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Adaptive variability of early potato in the Forest-Steppe of Ukraine

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Abstract. The purpose of this study was to investigate the dynamics of early potato yield formation at 40 days depending on the weather conditions of the research years and the adaptive potential of early potato cultivars. During 2018-2024, 10 cultivars of early potatoes common in the Forest-Steppe zone were investigated in the field (Uman, 48°46′N, 30°14′E). To analyse the results obtained, the study employed generally accepted methods of field and genetic-statistical research. During the study, the number and weight of marketable tubers in the bush, the dynamics of crop formation on the 40th day after germination, and the strength of the correlation between yield and rainfall were investigated. As a result of the data obtained, the most promising cultivars were identified for early potato harvest in the Forest-Steppe region of Ukraine. It was found that this climatic zone is best suited

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to the cultivars Bazaliia, Tornado and Madison with a yield of 11.0-11.7 t/ha and a large weight of marketable tubers – 58-60 g. In the full ripeness phase, the most productive cultivars were Madison – 37.2 t/ha (+18.6 t/ha of control), Tornado – 34.7 t/ha (+16.1 t/ha of control), Duma and Bazaliia – 31.4 and 32.2 t/ha, respectively (+12.8 t/ha 13.6 t/ha of control, respectively). The study found that the Tornado and Madison cultivars form the largest number of marketable tubers in the bush. Analysis of the semi-ratio of plasticity and stability parameters contributed to the grouping of cultivars into intensive ones (Sanibel, Radomysl, Duma, Bazaliia and Madison had indicators $bi > 1$, $\sigma^2 d > 0$ and plastic (Povin, Vzirets, Skrabnytsia, Bernina and Tornado). As a result of the study, the most productive potato cultivars for early production were identified, which will ensure the stable development of the vegetable growing industry in the Forest-Steppe zone of Ukraine, and the calculated statistical models will allow predicting and directing the programming of potato yields

Keywords: early harvest; stability; plasticity; environmental variation; genetic variation

INTRODUCTION

In modern environment, the development and implementation of environmentally friendly, resource-saving technologies for growing crops, including potatoes, is of particular significance. This is cause by the fact that potatoes are one of the most popular food crops in Ukraine, with high demand. It is planned to increase the efficiency and competitiveness of vegetable production by providing the population with high-quality, affordable products. The key task in developing zonal cultivation technologies is to select potato cultivars.

According to FAOSTAT (n.d.), about a tenth of the world's agricultural land is suitable for potato cultivation, but in other areas, the possibility of obtaining consistently high yields is limited by various factors. The conclusions drawn by R. Ilchuk *et al*. (2023) suggest that potatoes are a major crop characterised by high adaptability, plasticity and potential productivity. It is cultivated in 130 countries and is considered a strategically important product. M. Furdyha (2022) notes the advantage of potatoes compared to other crops in their ability to generate high productivity in a wide range of agricultural systems.

A. Bombik *et al*. (2023) note that modern progress in potato production is possible due to the introduction of new promising high-yielding cultivars, their seed production on a virus-free basis, improvement of adaptive potato production technologies based on biologisation, energy and resource saving in the conditions of an adaptive landscape economically justified farming system. M. Ostrenko *et al*. (2020) pointed out that the most relevant and practically significant aspects of potato growing are expanding the range of high-yielding early cultivars, considering consumer demand and farm specialisation. According to L. Korol *et al*. (2023), it becomes clear that special attention is paid to food and table cultivars with yellow or creamy flesh and high palatability. There are also cultivars of interest for industrial processing with a high starch content and certain technological qualities, as well as for feed use with a high dry matter and starch content.

From the findings of R. Nicolao *et al*. (2023), it is known that despite the large number of potato cultivars available, there is a need for new cultivars that have high productivity yields at low inputs, resistance to diseases and pests, and resistance to environmental stresses such as high or low temperature, drought and salinity. The researchers also noted that, if possible, potato cultivars should also have improved nutritional properties. To achieve this goal, it is necessary to develop, introduce and select cultivars that are well-adapted to concrete soil and climatic conditions.

R.M. Gutaker *et al*. (2019) stated that the spread of potatoes outside their native range required considerable adaptation to new environments, specifically moving crops along latitudinal gradients. In these cases, geographical expansion required the adaptation of plant development to a different day length and temperature. In case of a short day in Europe, potato tuberisation would only occur on short days in late autumn accompanied by frosts. Therefore, overcoming the dependence of a short day for tuberisation was probably the crucial adaptation to European conditions. Modern potato cultivars behave as facultative short-day plants because tuberisation occurs during the long day, but tuber differentiation is still accelerated after the plants are moved to shorter day lengths.

A. Chindi *et al*. (2020) noted that the adaptability of crops can vary depending on the climate zone, and therefore it is important to conduct site-specific adaptation trials to identify suitable cultivars. Accordingly, an adaptation trial of potato cultivars was conducted in the central highlands of Ethiopia to assess the performance and adaptability of introduced and improved cultivars in different potato agroecologies. The findings showed that plant height, number of stems, average number of tubers, and average tuber weight varied substantially between cultivars, and their yields ranged within 19.44-30.08 t/ha.

Earlier studies have shown that the key characteristics that determine high potato yields are adaptive capabilities, the number of stomata per unit leaf area, and the content of photosynthetic pigments (Laisina *et al.*, 2021). The quantitative value of these parameters, together with the number of tubers and the average tuber weight, helped to determine the differentiation of plants by the degree of yield. S.A. Jennings *et al.* (2020) concluded that considering the increasing significance of potatoes globally, there is a growing need to understand the impact of dynamic climate change on potato production. Temperature and precipitation can be limiting factors, as potatoes require a temperate climate and are inhibited by temperatures above 33°C and require more than 500 mm of precipitation during the growing season for high yields.

Due to the shift of climatic zones, the movement of the Steppe to the North of Ukraine and the geopolitical situation in Ukraine since 2022, the purpose of this study was to select early (young) potato cultivars for specific soil and climatic conditions and to investigate their adaptive and productive potential.

MATERIALS AND METHODS

The experiments were conducted in 2018-2024 in the city of Uman (coordinates: 48°46′N, 30°14′E). The study included 10 cultivars of early potatoes, which are particularly common in the Forest-Steppe zone. All studies conducted followed the provisions of the Convention "On Biological Diversity" (1992). The soil of the experimental field was podzolised heavy loamy chernozem with a humus horizon 40-45 cm thick and a humus content of 1.5%; pH (salt) – 6.65; hydrolytic acidity – 2.6 mg equivalents/100 g, soil saturation with bases – 90-95%, the indicator of the sum of absorbed bases – 24.6 mg equivalents/100 g. The focus of the study was on the investigation of the impact of weather conditions, specifically, the amount of precipitation during the growing season of potato plants. The data in Table 1 suggest that the most moisture-supplied growing season was in 2020, 2023 and 2024. According to the Uman Weather Station, these years were also characterised by an even distribution of precipitation by month, namely in May and June, which contributed to a high yield.

Table 1. *Amount of precipitation during the growing season of early potato plants*

Month	Year						
	2018	2019	2020	2021	2022	2023	2024
IV	17.5	22.4	21.0	49.9	57.7	129.6	55.0
V	18.3	35.6	101.0	56.4	22.4	42.4	103.0
VI	82.4	69.8	70.4	104.7	36.3	15.8	180.0
VII	92.9	33.8	21.4	89.8	28.1	92.5	92.5
Σ	211.1	161.6	213.8	300.8	144.5	280.3	430.5

Source: *data from the Uman Weather Station*

The study involved 10 cultivars of early potatoes (Skarbnytsia, Bazaliia, Bernina, Madison, Tornado, Povin, Duma, Radomysl, Vzirets, Sanibel), with the Skarbnytsia cultivar as the control, as it is the most tested in the Forest-Steppe zone. Tubers were planted in the second decade of April according to the scheme of 70 × 35 cm (40.8 thsd plants/ha). The area of the test plot was 25 m^2, replicated four times. The biometric measurements (leaf area of plantations, number of stems, number of marketable tubers per bush) and the dynamics of yield formation (at 40 and the phase of complete tops' death) were carried out using generally accepted methods (Bondarenko & Yakovenko, 2001; Ukrainian Institute of Plant Variety Expertise, 2016; Bondarchuk *et al.*, 2019).

Genetic and statistical processing of the results. Most methods for assessing adaptive capacity are based on the use of regression analysis, the mathematical model of which was developed by K.W. Finlay & G.N. Wilkinson (1963) and supplemented by S.A. Eberhart & W.A. Russell (1966). To systematise the obtained findings, the ranking of cultivars was used according to the ratio of the parameters of plasticity (bi) and stability $\sigma^2 d$:

1) $bi < 1, \sigma^2 d > 0$ – shows a better result under adverse conditions, unstable;

2) $bi < 1, \sigma^2 d = 0$ – shows a better result under unfavourable conditions, stable;

3) $bi = 1, \sigma^2 d = 0$ – responds well to improving conditions, stable;

4) $bi = 1, \sigma^2 d > 0$ – responds well to improving conditions, unstable;

5) $bi > 1, \sigma^2 d = 0$ – shows best results under favourable conditions, stable;

6) $bi > 1, \sigma^2 d > 0$ – shows best results under favourable conditions.

Therewith, a cultivar with $bi > 1$ is classified as highly plastic (relative to the average group), and with $1 > bi = 0$, it is classified as conditionally low plastic. Stability coefficient – $\sigma^2 d$, the lower it is, the more stable the genotype is.

The genotype homeostasis parameter (*Hom*) was determined according to the following formula:

$$H_{om} = \frac{\overline{X}^2}{\sigma}, \quad (1)$$

where $\overline{x}$ – the arithmetic mean of the genotype; σ – the generalised standard deviation.

The breeding value of a genotype was calculated using the following formula:

$$(S_c) = \bar{X} \cdot \frac{\bar{X}_{lim}}{\bar{X}_{opt}}, \quad (2)$$

where $\overline{X}$ – the arithmetic mean of the genotype; $\overline{X}_{lim}$ – the arithmetic mean of the limited (minimum) value of the trait; $\overline{X}_{opt}$ – the arithmetic mean of the optimum (maximum) value of the trait.

To avoid a linear artefact in the regression coefficient, a multiplicative coefficient (*MC*) was determined to compare the variability of the trait. The higher the numerical value of the coefficient, the more volatile the trait is:

$$MC = \frac{\overline{X}i + bi \cdot yi}{Xi}, \quad (3)$$

where $\overline{X}i$ – the average value of the studied trait in the *i*-th cultivar; *bi* – the linear regression coefficient of the *i*-th cultivar; *yi* – the average value for all averages for all cultivars *yi* for each *j*-th experiment point (year).

Environmental plasticity index:

$$EPI = \frac{\left(\frac{YV_1}{ATV_1} + \frac{YV_2}{ATV_2} + \dots + \frac{YV_n}{ATV_n}\right)}{n}, \quad (4)$$

where YV_1, YV_2... YV_n – the values of the trait in the genotype in different years of testing; ATV_1, ATV_2... ATV_n – the average trait values of the cultivars in each of the experimental variants.

The absolute adaptability coefficient (*AAC*) of genotypes was determined according to the following formula:

$$AAC = \frac{(XiC \cdot 100 \cdot Xm)}{100}, \quad (5)$$

where *XiC* – the average yield of the cultivar over the years of testing; *Xm* – the multi-year average yield of the cultivar.

Stress resistance and compensatory capacity of cultivars were calculated according to A.A. Rossielle & J. Hemblin (1981):

$$SR = Y_{min} - Y_{max}; \quad (6)$$

$$CC = \frac{Y_{min} + Y_{max}}{2}, \quad (7)$$

where Y_{min} and Y_{max} – the minimum and maximum values of the cultivar trait.

The results were statistically processed using the arithmetic mean (x) and standard deviation (SD) calculated using Microsoft Excel 2019. Correlations were calculated using Statistica 12 software. The Chaddock scale was used to qualitatively assess the correlation coefficients. The results of the correlation studies were presented graphically, as the graphical method plays an essential role in statistical research, where the interrelationships of phenomena and processes in the movement of dynamics indicators are studied. For this, a correlation field was used, which reflects the statistical relationship between the measurement results. A visual analysis of the correlation field allows qualitatively assessing the shape, direction and closeness of the relationship. The form is determined by the type of correlation field: if a straight line can be drawn through the correlation field, the form of the relationship is linear, otherwise it is non-linear.

In the experiments, the phenotypic, genotypic and environmental variability of cultivars was determined (Burton & DeVane, 1953; Shing *et al.*, 1993) using the formulas (8-13).

Genetic variance:

$$\sigma_G^2 = \frac{CM_p - CM_e}{r}, \quad (8)$$

where CM_p – the generalised root mean square value of the population trait; CM_e – the generalised root mean square error; *r* – the number of repetitions.

Environmental variance:

$$\sigma_A^2 = CM_e. \quad (9)$$

Phenotypic variance:

$$\sigma_F^2 = \sigma_G^2 + \sigma_A^2. \quad (10)$$

Genotypic variation coefficient:

$$CVG = \frac{\sqrt{\sigma_G^2 \cdot 100}}{\overline{X}}. \quad (11)$$

Phenotypic variation coefficient:

$$CVF = \frac{\sqrt{\sigma_F^2 \cdot 100}}{\overline{X}}. \quad (12)$$

Environmental variation coefficient:

$$CVA = \frac{\sqrt{\sigma_A^2 \cdot 100}}{\overline{X}}. \quad (13)$$

RESULTS AND DISCUSSION

Reports by FAOSTAT (n.d.) show that one of the reasons for the low efficiency of potato production in Ukraine was the falling behind of the agro-industrial complex in terms of global agro-technological advance. At the same time, potato growing in Ukraine has switched to an adaptive landscape farming system in the modern market economy. According to FAO (2024), potatoes are on the list of crops whose production has been fairly stable over the period of economic reforms in Ukraine: the area under cultivation is 505 thsd ha, the gross harvest is 20.9 mn t, and the average yield is 41 t/ha higher than the global average yield of 20.0 t/ha.

An evaluation method that allows for the analysis of stability and plasticity parameters is a significant step in breeding programmes and provides more accurate information about the adaptive potential of a genotype. This approach allows determining the effect of genotype, environment and their interaction (GEI) on yield, as well as identifying stable and high-yielding populations in trials.

Analysing the cultivars according to the trait "number of marketable tubers", it can be observed that the variation over the years was noticeable from 4.1 pcs/plant in 2022 in the Sanibel cultivar to 10.4 pcs/plant in 2024 in the Madison cultivar. The maximum number of tubers was formed in 2020, 2021, 2023 and 2024, where the average cultivar index ranged within 7.0-7.6 pcs/plant. The variation in this indicator was within 11-19%, with the most stable being Madison and the least stable being Sanibel and Radomysl. The impact of weather conditions during the years of research was substantial. The lowest variation was in 2024 – 16%, and the highest was in 2019 – 29%.

The largest number of marketable tubers per plant over the years was formed by the cultivars Bazaliia (5.5-8.3 pcs.), Duma (5.9-9.6 pcs.), Tornado (6.7-9.8 pcs.) and Madison (7.9-10.4 pcs.). To achieve high crop productivity, a ratio of *CVG/CVA* ⩾ 1 is required. The study shows that environmental variation (*CVA* = 23.7%) outweighed genetic variation (*CVG* = 5.4%), suggesting a significant dependence of potato genotypes on environmental conditions. Ratio of *CVG/CVA* = 0.23, which indicates that the unstable weather conditions of the Forest Steppe were not favourable enough for the formation of marketable potato tubers (Table 2).

Table 2. *Dynamics of the number of tubers per bush, pcs., and average weight of marketable tubers, g (2018-2024)*

Cultivar	2018	2019	2020	2021	2022	2023	2024	*Xmed*	*SD*	*CV*, %	Tuber weight, g
Povin	5.9	4.4	6.0	4.9	4.2	4.6	5.9	5.1	0.72	14	33.0
Skarbnytsia (C)*	4.7	4.9	6.1	5.7	3.9	5.2	5.9	5.2	0.71	14	39.0
Vzirets	5.4	4.9	6.2	6.0	4.4	5.9	6.9	5.7	0.79	14	38.0
Sanibel	5.1	5.1	7.2	6.2	4.1	6.4	7.6	5.9	1.15	19	44.0
Radomysl	5.6	5.1	8.0	6.8	4.6	6.7	7.8	6.4	1.23	19	56.0
Bernina	7.2	6.5	9.2	7.6	5.6	7.8	7.5	7.3	1.03	14	46.0
Bazaliia	8.2	7.8	5.5	8.1	6.5	7.8	8.3	7.5	0.97	13	52.0
Duma	7.8	7.5	9.6	8.5	5.9	7.2	7.8	7.7	1.06	14	55.0
Tornado	7.2	9.1	6.7	9.8	7.8	8.6	8.5	8.2	1.00	12	58.0
Madison	8.5	10.3	7.9	9.1	7.8	9.8	10.4	9.1	1.00	11	60.0
Xmed	6.5	6.6	7.2	7.3	5.5	7.0	7.6	6.8			48.0
SD	1.30	1.92	1.31	1.51	1.42	1.50	1.24	1.28			8.9
CV, %	20	29	18	21	26	22	16	19			19
LSD_{05}	0.37	0.33	0.37	0.36	0.28	0.33	0.39	0.35			2.69
σ_G^2								0.1			
σ_A^2								2.6			
σ_F^2								2.7			
CVG, %								5.4			
CVF, %								24.3			
CVA, %								23.7			
CVG/CVA								0.23			

Notes: ** – control*
Source: *developed by the authors*

The largest average weight of marketable tubers (over 50 g) was formed by the cultivars Bazaliia, Duma, Radomysl, Tornado and Madison, which exceeded the control cultivar Skarbnytsia by 13-21 g. The dynamics of the early potato harvest by year showed that the weather conditions in 2020, 2021 and 2024 were the most favourable, with the average yield of 9.7, 10.6 and 15.9 t/ha. The analysis of the variability of this trait showed that the cultivars Bazaliia, Tornado and Madison had an average variation – *CV* = 23-24%, and all other cultivars had a significant variation – *CV* = 26-30%. The analysis by year showed that in 2019, 2022 and 2024, the yield variation between cultivars was low – 7-10%, while in all other years the variation was average – 11-18%.

On average over the years, only two cultivars produced lower yields than the control – Povin and Vzirets, with yields of 8.5 and 8.8 t/ha, which is 3.9 and 1.0% less than the control, or 0.3 and 0.1 t/ha, respectively. No significantly lower yields were recorded. All other cultivars had yields significantly higher than the control by 0.6-2.9 t/ha, or 7.2-32.2%. The most productive cultivars were Duma, Radomysl, Bazaliia, Tornado and Madison – 10.0-11.7 t/ha (Table 3).

Table 3. *Dynamics of early potato harvest, t/ha (2018-2024)*

Cultivar	2018	2019	2020	2021	2022	2023	2024	*Xmed*	*SD*	*CV*, %
Povin	7.1	7.7	7.9	7.7	6.1	8.6	14.6	8.5	2.58	30
Vzirets	7.3	8.4	8.3	8.1	6.4	8.4	14.6	8.8	2.47	28
Skarbnytsia (C)*	7.3	8.5	8.7	8.4	6.3	8.1	14.8	8.9	2.54	29
Sanibel	8.5	8.5	8.2	12.1	6.4	7.8	15.1	9.5	2.79	29
Bernina	7.5	9.0	9.0	10.8	7.2	8.5	15.1	9.6	2.50	26
Duma	10.0	7.8	8.2	11.2	7.6	8.6	16.7	10.0	2.98	30
Radomysl	7.8	9.1	11.2	11.2	7.3	8.8	16.5	10.3	2.90	28
Bazaliia	9.6	9.3	11.7	11.4	7.7	10.4	16.8	11.0	2.69	24
Tornado	11.9	9.4	12.4	12.1	8.0	11.0	17.1	11.7	2.66	23
Madison	10.7	10.0	11.7	13.0	8.1	11.2	17.4	11.7	2.71	23
Xmed	8.8	8.8	9.7	10.6	7.1	9.1	15.9	10.0		
SD	1.59	0.68	1.69	1.76	0.71	1.17	1.07	1.10		
CV	18	8	17	17	10	13	7	11		
LSD_{05}	0.45	0.45	0.50	0.54	0.36	0.47	0.81	0.51		
σ^2_G								1.0		
σ^2_A								8.4		
σ^2_F								9.5		
CVG, %								10.2		
CVF, %								30.8		
CVA, %								29.1		
CVG/CVA								0.35		

Notes: * – *control*
Source: *developed by the authors*

The statistical analysis showed that environmental variation (*CVA* = 29.1%) was superior to genetic variation (*CVG* = 510.2%), suggesting that the productivity of potato genotypes significantly depends on the environmental conditions of cultivation. Ratio of *CVG/CVA* = 0.35 and suggests that the climatic conditions of the Forest Steppe are favourable, but the biological potential of potato cultivars is not entirely fulfilled.

The genetic-statistical analysis of the yield of genotypes showed that the cultivars Vzirets, Skarbnytsia and Bernina were the most stable ($\sigma^2 d$). The study revealed that the cultivars Sanibel, Radomysl, Duma, Bazaliia and Madison had indicators of plasticity $bi > 1$ and stability $\sigma^2 d > 0$, which suggests their better results under favourable growing conditions, but they turned out to be unstable. The other cultivars had $bi < 1$ and

$\sigma^2 d > 0$, suggesting their ability to produce better results in unfavourable conditions, but they were also unstable.

Sanibel, Radomysl, Duma, Bazaliia and Madison cultivars can be classified as intensive in terms of plasticity (*bi*), while all other cultivars are classified as plastic. The cultivars were very evenly distributed in terms of homeostasis from 1.5 to 2.9, which confirms the stability or, on the contrary, the plasticity of a particular cultivar. The Tornado and Madison cultivars were distinguished by their high breeding value (*Sc*) and compensatory capacity (*CC*). The cultivars Radomysl, Duma, Bazaliia, Tornado, and Madison were distinguished with a high coefficient of adaptability – *AAC* was 1 and greater (Table 4).

Table 4. *Parameters of adaptability of early potato cultivars by yield, t/ha (2018-2024)*

Cultivar	*Xmed*	*σ²d*	*bi*	*Hom*	*Sc*	*MC*	*EPI*	*SR*	*CC*	*AAC*
Povin	8.5	1.61	0.96	1.5	6.2	2.12	0.85	-9	10	0.85
Vzirets	8.8	1.57	0.92	1.6	6.4	2.05	0.88	-8	11	0.88
Skarbnytsia (C)*	8.9	1.59	0.96	1.7	6.5	2.08	0.89	-9	11	0.89
Sanibel	9.5	1.67	1.01	1.9	6.9	2.07	0.95	-9	11	0.95
Bernina	9.6	1.58	0.94	1.9	7.0	1.99	0.96	-8	11	0.96
Radomysl	10.0	1.73	1.09	2.1	7.3	2.09	1.00	-9	12	1.00
Duma	10.3	1.70	1.09	2.2	7.5	2.06	1.02	-9	12	1.03
Bazaliia	11.0	1.64	1.02	2.6	8.0	1.93	1.10	-9	12	1.10
Tornado	11.7	1.63	0.97	2.9	8.5	1.83	1.18	-9	13	1.17
Madison	11.7	1.64	1.03	2.9	8.6	1.88	1.18	-9	13	1.17

Notes: * – *control*
Source: *developed by the authors*

The analysis of the averaged data over the years of research showed that the highest yield was recorded for the Madison cultivar, which reached 37.2 t/ha. Compared to the control cultivar Skarbnytsia, which yielded 18.6 t/ha, the Madison cultivar yielded 18.6 t/ha more, which is a 100% increase. The Tornado potato cultivar also showed a high yield of 34.7 t/ha, which was 16.1 t/ha higher than the control. The Duma and Bazaliia cultivars had slightly lower yields of 31.4 and 32.2 t/ha, respectively, but still outperformed the control by 12.8 and 13.6 t/ha.Phenotypic stability revealed a clear pattern: with increasing yields, the stability of the trait also increased. Thus, cultivars Radomysl, Madison and Bazaliia showed both high yields and stability of this trait (Fig. 1).

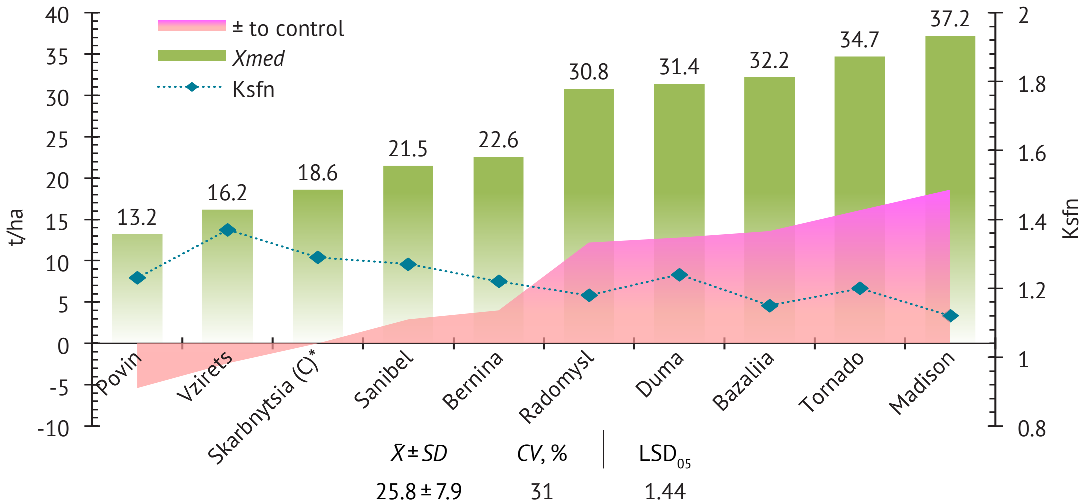

Figure 1. *Yield of early potato cultivars in biological ripeness (after complete death of tops)*
Notes: * – *control*
Source: *developed by the authors*

The study helped to establish the fact that the share of early harvest is 31.5-64.6% of the crop after the tops have completely died off. It was found that the more productive the cultivar is in the phase of complete tops' death, the smaller is the share allocated to the early harvest. As a result of statistical calculations, a strong correlation was found on the Chaddock scale between the yield of early production and the amount of precipitation during the growing season of potato plants – $r = 0.8577$ and the total yield and the amount of precipitation – $r = 0.7595$. Considering the statistical reliability of the equations, the corresponding dependence is presented graphically in Figure 2.

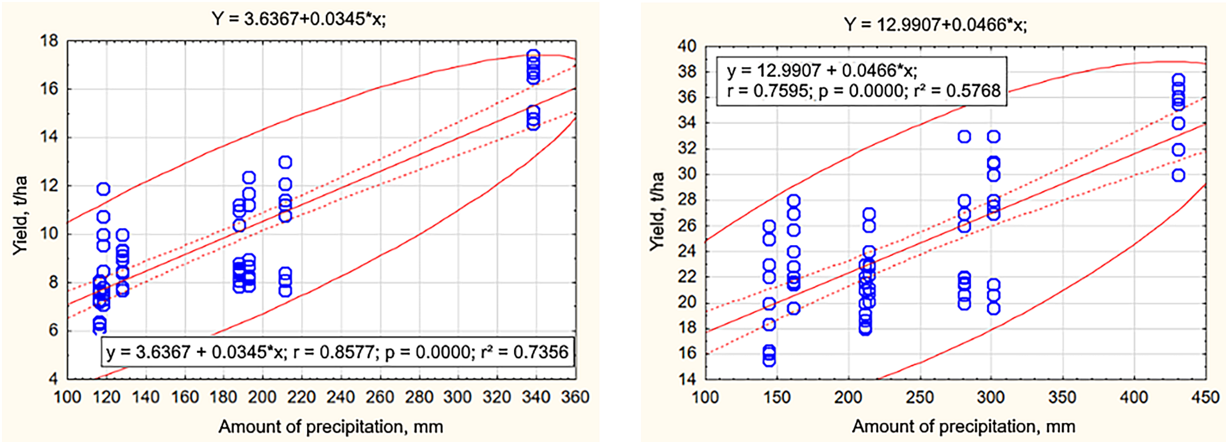

Figure 2. *Statistical models of potato yield dependence on the amount of precipitation*
Source: *developed by the authors*

The data obtained suggest that the difference in the number of tubers per plant is a genetic trait of the plant and is subject to a noticeable environmental influence. The findings of this study are in line with the data obtained by T.E. Eaton *et al.* (2017) and A. Khan *et al.* (2019), who noted that the number of tubers depends on genotype and environmental conditions. The findings of this study showed a significantly higher influence of environmental conditions than the genotypic component (*CVG* = 5.4%, *CVA* = 23.7%, while the ratio *CVG/CVA* = 0.23). D. Kumar *et al.* (2004) and C.K. Patel *et al.* (2008) also noted that tuber weight is more genotype-dependent and heritable.

Considerable standard deviations are unambiguous evidence of the significant influence of the environment on the investigated traits of potato cultivars. F. Elfnesh *et al.* (2011) reported a significant effect of environment on the performance of potato genotypes. These data are also consistent with the data presented in the current study: high SD scores (0.68-1.76), high coefficient of ecological variation (*CVA* = 29.1%) and a low ratio between *CVG/CVA* = 0.35 for early harvest, suggest a significant influence of environmental conditions on the productivity of potato cultivars. T. Abebe *et al.* (2012) reported a considerable effect of genotype and genotype × environment interaction on the productivity of 25 potato cultivars. W. Mohammed (2016) and M. Nasiruddin *et al.* (2017) reported analogous results in their studies.

M. Ostrenko *et al.* (2020) noted that the early yield of young potato tubers depended on varietal characteristics and ranged from 12.8 t/ha in the Skarbnytsia cultivar at 60 days after germination to 21.0 t/ha at full ripeness. The findings of the present study reflect comparable dynamics: the Skarbnytsia cultivar had an early potato yield of 8.9 t/ha at 40 days, and 18.6 t/ha after complete tops death, while in India, the tuber yield at 60 days was 18.52 t/ha (Deshmukh *et al.*, 2018).

According to the findings of this study, environment and genotype had an impact on tuber weight. According to G. Habtamu *et al.* (2016), tuber weight is strongly influenced by potato genotype, as well as management practices (cultivation), seed quality, or agro-ecological conditions. T.E. Eaton *et al.* (2017) also reported this. According to A. Borivskyi (2016), the variation in the total yield of early potato cultivars ranged within 26.0-31.0 t/ha. L. Korol *et al.* (2023) report potato yields of 16.8-31.9 t/ha and an adaptability coefficient of 0.72-1.27, which to some extent coincides with the findings of the present study. The obtained findings confirmed the previous ones and showed the adaptability of cultivars at 0.85-1.17. As a result of the discussion, comparable patterns of productivity formation of different potato cultivars in various soil and climatic conditions were revealed and a substantial intervarietal difference in productivity parameters was confirmed.

CONCLUSIONS

It was found that without adapting the farm to climate change by selecting cultivars, it is impossible to achieve high potato productivity. The investigation of the level of adaptability of different cultivars of early potatoes to the soil and climatic conditions of the Forest-Steppe helped to identify cultivars that allow procuring an early harvest of marketable tubers – Sanibel, Radomysl, Duma, Bazaliia and Madison. It was found that these cultivars provided yields of 9.5-11.7 t/ha 40 days after germination. The number of marketable tubers in the bush, which ranged on average from 5.1 pcs/plant in the Povin cultivar to 9.1 pcs/plant in the Madison cultivar, and their weight, which ranged within 33.0-60.0 g, influences the high yield. The cultivars that formed an increased number of marketable tubers in the bush were Bernina, Bazaliia, Duma, Tornado and Madison, and cultivars with a larger mass of marketable tubers were Bazaliia, Duma, Radomysl, Tornado and Madison. The analysis of the averaged data showed that the highest yields were recorded for the Madison cultivar, which reached 37.2 t/ha (+100%), compared to the standard cultivar Skarbnytsia, which yielded 18.6 t/ha. Phenotypic stability revealed a clear pattern: with increasing yields, the stability of the trait also increased. Thus, the cultivars Radomysl, Madison and Bazaliia showed both high yields and stability of this trait. Statistical studies contributed to the ranking of cultivars into two groups: Sanibel, Radomysl, Duma, Bazaliia and Madison cultivars had plasticity parameters $bi > 1$ and stability $\sigma^2 d > 0$, which suggests their better productivity under favourable growing conditions, although they were unstable. Other cultivars had $bi < 1$ and $\sigma^2 d > 0$, which indicates their high productivity in unfavourable conditions, although they were also unstable. The conducted genetic and statistical analysis showed a strong ecological variation (*CVA*) of the traits under study, which suggests a strong dependence of potato cultivars productivity on growing conditions and was confirmed by the correlation analysis of the dependence of yield on moisture supply – $r = 0.8577$. Prospects for further research lie in the possibility of growing seed potatoes of the studied cultivars with optimisation of the elements of growing technology (drip irrigation, mulching).

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CONFLICT OF INTEREST

None.

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Адаптивна мінливість картоплі ранньої у Лісостепу України

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Анотація. Метою було передбачено дослідити динаміку формування врожайності картоплі ранньої на 40 добу залежно від погодних умов років досліджень та адаптивний потенціал ранньостиглих сортів картоплі. Упродовж 2018-2024 рр. у польових умовах (м. Умань, 48°46′N, 30°14′E) досліджено 10 поширених в зоні Лісостепу сортів картоплі ранньостиглої. Для аналізу отриманих результатів використано загальноприйняті методи польових і генетико-статистичних досліджень. Під час проведення досліджень вивчено кількість і масу товарних бульб в кущі, динаміку формування врожаю на 40 добу після появи сходів та силу кореляційного зв'язку між врожайністю і сумою опадів. У результаті одержаних даних визначено найбільш перспективні сорти для отримання раннього врожаю ранньої картоплі у Лісостепу України. Встановлено, що даній кліматичній зоні найбільше відповідають сорти Базалія, Торнадо, Медісон з врожайністю 11,0-11,7 т/га та великою масою товарної бульби – 58-60 г. У фазу повної стиглості найбільш врожайними виявилися сорти Медісон – 37,2 т/га (+18,6 т/га контролю), Торнадо – 34,7 т/га (+16,1 т/га до контролю), Дума і Базалія – 31,4 і 32,2 т/га (+12,8 і 13,6 т/га до контролю). Дослідженнями встановлено, що сорти Торнадо і Медісон формують найбільшу кількість товарних бульб в кущі. За результатами аналізу співвідношення параметрів пластичності й стабільності проведено групування сортів на інтенсивні (Санібель, Радомисль, Дума, Базалія і Медісон мали показники $bi > 1$, $\sigma^2 d > 0$ і пластичні (Повінь, Взірець, Скарбниця, Берніна і Торнадо). У результаті проведених досліджень визначено найбільш продуктивні сорти картоплі на ранню продукцію, що забезпечать стабільний розвиток галузі овочівництва в зоні Лісостепу України, а розраховані статистичні моделі дозволять прогнозувати і програмувати врожайність картоплі

Ключові слова: ранній врожай; стабільність; пластичність; екологічна варіація; генетична варіація