Investigation note

Dimensional properties of the cobs for machine design

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Abstract

In order to design cutting machines and deburders of cobs (*Zea mays* L.), it is necessary to know the geometric properties of the fruit that form the input data for the evaluation of the mathematical models of the fruit-machine system. Three new geometric characteristics were determined: optimal cutting diameter (c), base length to the largest diameter (lbdm) and base length to the optimum cutting diameter (lbco) of a sample of 50 cobs of white corn of the variety Murano, from the state of Morelos, as well as total length (lt) and greater diameter (dm). Similarly, for a sample of 103 Arroz variety cobs of the state of Veracruz, lbco, lbdm, dm and lt were determined, a photographic record was also made and processed with OpenCV software with determination of two parameters plus-area (A) and length from base to centroid (lbc). Statistical analysis showed that there is a simple correlation of 0.905 between lbco-lbdm and two multiple correlation coefficients of 0.904 between dm-lbdm-lbco, and 0.917 between lt-lbdm-lbco for the Murano variety. The Arroz variety showed a multiple correlation of 0.66 between lbco-dm-lbdm-lt-A-lbc. With the results, different mathematical models of relationship between the parameters of the cob were established for its application in the design of an improved prototype of defoliator.

Keywords: *Zea mays* L. cob, correlation, geometric parameters.

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Corn (*Zea mays*) represents half of the total volume of food consumed each year and provide the population with about half of the required calories. In 2006, production amounted to 21.3 million tons, while the demand was 26.2 million tons, so it is about taking advantage of some of the parts of the plant such as the leaf or totomoxtle for different uses (Castañeda-Zavala, 2007).

The beneficiary Agroindustrias del Rio classifies the cut sheet into seven categories and presentations, the larger the length and width of the leaves the quality is greater. This depends on the variety of corn and the method of cutting, which can be manually, manually defolded with the help of a bank with a toothed disc and mechanized extraction of the leaf. Industrial machines partially cut the cobs in the base and final part for a later defoliation; the previous calibration that does not allow alterations of the cutting distance of the ends of the cob (Rossi and McGuire, 1992).

The Higher Technological Institute of Teziutlan developed a pedal-driven prototype that functions as a guillotine (Rodríguez-Ventura, 2010) but the position of the blades causes the blade to not have a uniform cut. Another machine that performs the separation of the leaves with a yield of 790 cobs h^{-1} generates damages of a maximum of 3.41% to the leaves and 53.35% of wasted grain with an average of 10.94% (Cruz-Meza *et al*., 2010).

These values indicate that the machine has deficiencies related to the variable geometry of the cobs. The considerations of the dimensional properties are factors to take into account in the design of a machine with a particular objective (Pérez-López, *et al*., 2009), as it is to obtain higher quality leaves. To optimize the cutting process, Romantchik *et al*. (2016) describes a methodology for adjusting the cutting disc of a tamale cob deleafing machine by image processing to calculate the optimum cutting length (lbco).

It makes use of this parameter to calculate with a processing card the distance from the center of a camera to the optimum cut (lcam), knowing the working width of the camera (atc), the position of the cob is located as x_0 that when added lbco becomes the distance x_1. With these values, equation (1) is applied, with which it is possible to determine the cutting distance of the cob to the origin of the device (dv), subtracting lcam from the preset distance from the origin to the center of the chamber (lcc) with the equation (2) and calculate the adjustment distance (da) of the cutting disc with equation (3). This device is under development at the Autonomous University Chapingo (Bernabe *et al*., 2018).

$$\mathrm{lcam} = \frac{\mathrm{atc}}{2} - \mathrm{x_1} \qquad 1)$$

$$\mathrm{dv} = \mathrm{lcc} - \mathrm{lcam} \qquad 2)$$

$$\mathrm{da} = \mathrm{dv} - \mathrm{dc} \qquad 3)$$

To improve options for the sale and design of machines in the agri-food industry, physical, mechanical, biological, thermal properties, etc. of agricultural products are used, as well as their mathematical models created from these characteristics (Prado-Martínez *et al*., 2012). The agronomic characteristics of the cobs are generally determined as productivity indicators (Ávila *et al*., 2009). Different parameters of native corn cobs have been analyzed among them: length, width, number of rows and width index between length in order to determine the quality of corn (Ortiz-Torres *et al*., 2013).

Corn leaves and biometric properties (length and diameter) to produce paper were chemically and morphologically characterized (Prado-Martínez *et al*., 2012). The knowledge of the physical-mechanical properties during the evaluation of mathematical models of the dynamics of the fruit-peduncle system is required, in order to optimize the working regimes of the machines (Bouza *et al*., 2006).

Likewise, the use of an artificial vision system provides a set of functions of pattern and image analysis, providing numerical attributes of the objects or scenarios that are examined (Velázquez-López *et al*., 2011), allowing the characterization of dimensional properties more accurately and quickly. Coconut circular image analysis has been used to determine two parameters, Feret's circularity and diameter (Ramírez-Ramírez and Hahn-Schlam, 2013), to predict the cutting location and optimize the extraction of coconut pulp (Hahn-Schlam *et al*., 2012).

In this work different models were determined to calculate the distance from the base to the optimum cut for cobs. This will make it possible to improve the design of cob deleafing machines by implementing a model to cut the peduncle precisely, so that all the leaves are free and can be quickly defolled without tearing them, thereby avoiding the waste of grains, which is limited just one row of grains per cob.

The experiment was conducted during the month of November 2015 with a sample of 50 cobs of white corn of the Murano hybrid variety, from the state of Morelos. The measurements were carried out with a Truper® digital Vernier with a tolerance of ±0.05 mm, a Pretul® measuring tape with a tolerance of ±0.1 mm and a Mitutoyo brand height gauge with a 300 mm millimeter scale with a precision of ±0.05 mm, in the metrology laboratory of the Department of Agricultural Mechanical Engineering of the Autonomous University Chapingo.

The geometric dimensions were measured in a single top view (Figure 1). The total length of each cob (lt), the largest diameter (dm) and the length of the base at it (lbdm) were determined. The length of the base to the optimal cutting area (lbco) and the optimal cutting diameter (do), was done by cutting each cob in a transverse way to visualize the peduncle and measure it with the measuring tape.

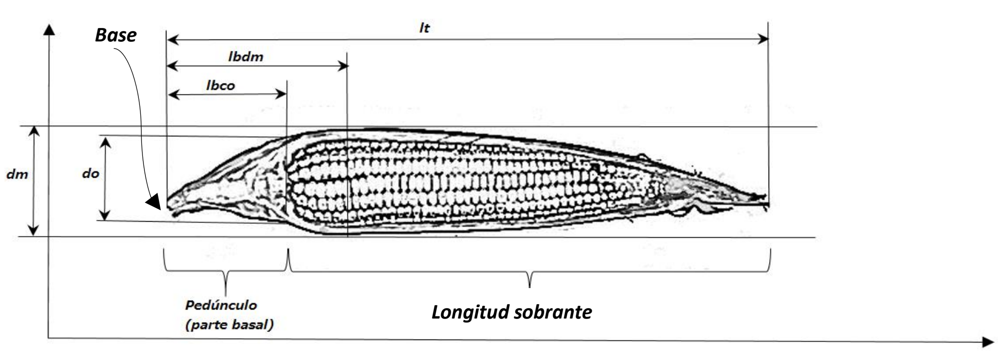

Figure 1. Geometric parameters measured in cobs of the Murano variety.

With the statistical test module of the Microsoft Excel version 2013 package, the statistical analysis was carried out (Table 1). It was established that for the correlation to be significant, the Pearson correlation coefficient (r) must meet the following condition: $r \geq 0.65$. Ten combinations of two variables with five parameters were made. An analysis of variance was made to determine the existence of a degree of correlation (Infante and Zarate de Lara, 1984).

Table 1. Descriptive statistics of the geometric parameters of the Murano variety cobs.

Parameters	lbco	lt	lbdm	dm	do
		(cm)		(mm)	
Mean	12.70	35.38	14.8	65.95	62.12
Median	12.45	35.75	14.65	66.26	62.03
Standard deviation	2.21	2.68	2.29	2.67	2.44
Variance	4.9	7.21	5.25	7.13	5.96
Range	10.7	11.5	9.9	11.83	13.91
Minimum	7.9	30	9.9	59.8	52.69
Maximum	18.6	41.5	19.8	71.63	66.6

The equation obtained with the absolute error was assessed. Ten combinations of three variables with five parameters were made and the multiple correlation coefficients (R) and the coefficient of determination (R^2) were calculated. It was established that for a significant correlation the following condition must be met, $R \geq 0.9$. An analysis of variance of the variables whose combinations met the aforementioned condition was carried out. For the combinations that met this criterion, we sought to relate them through a linear regression. Of the coefficients obtained from established linear models.

The procedure used to combine five parameters of three variables was repeated for four and five variables. With a sample of 103 cobs of corn of the creole variety Arroz collected randomly in the municipality of Papantla, Veracruz, the parameters lbdm, lbco, dm and lt were measured. Each cob was marked with a number for identification and a photographic record of each one was taken. This was done on a red area with a 12MP Fujifilm® camera placed parallel to the 900 lumens capture area.

Each image was processed with Visual C 2010 and OpenCV 249 software to determine the area in pixels. The area was included as a parameter to be evaluated with the variable A. The centroid was located using the OpenCV Moment routine, then the location of the midpoint of the tangent side to the base was programmed, from which the variable of the distance from the base to the centroid (lbc) (Figure 2).

The results of the measurements obtained from the sample of Murano variety cobs that were obtained were statistically processed with the Microsoft Excel version 2013 package. The experiment had as a total length of the cob a minimum of 30 cm, a maximum of 41.5 cm, an average 35.38 cm, while maximum lengths of 31.6 cm have been reported in tests (Cruz-Meza *et al*., 2010), and the indicated machine works with cobs with a minimum length of 16 cm.

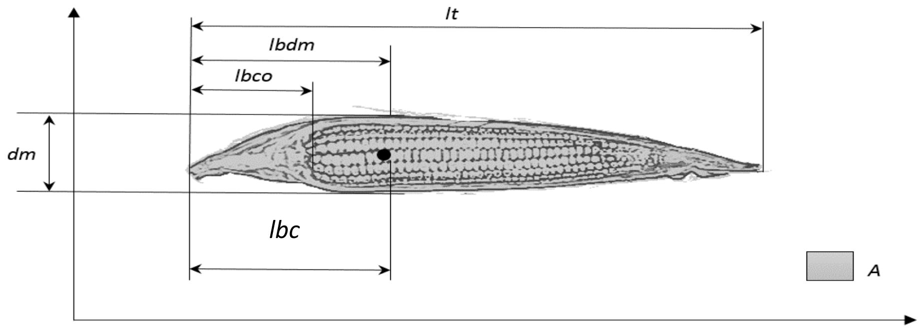

Figure 2. Geometric parameters measured in cobs of the Arroz variety.

Of the ten combinations of two variables, lbco was positively related to the variable lbdm with a correlation of 0.91 (Table 2), which indicates that there is a strong relationship between these two parameters.

Table 2. Pearson correlation coefficient (r) for two parameters.

Parameters		r	Parameters		r
Do	dm	0.537¶	do	lbco	0.021¶
Do	lbdm	-0.125¶	lbco	lt	0.666¶
lbco	dm	-0.043¶	dm	lbdm	-0.049¶
lbco	lbdm	0.905	dm	lt	0.15¶
do	Lt	0.203¶	lbdm	lt	0.6¶

¶= Non-significant correlation.

From the parameters of the indicated combination it was proved that there is a non-zero slope of the model sought. An analysis of variance was carried out taking into account the Fisher value of $F^{m}_{n,\ 0.05}$, the statistic F= 216.39 that was compared against $F^{48}_{1,\ 0.05} = 4.04$. As: F > F^{m}_{n} it is proved that there is at least a degree of correlation between the variables. In this test, a relationship was found between the fruit-peduncle system of a cob, using a linear regression the data were adjusted to a line to find the optimal cutting distance:

$$\text{lbco} = A_1 + B_1 * \text{lbdm} \qquad 4)$$

Where: A_1= 0.8738, B_1= -0.2384.

When evaluating equation (4), an absolute error $\in_1$ = 0.737 cm was obtained. For the composition with three variables, ten combinations were made between five variables, obtaining their multiple correlation coefficients and determination coefficient (Table 3). When analyzing Table 3, it is noted that the combinations lbco-lbdm-lt and lbco-dm-lbdm have a correlation coefficient greater than 0.90, so the existence of a model was checked by means of an analysis of variance for each one.

From the first combination the statistic F= 125.27 was obtained, which was compared with $F^{48}_{2,\ 0.05} = 3.19$. As: 125.27> 3.19 it is concluded that there is a degree of correlation between the tested variables. When analyzing the data of the lbco-dm-lbdm combination, it is observed that F= 105.94. Since $105.9 > F^{48}_{1,\ 0.05}$ there is experimental evidence that there is a degree of correlation between the parameters.

Table 3. Multiple correlation coefficient (R) and determination coefficient (R^2) between ten different combinations with three variables of five parameters.

Parameters			R	R^2	Parameters			R	R^2
do	lt	lbco	0.254¶	0.064	lbco	dm	lt	0.681¶	0.464
lbco	lt	do	0.676¶	0.457	do	dm	lbdm	0.545¶	0.297
do	lt	lbdm	0.369¶	0.136	lbco	dm	do	0.067¶	0.004
lbco	lbdm	lt	0.917	0.842	do	dm	lt	0.550¶	0.303
do	dm	lbco	0.538¶	0.289	Lbco	dm	lbdm	0.904	0.818

¶= non-significant correlation.

Linear regression was carried out for both compositions and each surface were adjusted to the data. Of the coefficients obtained by these two models were established that were evaluated by means of the analysis of the absolute error:

$$\text{lbco} = A_2 + B_2 * \text{lbdm} + C_2 * \text{lt} \quad 5)$$

Where: A_2=-4.1894, B_2=0.7624, C_2=0.1582.

$$\text{lbco} = A_3 + B_3 * \text{lbdm} + C_3 * \text{dm} \quad 6)$$

Where: A_3=-0.3329, B_3=0.8739, C_3=0.0014.

It is proceeded to look for a correlation between 4 and 5 variables, but it is noted that there is no correlation that exceeds 0.9, so multiple regression and analysis of variance were not carried out. The data obtained manually from the sample of 103 cobs, the photographic record and the subsequent processing of the images allowed binarization by extracting the proper color of the cobs turning them into black pixels, the count of them determines the area (A) of the cob (Figure 3) integrating as another statistical data. The value of A and lbc were handled in pixels.

Figure 3. Processing of cobs in OpenCV to a) determine the area and b) lbc.

The measured values in pixels present an error of ±30 pixels per processed image generated by the noise present in each photographic take. Table 4 shows that the maximum length of this variety is similar to that of the Murano variety, but this one has a greater variance, this is because the Arroz variety is creole while the first one is hybridized.

This variability foresees a lower correlation between the variables. In addition, this has a variance of 1.6 cm lbco, compared with the 4.9 cm of the hybrid sample, the creole sample could generate an algorithm that does not need a large adjustment, so it should be considered for the design of cob deleafing machines.

Table 4. Descriptive statistics of cobs of the Arroz variety.

Characteristics	lbco	lt	lbdm	dm	A	lbc
	(cm)		(mm)		(pixels)	(mm)
Mean	4.49	33.1	90.94	58.33	26967	204.89
Median	4.53	33	91.27	57.94	26731	201
Standard deviation	1.26	3.42	20.62	5.79	3970.25	28.49
Sample Variance	1.6	11.68	425.06	33.54	15762892.75	811.92
Minimum	1.07	25	42.95	42.91	17054	143
Maximum	7.58	40	165.67	72.2	37312	290

When observing the correlation data of the Pearson coefficient and the multiple correlation coefficient for three parameters, it was noted that there is no significant correspondence. Table 5 shows the values of the multiple correlation coefficients for four parameters, of which only the combination lbco, dm, lbdm and lbc meets the condition of significance. It is also noticeable that after the lbdo variable, lbc has the highest correlation values.

Table 5. Multiple correlation coefficient (R) and determination coefficient (R^2) between ten different combinations with four parameters.

Parameters				R	R^2
Lbco	dm	Lbdm	lt	0.637 ᵖ	0.406
lbco	dm	Lt	A	0.423 ᵖ	0.179
lbco	lbdm	Lt	A	0.624 ᵖ	0.389
lbco	dm	Lbdm	A	0.635 ᵖ	0.403
lbco	dm	Lbdm	lbc	0.657	0.431
lbco	lt	A	lbc	0.471 ᵖ	0.222
lbco	lbdm	A	lbc	0.642 ᵖ	0.412
lbco	dm	A	lbc	0.475 ᵖ	0.225
lbco	dm	Lt	lbc	0.493 ᵖ	0.243
lbco	lbdm	Lt	lbc	0.641 ᵖ	0.41

ᵖ= non-significant correlation.

When performing the analysis of variance, the statistic $F_{3,\ 0.05}^{102} = 2.69$ was compared with F= 25.05, since $F > F_{3,\ 0.05}^{102}$ there is a degree of correlation between the variables to which linear regression was performed. From the multiple linear regression the following equation was obtained:

$$\text{lbco} = A_4 + B_4 * \text{dm} + C_4 * \text{lbdm} + D_4 * \text{lbc} \qquad 7)$$

Where: A_4=-1.92, B_4=0.03, C_4=0.03 and D_4=0.01.

This equation was evaluated and obtained ϵ_4= 0.755 cm which compared to equation (6) have a difference of 0.018 cm in the absolute error evaluated. For the combination of five parameters. In Table 6 two compositions have a multiple correlation coefficient greater than 0.65, so both were analyzed by analysis of variance. It is known that $F > F_{4,\ 0.05}^{102} = 2.46$, verifying the existence of a significant correlation between the parameters, so that a multiple regression was performed for each combination.

Table 6. Multiple correlation coefficient (R) and determination coefficient (R^2) between four different combinations with five parameters.

Parameters					R	R^2
lbco	dm	lbdm	lt	A	0.637ᵖ	0.406
lbco	dm	lbdm	lt	lbc	0.657	0.432
lbco	dm	Lt	A	lbc	0.499 ᵖ	0.249
lbco	lbdm	Lt	A	lbc	0.643 ᵖ	0.413
lbco	dm	lbdm	A	lbc	0.662	0.438

ᵖ= non-significant correlation.

From the multiple linear regression, the following equations were obtained:

$$\text{lbco} = A_5 + B_5 * \text{dm} + C_5 * \text{lbdm} + D_5 * A + E_5 * \text{lbc} \qquad 8)$$

Where: A_5=-2.32, B_5=0.05, C_5=0.03, D_5=0.00 and E_5=0.01.

$$\text{lbco} = A_6 + B_6 * \text{dm} + C_6 * \text{lbdm} + D_6 * \text{lt} + E_6 * \text{lbc} \qquad 9)$$

Where: A_6=-1.74, B_6=0.03, C_6=0.03, D_6=-0.01 and E_6=0.01.

When evaluating the equalities, an error $\in_5$= 0.761 was found for (8), for (9) an error $\in_6$= 0.759. Table 7 shows that the combination of six parameters also meets the condition, to which the analysis of variance was carried out. This combination also has the highest multiple correlation value.

Table 7. Multiple correlation coefficient (R) and determination coefficient (R^2) with six parameters.

Parameters						R	R^2
lbco	dm	lbdm	lt	A	lbc	0.662	0.438

The statistic $F^{102}_{5,\ 0.05} = 2.3$, was compared with F, showing that $F > F^{102}_{5,\ 0.05}$, so the linear regression was continued. The following equation was obtained, that once evaluated the error $\in_7$= 0.757 was evaluated, which is greater than the error of (9).

$$\text{lbco} = A_7 + B_7 * \text{dm} + C_7 * \text{lbdm} + D_7 * \text{lt} + E_7 * A + F_7 * \text{lbc} \qquad 10)$$

Where: A_7=-2.62, B_7=0.05, C_7=0.03, D_7=0.02, E_7=0.00 and F_7=0.01.

Although the Murano variety had the highest correlation values, its use for leaf trade is minimal, in the corn-producing areas for leaf, creole varieties are grown with a high index of variability in their size. This particularity makes equation (10) the most convenient for use in a programming environment considering that the absolute error in the cutting distance is less than 8 mm in all equations.

Conclusions

The analysis of the geometric parameters showed that there is a relationship between the measured parameters of the cobs that allows to determine the length of the base to the optimum cutting diameter through mathematical models that vary according to the varieties, Murano and Arroz. Algorithms were developed to calculate two more parameters to consider in the analysis, area and length of the base to the centroid, through the use of OpenCV software.

From the experimental data, three linear models were established to calculate the length of the base at the optimum cutting diameter in a uniform hybrid variety of maize of the Murano variety. Four models were also generated to determine the length of the base at the optimum cutting diameter in a creole variety of Arroz Corn.

It is possible to use these models to calculate the ideal cutting length in corn cobs of the Murano and Arroz variety. Since the productivity of a tamale cob deleafing machine is nine times higher than the manual, applying these equations in an automatic control system to improve such machinery would increase the efficiency of the crop, obtaining better results in quality of leaves and a less waste of grain.

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