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ECOLOGICAL SUITABILITY PEAS (*Pisum sativum*) VARIETIES TO CLIMATE CHANGE IN UKRAINE

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ABSTRACT. The varieties of peas can realize about 50% of their productive potential. One of the main reasons for this is the wrong choice of variety for specific ecological growing conditions. Therefore, the purpose and task of our research are to analyze the current range of peas, included in the State Register of plant varieties suitable for cultivation in Ukraine in terms of their real productivity and resistance to drought and disease in the context of climate change in the direction of drought and temperature rise. Assessment of agroecological stability of pea varieties was carried out by elaboration of the State Register of Plant Varieties Suitable for Distribution in Ukraine for 2020, 2010 and Official Descriptions of Plant Varieties and Suitability Indicators submitted in the official bulletins "Protection of Plant Variety Rights" published in Information and reference system "Variety". The most resistant to disease in Ukraine are varieties of peas 'Verbal', 'Prystan', 'Eco', 'Atanas', 'Haiduk'. Varieties are marked by the highest drought resistance 'Verbal', 'Album', 'Alssas', 'Kampus'. The most productive varieties were peas 'Kosmai', 'Album', 'Haiduk', 'Trendy'. The increase in the average annual air temperature in Ukraine during 2001–2020 by 19.3% (8.2–9.9 °C) led to a decrease in the yield of peas by 13.7%, but an increase in the score of resistance of pea varieties to diseases by 25.0%, the score of drought resistance – by 18.8%. Comparison of indicators of disease resistance, drought resistance and productivity of pea varieties for 2020 and 2010 showed that the score of resistance of pea varieties sown to diseases in the period from 2010 to 2020 increased from 6.3 to 8.4 points, *i.e.* by 25.0%. Drought resistance of pea varieties in 2020 compared to 2010 increased from 6.5 to 8.0 points, which is 18.8%. At the same time, the grain productivity of pea varieties in 2020 compared to 2010 decreased from 3.57 t ha^{-1} to 3.08 t ha^{-1}, which is 13.7%.

Introduction

Among grain legumes grown in Eastern Europe, peas occupy the largest area – about 5 million hectares, which is about 30% of the world's area of this crop. This is due to the high average yield, valuable food and fodder qualities of peas, as well as the important agro-ecological impact of pea plants due to symbiotic nitrogen fixation to increase soil fertility and as an optimal precursor for winter crops (Mazur *et al*., 2019.

In Ukraine, peas are grown in all soil and climatic zones on a total area of 347 thousand hectares with an average yield of 2.28 t ha^{-1} (Pantsyreva, 2018; Telekalo, 2018; Mazur *et al.*, 2020; Palamarchuk, Tkachuk, 2020a). The share of peas in the structure of sown areas is slightly more than 1%, which requires a significant increase in its crops because the potential of the best varieties of peas can reach 5.5 t ha^{-1}. However, under adverse weather conditions during the growing season, there is a significant decrease in its yield.

One of the promising areas to increase sown areas and increase pea productivity is the introduction into production of high-yielding varieties with increased resistance to lodging, shedding, adapted to specific growing conditions, in particular to adverse growing conditions, among which drought has stood out in recent decades.

The variety must be characterized by a high adaptive capacity, which allows restoring to the optimal level of metabolic processes after the stress factor, which is especially important due to changes and instability of the climate. The main properties that determine the level of adaptability of peas include high harvest index, type of stem growth, ripening, resistance to disease, resistance to shedding, high real yield.

According to the results of many years of research, it is established that the high productivity of pea varieties is possible under favourable weather conditions. Given the extreme climate in Ukraine, the constant annual increase in average annual air temperature and reduced rainfall, to realize the potential for productivity in varieties of peas is quite difficult. The level of pea yield and its stability by 48% depends on the influence of weather conditions under the optimal parameters of the influence of other factors.

Meteorological conditions that develop during the growing season, largely determine the effectiveness of a particular agronomic technique, which also affects the productivity of pea crops. The results of research by many scientists (Peltonen-Sainio *et al.*, 2009; Kolesnik, 2012; Karkanis *et al.,* 2016; Witold, Cylwester, 2020) on modern technologies of pea cultivation are aimed at maximizing the biological potential of the crop, which cannot be achieved without taking into account the meteorological conditions of a particular region, which play an important role, and without optimizing pea growing technologies.

The determining factor in the expansion of sown areas under sowing peas is the correct selection of varieties taking into account modern environmental conditions. One of the main indicators in the selection of varieties of legumes for certain soil and climatic conditions is their real yield and manufacturability.

In modern conditions, fundamental and applied research has deepened, in which the problems of the greening of agriculture by optimizing the elements of varietal cultivation technology are the subject of special attention of scientists. In particular, the development of this issue includes many scientific works of Ukrainian scientists (Vdovenko *et al*., 2018a; Mazur *et al*., 2019; Pantsyreva, 2019; Didur *et al.,* 2020; Honcharuk, Pantsyreva, 2020; Mazur *et al*., 2020; Razanov *et al*., 2020b; Petrychenko *et al*., 2021; Puyu *et al.,* 2021).

The main indicators of the manufacturability of legumes are the resistance of plants against lodging, shedding of beans, the suitability of plants for direct combining, the height of attachment of the lower beans, plant height and others (Ermakov *et al*., 1987; Ma *et al.*, 2001; Kolesnik, 2012; Yanovych *et al.,* 2018; Bandura *et al.,* 2019; Kaletnik, Lutkovska, 2020; Kuznietsova *et al.*, 2020; Mazur *et al*., 2020; Pantsyreva *et al.*, 2020; Razanov *et al.,* 2020a; Tkachuk, 2020b; Tkachuk, Telekalo, 2020; Didur *et al.,* 2021;).

It is also necessary to take into account the maturity of varieties, their reaction to weather and soil conditions. Climate change in recent years has led to the fact that some varieties of peas have become severely depressed by drought, and this has affected their resistance to diseases, pests, and most importantly – their productivity.

Therefore, the ecological indicators of suitability of varieties of peas should include their drought resistance, as well as resistance to the most common diseases and pests (Yanovych *et al.,* 2017; Pantsyreva, 2019; Mazur *et al*., 2019; Mazur *et al*., 2020; Pantsyreva *et al.,* 2020; Razanov *et al.,* 2020a; Gunko *et al.,* 2021).

The varieties of peas can realize about 50% of their productive potential. One of the main reasons for this is the wrong variety for specific ecological growing conditions (Melnychuk, Patyka, 2011; Mazur *et al*., 2019; Solona *et al.*, 2020).

The purpose of the research was to develop competitive varietal technologies for growing peas seeds, which provides for the development of elements of the application of a set of alternative fertilizers for their cultivation in terms of short-term and long-term action and basic superstructure factor assessment of soil fertility, hydrothermal conditions.

The task of the paper was to analysis of the assortment of peas, included in the State Register of plant varieties suitable for cultivation in Ukraine in terms of their potential productivity and resistance to drought and disease in the context of climate change in the direction of drought and rising temperatures; formation of a new method for assessing the bioadequate productivity of arable land to determine the possibility of adaptation of plants to bioorganic technologies for growing legumes, in particular peas.

Material and Methods

Assessment of agroecological sustainability of pea varieties was carried out by elaboration of the State Register of Plant Varieties Suitable for Distribution in Ukraine for 2020 and Official Descriptions of Plant Varieties and Suitability Indicators submitted in the official bulletins "Protection of Plant Variety Rights" published in the Information Reference system "Variety" (Palamarchuk *et al*., 2018; Vdovenko *et al.,* 2018b; State Register ..., 2021).

Varieties of legumes in the state qualification examination to determine the indicators of suitability for distribution in Ukraine are assessed, among other things, by grain yield, resistance (tolerance) against disease, to adverse weather conditions and other indicators.

The parameters of agri-environmental sustainability, which are covered in official documents, are the relationship of plants to the effects of disease and drought. Quantitative stability was established on a relative nine-point scale (1–9 points), where 9 points correspond to the highest stability, and 1 point – the lowest stability. The following gradation of grades by points was used: 9 points – the grade is excellent; 7 points – good variety; 5 points – the variety is satisfactory; 3 points – bad grade; 1 point – unsatisfactorily. Pea seed yield levels were also analyzed. We compared the studied indicators with the use of mathematical-statistical correlation-regression analysis.

These indicators of sown peas were established based on the Methodology of examination of plant varieties of cereals, cereals and legumes for suitability for distribution in Ukraine. All experiments are performed on plots of 10–25 m^2 with four repetitions.

Establishment of resistance of pea plants to diseases: peronosporosis (*Peronospora pisi* Syb.), Root rot (*Fusarium* Link), ascochitosis (*Ascochyta pisi* Libert.) and anthracnose (*Colletotrichum pisi* Pat.) was carried out by methods: peronosporosis (*Peronospora pisi* Syb) phase of filling the bulk of beans by the percentage of the affected surface; root rot (*Fusarium* Link) – in the phase of full flowering by the percentage of affected plants and the development of the disease in points; ascochytosis (*Ascochyta pisi* Libert.) – during the period of filling the bulk of beans and before harvesting by the percentage of damage to leaves, stems and beans; anthracnose (*Colletotrichum pisi* Pat.) – in the phase of filling the bulk of beans by the percentage of affected plants and the development of the disease in points.

Assessment of varieties resistance to adverse weather conditions, in particular drought, was carried out by general guidelines. During the growing season, pea varieties are visually assessed for drought resistance. To determine the yield of plants, they are harvested separately or directly by combining, when the humidity was in the range of 30–35%, at grain moisture of 16–17%.

Results and Discussion

In Ukraine, as well as all over the world, the development of crop production is ensured by the creation and implementation of new breeding studies. Selection for resistance to climate change requires constant monitoring of plant growth and development. It is necessary to constantly study and identify reliably resistant varieties of peas – sources of resistance. One of the promising ways to address the issue of creating varieties with long-term resistance to climate change in the direction of warming is the use in the selection of sources characterized by genetic resistance to drought. The gene pool of plants is the basis for the identification of these sources with their subsequent introduction into breeding programs (Peltonen-Sainio *et al.*, 2009; Karkanis *et al.*, 2016; Witold *et al.*, 2020; Puyu *et al.*, 2021).

The results of the research show that in Ukraine there is a steady decline in yields of pea varieties in the period from 2001 to 2020. The ecological reason for this is the increase in the average annual air temperature in Ukraine, which causes the development of pea plants in a less favourable temperature range than required by its biological characteristics. This leads to the fact that the central zone of the Forest-Steppe of Ukraine after some time will be unsuitable for growing peas, and its favourable sowing zones will move to the north. In Ukraine, such a zone is Polissya, where pea crops have long been significantly affected by the disease.

At the same time, the selection of modern varieties of peas is developing in the direction of increasing their drought resistance. During the twenty-year observation period, the drought resistance of pea varieties increased by almost two points. The creation of more drought-resistant varieties of peas reduces their dependence on elevated temperatures and allows to keep the yield of pea seeds at a stable level, but in the long run, the yield of modern varieties of peas, despite increasing their drought resistance, decreases. In parallel with the increase in the score of drought resistance of pea varieties, their resistance to disease increases over the study period. An increase in the average annual air temperature objectively worsens the conditions for the development of fungal diseases in pea crops. Therefore, there was a lower level of disease in pea plants in 2020 compared to 2001. However, the increased score of resistance of pea varieties to diseases did not affect the yield, because, in conditions of elevated temperatures, the damage from them on pea plants is negligible.

Based on this, it follows that the increase in drought resistance and disease resistance of pea varieties did not increase or stabilize their yield. The main factor influencing the level of the yield of pea varieties was the average annual air temperature.

We analyzed the indicators of agroecological resistance varieties of peas to disease and drought, as well as their productivity according to the State Register of Plant Varieties of Ukraine, which were introduced during 2015–2020 and in comparison with pea varieties, which were introduced during 2005–2010.

The most common diseases of peas, resistance to which was analyzed, were downy mildew (*Pernosporosis pisi* Syb.), root rot (*Fusarium* Link), ascochitosis (*Ascochyta pisi* Libert.) and anthracnose (*Colletotrichum pisi* Pat.).

During the period 2015–2020, 39 varieties of sown peas were entered into the State Register of Plant Varieties of Ukraine. The range of scores of resistance to diseases varieties of peas, which were included in the State Register during 2015–2020, was 7.8–8.8 points out of 9 maximum possible. The highest resistance to disease was characterized by varieties of peas 'Verbal', 'Prystan' – 8.8 points; 'Eso', 'Atanas', 'Haiduk' – 8.7 points each. The lowest resistance to disease was found in 'Kentso' pea varieties – 7.8 points; 'Kosmai', 'Impuls', 'Trendy' – 8.0 points each. The average score of resistance varieties of peas to disease was 8.4 points (Table 1).

Drought resistance varieties of sown peas were in the range of 7.0–8.8 points out of 9 maximum possible. The highest drought resistance was noted by 'Verbal' – 8.8 points, 'Album', 'Alssas' – 8.7 points, 'Kampus' – 8.6 points. 'Yump', 'Impuls', 'Malahit' varieties had the lowest drought resistance – 7.0 points each. The average score of drought resistance of all varieties of peas was 8.0 points.

Table 1. Indicators of agroecological sustainability and productivity of pea varieties according to the State Register of Plant Varieties of Ukraine for 2020

Varieties	Stability to diseases, points	Drought stability, points	Real yield, t ha^{-1}
'Abars'	8.3	7.8	2.68
'Album'	8.6	8.7	3.78
'Alex YU.L.'	8.3	8.0	3.19
'Alssas'	8.5	8.7	2.92
'Astronavt'	8.2	8.2	2.96
'Atanas'	8.7	8.3	2.90
'Avenger'	8.2	8.2	2.96
'Bokser'	8.3	8.2	3.18
'Bosfor'	8.5	7.5	2.47
'Darunok stepu'	8.5	8.3	3.29
'Eco'	8.7	8.3	3.53
'Haiduk'	8.7	8.5	3.76
'Hambit'	8.2	8.2	2.95
'Heizer'	8.3	7.7	2.41
'Impuls'	8.0	7.0	3.16
'Kampus'	8.6	8.6	3.23
'Kareni'	8.3	8.0	3.14
'Karpaty'	8.3	8.0	3.37
'Kentso'	7.8	7.8	2.44
'Korvet'	8.5	8.3	2.69
'Kosmai'	8.0	8.0	4.70
'Kruiz'	8.4	8.2	2.64
'Lessna'	8.4	7.6	2.55
'Malahit'	8.3	7.0	2.91
'Mazepa'	8.4	7.8	2.72
'Metsenat'	8.3	8.2	3.00
'Prystan'	8.8	8.5	3.25
'Salamanka'	8.4	8.0	2.91
'Slovan'	8.4	7.8	2.72
'Tip'	8.4	8.1	2.83
'Trendy'	8.0	8.0	3.75
'Velvet'	8.3	8.0	3.19
'Verbal'	8.8	8.8	3.67
'Yump'	8.3	7.0	3.29

Grain productivity of pea varieties in 2020, according to the State Register of Plant Varieties of Ukraine, was 2.44–4.70 t ha^{-1}. 'Kosmai' varieties in 2020 have the highest grain productivity – 4.70 t ha^{-1}, 'Album' – 3.78 t ha^{-1}, 'Haiduk' – 3.76 t ha^{-1}, 'Trendy' – 3.75 t ha^{-1}. The least productive varieties were 'Heizer' – 2.41 t ha^{-1}, 'Kentso' – 2.44 t ha^{-1}, 'Bosfor' – 2.47 t ha^{-1}, 'Lessna' – 2.55 t ha^{-1}. The average yield of all varieties of peas was 3.08 t ha^{-1}.

In 2010, 40 varieties of peas were presented in the State Register of Plant Varieties of Ukraine. The score of resistance of these varieties to diseases was in the range of 5.0–8.0. 'Harde', 'Yezero', 'Kardiff', 'Lavr', 'Maskara', 'Ulus', 'Chehbek', 'CHBL-5' pea varieties had the highest resistance to diseases – 8.0 points each. 'Damyr 3', 'Krasnodarskii 8', 'Lazer', 'Lord', 'Namysto', 'Poltavets-2' pea varieties were characterized by the lowest disease resistance – 5.0 points each. The average score of resistance of all varieties of sown peas, which were in the State Register of Plant Varieties of Ukraine in 2010, was 6.3 points.

Drought resistance of pea varieties, which were in the State Register of Plant Varieties of Ukraine for 2010, was 5.0–8.0 points. The most drought-resistant varieties were 'Zekon', 'Kaddi', 'Kardiff', 'Menhir', 'Maskara', 'Madonna', 'Nord', 'Stepovyk', 'Kharkivskii etalonnyi' – 8.0 points each. The lowest drought resistance varieties 'Krasnodarskii 8', 'Konto', 'Camelot', 'Namysto' – 5.0 points each. The average score of drought resistance of all varieties of sown peas in 2010 was 6.5 points (Table 2).

Table 2. Indicators of agroecological sustainability and productivity of pea varieties according to the State Register of Plant Varieties of Ukraine for 2010

Varieties	Stability to diseases, points	Drought stability, points	Real yield, t ha^{-1}
'CHBL-5'	8.0	6.0	3.08
'Chehbek'	8.0	7.5	3.06
'Damyr 3'	5.0	6.0	3.64
'Deviz'	6.0	7.5	3.87
'Efectnyi'	6.0	6.0	3.60
'Elehant'	6.0	6.0	3.12
'Fargus'	6.0	7.5	3.85
'Glyans'	6.0	6.0	3.90
'Harde'	8.0	6.0	4.10
'Hardi'	6.0	6.0	4.14
'Hotivskii'	7.0	6.0	4.16
'Kaddi'	6.0	8.0	3.86
'Kamelot'	6.0	5.0	3.08
'Kamerton'	6.0	6.0	3.56
'Kardiff"	8.0	8.0	4.05
'Keo'	6.0	6.0	3.50
'Kharkivskii etalonnyi'	6.0	8.0	3.60
'Kombainovanyi'	6.0	6.0	3.54
'Konto'	6.0	5.0	3.08
'Krasnodarskii 8'	5.0	5.0	2.60
'Lavr'	8.0	6.0	3.08
'Lazer'	5.0	6.0	3.64
'Madonna'	6.0	8.0	4.64
'Maskara'	8.0	8.0	4.06
'Menhir'	6.0	8.0	3.62
'MoDus'	6.0	6.0	3.64
'Namysto'	5.0	5.0	2.53
'Nord'	5.0	8.0	3.57
'Petroneun'	6.0	6.0	4.06
'Poltavets-2'	5.0	6.0	3.11
'Rialto'	7.0	6.0	3.07
'Santana'	7.0	7.0	3.09
'Stepovyk'	6.0	8.0	3.58
'Svit'	6.0	7.0	3.10
'Tsarevych'	6.0	6.0	3.10
'Ulus'	8.0	6.0	3.12
'Yavor'	6.0	6.0	4.10
'Yezero'	8.0	6.0	4.10
'Zekon'	6.0	8.0	4.12
'Zinkivskii'	6.0	6.0	3.90

Productivity of pea varieties for 2010 was 2.53–4.64 t ha^{-1}. The most productive varieties were 'Madonna' – 4.64 t ha^{-1}, 'Hotivskii' – 4.16 t ha^{-1}, 'Hardy' – 4.14 t ha^{-1}, 'Zekon' – 4.12 t ha^{-1}, 'Yavor' – 4.10 t ha^{-1}. The lowest yields were 'Namysto' – 2.53 t ha^{-1} and 'Krasnodarskii 8' – 2.60 t ha^{-1}. The average seed yield of pea varieties for 2010 was 3.57 t ha^{-1}.

Of the forty varieties of peas that were in the State Register of Plant Varieties of Ukraine for 2010, currently (2021) there are 9 varieties in this article: 'Hotivskii', 'Glyans', 'Zekon', 'Zinkivskii', 'Madonna', 'Namysto', 'Svit', 'Ulus', 'Tsarevych'. Among them, 'Ulus' had the highest disease resistance score, 'Zekon' and 'Madonna' had the highest drought resistance score, and 'Madonna', 'Hotivskii', 'Zekon', 'Zinkivskii' and 'Glyans' had the highest yield.

Comparison of indicators of disease resistance, drought resistance and productivity of pea varieties for 2020 and 2010 showed that the score of resistance of

pea varieties sown to diseases in the period from 2010 to 2020 increased from 6.3 to 8.4 points, *i.e.* by 25.0%. Drought resistance of pea varieties in 2020 compared to 2010 increased from 6.5 to 8.0 points, which is 18.8%. At the same time, the grain productivity of pea varieties in 2020 compared to 2010 decreased from 3.57 t ha^{-1} to 3.08 t ha^{-1}, which is 13.7%.

A comparison of agroecological indicators of pea varieties that remained in the state register from 2010 to the present with other sowing pea varieties that were in the register at that time showed that the score of disease resistance of these varieties was 1.6% lower than the average of all varieties, the drought resistance score was 1.5% lower than the average of all varieties, but 1.1% higher yield.

Correlation-regression analysis revealed an average positive relationship between the score of disease resistance and the score of drought resistance of varieties of peas, which are in the State Register of Ukraine for 2020 ($r = 0.142$; $P > 0.05$) (Fig. 1). The average positive relationship between the score of disease resistance and the score of drought resistance of pea varieties shows that there was no direct relationship between the studied factors, but there was a tendency to increase the resistance of pea varieties to disease with increasing drought resistance.

Correlation-regression analysis revealed an average positive relationship between the score of drought resistance and the yield of pea varieties that were in the State Register of Ukraine in 2010 ($r = 0.442$; $P < 0.01$) (Fig. 2). The average positive relationship between the drought resistance score and the yield of pea varieties shows that with increasing drought resistance of pea varieties, their yield increases. Given the increase in the average annual air temperature in Ukraine, the conditions of pea development are deteriorating, as peas belong to cold-resistant crops, with moderate moisture, which leads to a decrease in its yield. The direction of breeding science to create more drought-resistant varieties provides high productivity in drought conditions. The coefficient of determination ($R^2 = 0.1954$) shows that increasing the score of drought resistance of pea varieties per unit contributes to increasing its yield by 0.19 t ha^{-1}. The average seed yield of pea varieties for 2010 was 3.57 t ha^{-1}.

At the same time, separate combinations of both positive and positive with negative characteristics of pea varieties have been established. In particular, the 'Album' pea variety combined high seed productivity with the highest drought resistance score, the 'Haiduk' variety with high disease resistance, the 'Kosmai' and 'Trendy' varieties with the highest seed yield with the lowest plant resistance, and the 'Kentso' variety with the lowest productivity and the lowest resistance to diseases.

The pea varieties on the state register as of 2010, such as 'Madonna' and 'Zekon', combining high productivity with high drought resistance, and 'Namysto' and 'Krasnodarskii 8' combined low productivity with the lowest score on disease and drought resistance.

According to the Central Geophysical Observatory of Ukraine. Central Geophysical Observatory of Ukraine, named by Borys Sreznevsky from 2001 to 2010, the average annual air temperature in the middle part of Ukraine was in the range of 8.2–9.9 °C. The average temperature for ten years was 9.0 °C. During the second decade – from 2011 to 2020, the average annual air temperature increased by 0.8 °C and amounted to 9.8 °C with an amplitude of 9.0–10.9 °C (Table 3).

Table 3. Dynamics of average annual air temperature in the Forest-Steppe conditions of the Right Bank of Ukraine during 2001–2020 (Central Geophysical Observatory of Ukraine, named by Borys Sreznevsky)

Years	Temperature, °C	Years	Temperature, °C
2001	8.8	2011	9.2
2002	9.3	2012	9.0
2003	8.2	2013	9.4
2004	8.7	2014	9.4
2005	8.7	2015	10.5
2006	8.4	2016	9.5
2007	9.9	2017	9.8
2008	9.6	2018	9.5
2009	9.4	2019	10.6
2010	9.4	2020	10.9
Average for 2001–2010	9.0	Average for 2011–2020	9.8
Average perennial	7.7	Average perennial	7.7

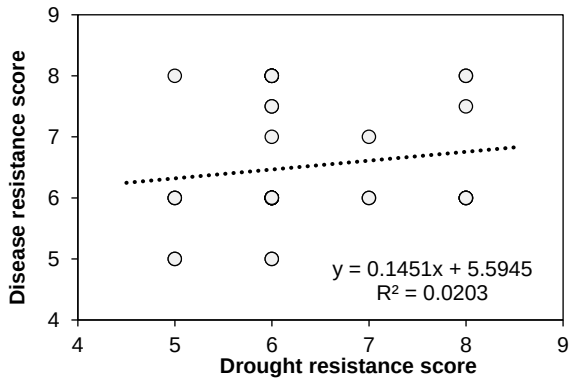

Figure 1. Regression between the score of drought resistance and the score of resistance to diseases of pea varieties included in the State Register of Plant Varieties of Ukraine for 2020

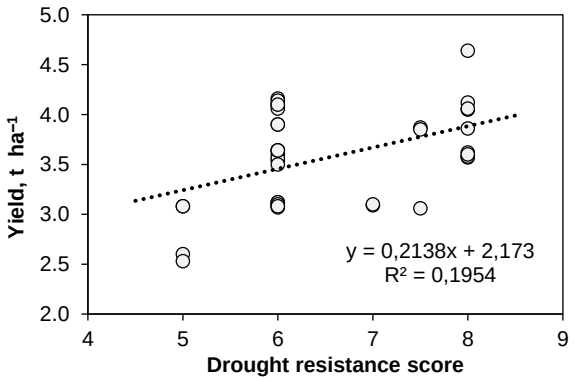

Figure 2. Regression between the score of drought resistance and yield of pea varieties included in the State Register of Plant Varieties of Ukraine for 2010

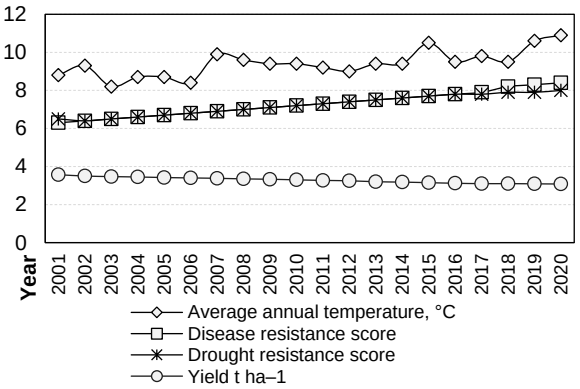

Figure 3. Dynamics of average daily air temperature, the score of disease resistance and drought resistance and yield of pea varieties in Ukraine during 2001–2020.

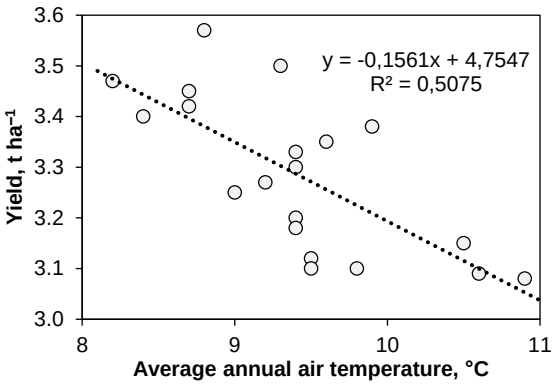

Figure 4. Regression between the average annual air temperature and yield of varieties of peas in 2001–2020

Thus, over the last ten years, the average annual air temperature has risen by 0.8 °C, and compared to the long-term average – by 1.6 °C. Graphic representation of the dependence of changes in average annual air temperature over twenty years on productivity and resistance to disease and drought resistance of pea varieties showed that the growth of average annual air temperature in Ukraine during 2001–2020 by 19.3% led to a decrease in pea yield by 13.7%, but the increase in the score of resistance of pea varieties to diseases by 25.0%, the score of drought resistance – by 18.8% (Fig. 3).

Correlation-regression analysis revealed a strong positive relationship between the average annual air temperature and the score of resistance to diseases of pea varieties ($r = 0.754$; $P < 0.001$); drought resistance score ($r = 0.728$; $P < 0.001$); the strong negative relationship between average annual air temperature and seed yield of pea varieties ($r = –0.712$; $P < 0.001$).

The mathematical relationship between the average annual air temperature and seed yield of pea varieties is described by the correlation-regression chart and the regression equation presented in Figure 4.

The presence of a strong negative relationship between the average annual air temperature and seed yield of pea varieties ($r = –0.712$) shows that with increasing average annual air temperature in Ukraine there was a decrease in the yield of pea varieties under observation for a period of twenty years (2001–2020). The coefficient of determination ($R^2 = 0.5075$) shows that an increase in the average annual air temperature by 1 °C causes a decrease in the average pea yield by 0.5 t ha^{-1} in the twenty-year dynamics of observations.

Conclusion

In 2020 the most diseases resistant in Ukraine are pea varieties 'Verbal', 'Prystan', 'Eso', 'Atanas', 'Haiduk'. 'Verbal', 'Album', 'Alssas', 'Kampus' varieties have the highest drought resistance. The most productive varieties of peas were 'Kosmai', 'Album', 'Haiduk', 'Trendy'. The increase in the average annual air temperature in Ukraine during 2001–2020 by 19.3% led to a decrease in the yield of peas by 13.7%, but an increase in the score of resistance of pea varieties to diseases by 25.0%, the score of drought resistance – by 18.8%.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

VM, OT – study conception and design;
IK, MM, OC – acquisition of data;
OT, HP, OC – analysis and interpretation of data;
MM, HP – drafting of the manuscript;
IK – editing the manuscript;
VM, HP – critical revision and approval of the final manuscript.

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