Research Square

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Can objective peel-color measurements by *L*a*b** and RGB color spaces predict bioactive compounds and antioxidant properties in umbuguela fruits (*Spondias* sp.) across maturity?

Ana Lima Dantas
Laboratório de Biologia e Tecnologia Pós-Colheita (CCA-UFPB) https://orcid.org/0000-0002-0572-8274

Renato Dantas
Instituto Nacional do Semiárido https://orcid.org/0000-0002-5464-9476

Renato Pereira Lima
Instituto Nacional do Semiárido

Walter Esfrain Pereira
Departamento de Ciências Fundamentais e Sociais, Centro de Ciências Agrárias, Universidade Federal da Paraíba, 58397-000 – Areia – PB – Brazil. https://orcid.org/0000-0003-1085-0191

Raylson de Sá Melo
Laboratório de Biologia e Tecnologia Pós-Colheita, Centro de Ciências Agrárias, Universidade Federal da Paraíba, Caixa Postal 04 CEP 58397-970 – Areia – PB – Brazil.

Randolph M. Beaudry
Department of Horticulture, Michigan State University, Plant and Soil Sci. Bldg. East Lansing, Michigan, 48824-1325, United States of America https://orcid.org/0000-0001-9238-9647

Silvanda de Melo Silva
silvasil@cca.ufpb.br

Laboratório de Biologia e Tecnologia Pós-Colheita, Centro de Ciências Agrárias, Universidade Federal da Paraíba, Caixa Postal 04 CEP 58397-970 – Areia – PB – Brazil https://orcid.org/0000-0003-2106-6458

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Abstract

The umbuguela (*Spondias* sp.) is a native fruit from Brazil widely consumed in the Northeast region, which presents rapid changes during maturation. A chemometric study was conducted with this fruit through the CIE-*L*a*b** and RGB color spaces to estimate the content of bioactive compounds in the peel and pulp comprising five maturity stages. Color parameters changed in the two-color spaces when the chlorophyll content was significantly reduced in the fruit peel, and total carotenoids, yellow flavonoids, and anthocyanins had increased in the two fruit portions, especially in the peel, except for yellow flavonoids in the pulp which declined during maturation. The antioxidant properties in the pulp enhanced as the maturation process of the fruit advanced. The predictive models showed high coefficients of determination (R^2) and high correlation between the measured and predicted phytochemicals content through PLS, which indicates the accuracy of predictive models that can be applied in breeding programs for selection of umbuguela genotypes based on presence of these antioxidant compounds, as well as to support future research with other *Spondias* plants.

1. Introduction

Spondias fruits hold significant global importance among non-traditional crops, boasting recognized commercial potential due to strong consumer acceptance, exceptional nutritional value, and broad diversity in fruit traits across ecotypes (Álvarez-Vargas et al., 2022; Park et al., 2015). This genus covers 18 species native to tropical America, Asia, and Madagascar (Mitchell & Daly, 2016). Several highly appreciated species occur naturally in the Brazilian semiarid region, including umbu (*S. tuberosa*), yellow mombin (*S. mombin*), red mombin (*S. purpurea*), golden apple (*S. dulcis*), and the endemic umbu-cajá (*Spondias bahiensis* sp. nov.) (Machado, Carvalho & Van Den Berg, 2015).

These plants produce highly flavorful, juicy fruits consumed fresh or processed into juices, jams, and jellies. Among these, umbuguela (*Spondias* sp.), hybrid whose genetic origin remains unclear, undergoes rapid physicochemical shifts during development, characterized by an intense respiration rate and a sharp green-to-red skin transition (Santos & Oliveira, 2008; Dantas, Silva, Dantas, Sousa, & Schunemann, 2016).

Maturation is the primary process driving these profound compositional changes, directly influencing consumer preferences and perceptions, as documented across various species like *S. mangifera* (Sivaprasad, Policegoudra, & Aradhya, 2010), *S. tuberosa* (Moura, Silva, Schunemann, & Martins, 2013), and *S. mombin* (Silva, Silva, Silva, & Schunemann, 2013). Concurrently, global interest in the functional properties of tropical fruits has surged, driven by the discovery of health-promoting phytochemicals (Danyo & Ivantsova, 2025). In *Spondias*, these traits are highly dynamic; for instance, red mombin displays a strong antioxidant capacity, with functional compounds like phenolics, carotenoids, and vitamin C heavily concentrated in the epicarp compared to the pulp (Solorzano-Morán et al., 2015).

In postharvest research, external ripening, especially peel color, are widely assumed to be practical, non-destructive indicators of internal maturity and quality. However, evidence shows that external color transitions do not always progress in parallel with internal attributes such as sweetness, firmness, or antioxidant accumulation (Ma et al., 2022; Šalagovič et al., 2025). In *Spondias*, this relationship is further complicated by variations in ecotype, harvest stage, storage conditions, and respiration behavior (Maldonado-Astudillo et al., 2023; Cancino-Labra et al., 2024; Montalvo-Gonzalez et al., 2011; Alia-Tejacal et al., 2022). While existing studies document a broad diversity in both color and internal composition (Alia-Tejacal et al., 2012; Álvarez-Vargas et al., 2022), it remains conceptually undefined when objective color measurements (such as L*, C*, and H*) act as robust indicators of internal quality and when that biological relationship breaks down (Nordey et al., 2019; Gao et al., 2025).

Because external appearance alone fails to reliably capture internal conditions, evaluating fruit quality becomes a complex, multivariate problem. To address this, postharvest science has turned to chemometrics, multivariate statistical approaches used to decode joint variability and explain complex biological phenomena (Yi et al., 2016; Zielinski et al., 2014a; Zielinski et al., 2014b; Xu et al., 2017). In particular, Partial Least Squares Regression (PLSR) has become an efficient tool to model continuous quality attributes, functional compound contents, and antioxidant properties using non-destructive inputs like color coordinates or spectral data (Gidado et al., 2026; Saeys et al., 2019; Lou, Hu, Zhang, Sun, & Lu, 2012; Munera et al., 2017).

Therefore, this study aimed to assess the functional compound content and antioxidant properties in the fruit of umbuguela plants (*Spondias* sp.) during the ripening process, and to use the Partial Least Squares (PLS) regression method to develop predictive models as a non-destructive tool for evaluating these fruits.

2. Materials and Methods

2.1. Plant Material

Umbuguela fruit (*Spondias* sp.) were harvested from a plant located in the fruit nursery of the *Centro de Ciências Agrárias* of the *Universidade Federal da Paraíba*, Brazil. Fruits were categorized in five stages of maturation based on visual peel coloration and evaluated in five replications composed of 25 fruits. These stages were named as totally green (TG), breaker (B), predominantly yellow with green traces (PY), reddish yellow (RY), and purple red (PR), as shown in Fig. 1.

2.2. Peel color evaluation

Umbuguela fruit peel was evaluated using two objective methods, colorimeter and digital image processing (Fig. 1). Initially, a Minolta digital colorimeter (Color Reader CR-10 – Konica Minolta Sensing, Inc., Japan) which reads an area of 8 mm was employed. CIE color space parameters were measured based on L*, a*, b*, C*, and ºH. L* corresponds to the lightness/brightness; a*, and defines the transition

from green (-a*) to red (+ a*); b* represents the transition from blue (-b*) to yellow (+ b *); C* represents the chromaticity or color intensity; and finally, Hue angle (ºH), where 0° = red, 90° = yellow, 180° = green, 360° = blue. Four readings were taken from the median area of the fruit surface given the small reading area of the colorimeter and the low uniformity of peel coloration.

Fruit was photographed in all stages of maturation using a CoolPix P520 digital camera (Nikon Brazil Ltd.) in 12.1-megapixel resolution and using a black background. An internally coated box with diffuse white paper was developed to promote better image capturing, and illumination was controlled by four fluorescent 12 W lamps disposed distally (10 cm) (Lima et al., 2016). Mean values for the RGB channel (Red, Green, and Blue) with a scale from 0 to 255 were measured from the umbuguela fruit images and were obtained by the *Measure* RGB command of the ImageJ® program. A circular area was then selected covering approximately 50% of the fruit surface image from the result of each stage of ripeness, and values for the defined area were then obtained.

2.3. Bioactive compounds and total antioxidant activity

Total chlorophyll content in the peel was determined by spectrophotometry (Genesys TM 10S UV-VIS Spectrophotometer) at 652 nm, according to the method of Bruuinsma (1963) and applying the equations proposed by Engel & Poggiani (1991). An evaluation of total carotenoid content was performed in both the peel and pulp by spectrophotometry at 450 nm following the recommendations of Higby (1962); total anthocyanins and yellow flavonoids were quantified by spectrophotometry at 535 nm and 374 nm, respectively, according to the method by Francis (1995).

Total antioxidant activity (TAA) was measured in the phenolic extract obtained according to the method used by Dantas et al. (2015). First, 1 g of pulp was mixed with 10 mL of extraction solution (50% methanol, 70% acetone, and water). TAA evaluation by the capture of free radical $DPPH^{\bullet}$ was performed, adding 100 µL of each concentration (250, 450, and 650 µL/mL) into 3.9 mL of radical (60 mM), respecting the linearity of the curve (0–60 µM $DPPH^{\bullet}$). The mixture absorbance was read at 515 nm. The results were expressed in EC_{50} value, representing the amount of pulp required to reduce the initial concentration of $DPPH^{\bullet}$ free radical by 50% (g pulp/g $DPPH^{\bullet}$).

Total antioxidant activity in the system of co-oxidation of β-carotene/linoleic acid was determined according to the method used by Silva et al. (2012). Solutions were prepared using 5 mL of the β-carotene/linoleic acid system and 0.4 mL of the fruit extract/Trolox in three concentrations of the phenolic extract (0.75, 0.5, and 0.25 g/L). The absorbance readings were taken immediately at 470 nm, keeping the tubes in a water bath at 50°C. The results were expressed in percentage of inhibition of oxidation, in comparison to that of the antioxidant standard Trolox (200 mg/L).

2.4. Statistical analysis

The experimental design was completely randomized, with fruit harvested in five stages of maturation. Color parameter data, the pigment composition, and antioxidant activity were tested by performing a one-way ANOVA. Means were compared using the Tukey test up to 5% of error probability. Multiple

regression analysis was performed using the REG procedure of SAS® software and the predictive models were obtained using the PLSR regression method (Partial Last Square Regression) with NIPALS algorithm. Selecting the prediction models was based on the higher value of R^2.

3. Results and Discussion

3.1. Color parameters in the spaces L*a*b* e RGB

Objective color coordinates of umbuguela (*Spondias* sp.) fruit presented a noticeable variation during maturation, especially for *a** coordinate (Table 1). Lightness (*L**) was higher when fruits reached a predominantly yellow color in the peel (PY stage), and decreased when the peel color turned purple red (PR). In turn, chromaticity (*C**) showed this same behavior, and stood out in the stages with yellow (PY) and red (RY) colors. Variation in the Hue (°*H*) angle values best showed the significant transformation of the fruit's external coloration as a response to maturation. As the stages TG (107.03º) and B (101.29º) are above 90º (yellow position), there is a predominance of green color in this phase, also corroborated by *a** coordinate in both stages of maturation (-10.06 and − 8.21, respectively). In stage PY, the yellow color prevailed in the fruit's peel, conditioning an angle of 87.36º for hue together with *b** coordinate which increased until this stage, showing an average of 45.83. Afterwards, both color parameters decreased until the PR stage, when *b** was 33.46 and hue angle was 55.69º, with a purple red color predominating.

Table 1
Color changes in the peel of Umbuguela fruits (*Spondias* sp.) in five maturity stages called TG (Totally Green), B (Break), PY (Predominantly Yellow with green traces), RY (Reddish Yellow), and PR (Purple Red) from Northeastern Brazil.

Color parameters	**Maturity stages**				
	TG	**B**	**PY**	**RY**	**PR**
*L**	41.99 c[i]	46.51 b	52.98 a	51.62 a	42.52 c
*a**	-10.06 d	-8.21 d	0.01 c	10.56 b	22.45 a
*b**	32.13 c	37.41 b	45.83 a	44.36 a	33.46 c
*C**	34.22 d	37.49 c	45.92 a	45.65 a	41.26 b
°*H*	107.03 a	101.29 b	87.86 c	75.83 d	55.69 e
Blue	6.78 a	1.88 a	5.14 a	0.96 a	43.43 a
Green	102.56 c	152.3 a	165.61 a	132.1 b	28.15 d
Red	64.18 d	135.34 c	185.61 b	230.87 a	200.29 b

[i]Averages followed by the same letters do not fifer by Tukey test up to 5% error probability.

This color ranged from green to red is one of the aspects that mostly characterizes ripening evolution in umbuguela fruits, being well represented by *a** and *°H* coordinates. Additionally, RGB values were obtained based on digital image processing of fruits in the different studied stages of maturation (Table 1), and *red* indicated more precisely the overall change from green to red, when fruits reached their fully ripe stage, and ranged from 64.18 to 200.29 (from TG to PR stage, respectively), although peel coloration was not represented by solely a coordinate in both color spaces, but due to a joint response of them.

The *L*a*b** color space has better distinction between green and red without the lightness factor interfering as easily as occurring in the RGB system (Nicolaï et al., 2014). The RGB system has been explored for both objectives sorting of fruits, as well as for non-destructive evaluation of their internal components, thus establishing objective relations among external color and fruit compounds aiming at their prediction, and mainly the antioxidant activity through multivariate statistical analysis. This is exemplified by Lou et al. (2012) in mulberries (*Morus alba* L.) and by Taghadomi-Saberi (2014) in sweet cherries, following the trend conditioned by fruit ripening for both studies. *L*a*b** system parameters were explored with the same objective in carrots (Pace et al., 2013) and in strawberries (Yoshioka, Nakayama, Noguchi, & Horie, 2013). On the other hand, *L*a*b** system has mostly been used to objectively evaluate color in several *Spondias* fruits (Moura et al. 2013; Solorzano-Morán et al., 2015). However, monitoring RGB values during *Spondias* fruit maturation has not been reported thus far, and this could be a very useful tool to correlate with other maturity indices.

Umbuguela fruit maturation leads to the accumulation of these latter compounds in the pulp and mainly in the peel where the content is much higher (Table 2), and this is reported for several other fruits belonging to the *Spondias* genus (Silva et al., 2013; Maldonado-Astudillo et al., 2014; Sivaprasad et al., 2010; Solorzano-Morán et al., 2015). Therefore, different relations can be established through fruit color coordinates in food science, and classification strategies and prediction of internal composition have been proposed by different authors (Lou et al., 2012; Pace et al., 2013; Wanitchang, Terdwongworakul, Wanitchang, & Noypitak, 2010; Yoshioka et al., 2013).

Table 2
Changes in color compounds and antioxidant properties in the peel of Umbuguela fruits (*Spondias* sp.) in the maturity stages Totally Green (TG), Break (B), Predominantly Yellow with green traces (PY), Reddish Yellow (RY), and Purple Red (PR).

	Fruit portion	Maturity stages				
		TG	B	PY	RY	PR
Chlorophyll (mg/100 g)	Peel	9.20 a[i]	5.27 b	2.21 c	1.91 c	1.71 c
Carotenoids (µg/100 g)	Pulp	11.58 d	52.36 c	68.86 bc	88.43 ab	96.66 a
	Peel	368.67 c	414.39 c	417.38 c	562.07 b	784.10 a
Yellow Flavonoids (mg/100 g)	Pulp	7.12 b	6.72 b	7.06 b	7.49 b	9.16 a
	Peel	20.42 a	21.22 a	14.41 b	14.11 b	11.88 b
Anthocyanins (mg/100 g)	Pulp	0.35 b	0.33 b	0.36 b	0.43 a	0.52 a
	Peel	0.89 bc	0.75 c	0.94 bc	1.04 b	1.69 a
% OI	Pulp	40.54 b	41.96 b	55.58 a	40.27 b	20.62 c
EC_{50} (g/g $DPPH^{\bullet}$)	Pulp	692.05 a	612.92 b	571.86 b	420.55 c	445.10 c

[i]Means followed by the same letters do not fifer by Tukey test up to 5% error probability. OI = Oxidation Index (Total antioxidant capacity in the β-carotene/linoleic acid system).

3.2. Bioactive compounds and antioxidant properties

Total chlorophyll content in the peel of umbuguela decreased nearly 80% during ripening, indicating the transition from green to red, as shown before. Inversely, carotenoid and anthocyanin contents increased as a response of fruit ripening and still being attached to the plant (Table 2). Fully ripe fruit presents a considerable amount of carotenoid, anthocyanin, and mainly yellow flavonoid contents, despite these last compounds decreasing in accordance with fruit maturation. This reduction of chlorophyll content and the synthesis of new color compounds (carotenoids, anthocyanins, and flavonoids) were highly correlated with the changes in the *L*a*b**color coordinates (*a**, *b**, and *ºH*) and RGB (*red* and *green*) color spaces (Table 1).

Based on the objective color parameters, it is possible to establish statistical relations which reproduce the pulp component behavior from objective measurements of color, regardless of using digital imaging processing or colorimeters. This was closely reported for carotenoids in carrots (Pace et al., 2013) and tomatoes (Bicanic et al., 2015), as well as for carotenoids, flavonoids, and anthocyanins in pulp of several Brazilian fruits (Zielinski et al., 2014a). Hence, new and more accessible non-destructive evaluation strategies can be proposed, especially for fruits like umbuguela which have noticeable potential of spreading its uses beyond its fresh consumption. However, this establishment is not only

restricted to the antioxidant compounds, but it may also be extended to evaluate changes in enzyme activity and aromatic compound profile during maturation (Yi et al., 2016).

Carotenoid and flavonoid contents in *Spondias* genus fruit tend to present pronounced differences, not only among the different species, but also among genotypes of the same species and regarding the fruit portions (peel and pulp) and stage of fruit development (Silva et al., 2012). Thus, the maturation process itself must be considered as one of the factors that mostly contribute to increasing or decreasing these compounds (Silva et al., 2013; Solorzano-Morán et al., 2015), depending on the role they have during the fruit development, and participating in synthesizing volatile compounds and forming its characteristic color in ripening. In the pulp of yellow mombim fruits, lutein, zeinoxanthin, and β-cryptoxanthin were reported as the main carotenoids (Tiburski, Rosenthal, Deliza, Oliveira Godoy, & Pacheco, 2011; Hamano & Mercadante, 2001), and these compounds have pro-vitamin activity, as well as anti-inflammatory properties (Ciccone et al., 2013). In this sense, this is very important for accessing the carotenoid profile in native *Spondias* fruits like umbuguela.

Oxidation inhibition increased until the PY stage, reaching more than 50%, then decreasing drastically to nearly 20% when fruits ripened on the plant. For ripe yellow mombim fruit, Silva et al. (2013) reported high inhibition potential (more than 80%) for different genotypes in three stages of maturation, showing a reduction in the last stage, although comparatively much higher than shown herein for umbuguela.

Additionally, the predominant phenolic-type antioxidant compounds profile may not be enough to inhibit oxidation, since this capacity is dependent on the compound nature and concentration (Denardin et al., 2015). On the other hand, DPPH$^{\bullet}$ radical scavenging activity (EC_{50}) indicates that fruit maturation provides an increase in its sequestration capacity (Dantas et al., 2013). In general, umbuguela fruit at the PR stage presents higher antioxidant capacity (nearly 36%).

Even so, it seems that this behavior may be more related to the higher concentration of antioxidant compound groups which easily react with the free reactive DPPH$^{\bullet}$ bond, also considering that phenolic compounds have differentiated antioxidant capacity, and that the individual contribution changes according to the maturation stage, without necessarily having the same tendency of increasing or decreasing in concentration (Palafox-Carlos, Yahia, & González-Aguilar, 2012). The EC_{50} values reported herein for umbuguela extracts demonstrate that this fruit has a higher antioxidant capacity when compared to the pulp of ripe umbu (*S. tuberosa*), being 7074 g/g DPPH$^{\bullet}$, and is possibly associated with the capacity shown for acerola fruit (*M. emarginata*) of 670 g/g DPPH$^{\bullet}$, and camu-camu (*M. dúbia*) of 478 g/g DPPH$^{\bullet}$ (Rufino et al., 2010), all fruit known as rich sources of antioxidant compounds.

The maturation and ripening regulation in *Spondias* fruits is not known, although the higher production of CO_2 and ethylene has already been reported, which includes them as climacteric fruit (Maldonado-Astudillo et al., 2014). This suggests that ethylene triggers most of the biochemical transformations in both the peel and the pulp of umbuguela fruit, leading to change the texture and sugar content, in addition to indirectly promoting the increase of antioxidant compounds for yellow mombim (*S. mombin*)

and other native fruit from Brazil (Dantas et al., 2016), further resulting in antioxidant modulation according to maturation.

3.3. Multivariate prediction of bioactive compounds and antioxidant properties of umbuguela fruits

There was a high correlation among the color parameters of the peel and the total chlorophyll, total carotenoids, yellow flavonoids, anthocyanins contents and antioxidant activity (%IO and $DPPH^{\bullet}$) during umbuguela fruit maturation, with more than one adjusted model using PLS regression (Table 3), enabling high correlations among the values obtained destructively and the estimated values through the predictive models that reached higher R^2 value (Fig. 2 and Fig. 3). All color parameters correlated with the bioactive compounds in the pulp and peel, and this contributed to a higher number of variables composing the predictive models for the peel compounds like chlorophyll, anthocyanins, and yellow flavonoids, presumably due to their quantification which was also in the peel.

Table 3

Variables in model, fitted equations, correlation coefficients (R^2) and significance of the model in the prediction of total chlorophyll, total carotenoids, yellow flavonoids, total anthocyanin, DPPH$^{\bullet}$ radical scavenging (EC_{50}) and β-Carotene/Linoleic acid system (I.O) activities during maturation of umbuguela fruits by Partial Least Square (PLS).

Chemical Parameters	**Variables in model**	**Equations**	**R²**	**Pr > F**
Chlorophyll peel	*Red*	11.54 − 0.05(*Red*)	0.89	< 0.00
	C, Red*	17.15–0.18(*C**) − 0.034(*Red*)	0.92	< 0.00
	C, H, Red*	13.42 − 0.23(*C**) + 0.04(˚*H*) − 0.02(*Red*)	0.94	< 0.00
	a*, C*, ˚H, Red	**0.03 + 0.22(a*) − 0.24(C*) + 0.19(˚H) -0.02(Red)**	**0.96**	**< 0.00**
Carotenoids peel	*a**	0.47 + 0.02(*a**)	0.86	< 0.00
	a*, Green	**0.59 + 0.009(a*) − 0.0009(Green)**	**0.91**	**< 0.00**
Carotenoids pulp	*Red*	-0.02 + 0.0005(*Red*)	0.87	< 0.00
	˚H, Red	**0.071 − 0.0007(˚H) + 0.0003(Red)**	**0.93**	**< 0.00**
Anthocyanin peel	*a**	0.99 + 0.025(*a**)	0.80	< 0.00
	a, Blue*	0.91 + 0.02(*a**) + 0.009(*Blue*)	0.96	< 0.00
	a*, Blue, Green	**1.10 + 0.01(a*) + 0.008(Blue) − 0.001(Green)**	**0.98**	**< 0.00**
Anthocyanin pulp	*a**	0.39 + 0.008(*a**)	0.90	< 0.00
	a*, Red	**0.45 + 0.007(a*) − 0.0004(Red)**	**0.94**	**< 0.00**
Yellow Flavonoid peel	*a**	17.47 − 0.29(*a**)	0.74	< 0.00
	a, C**	29.19–0.23(*a**) − 0.29(*C**)	0.82	< 0.00
	C, Green*	40.63–0.73(*C**) + 0.05(*Green*)	0.85	< 0.00

Chemical Parameters	Variables in model	Equations	R^2	Pr > F
	a*, C*, Green	**37.80 – 0.06(a*) – 0.63(C*) + 0.04(Green)**	**0.86**	**< 0.00**
Yellow Flavonoids pulp	*a**	7.33 + 0.06(*a**)	0.71	< 0.00
	a*, b*	**9.89 + 0.06(a*) – 0.07(b*)**	**0.88**	**< 0.00**
% I.O	**Green**	**16.19 + 0.20(Green)**	**0.77**	**< 0.00**
EC_{50}	*Red*	788.29–1.47(*Red*)	0.72	< 0.00
	L*, Red	**466.96 + 7.95(L*) – 1.79(Red)**	**0.81**	**< 0.00**

Thus, the best model to predict total chlorophyll content in the peel was obtained combining the color parameters *a**, *C*, *˚H*, and *red* (R^2 = 0.96). The model estimators for total carotenoids were the variables a* and *green*. For both compounds, significant CIE-*L*a*b** and RGB parameters in the predictive models were responsible for expressing the green-red variation because these compounds noticeably invert their predominance in the peel during maturation, as already observed in other *Spondias* fruit (Sivaprasad et al., 2010; Silva et al., 2013). The best model combined *a*, blue*, and *green* (R^2 = 0.98) for prediction of anthocyanins in the peel. For yellow flavonoids, four predictive models combined the color parameters, but the best one reunited *a*, C**, and *green* as the estimators (R^2 = 0.94). However, either the number of models or the number of predictive variables to estimate the bioactive compounds in umbuguela pulp were lower compared to what was shown in the fruit peel. Therefore, the predictive model for carotenoids combined *˚H* and *red* (R^2 = 0,.3), *a** and *red* (R^2 = 0.94) for anthocyanins, and *a** and *b** (R^2 = 0.86) for yellow flavonoids. Umbuguela fruit maturation resulted in changing external coloration, including the peel and pulp composition, obtaining highly correlated values with color parameters using either digital image processing or the color reader. This allowed for non-destructive prediction of bioactive antioxidants in the pulp from CIE-*L*a*b** and RGB parameters measured in the peel by using the multiple linear regression method.

Additionally, assessing the antioxidant properties using these color parameters showed that *green* was the only variable in the adjusted model to predict oxidation inhibition percentage (R^2 = 0.72), and lightness (*L**) together with *red* composing the variables in the model to predict the capacity of $DPPH^{\bullet}$ free radical scavenging, having a high relation among values determined destructively in both cases, as well as those estimated through PLS regression (Fig. 3). Antioxidant properties in fruit are highly related with the compounds in different proportions, especially those responsible for fruit color like carotenoids and flavonoids, which can be non-destructively predicted using objective color parameters (Yi et al., 2016; Lou et al., 2012; Pace et al., 2013; Zielinski et al., 2014a).

The use of multivariate techniques to predict metabolites in fruit and vegetables falls within the field of chemometrics (Zielinski et al., 2014b), and applying such approaches has not only allowed us to obtain basic quality indices, but also groups of compounds with functional allegations. Obtaining parameter values in CIE-*L*a*b** and RBG spaces, however, is performed differently. However, both can be applied together to predict compounds in the pulp and peel of *Spondias* sp. (Table 3; Fig. 2 and Fig. 3). In this sense, Pace et al. (2013) evaluated the prediction of antioxidant capacity by DPPH$^{\bullet}$ assay using multiple linear regression and the phenolic compound content in carrots based on *L*, a** and *b**color parameters, also finding high correlation among the estimated and destructively measured values, while obtaining values of 0.30–0.52 for R^2.

In turn, RGB values were very efficient (R^2> 0.90) as predictive variables of flavonoids, total phenolic content, and ABTS$^{\bullet}$ radical scavenging during maturation of *mulberry* fruit (*Morus alba*) (Lou et al., 2012), indicating that maturation as the only dependent variable in chemometrics studies leads to obtain models with high predictive capacity, as observed herein for umbuguela (*Spondias* sp.). In strawberries, Yoshioka et al. (2013) performed a stepwise multiple regression in data of different color spaces (RBG, CIE-*L*a*b**, and HSL), verifying that the digital analysis of fruit images allowed accurately predict anthocyanins content. In turn, it was possible to predict both the number of bioactive compounds and the antioxidant capacity from objective color parameters using RBG system (computational vision) and CIE-*L*a*b** (colorimeter) for umbuguela fruit.

Obtaining predictive models using near infrared spectroscopy (NIR) has found a wide application as a strategy for non-destructively evaluating fruit and vegetables (Zielinski et al., 2014b). However, this technology is very expensive and is only being used by a low number of research groups. Therefore, spreading the colorimeter application (CIE-*L*a*b**) for this purpose, as well as for developing techniques to access and to digitally process the images using, for example, ImajeJ® which can obtain RGB values, may contribute to non-destructively accessing the internal composition of fruit.

4. Conclusion

From the objective color parameters of the CIE-*L*a*b** and RGB spaces measured in umbuguela (*Spondias* sp.) during maturation, predictive models have been proposed for chlorophyll in the peel, total carotenoids, anthocyanins, and yellow flavonoids in the peel and pulp, and antioxidant properties (IO % and DPPH$^{\bullet}$) in the pulp, which represent an applicable strategy for non-destructively analyzing internal fruit constituents by only using accessible optical instruments and the Java-based ImageJ® free software.

Additionally, our results show that PLS regression is suitable for establishing predicting models for bioactive compounds and antioxidant properties with highly precise estimates. Also, they can be used as a tool for identifying promising genotypes considering the high variability that this species has, as well as being useful for research including other *Spondia* fruit.

Declarations

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Figures

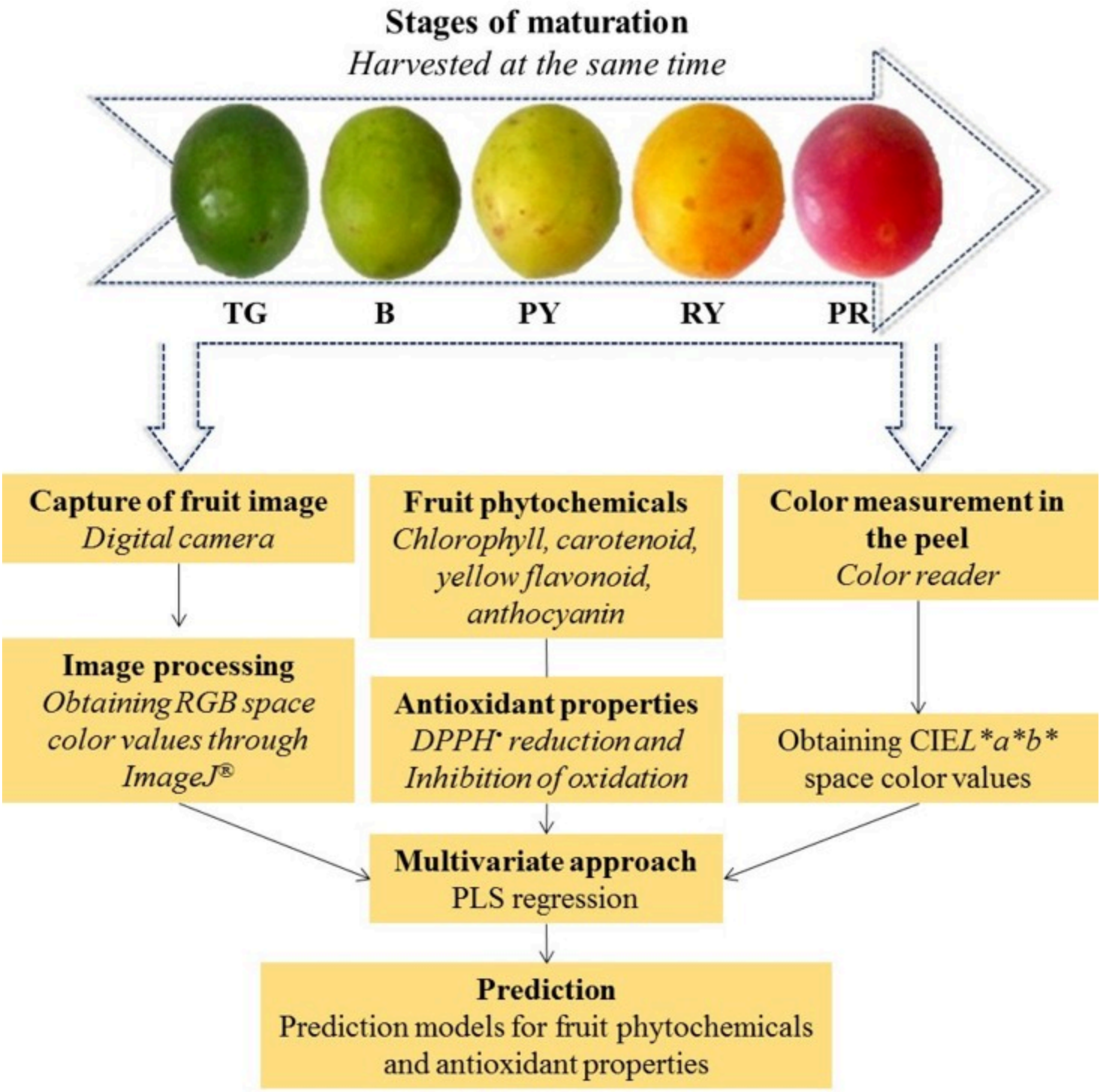


Figure 1

Flowchart of color measurements (CIE-*L*a*b** and RGB color spaces) for multivariate prediction of fruit phytochemicals and antioxidant properties in umbuguela fruits (*Spondias* sp.) in five maturity stages called TG (Totally Green), B (Break), PY (Predominantly Yellow with green traces), RY (Reddish Yellow), and PR (Purple Red) from Northeastern Brazil.

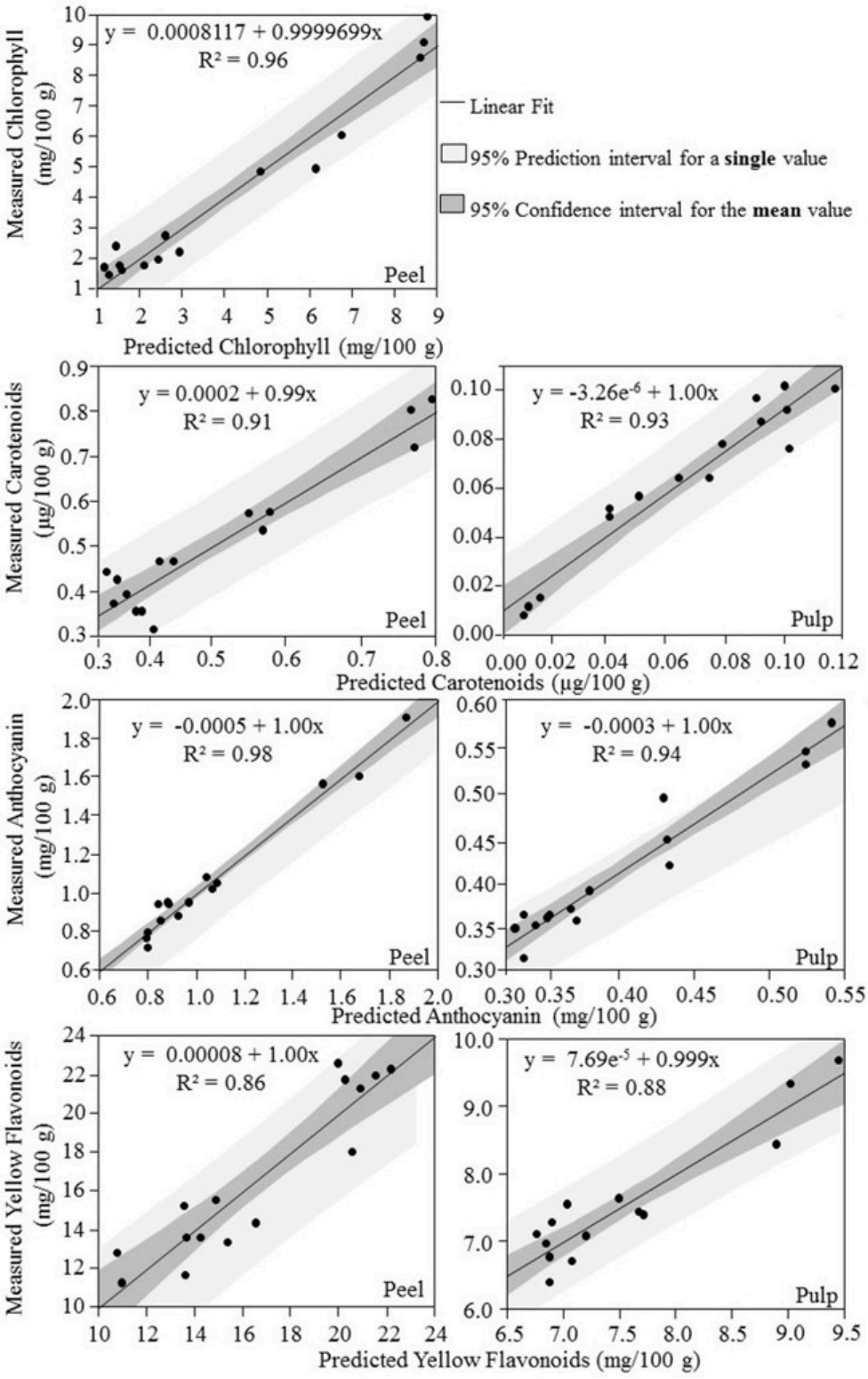


Figure 2

Predicted vs. measured compounds (carotenoids, anthocyanins, yellow flavonoids, and chlorophyll) in peel and pulp of umbuguela fruit (*Spondias* sp.): the multi regression models of prediction are based on the color analysis performed by the CIE-*L*a*b** colorimeter and RGB using ImageJ®.

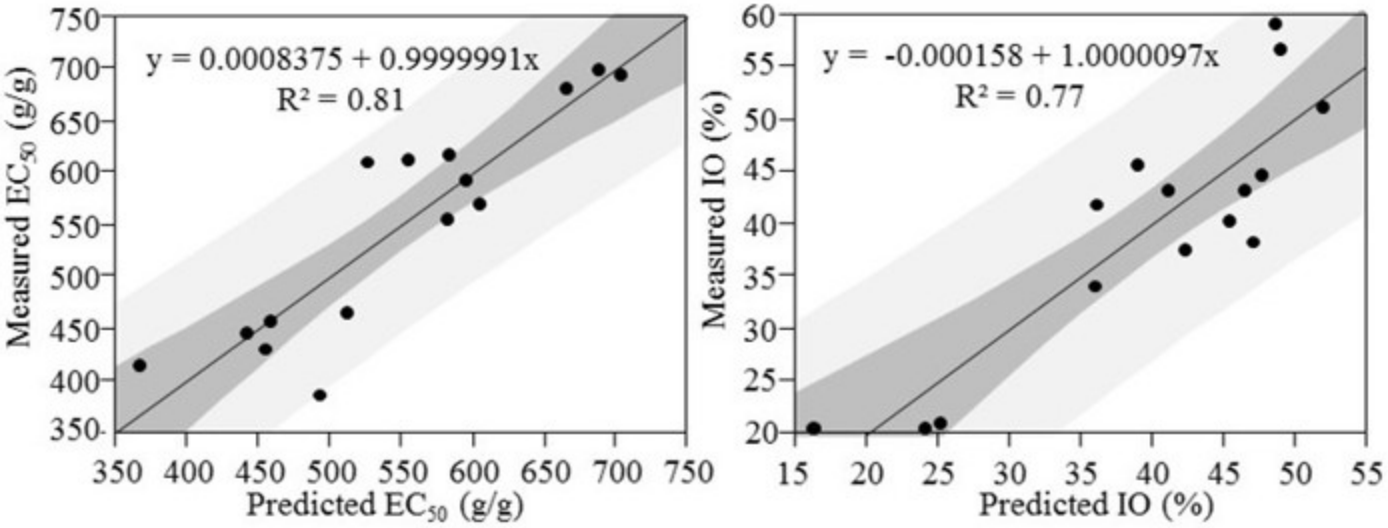


Figure 3

Predicted vs. measured antioxidant properties (DPPH$^{\bullet}$ radical scavenging and β-Carotene/Linoleic acid system) in peel and pulp of umbuguela fruit (*Spondias* sp.): the multi regression models of prediction are based on the color analysis performed by the CIE-*L*a*b** colorimeter and RGB using ImageJ®.