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A tool to predict fruit's days after anthesis based on fruit skin and pulp colour of Pitaya (*Stenocereus thurberi* (Engelm.) Buxb.)

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Abstract

The species *Stenocereus thurberi* of the Sonora desert produces a fruit known as pitaya. In recent years, potential economic benefits of marketing fruits from cacti species have been recognised, suggesting the importance of conducting more studies on pitaya fruit. However, controlled research in arid environments are difficult mainly due to the hard conditions characteristic of these places. With the goal of developing a tool to help in future studies, we developed a model to predict the fruit's development stage of *S. thurberi* (pitaya) in terms of days after anthesis (DAA). A randomized sampling of fruits with 5, 10, 15, 20, 25, 30, 37 and 40 DAA was done during two consecutive years. A Minolta Chroma Meter CR-300 set in the L*, a* & b* colour space was used to quantify fruit's skin colour (Ls, as, bs) and fruit's pulp colour (Lp, ap, bp). A multiple linear model was developed using the stepwise procedure in forward selection. F statistic, mean square error, coefficient of determination (r^2), Mallows coefficient (Cp) and distribution of residuals around zero were used as indicators of model prediction's efficiency. The best predictive model included the variables Ls, bs, Lp and bp with r^2=0.795 and C*p*=4.99. We concluded that it is possible to predict the DAA of *Stenocereus thurberi* fruit by measuring the fruit's pulp and fruit's skin using the L*, a* & b* space color.

Keywords: *Stenocereus thurberi* (Engelm) Buxb.; pitaya; fruit's days after anthesis; mathematical model; Sonora desert; fruit colour.

Introduction

Pitaya (*Stenocereus thurberi* (Engelm.) Buxb.) (*Cactaceae*) grows in the Sonora desert (Turner *et al.*, 1995) and produces edible fruits. Several studies had been done in this species in several diverse areas as microbiology (Foglemar and Starmer, 1985; Foster and Fogleman, 1993), ecology (Parker, 1988; Fleming *et al.*, 1996; Breitmeyer and Markow, 1998), biomechanics (Molinafreaner *et al.*, 1998) and plant physiology (Geller and Nobel, 1986; Nolasco *et al.*, 1997; Dubrovsky *et al.*, 1998), but few of them deals with the fruit developmental physiology (Ojeda and Barrera, 1986; Muy *et al.*, 1999).

The commercial exploitation of fruits from cacti species had been emphasised as an important alternative for countries like México (Pimienta-Barrios and Nobel, 1994; Mizrahi and Nerd, 1996) which clearly show the importance of continuing studies in the developmental physiology of pitaya fruit from Sonora desert.

Studies with *S. thrurberi* are difficult because it is a wild type population growing in a region with hard environmental conditions. Under these circumstances, the developing of a tool to avoid the need for monitoring the fruit development by tagging open flower will be helpful in future studies.

The ripening phenomena in many fruits is accompanied by changes in skin and pulp colour (Monseline, 1986). In ripening pitaya fruit, skin colour changes from green to red or purple whereas, pulp colour changes from white to red in most individuals (Muy *et al.*, 1999). Therefore, the skin and pulp colour constitutes a good reference to know the stage of fruit development in pitaya fruit.

In this work, we describe a mathematical model to predict the developmental stage of pitaya fruit in terms of days after anthesis by using changes in fruit skin and pulp colour.

Materials and methods

Study area and sampling: The experiment was conducted in an area of approximately 3.6 km^2 located at 50 km north from the city of Hermosillo, Sonora, México, during the months of June and July of 1999 and 2000.

The developmental duration of pitaya fruit in days after anthesis (DAA) was controlled by tagging at random open flower not showing symptoms of senescence. We tagged 64 *Stenocereus thurberi* individuals, for the two years of study, 24 during the first year and 40 during the second year.

At least eight and up to 32 pitaya fruits, for the two years of study, with 5, 10, 15, 20, 25, 30, 37 and 40 DAA stages of development, were randomly sampled. At every sampling point, fruits were packaged individually with plastic bags and kept in ice during the transportation to the laboratory.

Fruit analysis: Fruit's spines were carefully eliminated before measuring fruit skin colour in three different areas: close by the stem end, stylar end and the middle area. After this, pulp colour was determined by cutting the fruit in two halves and performing measurement twice in the pulp of each piece.

The quantification of skin and pulp colour was done with a Minolta Chroma meter CR-300 (Minolta Corporation. 101 Williams Drive, Ramsey, New Jersey 07446, U.S.A.) set in the L*, a* and b* colour space.

Multiple linear model: With the objective of finding the best prediction model, we started with a linear multiple regression model with DAA as the response variable, and all the possible combinations between the next group of regressor: L*, a* and b* variables measured in fruit's pulp and fruit's skin, square L*, a* and b* variables from fruit's pulp and fruit's skin, chroma and Hue angle calculated for fruit pulp and fruit skin from measured a* and b* values.

The model was analyzed with the stepwise procedure using forward selection with the level of significance for entry into the model of 0.15 and for staying in the model of 0.10. The F statistics, mean square error, coefficient of determination (r^2), Mallows coefficient (Cp) and evenly distribution of the residuals above and below zero, were used as criteria to select the best model. After finding the best predictor model, an independent sample of fruits were used to validate it.

All the statistical analysis was done using the statistical analysis software, version 6.08 (Statistical Analysis System. SAS Institute, Inc. Cary, N.C., U.S.A.).

Results

Quantification of colour in fruit's skin: Table 1 shows the L*, a* and b* values recorded for the skin of pitaya fruit at different stages of development. L* values showed a moderate tendency to diminish with the progression of fruit ripening. L* values indicates lightness and can change from 0 (black) to 100 (white). From here, L* variable suggest that colours developing in fruit's skin during ripening are similarly bright during all the ripening phenomena. Values of a* showed a moderate tendency to change, being negative at the beginning and slightly positive at later stages of fruit development. Positive values of a* indicates a red colour, whereas negative ones indicate a green colour. During ripening of pitaya fruit, values of a* indicates change in skin colour from green to red at later stages of fruit development, in good agreement with the variation known to occur during ripening of pitaya (Muy *et al.*, 1999). b* values showed the highest changes during fruit development going from 23 at 5 DAA to 17 at 40 DAA. Out of the three components of the space colour, variable b* was sensitive enough to detect changes in fruit's skin during both initial and late stages of fruit development. Positive b* values indicate a yellow colour and negative values are indicating a blue colour. From here, b* values indicate the presence of either a single or a mixture of components producing a yellow colour in fruit's skin which decrease with the progression of pitaya fruit ripening.

Quantification of colour in fruit's pulp: In Table 2, L*, a* and b* values recorded in pitaya fruit pulp with different stages of development have been presented. L* values greatly diminished with the advancement in fruit ripening *i.e.* from 77 to 32. Therefore, this component showed great sensitivity to the changes occurring in all the stages of fruit development studied in this experiment. a* values showed a moderate increase from 5 to 30 DAA stages of development. At 37 DAA, a sudden and large increase was recorded, also present at 40 DAA.

Values of b* decreased with the progress of fruit ripening with slight changes from 5 to 25 DAA stages of development. Therefore, as observed with the a* variable, b* was sensitive enough to discriminate among the same stages in fruit ripening.

Table 1. Changes in L*, a* and b* colour space variables measured in Pitaya fruit skin at different days after anthesis (DAA)[1,2]

DAA	Fruit skin color		
	L	a	b
5	45.84 ± 3.8	-4.52 ± 3.9	23.02 ± 3.8
10	46.61 ± 2.6	-5.98 ± 4.3	23.33 ± 2.7
15	45.15 ± 3.7	-4.64+3.2	19.89 ± 3.2
20	46.96 ± 3.8	-5.78 ± 3.6	19.67 ± 2.9
25	44.67 ± 2.6	-2.98 ± 3.2	17.53 ± 1.9
30	44.25 ± 3.1	-5.40 ± 3.1	18.56 ± 3.4
37	44.78 ± 2.3	-1.29 ± 4.3	19.18 ± 3.3
40	41.47 ± 3.5	0.69 ± 9.4	17.02 ± 4.1

Colour was measured in three different areas of the fruit skin after elimination of the fruit's spines.

1 Values represent the mean and standard deviation 2 L*, a* and b* colour space variables were recorded using a Minolta Chroma Meter.

Table 2: Changes in L*, a* and b* colour space variables measured in pitaya fruit pulp at different days after anthesis (DAA)[1,2]

DAA	Fruit pulp color		
	L	a	b
5	77.87 ± 2.9	-0.58 ± 0.9	19.27 ± 1.5
10	72.73 ± 2.9	1.63 ± 1.0	18.44 ± 1.9
15	69.46 ± 2.6	2.01 ± 0.5	18.61± 1.5
20	68.81± 9.2	2.61 ± 1.9	21.16 ± 3.6
25	56.64 ± 13.9	3.84 ± 3.1	18.05 ± 6.9
30	38.71 ± 8.8	2.23 ± 6.5	5.32 ± 3.1
37	29.87 ± 16.3	12.92 ± 5.6	9.21 ± 4.8
40	32.82 ± 10.3	11.09 ± 8.1	10.93 ± 6.9

Fruit was cut into two pieces and colour was measured twice in the pulp of each portion

[1] Values represent the mean and standard deviation.

2 L*, a* and b* colour space variables were recorded with a Minolta chroma meter.

Development and validation of the predictive model: In Table 3, the summary of the stepwise procedure used for developing the best model to predict DAA in fruit based on changes in skin and pulp colour is presented. The component L* measured in fruit's pulp explains most of the variation produced by the progress in fruit ripening as can be concluded from the model's partial r^2 (0.725). However, the incorporation into the model of the other three variables improved the model by increasing the model r^2 up to 0.795 and by reducing the Mallows statistics close to the number of regressors (Mallows, 1973). Also, the F test showed statistical significance in all the steps undertaken to develop the model at level lower than 1% (Table 3). Furthermore, study of the residuals showed a random distribution around zero, confirming the homoscedasticity of the data used in the model (data not shown).

The mathematical expression of the model developed is:

$DAA = 45.63 + 0.392*Ls - 0.729*bs - 0.582*Lp + 0.414b*bs$

Where:

DAA = days after anthesis

Ls = L* variable measured in fruit's skin

bs = b* variable measured in fruit's skin

Lp = L* variable measured in fruit's pulp

bs = b* variable measured in fruit's pulp

In Fig. 1, the validation of DAA model's prediction is presented. Points indicates the relation between real and predicted DAA whereas dotted line indicates the theoretical relation that can be obtained if the model was able to explain 100% of the variability. The two lines, real and theoretical, are very close to each other in most of the points, reflecting the high prediction efficiency of the model.

Table 3. Summary of the stepwise procedure for dependent Variable days after anthesis (DAA)[1]

Step	Variable entered	Partial r^2	Model r^2	F statistic	Mallows' statistic
1	"L" Fruit Pulp	0.725	0.725	445.608	55.83
2	"b" Fruit Skin	0.038	0.763	27.311	26.67
3	"b" Fruit Pulp	0.022	0.785	17.012	10.95
4	"L" Fruit Skin	0.009	0.795	7.961	4.99

[1]Stepwise procedure was done using the forward selection with the level of significance for entry into the model of 0.15 and for staying in the model of 0.10

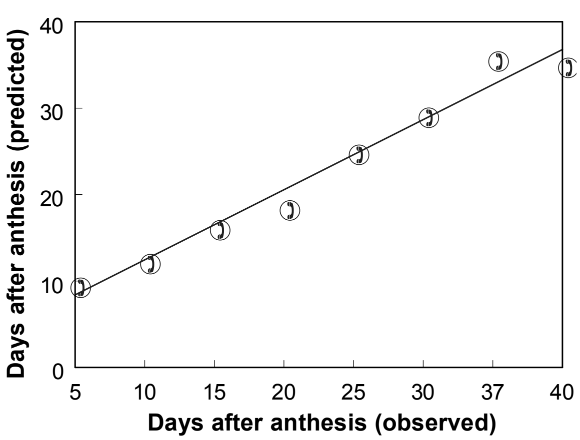

Fig. 1. Days after anthesis (DAA) observed and predicted by the model. Points indicate the relation between the DAA observed and predicted by the model.

Discussion

Quantification of colour in fruit's skin: For fruit's skin, b* component was more sensitive to changes than a*. It is difficult to explain why component b* is more sensitive to changes in skin colour as compared with a* values that indicates colour normally present in ripening pitaya fruit. Furthermore, a graphical representation of a* and b* values in the a* and b* chromaticity diagram point out that they are inside the central area which correspond with an achromatic or dull colour. It seems, therefore, that we can not define a characteristic skin colour of pitaya fruit by taking into account the absolute values of a* and b*. However, a* values did show the real tendency of skin colour changes from green to red colour during fruit ripening. Also, hue angle indicates a moderate trend to red colour with the progression of fruit ripening (data not shown).

Although, L*, a* and b* colour space components measured in pitaya skin did not show large changes during initial stages of fruit development, they showed large differences when compared at 37 and 40 DAA and the first stages of development (Table 1). This finding can be explained by considering that at 30 DAA stage major changes in colour development begins in ripening pitaya fruit, due to the synthesis of belalains and betacianins (Muy-Rangel, 1991).

Quantification of colour in fruit's pulp: Component L* was more sensitive to detect changes in fruit's pulp, as compared to a* and b* that basically showed large differences by the end of the ripening phenomena. This behaviour can be explained by the type of changes that occur in fruit's pulp. At early stages of development the pulp is white and the seeds still does not show their characteristic black colour, in such a way that large values in L* variable must be expected. At 30 DAA, pulp's colour is usually white although a change to a pink colour can be occasionally observed, whereas all the seeds show a black colour. By the end of fruit ripening, fruit pulp has a dark red colour and black seeds, which together produces low values of L* variable. By other side, the development of red colour as mentioned above begins to occur by 30 DAA and that is most likely why both a* and b* values showed broad changes around this time.

However, as happened in the case of fruit's skin, a graphical visualization of a* and b* values in the a* and b* chromaticity diagram show that the range of values for both variables falls within the zone of achromatic or dull colours and therefore, it is not possible to define a colour in fruit pulp by using the a* and b* values. In spite of this, a* values did show a trend to be more positive with the progress of fruit ripening, which reflects the real changes in pulp colour from completely white to a dark red. Also, hue angle showed a trend to a stronger red colour (data not shown), in agreement with the normal change in fruit's pulp colour during ripening as mentioned.

Development and validation of predictive model: The model developed in this study explains almost 80% of the variability in colour originating from the progress of fruit ripening. Attempts were carried out to increase the efficiency of the model by including more variables, however, by doing all possible combinations, only minor increase was observed. However, this percentage is fairly high considering that it is describing a wild type population through two consecutive years of growth, in which there was no effort to control the multiple sources of variations affecting changes in fruit colour during the ripening phenomena.

The largest differences in the values predicted by the model as compared with the theoretical prediction of 100% are observed by the beginning and the end of the ripening phenomena. This behaviour suggests that major changes in colour development in pitaya fruit occurs at the beginning and toward the end of the fruit ripening phenomena, although more experimental evidences are needed to support this statement. However, future experiments with the objective to study colour development in pitaya fruit should consider to focus attention on the beginning and the end of the phenomena.

It is possible that with an increase in the number of samples at the beginning and the end of pitaya fruit ripening, the efficiency of the model can be improved even more, in such a way that the predicted values will be even closer to the 100% in efficiency. Efforts are underway to improve the model's prediction efficiency in this way.

From our findings, it is possible to develop a model, from changes in fruit's pulp and skin colour to predict the stage of development of pitaya fruits, in days after anthesis, for the wild type population of *Stenocereus thurberi* from the Sonora desert.

The model is able to efficiently (r^2=0.79) predict the days after anthesis of pitaya fruit from changes in fruit's skin and pulp colour, using the non-transformed L*, a* and b* space value.

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