The ecological adaptation of new spring canola varieties in different environmental conditions

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Abstract. The study of phenotypic plasticity and stability, according to which the potential of new spring canola varieties adaptability for agroecological technology of spring canola growing in the strategy of intensification of plant production is actual. The new canola varieties, which were included in the State register of plant varieties suitable for dissemination in Ukraine was studied. Field studies were carried out in 2018–2019 on the testing sites of the Ukrainian Institute for Plant Variety Examination in Forest and Forest Steppe zones of Ukraine. The phenotypic plasticity and stability analysis for yield, 1,000 seeds weight, protein and oil content were carried out according to the Eberhart and Russell approach. As results of this study, it was determined that for yield Cleopatra and SAOKER CL varieties are considered as stable. CEBRA CL and Lavina varieties are characterized stability of 1,000 seeds weight during studied years. According to the Wricke's ecovalence deviation and standard deviation Lavina, Lakritz and CEBRA CL varieties consider as intensive type varieties for yield; for 1,000 seeds weight - Cleopatra and SAOKER CL varieties. According to standard deviation for protein and oil content CEBRA CL and SAOKER CL varieties are considered as highly adapted. Cleopatra, Lavina and Lakritz are stable for protein content. For oil content CEBRA CL and SAOKER CL varieties are considered as stable. For protein content CEBRA CL and SAOKER CL varieties are intensive. Thus, spring canola varieties, which are intensive for studied characteristics, respond positively to an improvement of growing conditions.

Key words: phenotypic plasticity, stability, spring canola, intensive and extensive varieties, yield, quality seed traits.

INTRODUCTION

The potential environmental benefit that can be obtained from replacing petroleum fuels with bioenergy derived from renewable biomass sources is one reason for promoting the production and use of bioenergy. The promotion of the use of biofuels for transport has become one of the main objectives of the European Union energy policy of recent years, in order to reduce greenhouse gas emissions, diversify fuel supply sources, and decrease dependency on fossil fuels (Forleo et al., 2018; Holúbek et al., 2019). Canola (*Brassica napus* L) is one of the most important plants for bioenergy purposes because its seed contains more than 40% oil. The global production of canola

in 2019 reached around 70 million ton and 23 million ton in Europe in particular (FAO, 2021). Due to the rise in world prices for canola, as a spring crop, it becomes competitive and promising for production (Kalenska et al., 2013). It is known, the canola cultivation in Ukraine today is aimed at the European Union market and is exported in the first months after harvest (Franchuk & Popiak, 2020). The originating varieties, with higher and more stable yield and qualitative traits, is a great challenge for both breeders and agronomists. It requires the unveiling of hidden information residing in multi-environment trials and data interpretation (Tsialtas et al., 2017). A new variety originating requires a lot of time, resources and labour inputs. Nowadays, taking account of climate change, in order to provide growers with high-quality varieties for obtaining biofuels raw materials, it is relevant both to create highly adapted varieties and to study those varieties which are marketed in different environmental conditions. One of the major problems in canola cultivation is a relatively yield and seed quality high variability, resulting from the sensitivity of this plant to weather conditions (Wilczewski et al., 2020).

Genotypic differences play a major role in adaptation of crop plants to specific environments. The differential response of genotypes to environmental changes is an interactions genotype and environment (Gunasekera et al., 2006; Babii et al., 2014). Understanding the biological significance and mechanism for these interactions could potentially lead to improved variety adaptation by selecting certain variety for specific environmental area. Thus, to identify highly adapted varieties which are able to realize their biological potential in different environmental conditions, it is advisable to study the stability and plasticity of quality traits and productivity of spring canola varieties which are valuable for cultivation and use in Ukraine. The estimation these indicators allow to define the abiotic factor effect of an environments on genotype and determine their impact on yield and quality traits.

During recent years different genotypes of canola have been investigated under environment factors impact. Aghdam et al. (2019) investigated the effects of water stress and delay cropping on the qualitative and quantitative traits of canola genotypes. Four canola varieties were tested in five environments represented limited and semi-limited dryland area by Hammed (2005). Gunasekera et al. (2006) demonstrate the adaptation and environmental response of canola genotypes in the Mediterranean-type environments of south Western Australia. The environments examined in their study were grouped into three categories based on environmental mean seed yield generated using Finlay-Wilkinson analysis. Based on studying the productivity and quality of canola varieties in various pedo-climatic environments in Greece and identify agronomic characteristics associated with high seed yield and quality Tsialtas et al. (2017) report that the size of genotype and environment interactions in comparison to genotype impact is large for yield, indicating the need for selecting varieties with specific adaptation. Peltonen-Sainio et al. (2011) studied the quantifying and comparing the plasticity, i.e., variety responsiveness to environment, in yield of canola, exploring correlations in the plasticity of agronomic, yield and quality traits. The canola varieties and environment interaction were studied by Ukrainian scientists also. The yield ecological plasticity and stability of winter canola varieties under different environmental conditions were investigated by Melnyk et al. (2016). Kalenska et al. (2013) studied the ecological plasticity and stability for yield of modern varieties and hybrids of spring canola in the Left-Bank Forest Steppe of Ukraine. The high adapted and intensive varieties were

identified by authors. The similar study was conducted by Melnyk (2014). The agrobiological features and stability of canola varieties for growing of the Left-Bank Forrest Steppe of Ukraine were determined. However, majority of scientific publications report of studying a canola varieties adaptation to certain environments with its weather and soil conditions. Furthermore, the focus is investigating the yield and factors which impact it. In Ukraine the similar researches aim to study canola varieties stability in certain environments or breeding materials estimation. Thus, the ecological adaptation studying of new canola varieties, which are characterized of high productivity and seed quality is relevant. The purpose of this study is to investigate the phenotypic plasticity and stability new spring canola varieties for yield and main quality seed traits.

MATERIALS AND METHODS

Field and laboratory analysis

Five varieties, which are registered in Ukraine were investigated (Table 1). The varieties were selected on the basis of novelty for Ukrainian growers and recommendations for growing zones. The field study was conducted during 2018–2019 at two locations of Forest Steppe zone of Ukraine (Ternopil and Chercasy regions) and three locations of Forest zone of Ukraine (Lviv, Volyn and Ivano-Frankivksk regions) within the plant varieties examination for the value for cultivation and use in Ukraine.

Table 1. Characteristics of spring canola varieties (State register, 2021)

Variety	Registration year in Ukraine	Purpose	Quality	Recommended zones for growing	Origin country
Cleopatra	2019	oil	low erucic acid content	Forest	Austria
CEBRA CL	2020	oil	low erucic acid content	Forest Steppe, Forest	Germany
SAOKER CL	2020	oil	low erucic acid content	Forest	France
Lavina	2020	oil	low erucic acid content	Forest	Germany
Lakritz	2020	oil	low erucic acid content	Forest	Germany

The study was carried out according to Methods of plant varieties examination of technical and fodder groups for the value for Cultivation and Use in Ukraine (VCU) (Tkachyk, 2015a). The oil content, protein content in seed meal, 1,000 seeds weight, glucosinolates and erucic acid concentrations in the oil were detected with Methods of state scientific and technical examination of plant varieties (Methods for determining the quality of crop products) (Tkachyk, 2015b) in Laboratory of Plant Varieties Quality Traits of Ukrainian Institute of Plant Variety Examination (UIPVE). The protein and oil content were detected using infrared analyzer Instalab 700 (DICKEY-john, USA). The glucosinolates concentration was assessed with Infratec 1241 (FOSS, Denmark). The analyzers calibration was carried out with reference standards and chemical methods: oil extraction using Soxhlet extractor and protein detection with Kjeltec 8200 distillation unit (FOSS, Denmark). The erucic acid concentration was detected with gas chromatography using 'Kristall 2000M' (Chromatec, Russia).

Statistical analysis

The ecological plasticity and stability of yield, 1,000 seeds weight, protein and oil content were estimated according to Eberhart and Russell model (Eberhart & Russell, 1966) using PTC Mathcad Prime 3.1 software (trial version). The phenotypic plasticity (β) is the regression coefficient of studied characteristic which are calculated taking into account the environment indices, which are assessed through the average of all the studied varieties that were grown under these conditions. The phenotypic plasticity reflects the variety response to changes of environmental conditions. The variety stability is considered as the ratio of variance to regression of the studied characteristic (Gunasekera et al., 2006; Peirson, 2015; Krüger et al., 2016). The stability model proposed by Wricke (1965) considers as intensive type varieties with highly plasticity and low values of ecovalence (W). Correlation analyses were used to test association between plasticity of different traits and estimated means of varieties with STATISTICA 12.0 software (trial version).

RESULTS AND DISCUSSION

Within the varieties testing and researching for the value for cultivation and use (VCU), the varieties quality and yield are studied. Based on these the purposes of varieties use are determined. The studied varieties of spring canola were characterized by a low erucic acid content (0.0–0.1%) and glucosinolate (0.3–0.6%), since a breeding is carried out to minimize the content of these substances in varieties. It was pointed that different environmental conditions can affect the varieties quality and yield and that effect could be unpredictable (Hammed, 2005; Prysiazhniuk et al., 2013; Tsialtas et al., 2017; Seregina, 2018). That is why the important challenge is varieties identification that would be suitable for cultivation in various soil and climatic zones of Ukraine. The results of analysis of the phenotypic plasticity and stability of studied traits indicate the variety reaction to the combined effect and degree of influence of abiotic and biotic environmental factors.

As result of this study the phenotypic plasticity and stability of 5 spring canola varieties for yield and 1,000 seeds weight were calculated (Table 2).

The plasticity of studied variety is determined by regression deviation from the average group value. So, varieties with β > 1 are considered as highly adapted, with 1 > β = 0 - varieties are low adapted. If the regression coefficient is close to 1, then a variety does not differ from the average group plasticity in response to changes of environmental conditions (Krüger et al., 2016; Beliavskaya, 2017).

Table 2. The phenotypic plasticity and stability of spring canola varieties for yield and 1,000 seeds weight in Forest and Forest Steppe zones of Ukraine

Variety	Yield, t ha^{-1}		1,000 seeds weight, g	
	β[1]	W[2]	β	W
Cleopatra	1.026	54,830	1.301	223,000
CEBRA CL	1.180	54,080	1.427	224,800
SAOKER CL	1.001	54,220	1.595	222,100
Lavina	0.981	53,940	0.256	226,200
Lakritz	0.813	53,340	0.442	222,200

[1]β - phenotypic plasticity; [2]W - Wricke`s ecovalence.

As results of this study, it was found that phenotypic plasticity for yield of all studied canola varieties do not differ from average group value because this indicator is close to 1. However, the regression coefficient for yield is above 1 in Cleopatra, CEBRA
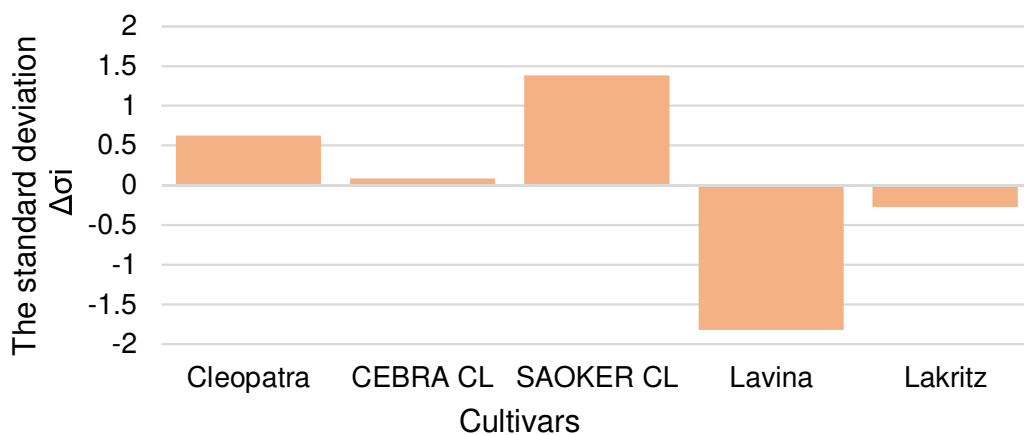
CL and SAOKER CL varieties. The regression coefficient for 1,000 seeds weight is above 1 in the same varieties. That allows to consider these varieties as adapted varieties for these characteristics. It should be noted that for 1,000 seeds weight the regression coefficient differs from average group value of all studied varieties. According to obtained results Lavina and Lakritz varieties are low adapted varieties for 1,000 seeds weight. It was determined that phenotypic plasticity for yield in CEBRA CL, Lavina and Lakritz varieties is above the average group plasticity (Fig. 1).
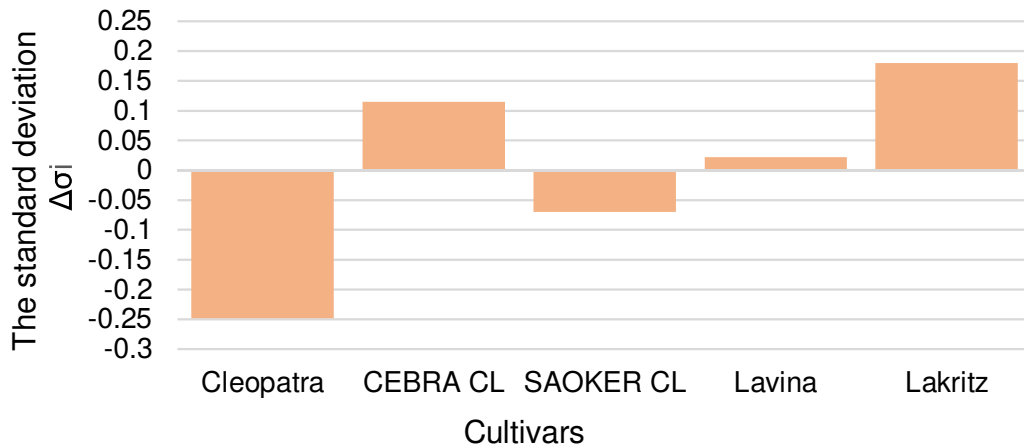
Figure 1. The standard deviation for yield of canola varieties.

Thus, according to obtained regression coefficients and standard deviation for yield in studied varieties it was found that CEBRA CL variety is highly adapted for both indicators. CEBRA CL, Lavina and Lakritz varieties are highly adapted within studied group only.

For 1,000 seeds weight the phenotypic plasticity is above the average group plasticity in Cleopatra, CEBRA CL and SAOKER CL varieties (Fig. 2).


Figure 2. The standard deviation for 1,000 seeds weight of canola varieties.

It was determined that Cleopatra, CEBRA CL and SAOKER CL varieties are highly adapted both for regression coefficients and standard deviation for 1,000 seeds weight. Thus, according to obtained results CEBRA CL, Lavina and Lakritz varieties

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form stable higher yield during 2018–2019. It was observed stable high 1,000 seeds weight in Cleopatra, CEBRA CL and SAOKER CL varieties during studied years.

Varieties with highly plasticity and low values of ecovalence (W) have a positive stable response to improved growing conditions. Varieties with a low W value and a low regression coefficient (low plasticity) do not reduce the characteristic value under limited conditions of environmental factors and an unlimited environment and are widely adapted. Extensive varieties consider as varieties that, despite negative growing conditions or deficiencies in growing technology, form a certain level of productivity (Wricke, 1965; Schlichting, 1986; Temesgen et al., 2015; Krüger et al., 2016).

As results of this study, it was found that for yield in Forest and Forest Steppe zones of Ukraine Cleopatra and SAOKER CL varieties are considered as stable. CEBRA CL and Lavina varieties are characterized stability of 1,000 seeds weight during studied years. This indicates the ability of the aforementioned varieties to retain the potential of yield and 1,000 seeds weight under limited environmental factors (Figs 3, 4).
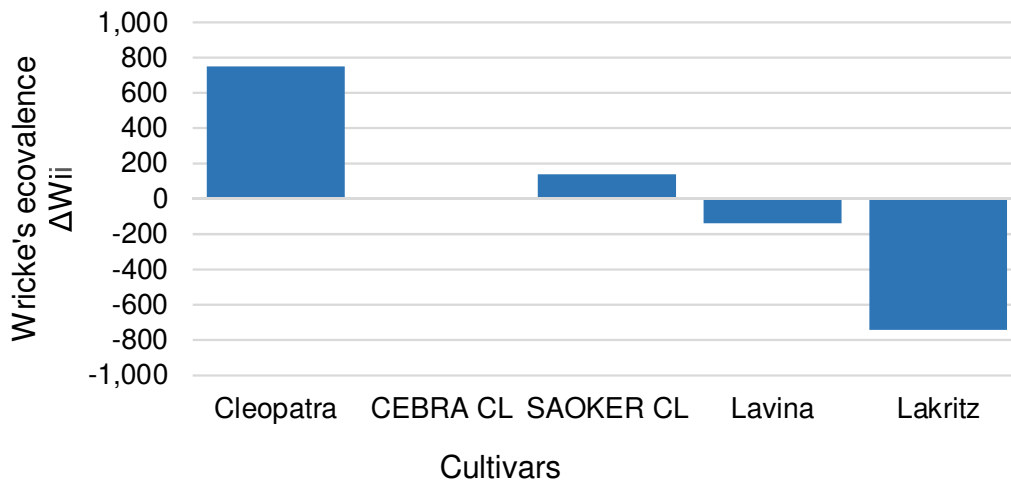
Figure 3. The Wricke's ecovalence deviation for yield of canola varieties (for CEBRA CL variety ΔW = -7.314).
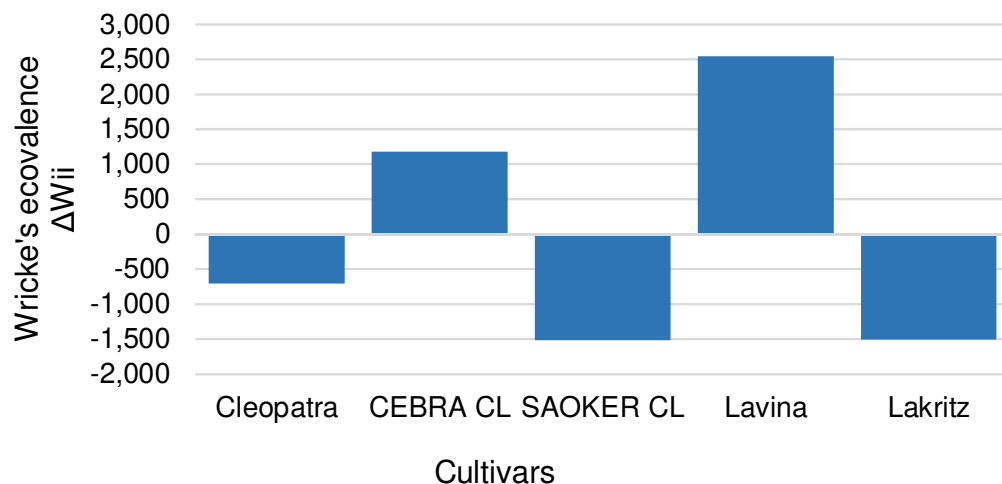
Figure 4. The Wricke's ecovalence deviation for 1,000 seeds weight of canola varieties.

According to the Wricke's ecovalence deviation and standard deviation Lavina and Lakritz varieties consider as intensive type varieties for yield; for 1,000 seeds weight - Cleopatra and SAOKER CL varieties. Lakritz variety which is, widely adapted belongs to extensive type for 1,000 seeds weight. CEBRA CL variety can be attributed to intensive type also despite the relatively low standard deviation and high value of Wricke's ecovalence deviation.

Krüger et al. (2016) used Eberhart & Russell model for to identify the arrangement of plants that allows higher grain yield with adaptability and stability in canola hybrids. Based on these indicators for grain yield the authors determined the more adequate canola population arrangement under favorable and unfavorable environments. Canola varieties were tested under limited and semi-limited dryland area by Hammed (2005). It was shown that average regression of variety mean on environmental mean and the contribution of individual varieties to genotype and environment variance indicated that varieties differed in their genetic potential for responding to a favorable environment. The author managed to identify highly adapted varieties for plant height, heading, yield and 1,000 seeds weight. The phenotypic plasticity and stability of spring canola varieties for seed yield in the Left-Bank Forest Steppe of Ukraine were determined by Kalenska et al. (2013). It was determined that phenotypic plasticity for yield of most studied varieties did not differ from average group value. The authors also found highly adapted varieties which formed a stable yield during the studied years. Based on phenotypic plasticity for yield Komarova et al. (2015) has managed to identify the most promising breeding accessions of spring canola. Thus, the parameters of adaptability and stability contribute to management adjustments and better recommendation of varieties.

In this study, in accordance with the average value of standard deviation and Wricke's ecovalence deviation for yield and 1,000 seeds weight, we also managed to identify varieties that have a positive reaction to improving growing conditions.

As result of plasticity and stability analysis it was determined that CEBRA CL and SAOKER CL canola varieties were found highly adapted both for protein and oil content with regression coefficient was above 1 (Table 3).

Table 3. The phenotypic plasticity and stability of spring canola varieties for protein and oil content in Forest and Forest Steppe zones of Ukraine

Variety	Protein content, %		Oil content, %	
	β	W	β	W
Cleopatra	0.753	7,915,000	0.753	7,915,000
CEBRA CL	1.087	7,672,000	1.087	7,672,000
SAOKER CL	1.396	7,495,000	1.396	7,495,000
Lavina	0.820	7,838,000	0.820	7,838,000
Lakritz	0.944	7,842,000	0.944	7,842,000

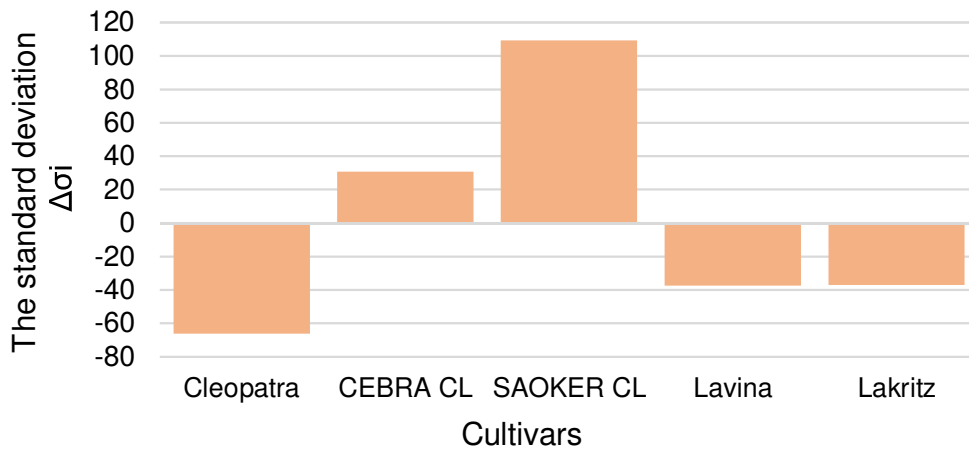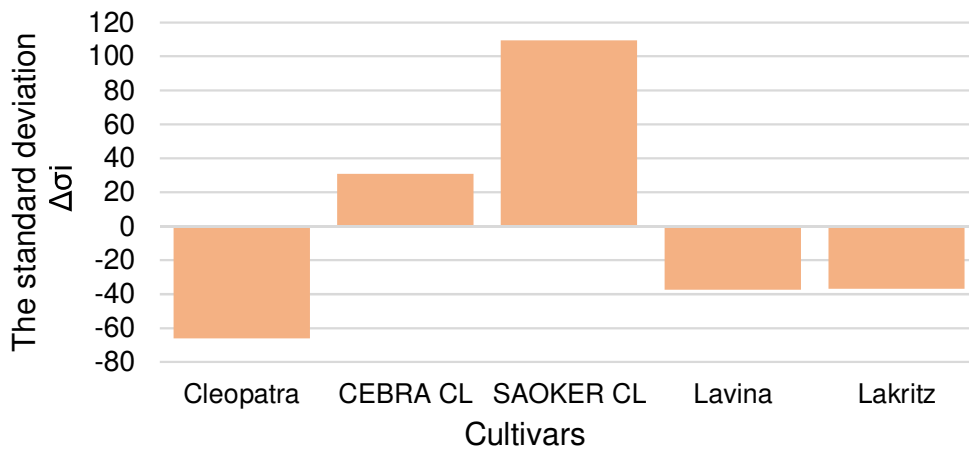[1]β - phenotypic plasticity; [2]W - Wricke`s ecovalence.

It should be noted that all studied varieties do not differ from average group value. The phenotypic plasticity for both protein and oil content are close to 1. The phenotypic plasticity for both protein and oil content in CEBRA CL and SAOKER CL varieties is above the average group plasticity (Figs 5, 6).

According to standard deviation for protein and oil content CEBRA CL and SAOKER CL varieties are considered as highly adapted. Thus, based on obtained data for protein and oil content in these varieties the stable high protein and oil content is observed during 2018–2019 in Forest and Forest Steppe of Ukraine.
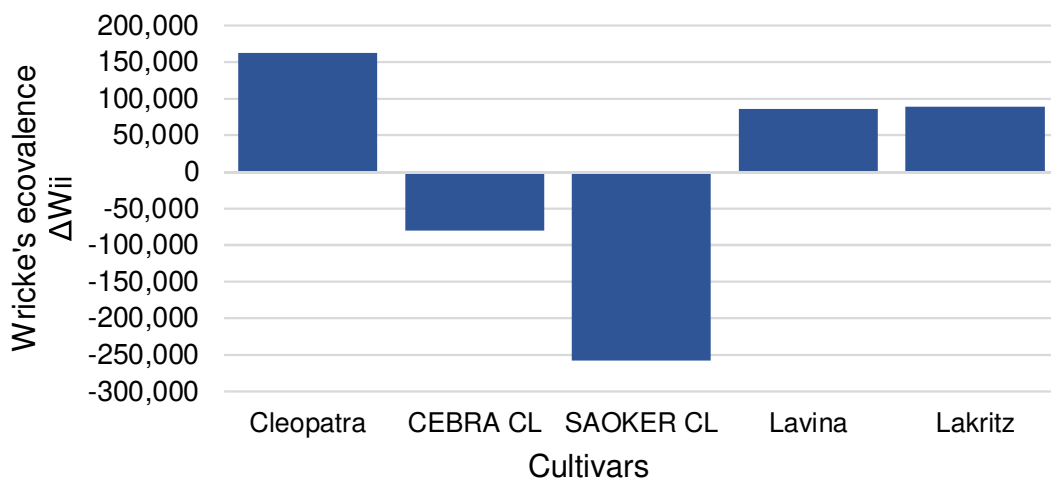
Figure 5. The standard deviation for protein content of canola varieties.
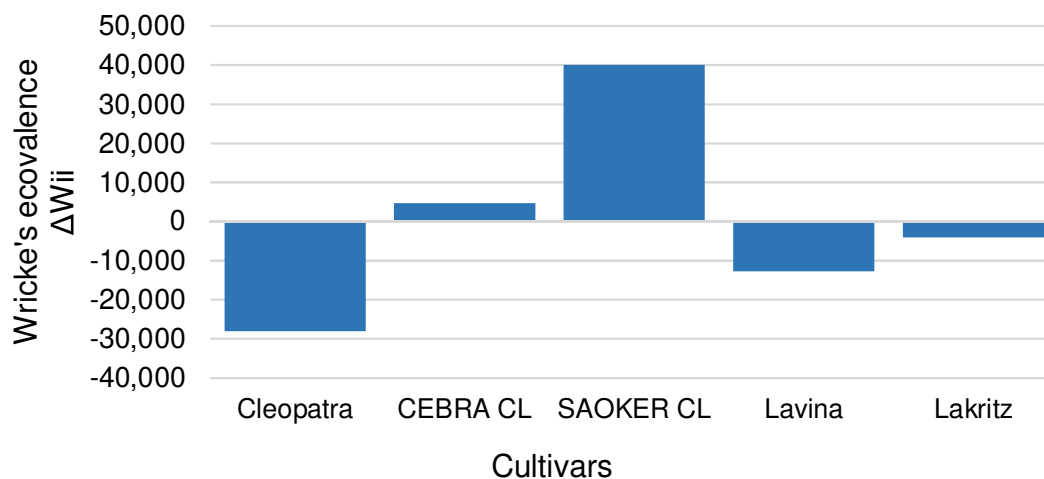

Figure 6. The standard deviation for oil content of canola varieties.

It was found that for protein content in Forest and Forest Steppe zones of Ukraine Cleopatra Lavina and Lakritz varieties are considered as stable. According to obtain results for oil content CEBRA CL and SAOKER CL varieties are stable and retain the potential of oil content under limited environmental factors (Figs 7, 8).

Figure 7. The Wricke's ecovalence deviation for protein content of canola varieties.

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Figure 8. The Wricke's ecovalence deviation for oil content of canola varieties.

Based on standard deviation and the Wricke's ecovalence deviation for protein content CEBRA CL and SAOKER CL varieties are intensive type varieties. It should be noted that for oil content there are not any intensive varieties. It can be explained that studied varieties was originated for oil production (oil purpose). Therefore, the average group value of oil content in studied varieties is high and does not barely vary in accordance growing locations and zones. Thus, these varieties accumulate high oil content regardless of environmental conditions. In contrast, Cleopatra Lavina and Lakritz varieties, which are low adapted, are considered as extensive varieties for this trait and are widely adapted.

As Aghdam et al. (2019) show that genetic factors are the main parameters determining the percentage of oil content in canola, moreover, the effect of environmental factors on the percentage of seed oil is very low. This statement is indirectly confirmed by our study according to fact that there were not identified any intensive varieties for oil content.

Thus, the complex estimation of varieties in this study with standard deviation and the Wricke's ecovalence deviation reflect that varieties, which are intensive, response positively to growing condition improving. In this study it shown that Lavina and Lakritz varieties can be used for high yield obtaining with intensive agrotechnology and favourable environment factors. Cleopatra and SAOKER CL varieties under favourable environment factors can allow to obtain the canola yield with high 1,000 seeds weight. It is an important trait for oil production due to high 1,000 seeds weight allow to decrease production waste (Gunasekera et al., 2006). CEBRA CL and SAOKER CL varieties, which are intensive for protein content, increase its level under growing condition improving. However, there is an inverse correlation between protein and oil content. It can reflect that the oil production can reduce under favourable environment factors for protein accumulation (Tsialtas et al., 2017). Therefore, SAOKER CL variety which are belonged to intensive type for both 1,000 seeds weight and protein content, under some environmental factors' combination in Forest and Forest Steppe zones of Ukraine could decrease oil content.

Kuht et al. (2013) report that oil content of spring oilseed rape seeds was in negative correlation with seed yields. That can be explained by increased access to nitrogen fertilizer. But in Kuht's et al. (2013) experiment the Sulphur containing nitrogen fertilizers increase the yield and oil content of oilseed rape seeds. In this study the use the same agrotechnical treatments were applied during spring canola examination, Thus, it has allowed to identify CEBRA CL variety which is intensive for yield and stable for oil content. That means yield of this variety can increase under growing condition improving and keep high oil content.

As results of correlations assessment between plasticity (dependent trait) and studied traits (independent traits) of spring canola varieties the significant linear correlations were found between plasticity for oil content and protein content ($b = 0.23$, $p < 0.003$) and oil content ($b = -0.28$, $p < 0.001$). It also confirms the existing an inverse correlation between protein and oil content. No significant associations with plasticity for yield and 1,000 seeds weight were found. According to Peltonen-Sainio et al. (2011), who studied phenotypic plasticity of yield and agronomic traits in cereals and canola at high latitudes, they found two types of associations between plasticity of yield and yield under stressful or favourable conditions for cereals but none for canola. The authors explain that it happed likely due to markedly fewer varieties and experiments compared to other crops.

CONCLUSIONS

As results of study a phenotypic plasticity and stability for new spring canola varieties in Forest and Forest Steppe zones of Ukraine for yield and main quality seed traits the intensive and low adapted varieties were identified. Based on the average value of standard deviation and Wricke's ecovalence deviation varieties which have a positive reaction to improving growing conditions were identified. It was found that Lavina, Lakritz and CEBRA CL varieties consider as intensive type varieties for yield. It was shown that Cleopatra and SAOKER CL varieties are intensive type for 1,000 seeds weight. Lakritz variety belongs to extensive type for this trait. CEBRA CL and SAOKER CL varieties are intensive type varieties for protein content. It was determined that studied varieties accumulate high oil content regardless of environmental conditions. Cleopatra, Lavina and Lakritz varieties, which are low adapted, are considered as extensive varieties for oil content and are widely adapted. According to obtained indicators, intensive highly adapted varieties respond positively to an improvement of growing conditions, use of additional fertilizers and other elements of agrotechnology. It was confirmed that stable varieties of spring canola retain the potential of yield and main quality seed traits under limited environmental factors. The growing of such varieties is advisable in conditions of a low level of agricultural technologies including marginal lands.

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