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Genotype-environment interaction in the variability of yield associated indices under stress conditions in sunflower

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Abstract: The impact of biotic (infestation with the *Orobanche cumana*) and abiotic stress (drought) factors on the productivity indicators of sunflower hybrids was evaluated in two years, 2020 and 2021, which were significantly different regarding to the weather conditions. The *Principal Component Analysis* (PCA) was applied on 10 parameters: plant height (PH); leaf number (LN); leaf area (LA); seed yield (SY); leaf area index (LAI); chlorophyll a content (Chla); chlorophyll b content (Chlb); carotenoids content (Car); chlorophyll pigment ratio (Chla/b); total of chlorophyll pigments (Chla+b), that are directly or indirectly associated with the productivity of sunflower hybrids. The first two PCs explained 75 % (drought stress for 2020) and 83 %, respectively (stress caused by broomrape infestation), of the total variance of parameters or hybrids. A higher number of positive correlations were identified between the studied morpho-physiological indices differentiating the hybrids. The SY index correlated with PH, LN, LAI, LA (r = 0.54–0.78) under biotic and abiotic stress. Also, seed yield related with the content of pigments (r = 0.65–0.79) in the case of infested hybrids with broomrape. The infested hybrid H11, in both years, showed the highest values for most of the analyzed indices, indicating a relatively high degree of tolerance to the combined stressors.

Keywords: sunflower; hybrids; *Principal Component Analysis*; broomrape; drought; correlations

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1 Introduction

Sunflower (*Helianthus annuus* L.) is considered one of the most important oilseed crops in the world, as well as in the Republic of Moldova. The high and stable yields are characteristics of the greatest importance in the commercial production. The sunflower seed yield is dependent on the genetic and physiological quality of the seeds, their high germination rate and tolerance to agro-ecological stress (Miklič et al. 2011). However, it is known that the sunflower yield and productivity are strongly influenced by environmental factors, becoming the main goal in its crop development and improvement.

Unfortunately, the sunflower crop is vulnerable to the environmental stressors and can be affected by biotic stress, i.e., the presence of various pests, and abiotic stress induced by water deficit, temperature extremes, salinity, floodings, insufficient/excessive light etc. All of this sub-optimal growth and development conditions in ontogenesis have a negative impact on productivity (Debaeke et al. 2017). The response of plants to stressors is achieved by self-regulation metabolic processes, so they are able to survive under difficult environmental conditions. Their adaptability and the establishment of high-performance genotypes is a long process and requires numerous investigations over many years. Thus, based on the results of the several researches on sunflower, it has been observed that its growth, development and productivity are limited by separate exposure to different conditions of drought (Clapco et al. 2018; Port et al. 2023), salinity (Aziz et al. 2013; Duca and Bârsan 2001), temperature (Lamaoui et al. 2018), as well as infection with broomrape (Acciu 2016; Gisca et al. 2013), downy mildew (Duca et al. 2014), etc.

The major question of the adaptive selection is how we to treat the mutual interaction in the genotype and environment relationships. The fundamental aspects of this relationship relate to the assessment of adaptability and the stability of genotypes under different growth conditions (Radić et al. 2020). The evaluation of the sunflower genotypes in a stress combination is quite rare and the effect of the combined stress on the genotypes, of the physiological and biochemical mechanisms are still unclear (Umar and Siddiqui 2018). The knowledge of the way that environmental factors influence plant growth and development would significantly reduce the yield losses and improve the seed quality (Marjanović-Jeromela et al. 2011). In this order to improve agricultural productivity, it is necessary to develop resistant hybrids by understanding the physiological and biochemical mechanisms or by selection of the capable genotypes of a good performance under combined stress conditions. Thus, the application of statistical tests can provide a new approach to evaluate the interaction between genotypes and different stressors. In the last decade the use of models, appropriate statistical tests by breeders and researchers in the efficient evaluation of genotypes with specific traits and their interaction with different environmental conditions has increased drastically (Alem et al. 2016; Duca et al. 2022; Jocković et al. 2019; Leite and Oliveira 2015; Radić et al. 2020; Riaz et al. 2020).

The aim of this study was to evaluate the impact of different stress factors on the productivity parameters of some sunflower hybrids using a multivariate statistical analysis. This research may provide new opportunities for breeders regarding the identification and the selection of the genotypes with better physiological responses to different stress conditions and their introduction into the crop.

2 Materials and methods

The research was carried out on 11 sunflower hybrids in the experimental fields of the State Commission for Plant Variety Testing (SCPVT) from different agroclimatic zones of the Republic of Moldova. The hybrids were grown in 2020 and 2021 (in five replicates) at the SCPVT stations, Visoca, Pelinia, Grigorievca and Svetii. No irrigation and no pesticides were applied in the test fields.

Hybrids were evaluated based on morpho-physiological indices such as: seed yield (SY, t/ha), plant height (PH, cm), leaf number (LN), leaf area (LA, cm^2), leaf area index (LAI, m^2/m^2), content of chlorophyll a (Chla, mg/g), chlorophyll b (Chlb, mg/g), carotenoids (Car, mg/g), total chlorophyll content (Chla+b) and ratio of chlorophyll a and b (Chla/b). The seed yield index of hybrids was analyzed from the data of CSTSP station registers. Leaf area and leaf area index were computed according to the Firouzabadi, 2015 (Firouzabadi et al. 2015). Leaf samples of hybrid plants from each experimental plot were taken for pigments analysis (Lichtenthaler and Buschmann 2001). All the measurements were carried out during the vegetation phase. The PCA analysis (Felipe et al. 2021) was applied on the data of these 10 morpho-physiological parameters associated with productivity.

Abiotic stress factor. The years of this research, 2020 and 2021, were significantly different in terms of climatic conditions, according the information's from the State Hydrometeorological Service databases. The total volume of the SCPVT region's precipitations (Visoca, Pelinia, Grigorievca, Svetlii) in 2020 was lower (p = 0.02) by 41 % (average/4 stations of 316.2 mm) comparing to 2021 (539.2 mm,

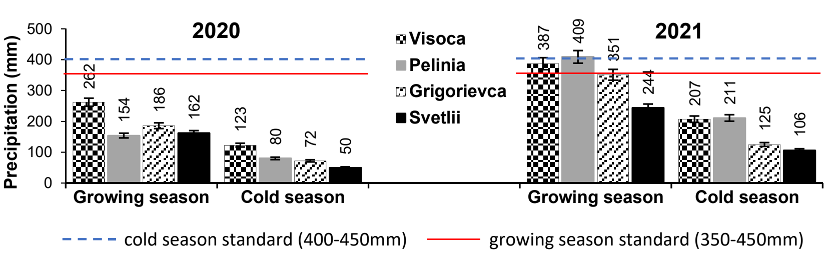

Figure 1: Amount of precipitation fallen on the territory of the studied stations for 2020 and 2021 (growing season of the year – April–September; cold season of the year – October–March).

respectively) (Figure 1). Therefore, 2020 was characterized as a dry year in terms of weather conditions for the studied sunflower hybrids. The mean of annual temperature recorded between the four stations showed statistically non-significant values in both 2020 (18.5 °C) and 2021 (16.5 °C).

Biotic stress factor. In the experimental fields was also registered the incidence of infestation by the parasite *Orobanche cumana* Wallr. (broomrape). Four from studied 11 sunflower hybrids were infested and only in Svetlii and Grigorievca. Infected hybrids had between 95 and 507 broomrape shoots per 100 host plants (Duca et al. 2023). Thus, the following comparative case studies were: hybrids grown in 2020 versus 2021 (abiotic stress impact) and infested versus non-infested hybrids (biotic stress impact).

3 Results and discussions

3.1 Multivariate statistical analysis on productivity parameters of the sunflower hybrids

The regulation of realizing of the genetic potential of hybrids during vegetative and generative growth and development depends on knowledge and understanding of the relationships between agricultural production and environmental factors (Clapco et al. 2019; Mijic et al. 2012). The yield, including its associated traits, is often underestimated due to the absence of the data on correlative relation between them. The information about variation of traits of interest under different stressors can be obtained by *Principal Component Analysis* (PCA). Thus, the PCA-2020 model included 10 principal components, but the first two (PC1, PC2) have shown 75 % of the total variance of the variables, compared to PCA-2021, which recovers only 60 % of the primary data (Table 1). Also, the comparison of the PCA results of infected hybrids with that of non-infested hybrids with broomrape was highlighted the similar data, 83 % of variance was explained by the first two PC and 62 %, respectively, revealing the high variability of the morpho-physiological parameters under stress conditions. This finding is also confirmed by the coefficient of variation (CV) of the studied parameters. Thus, in the case of infested hybrids, a high degree of variation in the values for seed yield (SY) (CV = 40.07 %), leaf area (LA) (CV = 36.54 %), leaf area index (LAI) (CV = 33.65 %) and plant height traits (PH) (CV = 25.42 %) was ascertained. The same parameters, but for hybrids grown in 2020, showed a relatively heterogeneous degree for SY (CV = 29.45 %), LA (CV = 25.72 %) and LAI (CV = 25.57 %). In contrast, most of the indices for the hybrids, with growth and development not affected by *O. cumana*, showed homogeneous, relatively homogeneous and relatively heterogeneous values for LAI (CV = 23.55 %) and LA (CV = 22.42 %). The data recorded for hybrids grown in 2021, a relative level of variation was identified for SY (CV = 23.93 %), LAI (CV = 22.70 %), content of carotenoids (Car) (CV = 22.04 %), LA (CV = 20.53 %).

Table 1: Principal component analysis on morpho-physiological parameters of the studied sunflower hybrids.

Components/factorial axes	2020 (drought)		2021		Infested		Non-infested	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
Variability (%)	51.54	23.19	33.96	25.89	66.58	16.32	36.87	24.78
Cumulative (%)	51.54	74.73	33.96	59.85	66.58	82.90	36.87	61.65
Parameters	**Correlations between parameters and components**							
Plant height (cm)	0.79*	0.42	0.71*	0.47	0.81*	0.32	0.60*	0.51
Leaf number	0.67*	0.38	0.56*	0.49	0.89*	−0.04	0.10	0.79*
Leaf area index (m^2/m^2)	0.72*	0.61	0.39	0.73*	0.88*	0.28	0.51	0.53*
Leaf area (cm^2)	0.75*	0.47	0.58	0.75*	0.88*	0.30	0.56	0.60*
Chlorophyll a content (mg/g)	0.82*	−0.51	0.82*	−0.37	0.92*	−0.14	0.86*	−0.44
Chlorophyll b content (mg/g)	0.77*	−0.55	0.67*	−0.61	0.81*	−0.57	0.76*	−0.16
Carotenoid content (mg/g)	0.69*	−0.49	0.46	−0.25	0.67*	0.45	0.66*	−0.57
Chlorophyll a/b ratio	−0.26	0.31	−0.10	0.42	−0.34	0.84*	−0.19	−0.27
Total chlorophyll content (mg/g)	0.83*	−0.54	0.84*	−0.48	0.92*	−0.29	0.90*	−0.38
Seed yield (t/ha)	0.70*	0.46	0.21	−0.24	0.87*	0.12	0.39	0.46

(PC – principal component; * – values that statistically indicated $cos^2 > 0.5$).

Correlative associations between components and productivity indices were identified. In the case of PCA-2020 (drought stress), all indices except chlorophyll a/b ratio (Chla/b) showed positive correlations of a strong intensity ($r > 0.6$) with the PC1 (Table 1). According to the PCA-2021, parameters such as PH, content of chlorophyll a (Chla), chlorophyll b (Chlb) and the total amount of chlorophyll a and b (Chla+b) correlated strong positively ($r > 0.6$) with PC1, and LAI ($r = 0.73$) and LA ($r = 0.75$) with PC2. Number of leaves (LN) showed positive and moderate strength correlations with both PC1 ($r = 0.56$) and PC2 ($r = 0.49$). Strong positive correlations with the first PCs were also determined at the infected hybrids (subjected to biotic stress). Thus, of the all analyzed indices, nine showed strong positive correlative associations with PC1 ($r > 0.6$) and one, Cchla/b ($r = 0.84$) with PC2. It is important to note that this group of hybrids was also affected by the climatic conditions of 2020 (combined stress). PCA analysis performed on the group of hybrids not infected with *O. cumana* showed strong correlations between PH ($r = 0.60$) and pigment contents (Chla, Chlb, Car, Chla+b) ($r > 0.6$) with the first component and between the second component and the leaf morphometric indices (LN, LA, LAI) ($r > 0.6$) (Table 1).

The contribution of the variables (Figure 2) calculated in percentages per PC indicates the quality of their representation on the PCA graph (Figure 3) and their significance in the interpretation of the principal components. Thus, the indices for hybrids grown in 2020 that reached the threshold value of 10 % and that have a significant contribution to hybrid differentiation are PH, LA, Chla, Chlb, Chla+b on PC1 and LAI, Chla, Chlb, Car and Chla+b on PC2. In the 2021 growing season, the parameters PH, Chla, Chlb, Chla+b showed the highest contribution in generation of PC1 and LAI, LA, Chlb of PC2. Analyzing the models generated by PCA for these two case studies, it can be concluded that the Chla/b ratio does not show significance in discriminating hybrids grown in both 2020 and 2021, regardless of climatic conditions. PCA analysis of broomrape infested hybrids revealed a similar percentage contribution of indices on the first PCs, analogous to the case of PCA-2020 hybrids, subjected to the abiotic stressor. The indices with the highest contribution for PC1 are: LN, LA, LAI, Chla, Chla+b, SY, PH and for PC2: Chlb, Car and Chla/b. It should be noted that, under the influence of the biotic stress factor, the contribution of the parameters in PC1 is more or less equal (Figure 2), showing very close correlations by intensity. In the PCA model of non-infested hybrids, the parameters that reach the significant threshold contribution for PC1 are: Chla, Chlb, Car, Chla+b and for PC2: PH, LN, LAI, LA and Car.

The analyzed morpho-physiological indices that showed the highest percentage contribution per PC1 and the highest positive correlations were Chla and Chla+b (Figure 2, Table 1) in all case studies. The pigments content, namely chlorophyll a, is the most sensitive indicator among those investigated in this study to the impact of stressors. Several studies have demonstrated (Bourioug et al. 2020;

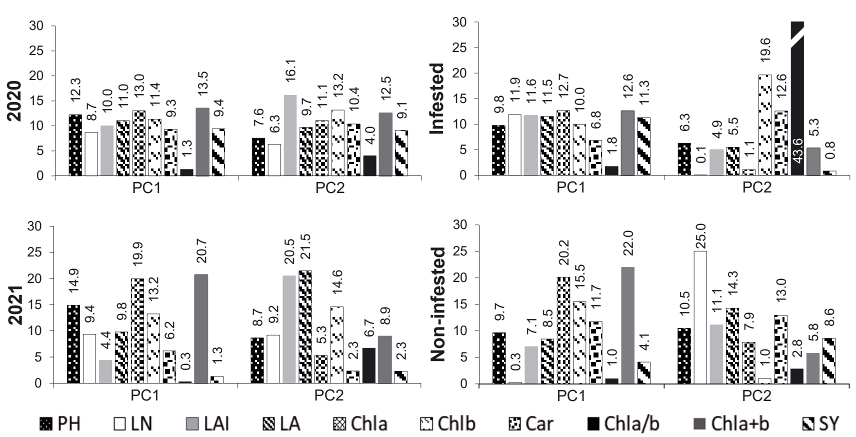

Figure 2: Contribution (%) of the analyzed productivity parameters in the characterization of sunflower hybrids (PH – plant height; LN – leaf number; LA – leaf area; SY – seed yield; LAI – leaf area index; Chla – chlorophyll a content; Chlb – chlorophyll b content; Car – carotenoids content; Chla/b – chlorophyll pigment ratio; Chla+b – total of chlorophyll pigments).

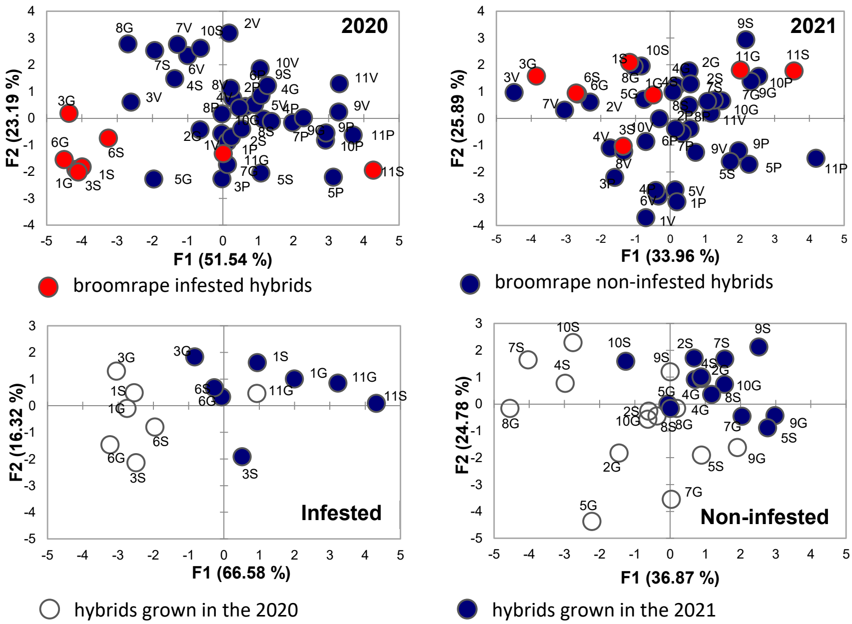

Figure 3: Presentation of the investigated sunflower hybrids on the PCA factorial axes. (G – Grigorievca, P – Pelinia, V – Visoca, S – Svetlii; 1–11 – sunflower hybrids in the testing phase at the SCPVT (State Commission for Plant Variety Testing)).

Manivannan et al. 2007; Umar and Siddiqui 2018) the influence of different environmental factors on the photosynthesis process, including chlorophyll content in leaves. Moreover, abiotic stress is known to cause the production of free radicals that induce chloroplast damage and, as a result, disruption of the chlorophyll synthesis process (Smirnoff 1995).

3.2 Analysis of the correlative relationships between productivity parameters of sunflower hybrids

The most statistically significant pairwise correlative associations were found for the hybrids affected by drought stress and that caused by the phyto-parasite *O. cumana*. The correlative pattern of the indices for non-affected plants differs essentially from that of the plants affected by a stressor through the small number of direct/indirect correlative relationships and a different intensity, from weak to strong.

The hybrids tested by SCPVT are characterized in 2021 by a significantly low number of correlations between parameters, similar to the group of hybrids not

Table 2: Correlations identified between productivity parameters of sunflower hybrids.

2020 (drought)	PH	LN	LAI	LA	Chla	Chlb	Car	Chla/b	Chla+b	SY	2021
PH		0.70*	0.45*	0.69*	0.33*	0.22	0.17	−0.01	0.32*	−0.09	PH
LN	0.62*		0.36*	0.53*	0.19	0.04	0.16	0.08	0.15	0.16	LN
LAI	0.77*	0.63*		0.87*	0.03	−0.07	−0.15	0.10	0.00	−0.02	LAI
LA	0.69*	0.65*	0.88*		0.19	−0.02	0.06	0.19	0.14	−0.10	LA
Chla	0.45*	0.29	0.30*	0.41*		0.67*	0.47*	0.11	0.97*	0.24	Chla
Chlb	0.32*	0.39*	0.21	0.32*	0.83*		0.26	−0.66*	0.83*	0.20	Chlb
Car	0.42*	0.11	0.21	0.27	0.91*	0.64*		0.13	0.43*	0.00	Car
Chla/b	0.01	−0.31*	0.04	−0.01	−0.14	−0.65*	0.09		−0.14	−0.02	Chla/b
Chla+b	0.43*	0.34*	0.28	0.39*	0.98*	0.92*	0.86*	−0.31*		0.24	Chla+b
SY	0.78*	0.54*	0.73*	0.59*	0.30	0.29	0.27	−0.12	0.31*		SY
Infested	**PH**	**LN**	**LAI**	**LA**	**Chla**	**Chlb**	**Car**	**Chla/b**	**Chla+b**	**SY**	**Non-infested**
PH		0.40*	0.50*	0.63*	0.28	0.19	0.24	−0.03	0.28	0.41*	PH
LN	0.75*		0.21	0.36	−0.20	0.04	−0.38*	−0.31	−0.13	0.46*	LN
LAI	0.84*	0.72*		0.92*	0.24	0.09	0.04	0.10	0.21	0.15	LAI
LA	0.88*	0.75*	0.99*		0.26	0.11	0.07	0.07	0.24	0.17	LA
Chla	0.61*	0.84*	0.67*	0.66*		0.65*	0.80*	0.10	0.97*	0.05	Chla
Chlb	0.44	0.71*	0.54*	0.52*	0.85*		0.37	−0.68*	0.83*	0.34	Chlb
Car	0.52*	0.47	0.65*	0.61*	0.62*	0.35		0.28	0.72*	0.08	Car
Chla/b	−0.10	−0.27	−0.18	−0.15	−0.29	−0.74*	0.16		−0.16	−0.42*	Chla/b
Chla+b	0.57*	0.83*	0.65*	0.64*	0.98*	0.93*	0.55*	−0.46		0.16	Chla+b
SY	0.66*	0.71*	0.74*	0.73*	0.79*	0.65*	0.66*	−0.16	0.77*		SY

(PH – plant height; LN – leaf number; LA – leaf area; SY – seed yield; LAI – leaf area index; Chla – chlorophyll a content; Chlb – chlorophyll b content; Car – carotenoids content; Chla/b – chlorophyll pigment ratio; Chla+b – total of chlorophyll pigments; * – statistically significant correlations $p \leq 0.5$).

infected with *O. cumana*. Therefore, strong, statistically significant linear dependencies ($p < 0.0001$) were attested between the parameters Chla:Chla+b ($r = 0.97$), Chlb:Chla+b ($r = 0.83$), LA:LAI ($r = 0.87$), PH:LN ($r = 0.70$) and PH:LA ($r = 0.69$). The seed yield of hybrids cultivated in 2021 did not correlate statistically with any of the investigated traits. For hybrids grown in 2020 under water stress (Table 2), more correlations were identified compared to those in 2021, especially for PH, LN and Chla+b with other parameters. The SY index correlated strongly with PH ($r = 0.78$; $p < 0.0001$) and LAI ($r = 0.73$; $p < 0.0001$), moderately with LN ($r = 0.54$; $p = 0.0002$) and LA ($r = 0.59$; $p < 0.0001$) and weakly with Chla+b ($r = 0.31$; $p = 0.04$). Also, relevant are positive correlations of moderate intensity between LA and Chla ($r = 0.41$; $p = 0.01$) and weak intensity between LA with Chlb ($r = 32$; $p = 0.04$) and Chla+b ($r = 0.39$; $p = 0.01$).

Infection with broomrape of sunflower hybrids modified the pattern of correlative relationships between different morpho-physiological and biochemical traits, both in intensity and direction (Table 2).

The seed yield, for the *O. cumana* susceptible hybrids, showed strong and moderate correlative dependencies ($r > 0.6$) with all studied indices except for the Chla/b ratio. The highest and statistically significant ($p < 0.0001$) correlative associations are between PH:LAI ($r = 0.84$), PH:LA ($r = 0.88$), LN:Chla ($r = 0.84$), LN:Chla+b ($r = 0.83$), LA:LAI ($r = 0.99$), Chla+b:Chla ($r = 0.98$), Chla:Chlb ($r = 0.85$) and Chla+b:Chlb ($r = 0.93$). From the small number of correlations between productivity indices identified in the group of non-infested hybrids it is important to mention the linear dependencies of moderate intensity directly associated with the SY, namely PH ($r = 0.41$, $p = 0.03$) and LN ($r = 0.46$, $p = 0.01$).

The formation of new correlative relationships between yield related traits (increase of the number of correlations between the analyzed parameters) with approximately equal contributions (Figure 2) in the response reaction of hybrids subjected to a stressor suggests on some tendencies of synchronized reorganization of metabolic processes in order to ensure a homeostatic balance of internal parameters (fluctuations of comparatively equal low intensity) during the whole period of action of the stress factor.

The differentiated distribution of hybrids on the PCs according to the analyzed parameters (Figure 3) showed genotype-specific peculiarities in the morpho-physiological and biochemical indices that provide the agricultural performance and that vary depending on environmental factors. The mean values for each studied parameter of the hybrids cultivated in these two years varied, so that in factorial plot they constituted two obvious groups, depending on the year and the presence of *O. cumana* infection (Figure 3). According to the pattern of association of variables with the PCs as well as the percentage contribution of parameters in the discrimination of genotypes (Figure 2), a differentiation of hybrids subjected to combined stress compared to the other investigated hybrids by locality and cultivation period was observed. Statistically significant differences ($p \leq 0.05$) were found between mean values of parameters for the hybrids grown in 2020 versus 2021 in the case of PH, LAI and LA in all investigated hybrids with and without infection. The infected H11 hybrid from Svetlii in 2020 showed the highest values for eight parameters except for Chla/b ratio and PH. The same hybrid, on the experimental field from Grigorievca, (11G) showed the greatest values for PH and comparatively higher values for all other indices in 2020. Of the genotypes grown in 2021, it was also highlighted the H11 genotype from Svetlii with the maximum values for PH, LN, LA, Chla, Chlb, Chla+b and SY, H11 and from Grigorievca with the greatest values for LAI and comparatively higher values of PH, LN, LA, Chla, Chlb, Car and Chla+b. Also, the H1 genotype from Svetlii recorded comparatively greater values for PH, LAI, LA, Car, Chla/b and, also, the same hybrid from Grigorievca – LAI, Chla, Chlb, Car, including SY.

Therefore, the PCA models revealed the hybrid performance of H11, especially for those cultivated in Svetlii in both 2020 and 2021 years and H1 from Svetlii and Grigorievca in 2021. It is relevant to note that the same hybrid (H11), which was not infected in the other localities, showed increased values of the indices on other experimental plots in Pelinia and Visoca in 2020, but only in Pelinia in 2021.

Among the hybrids not infected with *O. cumana*, H9 and H5 from all experimental plots grown in 2021, were differentiated by high values for the most of the studied indices. The data recorded in 2020 for hybrids with no infection also highlighted the H9 from Grigorievca, Pelinia, Visoca, Svetlii and H5 from Svetlii and Pelinia which showed the higher values than the group average for the most of the investigated parameters. The hybrids with the lowest values but a high degree of variation of the analyzed indices in both years are H4, H7, H10 from Svetlii and H5, H7 and H8 from Grigorievca and Visoca. The graphical models (Figure 3) in the case of non-infested hybrids grown in 2020 and 2021 highlighted H2, H8 and H6 (from Svetlii and Pelinia) which proved to have the most stable values for the analyzed indices.

It is important to note that, although, lower values of morpho-physiological indices were found for all infected and non-infected hybrids in dry year 2020, the genetic characteristics differentiated the response to biotic and abiotic stress. The level of adaptation of the hybrids to internal fluctuations induced by external factors depends on their intensity and frequency as well as on the capacity to regulate of the reserve substances and metabolic energy necessary to sustain the physiological status of resistance. In the PCA plots (Figure 3), greater differentiation was observed between hybrids subjected to combined stressors grown in the dry year 2020 compared to the 2021. These differences in the individual response of the hybrids to the environment factors highlight the genotype performance, in particular the degree of ecological plasticity that is predominantly manifested under abiotic stress conditions (2020) and specific resistance to *O. cumana* under favorable environmental conditions but in the presence of infection (2021). Also, the generated results by the PCA model and the correlation test suggest that in the case of the combined stress, drought and *O. cumana* infection, a large contribution in the response of the hybrids, could be attributed to the physiological non-specific mechanisms.

The investigation of sunflower genotypes for performance under different environmental conditions have been previously reported by other researchers using various appropriate statistical models (Alem et al. 2016; Jocković et al. 2019; Leite and Oliveira 2015; Radić et al. 2020; Ruzdik et al. 2015). Similar results were reported by Santos et al. (2018), using multivariate analysis (PCA) in the evaluation of the yield potential of eight sunflower genotypes based on several parameters such as plant height, lower stem diameter, upper stem diameter, chapter diameter, chapter weigh, achene weight and grouping, found strong positive correlations between plant height and stem diameter, between inflorescences diameter and weight with plant height, but also no correlative associations between lower stem diameter and achene weight. In another study (Riaz et al. 2020) was reported the PCA data on 49 sunflower genotypes, regarding their variability and the best ones. Among all the investigated quantitative characters (plant height, stem diameter, inflorescence diameter, number of leaves and achenes per head, filled achene percentage, etc.) a single linear dependence, between plant height and number of leaves, was observed. A recent study by Radić et al. (2020) was aimed the investigation genotype-environment interaction based on seed yield, seed germination rate, mass of 1000 seeds, seed protein content of 18 sunflower parental lines and were found the superior lines for seed yield and seed germination. In the same context, the performance and stability of 15 sunflower hybrids grown in different regions of South Africa were evaluated by statistical models. In terms of location (growing lot), Senekal was identified as the most discriminating and representative environment for evaluating sunflower genotypes (Ma'ali et al. 2019).

The study and characterization of the sunflower hybrids using morphological, physiological and biochemical data are necessary and essential for the breeding programs. The evaluation of the relationship between genotype and environment is typical for the studies using several agricultural areas with different climatic conditions and makes it possible to select and recommend the new sunflower genotypes for different regions.

4 Conclusions

The 11 hybrids in the testing phase at SCPVT were differentiated according to the growing season (2020 vs 2021), indicating a more pronounced decrease in values for the most morpho-physiological indices in 2020. Also, have been revealed a high variability of parameters for the infested hybrids in 2020 and 2021 under combined stress. The most variable indices for infested hybrids were SY (CV = 40.07 %), followed by LA (CV = 36.54 %), LAI (CV = 33.65 %) and PH (CV = 25.42 %), compared to the non-infested hybrids which showed a relatively heterogeneous level, especially for two parameters, LAI (CV = 23.55 %) and LA (CV = 22.42 %).

The higher number of statistically significant correlations were found in *O. cumana* infected hybrids compared to non-infected, the majority of parameters being associated with the seed yield. The SY index correlated strongly ($r > 0.65$, $p \leq 0.5$) with all analyzed parameters, except Chla/b ratio for infected, but for non-infected hybrids the SY index showed moderately correlative associations with plant height ($r = 0.41$) and leaf number ($r = 0.46$).

Among the broomrape infected hybrids, in both years evaluated, H11 showed the highest values for the most of analyzed indices, revealing a relatively high degree of tolerance to the combined stressors.

The influence of climatic conditions of 2020 on the productivity of hybrids was more significant in the discrimination of studied hybrids compared to the biotic stress factor (broomrape infection).

The obtained data suggest that a large contribution in the biologic response in the case of combined stress: drought and *O. cumana* infection could be have the non-specific physiological mechanisms.

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