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# VARIATION MODEL OF SOME FRUITS BIOMETRIC PARAMETERS IN RELATION TO APPLE TREES PHYSIOLOGICAL INDICES

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***Abstract***

*The study analyzed the variation of some biometric parameters of apple fruits, the 'Generos' variety, in relation to physiological indices, under the influence of foliar fertilizers. The experiment included 9 experimental variants, a control variant (T1) and 8 fertilized variants (T2 - T9) with foliar fertilizers: Foliarel combined with Uwafol, Waterfert, Biocomplex, Megafol and Calcium chloride. Fruit diameter (FD) and fruit weight (FW) were analyzed in relation to leaf area (LA) and chlorophyll content (Chl). The regression analysis facilitated the obtaining of mathematical models that described FD and FW variation in relation to LA and Chl, in statistical safety conditions. The optimal values for LA and Chl were determined and graphical representation of the FD and FW variation in relation to LA and Chl, in the form of isoquants, were generated. Based on PCA, PC1 explained 87.947% of variance, and PC2 explained 11.39% of variance. Grouping of variants based on affinity, under conditions of Coph.corr = 0.981, were obtained. According to similarity and distance indices (SDI), the highest affinity was recorded for T3 and T9 variants (SDI = 0.3027).*

**Key words**: *apple, mathematical model, PCA, physiological indices, similarity.*

## INTRODUCTION

Plant physiological indices and plant physiological response have been intensively studied in relation to different biotic and abiotic factors of influence (Jing et al., 2016), and numerous studies have been conducted in the context of climate change regarding plant physiological responses (Becklin et al., 2016; Gray and Brady, 2016; Zhou et al., 2017; Raza et al., 2019).

Physiological indices express the plant's vegetative state, plant relationship with the nutritional environment, the stages of plant development, the harvest quality (Nemeskéri and Helyes, 2019; Wang et al., 2019). On different crop plants, physiological indices were studied in relation to water regime (Lepaja et al., 2019; Nemeskéri and Helyes, 2019), in relation to plant nutrition (Wünsche and Lakso, 2000; Janusauskaite et al., 2017; Datcu et al., 2018; Belhassine et al., 2019), to productivity elements (Rawashdeh and Sala, 2016), with production and its quality (Jivan and Sala, 2014; Rawashdeh and Sala, 2015; Căbăroiu et al., 2019), or with stress factors (Füzy et al., 2019). In apple trees and apple orchards, physiological indices were studied in relation to different interstocks (Zhao et al., 2015), in relation to different apple varieties (Ghafir et al., 2009), to plant stress tolerance and apple rootstocks (Wang et al., 2018), and in relation to physiological disorders in fruits (Martins et al., 2013).

Mineral elements have a differentiated role in the nutrition of fruit trees in relation to the species, genotype, age of trees, vegetation conditions, vegetation cycle of trees, etc. (Ding et al., 2017; Cruz et al., 2019; Valverdi et al., 2019). The relationship of mineral elements with fruit trees, at the level of physiological indices, physiological processes, fruits and their quality, was studied in relation to different fertilizers application, in soil or foliar (Amiri et al., 2008; Jivan and Sala, 2012; 2014). Mineral elements reserve in wood structure of the fruit trees was studied based on the importance for the shoots maturation, for fruit buds differentiation, the start of buds vegetation, formation and quality of fruit production etc. (Sorrenti et al., 2017; Carranca et al., 2018). Studies on the influence of mineral elements on production, fruit quality indices, and fruit storage have been carried out in different horticultural species and genotypes in relation to various soil and climatic conditions and evaluation methods (Campeanu et al., 2009; Dobrei et al., 2009; Blidariu and Sala, 2012; Ikinci et al., 2014; Wang et al., 2015; Agnolet et al., 2017).

The present study evaluated the variation of some biometric parameters of apple fruits in relation to physiological indices and evaluated the safety degree of some mathematical models to describe this variation.

## MATERIALS AND METHODS

The aim of the study was to evaluate the variation of some biometric parameters of fruits in relation to apple physiological indices, under the influence of foliar fertilization and to found mathematical models to describe these relationships in statistical safety conditions.

The study was conducted in Fruit-Vine Research Center, Didactic and Experimental Station, USAMVB Timisoara, 2011 and 2012 period. The biological material was represented by the 'Generos' apple variety, cultivated in a semi-intensive system.

Five foliar fertilizers were used, compared with a control variant (T1). From the foliar fertilizers combination resulted experimental variants: T2 (Foliarel + Uwafol), T3 (Foliarel + Uwafol + Ca), T4 (Foliarel + Waterfert), T5 (Foliarel + Waterfert + Ca), T6 (Foliarel + Biocomplex), T7 (Foliarel + Biocomplex + Ca), T8 (Foliarel + Megafol), T9 (Foliarel + Megafol + Ca). Calcium was used as calcium chloride ($CaCl_2$). Three foliar treatments were applied.

Leaf area (LA) and chlorophyll content (Chl) were evaluated. Leaf area was determined by non-destructive method, based on the dimensional parameters of the leaves (length - L, and width - W) and a correction factor (CF), according to a general relationship of type as $LA = L \cdot W \cdot CF$. Chlorophyll content was determined with a portable chlorophyll meter (SPAD 502 Plus, Konica Minolta) with accuracy of ± 0.2 SPAD units.

Fruit quality was evaluated based on biometric parameters, FD - fruit diameter, and FW - fruit weight.

Fruits diameter was determined by measurement with an electronic calliper, with accuracy of ± 0.001 mm, and fruit weight was measured with a laboratory balance, with accuracy of ± 0.005 g.

Experimental data were analyzed to evidence the presence of variance and overall statistical safety (ANOVA test). The level of correlation between physiological indices and quality parameters was evaluated. LA and Chl contribution to FD and FW variation was analyzed, and the optimal level of LA and Chl was determined to ensure FD and FW in the experimental conditions. Correlation and regression coefficients (r, $R^2$), cophenetic coefficient, p parameter and F-test were used to evaluate the safety of the results.

## RESULTS AND DISCUSSIONS

Foliar fertilization applied to apple, the 'Generos' variety, influenced the values of physiological indices and photosynthetic processes, a fact highlighted at the level of leaf area (LA), chlorophyll content (Chl) and fruit size (FD - fruit diameter, FW - weight fruit). The values recorded for the physiological indices and for the fruits biometric parameters are presented in Table 1.

Table 1. Physiological indices and biometric parameters values of apple fruits, 'Generos' variety (average values 2011-2012)

| Trial | LA ($cm^2$) | Chl SPAD units | FD (mm) | FW (g) |
|---|---|---|---|---|
| T1 | 30.26 | 43.27 | 60.88 | 92.225 |
| T2 | 32.52 | 46.86 | 62.72 | 112.008 |
| T3 | 33.84 | 48.77 | 64.54 | 118.428 |
| T4 | 40.70 | 54.61 | 63.98 | 118.630 |
| T5 | 44.50 | 56.78 | 64.48 | 119.018 |
| T6 | 35.28 | 50.06 | 65.17 | 120.960 |
| T7 | 39.94 | 54.26 | 66.42 | 123.435 |
| T8 | 37.13 | 52.36 | 63.19 | 117.450 |
| T9 | 38.67 | 54.71 | 64.24 | 118.468 |
| SE | ±1.48 | ±1.46 | ±0.52 | ±3.09 |

Physiological index LA recorded values between 30.26 ± 1.48 $cm^2$ in the control variant (T1), and 44.50 ± 1.48 $cm^2$ in the T5 variant. A specific variation, in relation to the experimental variants, recorded the chlorophyll content (Chl), with the value 43.27 ± 1.46 SPAD units at T1 variant, and 56.78 ± 1.46 SPAD units at T5 variant. The parameter FD (fruit diameter) recorded values between 60.88 ± 0.52 mm for the control variant (T1) and 66.42 ± 0.52 mm for the T7 variant. The fruit weight (FW) parameter recorded values between 92.225 ± 2.09 g for the control variant (T1), and 120.960 ± 3.09 g for the T6 variant.

The statistical safety and the presence of variance in the data set (average values 2011-2012) was confirmed by the ANOVA test, according to the values of the parameters p and F-test, for Alpha = 0.001 ($p<<0.001$; $F>>$ Fcrit). The correlation analysis on the experimental data set revealed the existence of a very strong positive correlation between LA and Chl ($r = 0.967$), strong positive correlations between FD and FW ($r = 0.899$), and moderate and weak correlations between FW and LA ($r = 0.664$), FW and Chl ($r = 0.776$), FD and LA ($r = 0.604$), and between FD and Chl, respectively ($r = 0.680$).

The interdependence relationship identified between LA and Chl under the influence of foliar fertilization, was described by equation (1), under conditions of $R^2 = 0.989$, $p<<0.001$, $F = 292.08$.

$$LA = -0.05194 \cdot Chl^2 + 4.818 \cdot Chl - 54.93 \quad (1)$$

Dependency relationships were found between the fruits biometric parameters (FD and FW) and the physiological indices, LA and Chl.

The variation of the FD parameter depending of LA was described by equation (2), but under low statistical safety conditions ($R^2 = 0.592$, $p = 0.0678$, $F = 4.354$).

The variation of FD in relation to Chl was described by equation (3) under conditions of moderate statistical safety ($R^2 = 0.639$, $p = 0.0471$, $F = 5.3066$).

$$FD = -0.03792 \cdot LA^2 + 3.036 \cdot LA + 4.217 \quad (2)$$

$$FD = -0.03867 \cdot Chl^2 + 4.122 \cdot Chl - 45.05 \quad (3)$$

Fruit weight (FW) registered a much closer variation in relation to the values of the two physiological indices, LA and Chl. Thus, the regression analysis led to equation (4) which described the variation of FW values in relation to LA under high statistical safety conditions ($R^2 = 0.802$, $p = 0.0077$, $F = 12.153$). Also, the regression analysis resulted in equation (5) which described the variation of FW in relation to Chl, in very high statistical safety conditions ($R^2 = 0.934$, $p = 0.00029$, $F = 42.201$). Graphical distribution is presented in Figure 1.

$$FW = -0.2819 \cdot LA^2 + 22.37 \cdot LA - 321.1 \quad (4)$$

$$FW = -0.3117 \cdot Chl^2 + 32.9 \cdot Chl - 746.7 \quad (5)$$

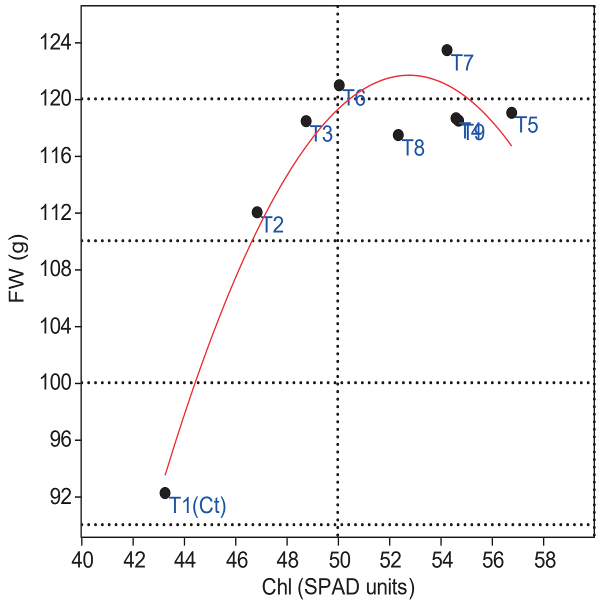


Figure 1. Graphical distribution of the FW parameter variation according to Chl in apple, 'Generos' variety

The interdependence relationship between fruits biometric parameters (FD and FW) was described by equation (6) under very high statistical safety conditions ($R^2 = 0.967$, $p<<0.001$, $F = 87.832$).

$$FW = -1.193 \cdot FD^2 + 157 \cdot FD - 5045 \quad (6)$$

Principal Component Analysis led to the diagram in Figure 2, which includes the distribution of variants (T1-T9) in relation to the indices and parameters studied (LA, Chl, FD and FW, as biplots). PC1 explained 87.947% of variance, and PC2 explained 11.39% of variance.

Cluster analysis led to the grouping of affinity-based variants in relation to fruit biometric parameters (FD and FW), in statistical safety conditions (Coph.corr = 0.981). The separate positioning of the control variant T1 (Ct) was found, with the lowest values for parameters FD and FW (cluster C1). T2-T9 variants were grouped based on affinity in a cluster (C2) with several sub-clusters. Variant T2 occupied a distinct position (sub-cluster C2-1), and the other variants were associated within two groups: sub-cluster C2-2a [(((T3, T9), T4), T5); T8], and a second sub-cluster C2-2b with variants (T6, T7), respectively, Figure 3.

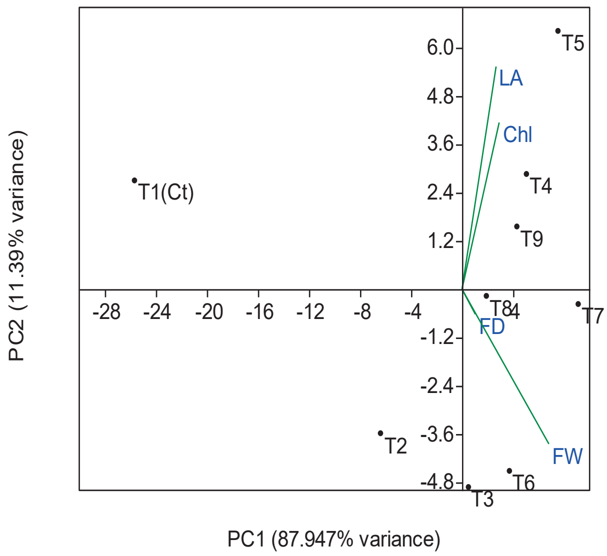


Figure 2. PCA diagram with the variants distribution, 'Generos' apple variety

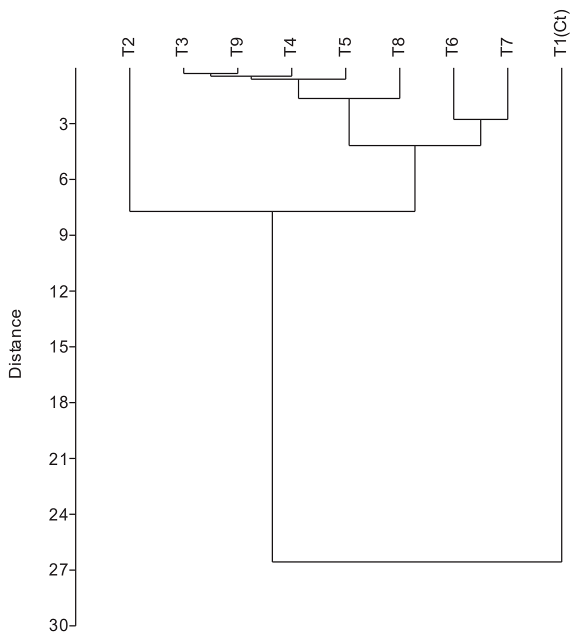


Figure 3. Dendrogram of the variants grouping based on Euclidean distances in relation to FD and FW, 'Generos' apple variety

By the analysis of SDI values (similarity and distance indices) found the highest affinity for T3 and T9 (SDI = 0.3027), followed by T9 and T4 (SDI = 0.3063), T3 and T4 (SDI = 0.5953), T3 and T5 (SDI = 0.5930), T9 and T5 respectively (SDI = 0.6001).

The complete set of values expressing the degree of similarity of the experimental variants in relation to FD and FW is presented in Table 2.

Based on the correlations recorded, on the relationships identified between fruit biometric parameters and physiological indices, as well as on SDI index values, multiple regression analysis was used to find how the FD and FW fruit quality parameters were influenced by the two physiological indices (LA and Chl), as their simultaneously action.

Equation (7) was obtained for the variation of FD in relation to LA and Chl, in general conditions of moderate statistical safety ($R^2 = 0.674$). Starting from the general equation (6) the optimal values for x (LA) and y (Chl) were determined in relation to FD and resulted $x_{opt} = 40.64$ cm$^2$, $y_{opt} = 54.53$ SPAD units. The graphic distribution in 3D form is presented in Figure 4, and the graphic distribution in the form of isoquants is presented in Figure 5.

$$FD = ax^2 + by^2 + cx + dy + exy + f \qquad (7)$$

where: x - LA - leaf area (cm$^2$);
y - Chl - Chlorophyll content (SPAD units);
a, b, c, d, e, f - coefficients of the equation (7);
a = -0.217077868276657;
b = -0.273233884443766;
c = -7.45835582731484;
d = 11.0931639949924;
e = 0.460316337521112;
f = -85.8661919487794.

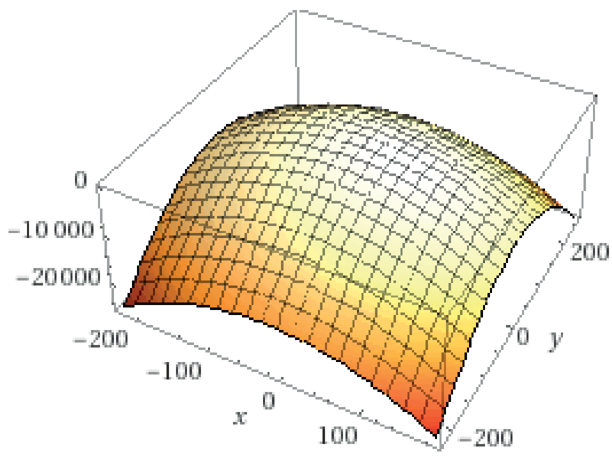


Figure 4. 3D graphical distribution of FD values according to LA (x-axis) and Chl (y-axis), 'Generos' apple variety

Table 2. SDI values in relation to biometric parameters FD and FW, 'Generos' apple variety

| | T1(Ct) | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 |
|---|---|---|---|---|---|---|---|---|---|
| T1(Ct) | | 19.8680 | 26.4570 | 26.5860 | 27.0340 | 29.0530 | 31.6980 | 25.3310 | 26.4570 |
| T2 | 19.8680 | | 6.6730 | 6.7408 | 7.2276 | 9.2812 | 12.0110 | 5.4623 | 6.6364 |
| T3 | 26.4570 | 6.6730 | | 0.5953 | 0.5930 | 2.6092 | 5.3483 | 1.6670 | 0.3027 |
| T4 | 26.5860 | 6.7408 | 0.5953 | | 0.6329 | 2.6163 | 5.3890 | 1.4200 | 0.3063 |
| T5 | 27.0340 | 7.2276 | 0.5930 | 0.6329 | | 2.0609 | 4.8243 | 2.0304 | 0.6001 |
| T6 | 29.0530 | 9.2812 | 2.6092 | 2.6163 | 2.0609 | | 2.7727 | 4.0300 | 2.6599 |
| T7 | 31.6980 | 12.0110 | 5.3483 | 5.3890 | 4.8243 | 2.7727 | | 6.8010 | 5.4243 |
| T8 | 25.3310 | 5.4623 | 1.6670 | 1.4200 | 2.0304 | 4.0300 | 6.8010 | | 1.4625 |
| T9 | 26.4570 | 6.6364 | 0.3027 | 0.3063 | 0.6001 | 2.6599 | 5.4243 | 1.4625 | |

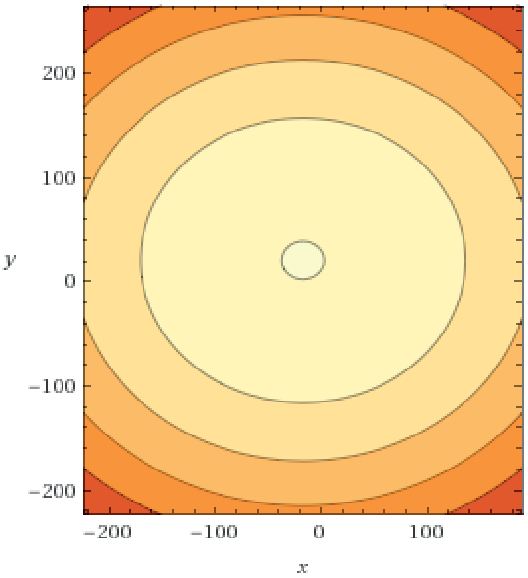


Figure 5. Graphical distribution as isoquants of FD values according to LA (x-axis) and Chl (y-axis), 'Generos' apple variety

In the case of the FW parameter the multiple regression analysis led to equation (8), which described the variation of FW in relation to LA and Chl, as simultaneous action, in conditions of very high statistical safety ($R^2$ = 0.963, p = 0.0233, F = 15.60669).

$$FW = ax^2 + by^2 + cx + dy + exy + f \quad (8)$$

where: x - LA - leaf area ($cm^2$);
y - Chl - Chlorophyll content (SPAD units);
a, b, c, d, e, f - coefficients of the equation (8);
a = -1.04855116323077;
b = -1.8234743024433;
c = -65.8996248409577;
d = 88.5299133910003;
e= 2.75191899805017;
f = -973.360137346891.

Starting from the general equation (8) the optimal values for x (LA) and y (Chl) were determined in relation to FW, and resulted $x_{opt}$ = 43.95 $cm^2$, $y_{opt}$ = 57.44 SPAD units. The graphic distribution in the form of 3D is presented in Figure 6, and the graphic distribution in the form of isoquants is presented in Figure 7.

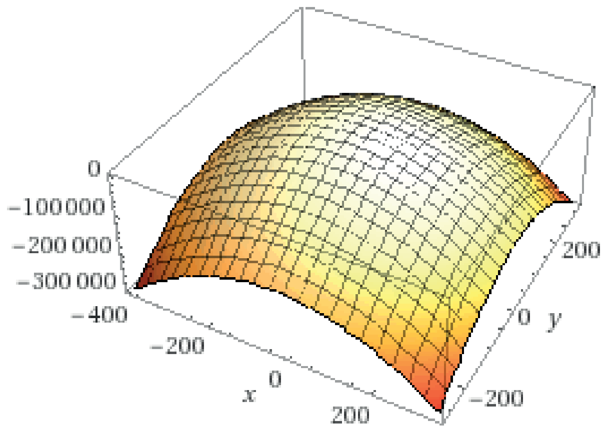


Figure 6. 3D graphical distribution of FW values according to LA (x-axis) and Chl (y-axis), 'Generos' apple variety

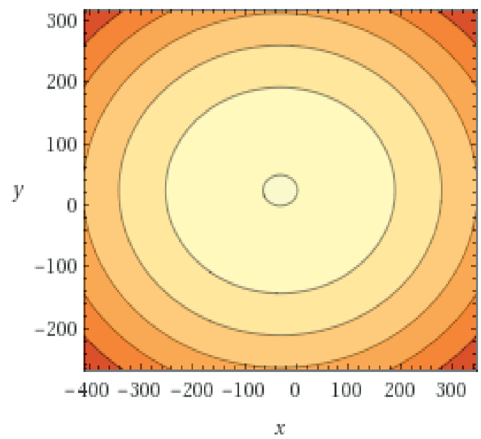


Figure 7. Graphical distribution as isoquants of FW values according to LA (x-axis) and Chl (y-axis), 'Generos' apple variety

Modeling and imaging analysis have long been used as tools and methods for studied and evaluation in large-scale of agro-forestry and horticultural ecosystems (Herbei and Sala, 2014; Herbei et al., 2015a;2015b), for analysis at horticultural farm level, plots, plants, vegetative organs, production and fruits quality elements (Govedarica et al., 2015; Barikloo and Ahmadi, 2013; Cheng et al., 2017).

For the leaf area (LA) study, the non-destructive methods are of high interest especially due to the fact that it is not necessary to detach the leaf samples for the test, and this methods are fast and sufficiently accurate. Various models and software applications have been developed for the rapid and accurate assessment of LA (Khan et al., 2016; Drienovsky et al., 2017a; Kumar et al., 2017; Cândea-Crăciun et al., 2018), as well as software applications for assessment of the degree of pathogens attack (Drienovsky et al., 2017b, Drienovsky and Sala, 2019).

Fruit size and size index have been studied and are important in the general definition of fruit quality, as well as in relation to the fruits storage, marketing and industrialization (Salvador et al., 2006; Gonçalves et al., 2017).

The usefulness and importance of the models resulted from other studies, in which they were used to evaluate the dynamics of fruit formation, quality, harvest time etc., useful elements in plantation management (Li et al., 2015; Marini et al., 2019).

In the context of interest in the quality of apple production, models and methods for estimating the quality of fruit production, confirmed by the literature, this study proposed models for evaluating the dimensional parameters of apples based on physiological indices, in statistical safety conditions.

## CONCLUSIONS

The regression analysis facilitated the obtaining of models that has described the variation of FD and FW according to LA and Chl, in statistical safety conditions. From the mathematical equations were found the optimal values for LA and Chl in relation to fruits parameters studied, FD and FW.

PCA generated the variants distribution diagram, in which PC1 explained 87.947% of variance and PC2 explained 11.39% of variance.

The clusters analysis led to the grouping of variants in clusters based on affinity, in conditions of high statistical safety, Coph.corr = 0.981. According to similarity and distance indices (SDI), the highest affinity was recorded for T3 and T9 variants (SDI = 0.3027).

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