yet been fully studied. It is known that depending on the treatment modes it can act as both a stimulator and an inhibitor of tuber germination. We have developed a new method for increasing potato yield based on the property of phytohormone ethylene to suppress apical dominance at the beginning of tuber germination and thereby promote the formation of a larger number of lateral sprouts from which additional stems are formed. The aim of the research was to determine the effect of seed potato tubers treatment with ethylene on their biochemical parameters, as well as on the growth, development and tuber yield of the crop. The experiments were conducted on the basis of storage facilities of JSC Ozyory (Ozyorsky District, Moscow Province). For gassing, the adapted technology of the company «Restrain Company Ltd» (Great Britain) was used. The storage temperature for seed potatoes was 4 °C; the period of ethylene gassing was from November to the end of April. The treatment with ethylene was stopped 3-5 days before planting. Ethylene-treated potatoes were planted in 2015-2017 on the territory of the Moscow region. A two-factor small-plot field trial was conducted in the Lyuberetsky District at the Korenevo experimental base, the soil was sod-podzolic sandy loam. Seed tubers of potato varieties Lady Claire (early), Gala (mid-early) and Saturna (mid-late) were treated with ethylene. In the control, ethylene was not applied. A three-factor large-scale (40 ha) field trial was performed during commercial potato growing of the same varieties (JSC Ozyory, Ozyorsky District, Moscow Province, sod-podzolic loamy soil). We used the same treatment as in experiment 1 added with 2-3 irrigation (200 m^3/ha). In both experiments, the potatoes were planted in the first decade of May (45 thousand tubers per hectare, row spacing width of 75 cm; $N_{60}P_{120}K_{120}$ applied locally). Biochemical, biometric parameters, and potato yield were measured. It was found that the treatment of potato seed tubers with ethylene at 4 °C changes their biochemical parameters, i.e., dry matter content decreases by 0.2-0.5 % while sucrose increases by 0.03-0.08 %, which indicates the breakdown of tubers' dormancy. There was a suppression of apical dominance and the formation of more lateral sprouts on tubers, a greater number of stems per plant (by 19.9-36.0 %), and an increase in number of tubers per plant (by 6.3-19.0 %, especially in the Gala variety). Potato yield increased by 9.9-19.0 % depending on the variety, growing area and irrigation. The produced potato tubers were more uniform and marketable. Depending on the common agricultural level and the technology used at a farm, a differentiated approach is proposed in choosing the planting rate. If low agricultural technology and no irrigation, the planting rate of ethylene-treated tubers reduced by 10-15 % allows for the same yield as that for high technology and irrigation.

Keywords: potato, variety, ethylene, phytohormone, phenological phases, number of stems, yield, crop structure, Restrain technology

The phytohormone ethylene can act as both a stimulant and an inhibitor of potato germination. The stimulating properties of ethylene, which determine the release of tubers from the state of natural dormancy, have been known since 1925 [1], and its inhibitory properties were revealed in 1932-1933 [2, 3]. In the work of Rylski et al. [4], the double effect of ethylene was shown. Its short-term exposure (72 h in the range of 0.02-20 ppm) stimulated the onset of germination of tubers, and continuous action during long-term storage of potatoes suppressed the development of sprouts. There is information [5-8] that ethylene promotes an increase in the number of sprouts, but at the same time prevents their growth in length (elongation).

The perception of ethylene begins with its binding to receptors localized in all higher plants in the membrane of the endoplasmic reticulum and the Golgi apparatus [9]. The unusual intracellular localization of receptors does not interfere with the perception of the hormone, since gaseous ethylene freely diffuses in lipid and aqueous media [10, 11]. It is assumed that the binding of ethylene to receptor histidine kinases changes their conformation, inactivates the complexes of receptors with CTR1 (Ser/Thr-protein kinase, similar to protein kinases of the Raf family). This leads to dephosphorylation of the EIN2 protein, similar to the metal ion transporter Nramp, and the cleavage of its C-terminal domain, which is transferred into the nucleus and initiates the transcriptional response of ethylene-dependent genes due to the sequential activation of transcription factors of the EIN3/EIL1 and ERF families [12]. It is known that with continuous prolonged exposure to ethylene in tubers, the ratio of polyamines involved in the regulation of cell division and growth changes [13, 14]. Such changes are variety-specific and associated with potato germination [15, 16].

Previously, various chemical compounds, primarily 2-chloroethylphosphonic acid, were used as “ethylene producers”; however, as applied to potato culture, other ethylene supply systems are more technologically advanced [17, 18].

Currently, two UK companies supply ethylene management systems for potato storage. Both use the same standards for permitted ethylene concentrations (up to 50 ml/m^3, the dosage is specified by the manufacturer, depending on the purpose of the potato). One of the companies (BioFresh Ltd.) supplies pure ethylene in cylinders (which is potentially explosive); the gas concentration in the storage is monitored by a chemiluminescent sensor. Another company (Restrain Company Ltd., represented in Russia by Peya Agro LLC) produces a system in which ethylene is made of ethanol [19].

There are many techniques and methods aimed at increasing the yield of potatoes, e.g., the use of virus-free seeds of high reproduction, pre-planting treatment of tubers by chemical and physical methods, protection of plantings from weeds, diseases, and pests, application of fertilizers, primarily mineral fertilizers [20]. However, the use of mineral fertilizers, even with an optimal NPK ratio, taking into account soil and climatic conditions, often leads to a decrease in the accumulation of dry matter, starch in the tubers, a deterioration in consumer (pulp resistance to darkening) and culinary parameters (taste, friability), as a result of which the suitability of potatoes for processing, such as vacuum packaging and quick freezing, is reduced [21].

Here, a new method are reported for increasing potato productivity, based on the property of the phytohormone ethylene to suppress apical dominance at the beginning of tuber germination and thereby promote the formation of a larger number of lateral shoots from which additional stems are formed.

The aim of the research is to determine the effect of ethylene treatment of seed tubers of potatoes (*Solanum tuberosum* L.) on their biochemical parameters, as well as on the growth, development, and yield of the crop.

Materials and methods. The experiments were carried out on the basis of the storage facilities of Ozyory JSC (Ozyorsky District, Moscow Province). The storage capacity was 2000 tons. For gassing, the adapted technology of the Restrain

Company Ltd. (Great Britain) was used. The adaptation of the technology to Russian conditions consisted in the fact that the storage temperature of seed potatoes was not 6-8 °C, as is recommended for the climatic conditions of Western countries, but 4 °C; the period of gassing with ethylene was 1 month longer (from November to the end of April, and not to the end of March). Since the winters in the Central region of Russia are colder and longer, and the planting of potatoes begins 1 month later, it was risky to maintain an elevated temperature in the storage, since in this case, premature germination of tubers is possible. In order for the tubers to start germinating in a timely manner, the ethylene supply was stopped 3-5 days before planting.

Potatoes treated with ethylene were planted in 2015-2017 in the Moscow Province. A two-factor field experiment (experiment 1; factor A was a potato variety and factor B was ethylene treatment) was carried out in the Lyuberetsky District at the Korenevo experimental base (a small plot experiment, sod-podzolic sandy loam soil). Seed tubers of potatoes of foreign breeding varieties Lady Claire (early), Gala (mid-early), and Saturna (mid-late) were treated with ethylene (gassing at a dose of 15 ml/m^3; no treatment was carried out in the control). The experiment was repeated 3 times. A three-factor experiment (experiment 2; factor A was a potato variety, factor B was treatment with ethylene, factor C was irrigation) was performed in the Ozyorsky District during large-scale production of potatoes on the basis of the Ozyory JSC farm. The soil was sod-podzolic loamy; the total area of the experiment was 40 hectares. The cultivars and the tillage were the same as in experiment 1. Irrigation of crops (2-3 irrigations of 200 m^3/ha, control without irrigation) was carried out using sprinkler machines of the Fregat type (Plant Fregat PJSC, Ukraine). In the experiment, there were two variables (with and without irrigation). The experiment was repeated 3 times.

In both experiments, potatoes were planted in the first decade of May. Planting density was 45 thousand tubers/ha, row spacing 75 cm, background mineral nutrition $N_{60}P_{120}K_{120}$ with local fertilization.

Biochemical (the content of dry matter, sucrose, glucose, reducing sugars, nitrates, vitamin C) and biometric (the number of stems and tubers per bush) indicators, as well as the yield of potatoes, were determined according to GOST 29270-95 [22] and the methodology of the Federal State Budgetary Scientific Institution of the Federal Research Center of Potatoes named after A.G. Lorch (Russian Potato Research Centre) [23]. Mathematical data processing by the method of analysis of variance was carried out according to Dospekhov [24] using the AgCStat software package as an add-on to Microsoft Excel. The mean value of the sample (M) and the standard deviation of the mean ($\pm\sigma$) were calculated. The significance of differences was assessed by Fisher's F-test. With $F_{\text{fact.}} \geq F_{\text{theor.}}$, the null hypothesis was rejected (there are significant differences between the sample means), and the test ended with the calculation of the least significant difference for the 5% significance level (LSD_{05}).

Results. The equipment used in the experiment is shown in Figure 1. Treatment with ethylene during long-term storage of seed tubers led to a change in their biochemical parameters. The amount of dry matter decreased by 0.2-0.5% (LSD_{05} 0.3%), sucrose increased by 0.03-0.08%, glucose varied within the statistical error (LSD_{05} 0.05%). This indicates the physiological effect of ethylene on the release of tubers from the state of natural dormancy [25-27], accompanied by a short-term increase in respiration intensity, which is consistent with the literature data [28-30]. The nitrate content did not exceed the maximum permissible concentration (90-100 mg/kg, LSD_{05} 28 mg/kg). The amount of vitamin C depended on the variety and shelf life of potatoes (19.7-29.0 mg% at LSD_{05} 1.3-1.5 mg%), but not on the use of ethylene.

A B

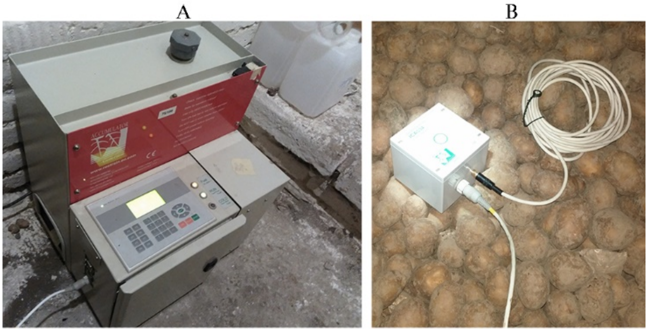

Fig. 1. Equipment used for ethylene treatment of seed tubers of potatoes (*Solanum tuberosum* L.) varieties Lady Claire, Gala and Saturna: A — ethylene generator ACCUMULATOR (Restrain Company Ltd., Great Britain) (installed in the storage and, when heated, catalyzes the catalytic decomposition of 96% alcohol ethanol for ethylene and water), B — an ICA534 ethylene concentration sensor (Restrain Company Ltd., Great Britain), located on the surface of the potato bulk, which controls the operation of the generator.

The growth and development of plants in field experiments were largely determined by the meteorological conditions of the growing season, especially when grown in the Lyuberetsky District of the Moscow Province, where irrigation was not used. Therefore, the analysis of the efficiency of ethylene use is given in close relationship with meteorological conditions (Table 1), separately for each year.

As known, the lack of moisture in the budding-flowering phase cannot be compensated for by subsequent precipitation (critical phase of development). The rains in May and June determine the number of potato tubers, and the rains in July and August determine the mass of tubers [31].

1. Brief characteristics of meteorological conditions during the growing season of potatoes in the areas of field trials (Moscow Province)

District	2015				2016				2017			
	May	June	July	August	May	June	July	August	May	June	July	August
Lyuberetsky	++	+	–	––	++	–	++	++	+	+	++	++
Ozersky	++	+	++	––	++	++	+	++	+	+	++	++

Note. “++" — very favorable conditions for the growth and development of potatoes, "+" — favorable (slightly higher than the average long-term norm), "–" — unfavorable (slightly lower than the average long-term norm), "––" — very unfavorable (drought).

The year 2015 was the least favorable for the growth and development of potatoes. In the Lyuberetsky District, a drought was observed in July-August (see Table 1). In the Ozyorsky District, it only began in August, therefore, due to the greater water-holding capacity of the loamy soil in comparison with the sandy loam plants of the varieties Lady Claire, Gala, and Saturna, it was possible to accumulate a larger crop than in the Lyuberetsky District by 45%, 50%, and 50%, or 7.6, 8.1 and 7.1 t/ha, respectively. With double irrigation in Ozyorsky District in August, the moisture deficit was almost completely compensated, which ensured an increase in yield (without treatment of tubers with ethylene) in the variant with irrigation compared to the variant without irrigation by 27%, 33%, and 21%, or 6.6, 7.9, and 4.4 t/ha, respectively. In addition, watering helped to increase the yield of commercial fraction tubers (> 50 mm in size) by 4-5%.

In 2015, potato varieties with a longer ripening period (Saturna, Gala), when grown without irrigation in the Lyuberetsky District, were in a less favorable position compared to the early maturing variety Lady Claire, which to a greater extent managed to realize the biological potential of yield before the onset of drought.

Treatment of potato seed tubers with ethylene in 2015 led to an increase in the number of peaked eyes (mainly due to lateral ones with the exclusion of apical dominance) and the emergence of seedlings 3-5 days earlier than in the control. The plants were 3-5 cm taller and outperformed the control in terms of leaf area. The number of stems per bush was higher in the varieties Lady Claire, Gala, and Saturna by 20.0-22.4, 33.3-40.0, and 16.3-22.2%, respectively. The phase of the onset of tuberization began a few days earlier, and the number of tubers per bush was greater – by 18.6-22.2, 23.5-31.9, and 11.8-19.1%, respectively (Fig. 2).

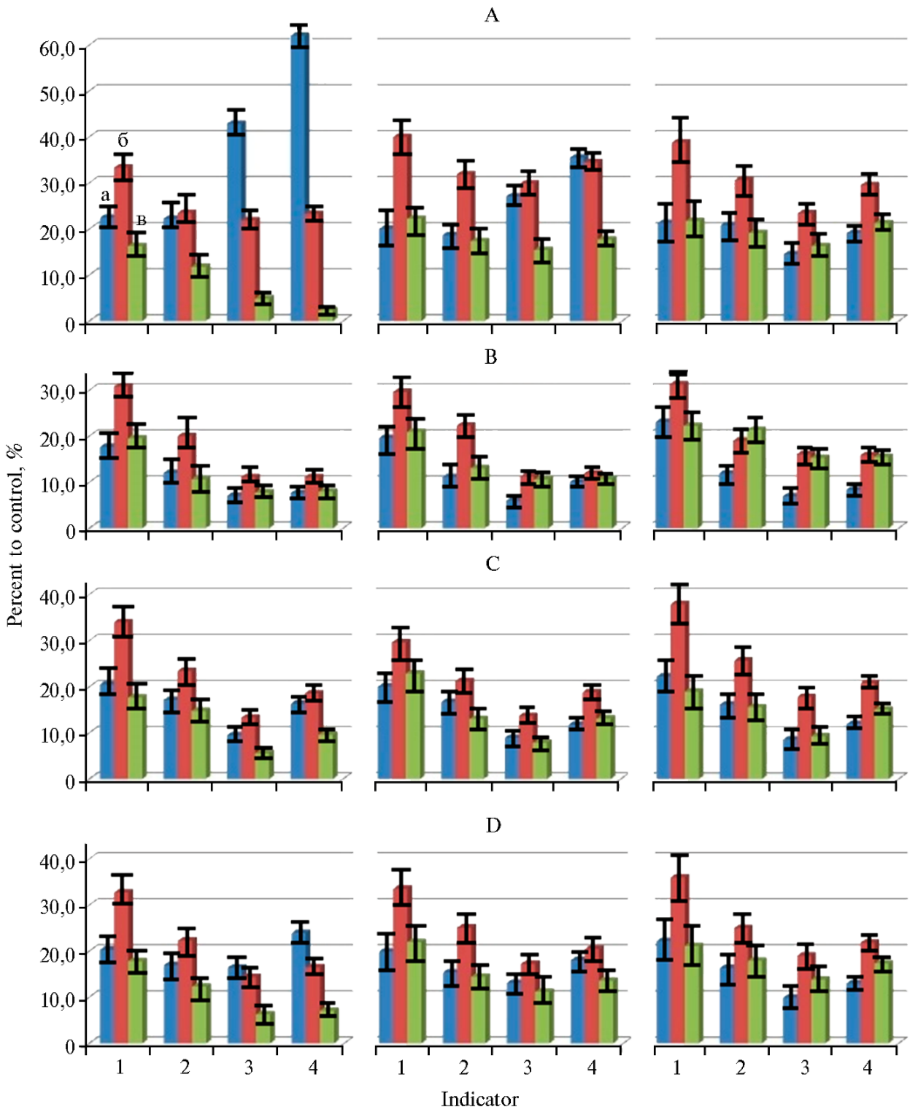

Fig. 2. Increase in growth indicators, development and yield of potatoes (*Solanum tuberosum* L.) varieties Lady Claire (a)**, Gala** (b)**, and Saturna** (c) **when treating seed tubers with ethylene in 2015** (A)**, 2016** (B)**, and 2017** (C) **and on average for three years** (D)**:** 1 — number of stems, 2 — number of tubers, 3 — total yield, 4 — marketable yield; Lyuberetsky District, sandy loam soil, without irrigation (left), Ozyorsky District, loamy soil, without irrigation (the center),— Ozyorsky District, loamy soil, with irrigation (right) ($M \pm \sigma$; Moscow Province). The observed differences with the control are statistically significant at $p < 0.05$.

Ultimately, the yield in variants with the treatment of seed tubers with ethylene in 2015 for these varieties increased depending on the area of cultivation and the use of irrigation by 14.5-42.9, 21.9-29.9, and 4.9-16.3%, or 4.5-7.2, 3.5-7.5, and 0.7-4.2 t/ha, respectively. A more homogeneous crop structure was also noted (Fig. 3).

Fig. 3. Potato tubers (*Solanum tuberosum L.*) under a bush of the Lady Claire variety when grown on sod-podzolic loamy soil: А — без обработки этиленом (контроль), Б — с обработкой семенных клубней этиленом (Озерский р-н, Московская обл., 15 августа 2015 года).

The revealed patterns applied to all the studied varieties, but they were especially evident in the early variety Lady Claire when grown in the Lyuberetsky District without irrigation. Under these conditions, an increase in the total yield, as well as an increase in marketable yield, which reached 62.3%, or 7.6 t/ha, was due not only to the stimulating effect of ethylene on the formation of additional tubers but also to a shift in the passage of phenological phases of development by more early timing, which was critical. Varieties of later maturity groups, especially Saturna, under conditions with a shortened favorable growing season were less responsive to the treatment of seed tubers with ethylene. In the structure of their yield, the fine fraction increased, that is, the advantage in additional tuberization was not realized.

2. Biometric indicators and yield of potatoes (*Solanum tuberosum* L.) of different varieties in the control and in the treatment of seed tubers with ethylene, depending on the area of cultivation and the use of irrigation ($M \pm \sigma$, Moscow Province, 2015-2017)

District (soil)	Treatment (irrigation)	Number per bush		Yield, t/ha	
		stems	tubers	total	commercial (tubers of fraction > 50 mm)
	Cv. L a d y C l a i r e (e a r l y)				
Lyuberetsky	Control	5.1±0.4	10.0±0.6	23.8±0.9	18.9±0.7
(sandy loam soil)	Ethylene	6.1±0.5	11.7±0.7	27.7±1.0	23.5±0.8
LSD_{05}		0.3	0.5	0.8	0.6
Ozyorsky	Control (no irrigation)	5.2±0.4	11.3±0.8	28.3±1.4	24.0±1.1
(loamy soil)	Ethylene (no irrigation)	6.2±0.6	13.0±0.9	32.0±1.5	28.3±1.2
	Control (irrigation)	5.3±0.5	12.3±0.7	32.4±1.5	28.8±1.2
	Ethylene (irrigation)	6.4±0.6	14.3±1.0	35.6±1.6	32.5±1.3
LSD_{05}		0.4	0.7	1.2	1.0
	Cv. G a l a (m e d i u m e a r l y)				
Lyuberetsky	Control	5.4±0.5	17.4±0.7	23.9±1.0	19.1±0.7
(sandy loam soil)	Ethylene	7.2±0.6	21.2±0.7	27.3±1.1	22.2±0.8
LSD_{05}		0.3	0.6	0.8	0.6
Ozyorsky	Control (no irrigatio)	5.8±0.4	18.3±1.0	29.4±1.3	25.3±1.1
(loamy soil)	Ethylene (no irrigatio)	7.7±0.6	22.9±1.1	34.5±1.5	30.5±1.2
	Control (irrigatio)	6.3±0.6	19.2±0.9	33.9±1.4	30.4±1.2
	Ethylene (irrigatio)	8.6±0.7	24.0±1.0	40.3±1.6	37.0±1.4
LSD_{05}		0.5	0.9	1.2	1.0
	Cv. S a t u r n a (m e d i u m l a t e)				
Lyuberetsky	Control	3.9±0.3	9.8±0.5	19.7±0.8	14.6±0.6
(sandy loam soil)	Ethylene	4.6±0.3	11.0±0.6	20.9±0.8	15.7±0.6
LSD_{05}		0.2	0.5	0.7	0.5
Ozyorsky	Control (no irrigatio)	4.1±0.4	10.6±0.7	23.3±1.1	19.3±1.0
(loamy soil)	Ethylene (no irrigatio)	5.0±0.4	12.2±0.8	25.9±1.2	22.0±1.1
	Control (irrigatio)	4.3±0.4	11.0±0.7	26.4±1.4	22.7±1.1
	Ethylene (irrigatio)	5.2±0.5	13.0±0.8	30.0±1.5	26.7±1.3
LSD_{05}		0.4	0.6	1.2	1.0

The use of ethylene on seed potatoes in 2016 and 2017, more favorable in terms of moisture supply, had a similar effect on the growth of biometric indicators and yield (see Fig. 2). In relative terms, the effect of ethylene was noticeably lower than in 2015 (for the varieties Lady Claire, Gala, and Saturna, the increase in yield was 6.9-9.5, 11.1-17.8, and 5.6-15.3%, respectively, compared to the control); however, in absolute values, taking into account the higher yield, there was almost no difference compared to 2015 (1.8-2.8, 3.1-6.2, and 1.2-4.5 t/ha, respectively). The Gala variety was the most responsive to the use of ethylene under favorable growing conditions and on average over 3 years (Table 2).

Similar data using the Restrain technology adapted to Russian conditions on seed potatoes were obtained in 2015-2016 in the Dmitrovsky District of the Moscow Province [32, 33]. The use of the original Restrain technology when growing the same varieties in Great Britain and the Netherlands in combination with more favorable climatic conditions (moisture supply is 2 times higher) and with a high culture of farming provided a comparable increase in plant growth and development (+40% stems per bush; +20% of tubers per bush) and an increase in total yield up to 20% [34].

The increase in the yield of potatoes when treated with ethylene in our experiments was not accompanied by a decrease in the content of starch and dry matter in the tubers, which often happens with the introduction of increased doses of mineral fertilizers. In the control, these indicators over 3 years averaged 17.5 and 23.2% for the Lady Claire variety, 16.4 and 22.0% for Gala, 18.2 and 23.9% for Saturna. When treating seed tubers with ethylene, the values were as follows: Lady Claire 17.6 and 23.3%, Gala 16.5 and 22.1%, Saturna 18.1 and 23.8%. The content of reducing sugars in the post-harvest period for the studied varieties, regardless of the treatment option, was 0.15-0.20%. The resistance of the pulp of tubers to darkening did not decrease (8.0-8.5 points on a 9-point rating scale both in the control and in the variant with ethylene treatment). In combination with achieving a more uniform crop structure, this is extremely important when growing potatoes for processing into crisp, frozen potatoes (taking into account the requirements for the shape of the tubers) and in vacuum packaging. With early harvesting periods, it becomes possible to obtain a higher yield of a uniform seed fraction of potatoes.

In addition, the treatment of seed tubers with ethylene makes it possible to use a differentiated approach in the choice of the seeding rate depending on the level of crop cultivation. In the absence of irrigation and low agricultural technology, the seeding rate can be reduced by 10-15%, based on the fact that the use of ethylene will achieve the same stalk per hectare and no less yield than with the usual seeding rate, that is, one can save on seed material. With a high level of agricultural technology, the availability of irrigation systems, and the use of fertilizers, it is possible not to reduce the seeding rate of ethylene-treated seeds, since potato plants will be able to realize their full biological potential and accumulate high yields.

Thus, the treatment of seed tubers of the potato varieties Lady Claire, Gala, and Saturna with ethylene according to the Restrain technology adapted to Russian conditions contributed to a change in the biochemical parameters of tubers (the dry matter content decreased by 0.2-0.5%, the amount of sucrose increased by 0.03- 0.08%), suppression of apical dominance, the formation of a larger number of stems (by 19.9-36.0%) and tubers (by 6.3-19.0%) per bush, the formation of additional lateral shoots, and an increase in yield by 9.9-19.0%, depending on the variety, the area of cultivation, and the use of irrigation. A more homogeneous crop structure was also noted. There was no significant effect on the content of nitrates and vitamin C in tubers. The most responsive of the studied varieties was the medium early variety Gala under irrigation. In general, the treatment of seed tubers with phytohormone ethylene makes it possible to increase the yield of potatoes without the use of increased doses of mineral fertilizers, which eliminates the associated negative consequences such as a decrease in the content of dry matter, starch, and suitability for processing.

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