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STUDY ON SUNFLOWER PRODUCTION ESTIMATION BASED ON AERIAL IMAGES (UAV)

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Abstract

The study used the technique based on aerial images (UAV) to estimate the production of the sunflower crop, hybrid P64LE25. The experiment was organized within SCDA Lovrin, Timis County, Romania, in the 2021-2022 agricultural year, under the conditions of a chernozem type soil, non-irrigated system. The images were taken with the drone (DJI Phantom 4), at variable heights (H, 3 to 50 m). From the analysis of the digital images, the values of the RGB color parameters were obtained. The distribution of the RGB data series was of normal type (r = 0.950 for R, r = 0.960 for G and r = 0.965 for B). Very strong correlations were recorded between color parameters (r = 0.994 for R and G, r = 0.954 for R and B, r = 0.948 for G and B), and weak correlations between RGB and H. From PCA, PC1 explained 97.698% of variance, and PC2 explained 2.1027% of variance. Regression analysis facilitated the prediction of sunflower production based on RGB values, under statistical safety conditions (p<0.001; RMSEP = 1.7907 in relatin to R and G; RMSEP = 4.5869 in relation to R and B; RMSEP = 3.6978 in relation to G and B).

***Key words**: imaging analysis, modeling, production estimation, sunflower, UAV images.*

INTRODUCTION

The sunflower is a plant of interest for seed production, as a resource for the food industry, the pharmaceutical industry, as a honey plant, for biodiesel, but also in animal feed (Adeleke and Babalola, 2020; Giannini et al., 2022).
Although today the sunflower has multiple uses, initially, for a long period of time, it was used for ornamental and medicinal purposes (Giannini et al., 2022).
Within agricultural crops, sunflowers are important in the structure of crop plants, in crop rotations, for an integrated management of crops and offer multiple ecosystem benefits (Debaeke et al., 2017)
The sunflower is also considered to be an "ecological crop", as a result of the lower amounts of nitrogen required, the high tolerance to thermal and water stress (reduction of irrigation), as well as the reduced pesticides (Debaeke et al., 2017a, 2017b).
Against the background of climate changes and in the context of geopolitical scenarios, it is considered important for the perspective to improve sunflower genotypes with tolerance and resistance to stress factors (biotic, abiotic), better/updated agronomic practices, exploration and expansion of new cultivation areas (Debaeke et al., 2017a; 2017b; Duca et al., 2022; Giannini et al., 2022).
In the context of the ideas of expanding the cultivation areas for sunflower, including through the valorization of some lands considered marginal, as well as for the improvement, updating and adaptation of culture technologies, different inputs have been tested and studied for the culture of sunflower, as a biocar, nanoparticles, etc. (Pîrvulescu et al., 2015; Chiaramonti and Panoutsou 2019; Kornarzyński et al., 2020).
The evaluation and monitoring of crops based on image analysis (satellite, aerial, terrestrial images) is of high importance and has been highlighted in various studies (Govedarica et al., 2015; Sala et al., 2020; Omia et al., 2023).
Techniques based on remote sensing, as well as different models obtained from spectral information, were used in the study of sunflower culture to evaluate and characterize the dynamics of vegetation stages (Herbei and Sala, 2015), to evaluate the water regime and the

carbon budget (Pique et al., 2020), or for the estimation of sunflower production (Dicu et al., 2021; Amankulova et al., 2023).

As a result of specific facilities, the technique based on UAV images was used in the study of sunflower culture to evaluate weed management (López-Granados et al., 2016), plant lodging and associated effects, quantitative and qualitative yield losses (Song et al., 2020; Li et al., 2021), obtaining information for precision agriculture, regarding aerial biomass, N content, yield (Vega et al., 2015).

The present study used the technique based on UAV images in the analysis, characterization of sunflower crop and prediction of sunflower yield, based on a set of images taken at variable heights and the generation of prediction models in relation to RGB color parameters obtained from digital images.

MATERIALS AND METHODS

The study took place within ARDS Lovrin, Romania, and used the technique based on aerial images (UAV) to analyze, characterize a sunflower crop and predict seed production according to spectral information (RGB) obtained from digital images.

The sunflower hybrid P64LE25 (Corteva) was cultivated under non-irrigated conditions, on a medium-fertility chernozem soil. Sowing was done on April 13, 2022. Fertilization was done with complex fertilizers (15:15:15) 200 kg ha^{-1}, and granular ammonium nitrate 250 kg ha^{-1} (a fraction of AAG applied in vegetation, stage 6 leaves). Weed control was ensured by herbicides with a mono and dicotyledonous spectrum (Spectrum, 1.5 L ha^{-1}, pre emergent application; Fusilade 1.5 L ha^{-1}, Express 30 g ha^{-1}, post emergent application). Plant protection against diseases was done with appropriate products (eg. Retengo 1 L ha^{-1}, applied on May 31). The crop had a normal vegetative course, but the climatic conditions specific to the year 2022 had an effect on the production. At physiological ripening, seed production was harvested, with an average value per plot of 3650 kg ha^{-1}.

To carry out the study, a logical flow diagram was designed (Figure 1).

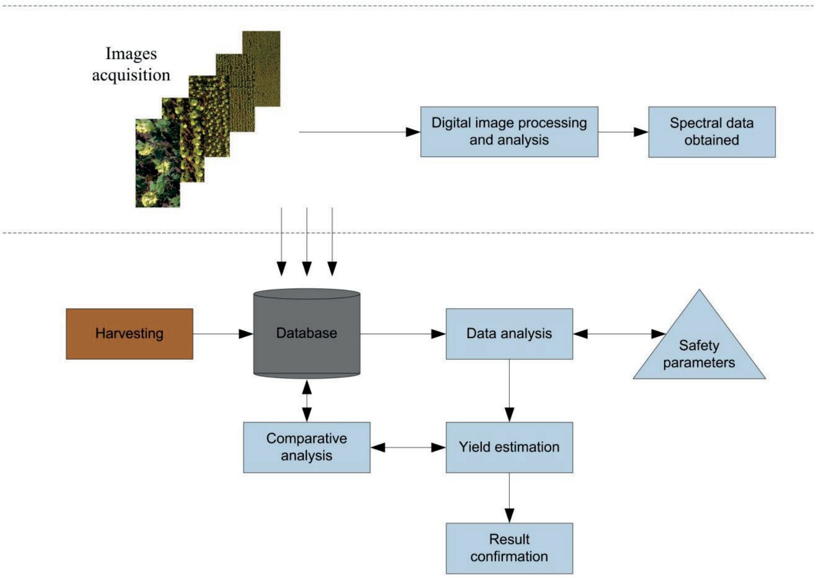


Figure 1. Logical flow diagram of the study process

In the vegetation stage of the crop, 7 BBCH Code (Meier 2001), aerial images were taken with the drone (DJI Phantom 4) at variable heights from the ground level, between 3 and 50 m, and resulted in 16 series of images (16 experimental variants, T1 to T16). The images, digital format, jpeg, were analyzed to obtain the RGB spectral values. The obtained data were analyzed to evaluate the distribution of the data series, the presence of variance and statistical reliability, the interdependence between RGB color parameters, the distribution and the degree of similarity between variants.

Regression analysis was used to estimate production based on RGB parameters (in different combinations). The safety level of the results was assessed based on appropriate statistical safety parameters.

The results obtained, in the form of series of values of the RGB color parameters, and data obtained through calculations and were analyzed by appropriate methods (Hammer et al., 2001; Wolfram Alpha 2020).

RESULTS AND DISCUSSIONS

Numerical information for RGB color parameters was obtained from the analysis of aerial images taken with a drone (UAV). In relation to the height of taking the images, the variation of the values of the color parameters was found, R = 83.12-94.39±0.91, G = 77.75-86.78±0.76, respectively B = 33.85-39.32±0.45 (Table 1).

Table 1. The values of the RGB color parameters in relation to the UAV image capture height, the sunflower crop, the P64LE25 hybrid

Trial	H (m)	R	G	B
T1	3	91.85	84.57	37.51
T2	4	92.58	85.75	37.29
T3	5	91.11	84.14	37.72
T4	6	92.1	85.49	38.55
T5	7	93.27	86.72	39.13
T6	8	83.12	77.75	33.85
T7	9	84.66	78.975	34.37
T8	10	86.2	80.2	34.9
T9	15	83.36	77.8	34.94
T10	20	87.31	80.52	35.76
T11	25	89.32	82.47	36.52
T12	30	90.52	83.18	37.54
T13	35	91.42	84.13	38.39
T14	40	91.48	84.44	38.9
T15	45	93.35	85.84	39.04
T16	50	94.39	86.78	39.32
SE		±0.92	±0.77	±0.45

The series of values, for color parameters (RGB), resulting from the analysis of digital images, presented normal distributions, under statistical safety conditions (r = 0.950 for R, r = 0.960 for G, and r = 0.965 for B). Figure 2 shows the distribution of the data series for the analyzed RGB parameters.

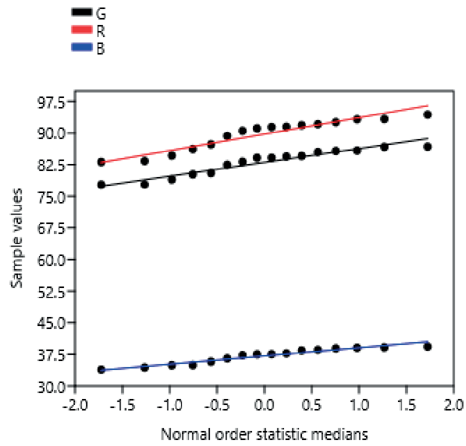


Figure 2. Distribution of RGB values in relation to the image acquisition height (UAV), sunflower crop, hybrid P64LE25

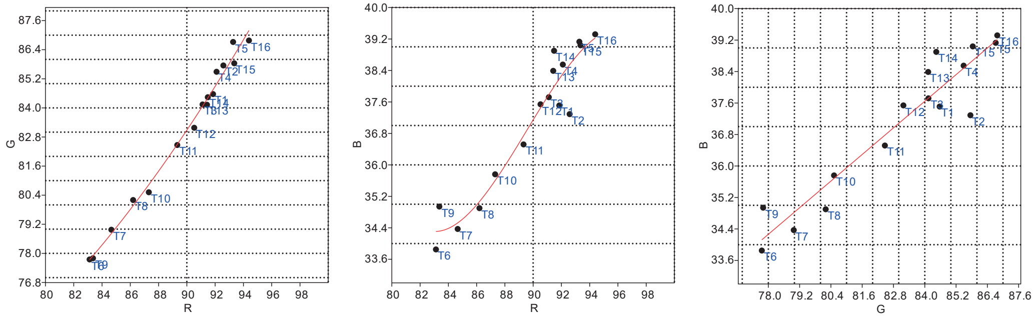
Very strong, positive correlations were recorded between RGB color parameters (r = 0.994 for R with G, r = 0.954 for R with B, and respectively r = 0.948 for G with B). Weak correlations were the result, from the analysis, between the RGB color parameters and the image capture height.

The interdependence relationship between color parameters in the characterization of the sunflower crop, the hybrid P64LE25, was evaluated by regression analysis. The interdependence relationship between R and G was described by a 2nd degree polynomial equation, equation (1), under conditions of $R^2 = 0.944$, $p < 0.001$, F = 635.02. The interdependence relationship between R and B was described by a polynomial equation of degree 3, equation (2) under conditions of $R^2 = 0.921$, $p < 0.001$, F = 46.739. The interdependence relationship between G and B was described by a linear equation, equation (3), under conditions of $R^2 = 0.898$, $p < 0.001$, F = 124.53. The graphic distribution of the interdependence of the identified color parameters, and the expressions of the obtained equations, is presented in Figure 3.

$$G = 0.0141 \cdot R^2 - 1.672 \cdot R + 119 \quad (1)$$

$$B = -0.004655 \cdot R^3 + 1.251 \cdot R^2 - 111.4 \cdot R + 3328 \quad (2)$$

$$B = 0.5638 \cdot G - 9.71 \quad (3)$$



(a) (b) (c)

Figure 3. The graphic distribution of the interdependence of the RGB color parameters in the description of the sunflower crop, the hybrid P64LE25; (a) G in relation to R, (b) B in relation to R, (c) B in relation to G

On the basis of PCA, correlation, the distribution diagram of the variants, represented by the image capture height (T1 to T16), was obtained in relation to RGB parameters, as biplot (Figure 4).

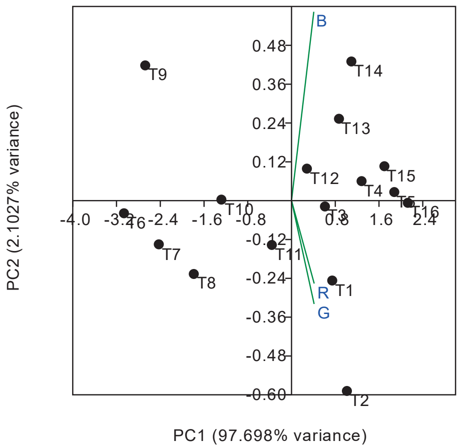


Figure 4. PCA diagram, correlation, regarding the distribution of variants in relation to RGB color parameters, sunflower crop, hybrid P64LE25

According to PCA, PC1 explained 97.698% of variance, and PC2 explained 2.1027% variance. It was found the independent positioning of some variants in relation to RGB parameters (T6, T7, T8, T9, T10 and T11) and the placement of the other variants associated with color parameters (T1 associated with R and G; T12, T13 and T14 associated with B; the other variants had an intermediate position between R, G, respectively B).

The cluster analysis led to obtaining a grouping of the variants based on similarity in relation to the values of the RGB color parameters. The dendrogram in Figure 5 was obtained, in which the variants (T1 to T16) were grouped based on similarity in relation to the values of the RGB color parameters. Two distinct clusters resulted, with several sub-clusters each.

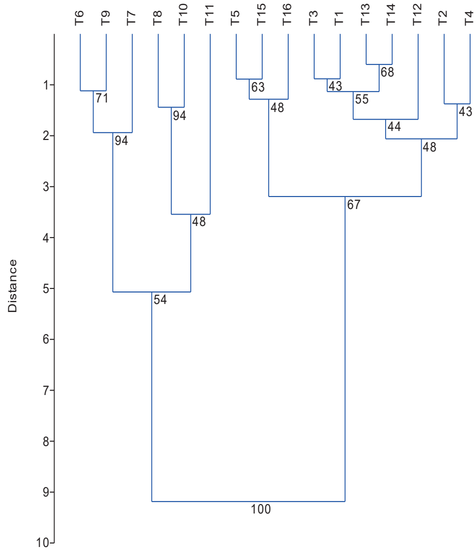


Figure 5. The cluster grouping based on the Euclidean distances of the variants, in the imaging analysis of the sunflower crop, hybrid P64LE25

A cluster C1 included the variants [(T6, T9) T7] within a subcluster C1-1 and the variants [(T8, T10) T11] within a sub-cluster C1-2, variants with position independent of RGB parameters. Within the C2 cluster, the other variants were grouped in two sub-clusters. Sub-cluster C2-1 included the variants [(T5, T15), T16], with an intermediate position, relative to RGB parameters.

Within the sub-cluster C2-2, variants (T1, T3) were associated in close relation with parameters R and G, variants [(T13, T14) T12 were associated in close relation with parameter B], and variants (T2, T4) were positioned associated, as a similar position in relation to RGB.

Based on the SDI values, the highest level of similarity was assessed between variants T13 and T14 (SDI = 0.5998), followed by variants T1 and T3 (SDI = 0.8812) and variants T5 and T15 (SDI = 0.8882) within the C2 cluster.

Within the C1 cluster, a high level of similarity was recorded between the variants (SDI = 1.1172), followed by the T8 and T10 variants (SDI = 1.4402).

Considering the level of safety regarding the distribution of the data series for RGB parameters, the distribution and association of the variants (T1 to T16) obtained through PCA and CA in relation to RGB parameters, the estimation of sunflower production, hybrid P64LE25, was analyzed through the analysis of regression.

A general equation in the form of equation (4), was obtained, which facilitated the estimation of sunflower production based on RGB parameters in different combinations (Table 2).

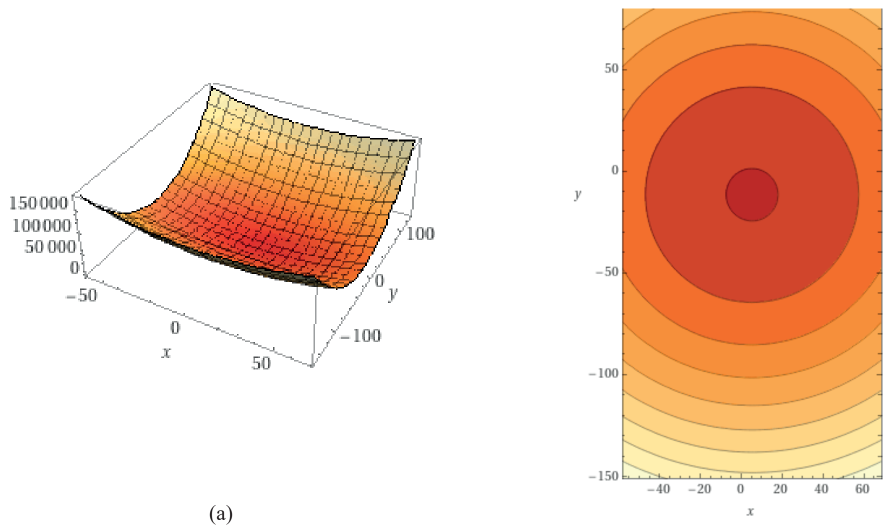
$$Y = ax^2 + by^2 + cx + dy + exy + f \quad (4)$$

where: Y - sunflower production; x and y RGB color parameters in combinations according to Table 2; a, b, c, d, e, f - coefficients of the equation (4) (Table 2).

In relation to R and G, the estimation of Y production (kg ha^{-1}) was made under conditions of $R^2 = 0.999$, $p < 0.001$ (Figure 6). In relation to R and B, production was estimated under conditions of $R^2 = 0.999$, $p < 0.001$, and in relation to G and B, production was estimated under conditions of $R^2 = 0.999$, $p < 0.001$.

Table 2. Values of the coefficients of equation (4) in relation to the combination of RGB color parameters

Coefficients of equation (4)	Values of the coefficients in relation to the combination of RGB parameters		
	x - R, y - G	x - R, y - B	x - G, y - B
a	7.79473007	-0.62392957	-0.99258669
b	7.57721869	-0.65416289	-0.68373757
c	-82.19636475	86.05933728	115.37488965
d	176.42044845	-8.22191157	-59.82367318
e	-15.92116254	0.649730337	1.32391351
f	0	0	0
RMSEP	1.79072	4.58693	3.69784



(a) (b)

Figure 6. The graphic distribution of sunflower production, hybrid P64LE25, depending on the R and G values; (a) 3D model; (b) model in the form of isoquants

Based on the RMSEP parameter, higher accuracy was found in the estimation of production based on R and G parameters (RMSEP = 1.79072), compared to the other combinations of color parameters (RMSEP = 4.58693 in the case of R and B parameters; RMSEP = 3.69784 in the case of parameters G and B), under the conditions of using two color parameters each.

The estimation of sunflower production was considered in relation to all three color parameters, as a direct and interaction effect, and the regression analysis led to equation (5).

$$Y = x^2 + y^2 + z^2 + xy + xz + yz + x + y + z \qquad (5)$$

where: x - R color parameter; y - G color parameter; z - B color parameter.

The reliability of the prediction was confirmed by the values $R^2 = 0.999$, $p < 0.001$, RMSEP = 1.46267. The level of statistical safety, assessed on the basis of RMSEP, was higher than the situation in which combinations of two color parameters were used (Table 2).

The graphic distribution of the errors recorded in relation to the image acquisition variants (T1 to T16) and color parameters considered in the regression analysis, are presented in Figure 7.

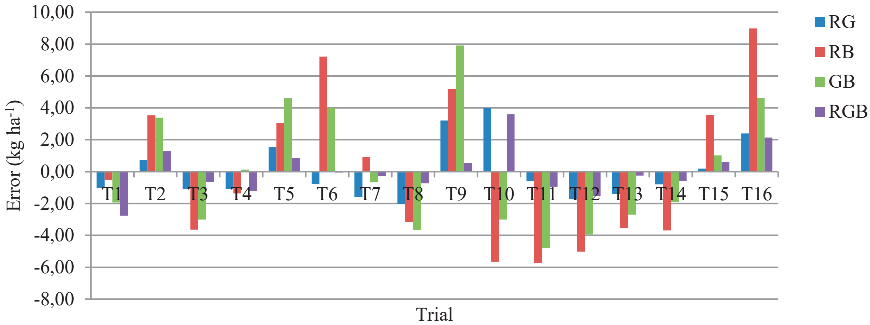


Figure 7. The graphic distribution of the estimation errors of sunflower production, the P64LE25 hybrid, in relation to RGB parameters and the image capture height

Estimating the production of agricultural crops, even during the vegetation period, is important for the appropriate management of the crop, for intervention works, as well as for aspects of harvesting logistics, storage or production utilization (Hassanzadeh et al., 2020; Chang et al., 2023).

In the context of the present study, the prediction of sunflower production was made based on UAV images taken during the fruit development period (BBCH 7 code).

The prediction errors varied in relation to the image capture height, but also in relation to the RGB parameters used in the regression analysis.

In the case of using the RGB parameters in combinations of two in the repression analysis, and in relation to the image capture height, the errors reached values of 3.984 kg (RG, at T10), 7.214 kg (RB, at T6) and 7.914 kg (GB, at T9). Under the conditions of using the three RGB parameters together in the regression analysis, the maximum errors only reached 3.592 kg (RGB, at T10). The presentation of the errors in relation to the RGB parameters and the image capture height (T1 to T16) is shown in the dendrogram in Figure 8.

In estimating the biomass production, the N content of the biomass and the yield in sunlight, Vega et al. (2015) communicated that the time of day of image acquisition (UAV), the classification process and the resolution of the images variably influenced the results in study conditions.

The prediction of some physiological indices and production (biomass, seeds, etc.) based on the UAV images was made for different agricultural crops in variable statistical confidence bands, depending on the study conditions. Constantinescu et al. (2018) reported a moderate correlation between chlorophyll and fresh biomass ($r = 0.772$; $p < 0.01$), respectively a strong correlation between chlorophyll and the DGCI index ($r = 0.846$; $p < 0.01$) as part of a study based on UAV images of grass cereals.

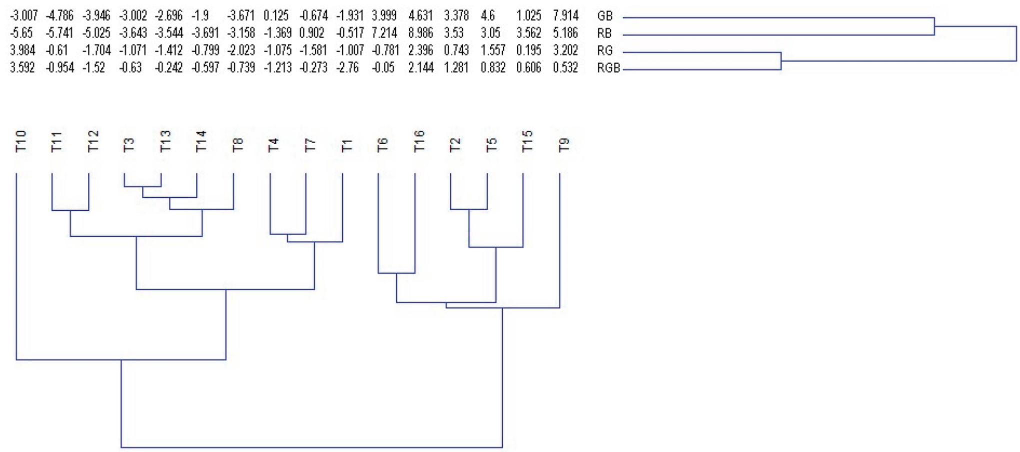


Figure 8. Dendrogram of the distribution of the variants in relation to the error values, results depending on the image capture height and RGB parameters used in the analysis (Coph. corr = 0.839)

In the estimation of biomass, water flow and CO_2 in the sunflower crop through imaging analysis (remote sensing), Pique et al. (2020), obtained models that facilitated the estimation of the considered parameters under high statistical safety conditions ($R^2 = 0.79$ to $R^2 = 0.83$).
In the conditions of the study of the sunflower weed spectrum based on aerial images (UAV) at two flight heights (30 and 60 m altitude), López-Granados et al. (2016), found that high accuracy (~100%) in the discrimination of weeds was recorded under the conditions of using the multispectral camera, regardless of the flight height, and low accuracy (50-60%) was obtained under the conditions of using the camera in the spectrum visible.
In estimating the lodging phenomenon in sunflowers based on UAV images, Li et al. (2021) obtained 12 models and found better accuracy in the assessment/characterization of the studied phenomenon (lodging) by using NIR information to RGB ones, than by using RGB alone. Studying the same sunflower phenomenon (lodging) based on UAV imagery, but with different analysis methods, Song et al. (2020) found that by using improved methods, the level of estimation was more accurate.
The results communicated through this study are comparable to similar studies on sunflower, but also on other agricultural crops, and can contribute to the improvement of agricultural technologies and an adequate management of crops.

CONCLUSIONS

The images taken with the drone, in the height range between 3 m and 50 m, captured the sunflower crop status, the P64LE25 hybrid, and the image analysis facilitated obtaining the values for the RGB color parameters in conditions of statistical safety.
Based on the recorded values, it was possible to characterize the sunflower crop, and different levels of interdependence between the RGB values, described by polynomial or linear equations, were identified.
The distribution and grouping based on the affinity of the variants was possible through PCA and cluster analysis, based on the RGB values and the image acquisition heights (T1, to T16).
The estimation of sunflower production, based on the RGB parameters obtained from the aerial images (UAV) taken in stage 7 BBCH, was possible under statistical safety conditions. Variable accuracy of production estimation was recorded, in relation to the color parameters used (RGB) and the image capture height.

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