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Original

Physicochemical changes in cubiu fruits (*Solanum sessiliflorum* Dunal) at different ripening stages

Mudanças físico-químicas em frutos de cubiu (Solanum sessiliflorum Dunal) em diferentes estádios de maturação

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Abstract

Cubiu shrubs (*Solanum sessiliflorum* Dunal) have drawn the attention of researchers for their biological versatility (preferential heliophilous or facultative ombrophilous shrubs), their capacity to grow in upland or lowland areas, and the good technological quality of their fruits for the food industry. The aim of this study was to verify physicochemical changes in cubiu fruits during maturation. The fruits were harvested from the experimental station of olericulture of the Instituto Nacional de Pesquisas da Amazônia (INPA), Brazil. The analyses were performed in whole cubiu fruits (peel, pulp, and placenta) at four traditional ripening stages (green, turning, ripe, and fully ripe) for the determination of weight, moisture, total solids, total carotenoids, proteins, lipids, and ash. Cubiu fruits showed large weight variation, with amodal distribution. The ripe stage was critical to maintain moisture, and from that stage on, water loss became evident. The lipids increased steadily over the four ripening stages, maintaining, however, insignificant calorie content. Total carotenoids, proteins, and ash reached the maximum level at the fully ripe stage. With the exception of weight and moisture, all physicochemical changes exhibited the same general behavior, i.e. they increased as the fruits ripened at the four investigated stages.
Keywords: *ash; carotenoids; lipids; moisture; proteins; weight.*

Resumo

Arbustos de cubiu (*Solanum sessiliflorum* Dunal) têm atraído a atenção de pesquisadores por sua versatilidade biológica (heliófilos preferenciais ou ombrófilos facultativos), sua capacidade de crescimento em terra firme ou várzea e seus frutos de boa qualidade tecnológica para a indústria alimentícia. O objetivo deste estudo foi verificar mudanças físico-químicas em frutos de cubiu durante a maturação. Os frutos foram colhidos na estação experimental de olericultura do Instituto Nacional de Pesquisas da Amazônia (INPA), Brasil. As análises foram realizadas em frutos integrais de cubiu (casca, polpa e placenta) em quatro estádios de maturação tradicionais (verde, de vez, maduro, muito maduro), compondo-se de peso, umidade, sólidos totais, carotenoides totais, proteínas, lipídios e cinza. Os frutos de cubiu apresentaram grande variação de peso, com distribuição amodal. O estádio maduro foi crítico na manutenção da umidade e, a partir desse estádio, a perda de água tornou-se evidente. Os lipídios aumentaram progressivamente ao longo dos quatro estádios, mantendo, todavia, níveis insignificantes em termos calóricos. Os carotenoides totais, as proteínas e as cinzas alcançaram níveis máximos no estádio muito maduro. Com exceção do peso e da umidade, todas as mudanças físico-químicas exibiram o mesmo comportamento geral, i.e., aumentaram conforme os frutos amadureceram nos quatro estádios investigados.
Palavras-chave: *carotenoides; cinza; lipídios; peso; proteínas; umidade.*

1 Introduction

Cubiu shrubs (*Solanum sessiliflorum* Dunal) are members of Solanaceae family, whose fruits of various shapes are appreciated not only for their high viscosity and acid taste, but also for their content in water and minerals, usually accompanying fish dishes as important dietary supplements in Brazil's Amazon region. During harvest, the selection of the ripening stages of the fruits is based on four distinct, vivid colors further described in this article. In spite of being consumed at all stages, there is no basic data regarding the physicochemical changes of cubiu fruits during maturation, such as those related to weight, moisture, total solids, total carotenoids, proteins, lipids, and ash, as discussed below.

According to Chitarra and Chitarra (1990), weight is one of the main physical indexes of fruit quality. Most fruits reach the maximum weight during a 15-week period between anthesis and maturity (FERRI, 1986; CHITARRA; CHITARRA, 1990). Cubiu fruits have a variable mean weight probably due to genetic factors (SILVA FILHO; CLEMENT; NODA, 1989). During maturation, however, weight change of cubiu fruits is unknown at the present time.

One of the most fundamental analytical procedures that can be performed on a food product is an assay for the amount of moisture; the dry matter that remains after moisture removal, commonly referred to as total solids (BRADLEY JUNIOR, 2003). Adequate moisture after fruit set is essential to sustain its growth because any setback in fruit growth is irreversible (BOWER; CUTTING, 1988). Moisture loss is an initial trigger for ripening; the greater retardation in moisture loss will increase

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the potential for extending storage life (BOWER; CUTTING, 1988). There are no published data on moisture in cubiu fruits at different ripening stages. This study aims, in part, to fill this gap.

As mentioned above for cubiu (specifically), fruit ripening (in general) involves other changes such as those in color (natural pigments), flavor (taste, aroma) and texture making fruits suitable for consumption in natura and/or after technological process. Among the natural pigments, carotenoids are considered important in human nutrition because they include precursors of vitamin A with antioxidant action (β-carotene) and other antioxidants such as lycopene (CHITARRA; CHITARRA, 1990; BARTLEY; SCOLNIK, 1995; CARDOSO, 1997). Chloroplasts contain most of the enzymes necessary for the synthesis of chlorophyll, fatty acids and galactolipids, and carotenoids, among other compounds (KROGMANN, 1973). Carotenoids are not toxic even when ingested in large amounts (anorexia nervosa and/or bulimia nervosa) due to their low intestinal absorption, but when the latter increases, the pigments are deposited in the subcutaneous tissue and the skin becomes yellow (carotenodermia), a condition that usually resolves spontaneously (SPALLHOLZ; BOYLAN; DRISKELL, 1999). Plasma carotenoid concentrations are indicative of dietary intake, but the large intra-individual variation in plasma concentrations indicates that any assessment of longer-term status from data at any one time-point should be treated with caution (SCOTT et al., 1996). In despite of all this fundamental and clinical data supporting the importance of carotenoids to human health, their profile during maturation of cubiu fruits is not currently known.

Regarding proteins, there is generally an increased biosynthesis of these macronutrients in many ripening fruits; conversely, there is an acceleration of protein degradation during fruit senescence (FERRI, 1986). However, there is no data about their change during cubiu fruit maturation. Likewise, if, on the one hand, little is known about changes in lipid content during fruit ripening in general, on the other hand, nothing is known about lipid changes in cubiu fruits during ripening in particular (GOODWIN; MERCER, 1983).

Lastly, ash content represents the total mineral amount in foods (HABERS; NIELSEN, 2003). Nonetheless, its equivalent amount in cubiu fruits is not known during ripening.

Although essential for a judicious use of cubiu fruits by the Brazilian population, all the nutritional above-mentioned data are inexistent. Thus, the aim of this study was to verify basic physicochemical modifications in cubiu fruits during four traditional ripening stages (green, turning, ripe, and fully ripe).

2 Material and methods

2.1 Sample preparation

Cubiu fruits (*S. sessiliflorum* Dunal) were obtained from the experimental station of olericulture, located in the Central Amazon Floodplains (Iranduba), of the Instituto Nacional de Pesquisas da Amazônia (INPA), Brazil. During harvest, the selection of the ripening stages of the fruits was based on four colors described as patterns by the native population: green (fruit surface is completely green and shiny), turning (fruit surface is mid green, turning to light green or greenish-yellow), ripe (fruit surface is completely yellow and shiny), and fully ripe (fruit surface is deeply colored red wine). In addition to these standard colors, another criterion for the selection of the fruits to be used in this study was their structural integrity (absence of injuries). After harvest, the fruits were transported in plastic containers to the laboratory of food biochemistry and postharvest physiology, Department of Food Technology at INPA. Upon arrival at the laboratory, the fruits were washed and dried at ambient temperature (22 °C) composing a sample of 70 whole cubiu fruits (peel, pulp, and placenta) with average weight of 206.83 g and standard deviation of 31.35. The entire sample was diced, ground in a blender, and homogenized. Part of the homogenized material was immediately used for physicochemical analyses (moisture and total carotenoids). The remaining part of the homogenized material was stored in polyethylene bags and kept in a refrigerator at –20 °C until further analyses (lipids, proteins and ash). All analyses were performed in triplicate.

2.2 Fruit weight

Cubiu fruits were separated from the total sample previously described and regrouped according to the color patterns of their respective ripening stages. Subsequently, they were counted and weighed.

2.3 Moisture and total solids

Freshly harvested cubiu fruits were homogenized and immediately kept in a furnace at 105 °C until constant weight was reached, according to general methodology described by the Instituto Adolfo Lutz (2008). Total solids were estimated by difference.

2.4 Total carotenoids

Total carotenoids were extracted with isopropanol, hexane, and water; the washed hexane solution (with the pigments) being dried, and its absorbance being read at 450 nm on spectrophotometer (Spectrum, SP-2000, Shanghai, China), according to methodology described by Higby (1962).

2.5 Lipids

Lipids of dry homogenized cubiu fruits were extracted with petroleum-ether by the traditional Soxhlet method described by Instituto Adolfo Lutz (2008).

2.6 Proteins

Proteins were determined by the Kjeldahl digestion process for the determination of nitrogen in the fruits, according to general method described by the Instituto Adolfo Lutz (2008). In the digestion process, the nitrogen released by the decomposition of dry organic matter was transformed into ammonia (NH_4OH). This compound, in the presence of boric acid (H_3BO_3), could be titrated with a solution of hydrochloric acid (HCl) of known normality. In the final calculation, the empirical factor 6.25 was introduced to convert the number of grams of nitrogen found in the sample into the number of grams of proteins.

2.7 Ash

The analytical procedure consisted of carbonization of dried whole cubiu fruits followed by burning at 550 °C for four hours and measuring the total residual ash according to the general method described by the Instituto Adolfo Lutz (2008).

2.8 Energy content of the fruits

The energy content of the fruits was calculated using the traditional conversion factors for lipids (9), carbohydrates (4) and proteins (4); the results were expressed in kcal.100 g^{-1} of fruit. The carbohydrate content was estimated by the difference of the average values of the other measured components, according to Standal (1963).

2.9 Statistical analysis

The data were analyzed by descriptive statistics, correlation coefficient, and multiple regression using the SPSS computer program (SPSS Statistical Software Inc., Chicago, Illinois). The ripening stages were translated from colors to numerical scale in the following order: green (1-2), turning (2-3), ripe (3-4), and fully ripe (4). The level of significance was $p \leq 0.05$.

Table 1. Descriptive statistics of the weight of 70 cubiu fruits at four ripening stages.

Ranked observations	Ripening stages			
	Green	Turning	Ripe	Fully ripe
Total number	14	12	26	18
Minimum weight	79.31	141.32	175.75	153.86
Maximum weight	292.12	256.81	348.24	277.02
Mean	167.11	204.00	243.23	212.98
Median	149.10	210.70	239.13	219.27
Mode	Amodal	Amodal	Amodal	Amodal
Standard deviation	52.93	34.06	57.07	35.21

3 Results and discussion

The results of descriptive statistics and data variability (standard deviation) of fruit weights are summarized in Table 1. Cubiu fruits showed large weight variation with amodal distribution. Moreover, except for weight and moisture, all physicochemical indexes exhibited the same general behavior, i.e. they increased as the fruits ripened during the four investigated stages.

The results of the hypothesis test, correlation coefficient, and regression analysis are summarized in Table 2. Through regression analysis, weight was the only variable that did not show a relationship with the ripening stages of cubiu fruits. The other studied variables had a p-value of 95%.

Moisture slightly decreased from the green stage to the ripe stage. Additionally, the ripe stage was critical to maintain moisture because from that stage on, water loss became evident (Figure 1).

Lipids comprise less than one percent of most fruits and are associated with protective cuticle layers; avocado and olive constitute striking exceptions and have respectively 20 and 15% of oil droplets in their cells (WILLS et al., 1982). In cubiu fruits, lipids increased steadily from the green stage (0.21 g.100 g^{-1}) to the turning stage (0.30 g.100 g^{-1}) and the ripe stage (0.34 g.100 g^{-1}) reaching the maximum level at the fully ripe stage (0.35 g.100 g^{-1}), although maintaining insignificant calorie content, less to 1 g.100 g^{-1} (Figure 2). In fact, the calorie content of lipids in cubiu fruits was 1.89 kcal.100 g^{-1} at the green stage, 2.7 kcal.100 g^{-1} at the turning stage, 3.06 kcal at the ripe stage, and 3.15 kcal.100 g^{-1} at the fully ripe stage. Such fruits would potentially fit in any low fat diet.

Fruits are generally poor in proteins and have essential limiting amino acids. However, over time, different human cultures have found the proper mixture of amino acids in traditional dishes (cereals and legumes; cereals and dairy products; legumes and seeds) promoting protein balance and healthy weight and height development for their children (MAHAN; ESCOTT-STUMP, 2002). Proteins were shown to be low in cubiu fruits, gradually increasing from the green stage (0.66 g.100 g^{-1}) to the turning stage (0.69 g.100 g^{-1}) and the ripe stage (0.72 g.100 g^{-1}) reaching the maximum level (0.86 g.100 g^{-1})

Table 2. Physicochemical indexes of cubiu fruits evaluated at four ripening stages*.

Variables	Coefficient of determination (R^2)	t-test	Confidence interval (95%)	Rejection or acceptance of H_0	Adjusted linear regression model
Moisture	0.924	–4.921	(–0.312 - 0.021)	Rejection	$\hat{y} = 92.148 - 0.167x$
Weight	0.746	1.503	(–32.949 - 68.317)	Acceptance	$\hat{y} = 162.62$
Proteins	0.860	3.500	(–0.014 - 0.136)	Rejection	$\hat{y} = 0.581 + 0.061x$
Total carotenoids	0.893	4.083	(–0.001 - 0.028)	Rejection	$\hat{y} = 0.160 + 0.014x$
Lipids	0.729	0.706	(–0.231 - 0.322)	Rejection	$\hat{y} = -1.164 + 2.002x - 0.779x^2 + 0.0093x^3$
Ash	0.913	4.576	(0.002 - 0.079)	Rejection	$\hat{y} = 0.277 + 0.041x$

*$p \leq 0.05$.

at the fully ripe stage (Figure 3). The caloric content of proteins in cubiu fruits in that same order above was 2.64 kcal.100 g^{-1}, 2.76 kcal.100 g^{-1}, 2.88 kcal, and 3.44 kcal.100 g^{-1}. Such low protein fruits could be potentially useful in renal diseases requiring conventional protein restriction.

Nevertheless, in comparison to other solanaceous fruits (eggplant, gilo, pepper, potato, sweet bell pepper, and tomato), cubiu fruits at the ripe (or fully ripe) stage are not widely consumed in Brazil. In contrast, at the ripe (or fully ripe) stage, cubiu fruits are relatively poor in macronutrients such as proteins and lipids, but rather rich in secondary metabolites such as total carotenoids (FAVIER et al., 1999; PENTEADO, 2003; EL-QUDAH, 2009).

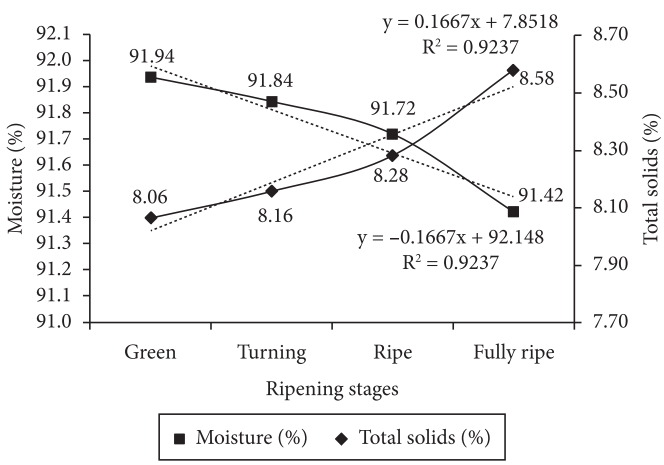

Figure 1. Changes in moisture of cubiu fruits at four ripening stages.

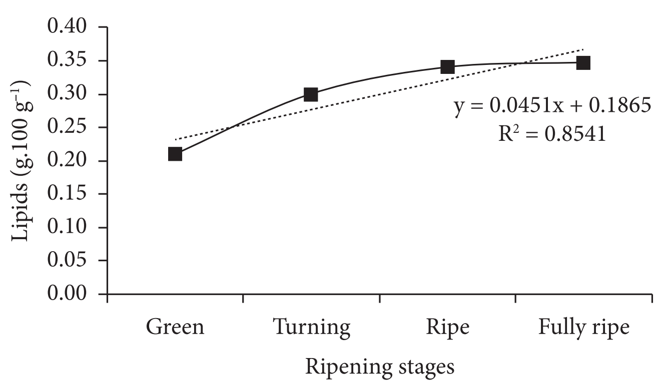

Figure 2. Changes in lipids of cubiu fruits at four ripening stages.

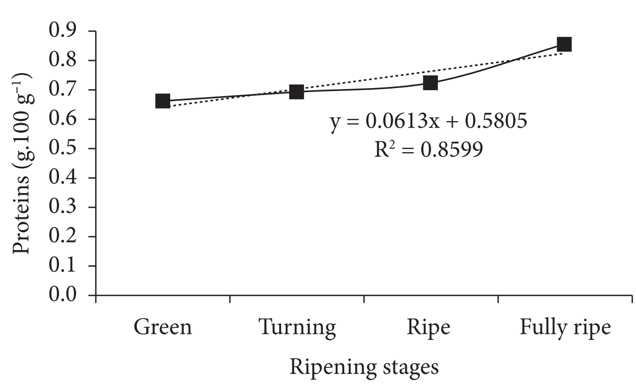

Figure 3. Changes in proteins of cubiu fruits at four ripening stages.

Color changes are not only indicative of the ripening stages of the fruits (in general); they are equally related with changes in pigment content of fruit tissues (CHITARRA; CHITARRA, 1990). In fact, the ripening stage is crucial in the degradation of chlorophyll and increase in carotenoids (CHITARRA; CHITARRA, 1990; BARTLEY; SCOLNIK, 1995). Accordingly, total carotenoids increased from the green stage (0.171 mg %) to the turning stage (0.195 mg %), maintaining this very same value at the ripe stage and reaching the maximum level at the fully ripe stage (0.217 mg %), when cubiu fruits exhibited deep red wine colored surface (Figure 4). This result was similar to that of another genus (*Capsicum*) of Solanaceae family (RAHMAN; BUCKLE, 1980).

Although investigating carbohydrates was not the purpose of this study, considering their major importance in fruit ripening, their estimation by simple difference proved not adequate for cubiu fruits. Further research is needed in this area.

Finally, the ash content increased progressively from the green stage (0.33 g.100 g^{-1}) to the turning stage (0.34 g.100 g^{-1}) and the ripe stage (0.41 g.100 g^{-1}) reaching the maximum level

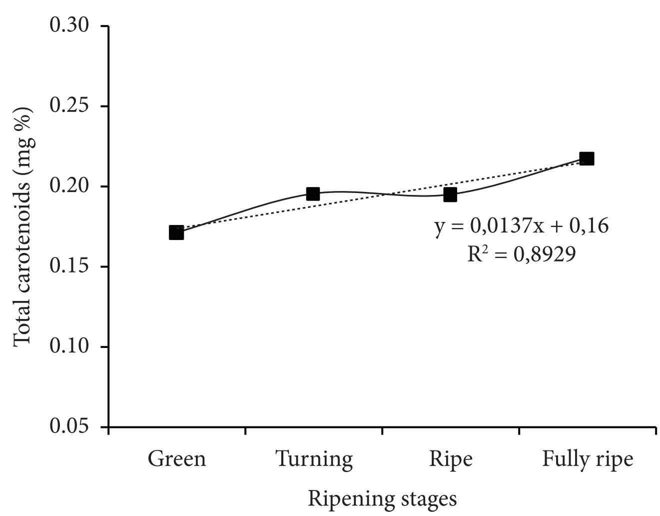

Figure 4. Changes in total carotenoids of cubiu fruits at four ripening stages.

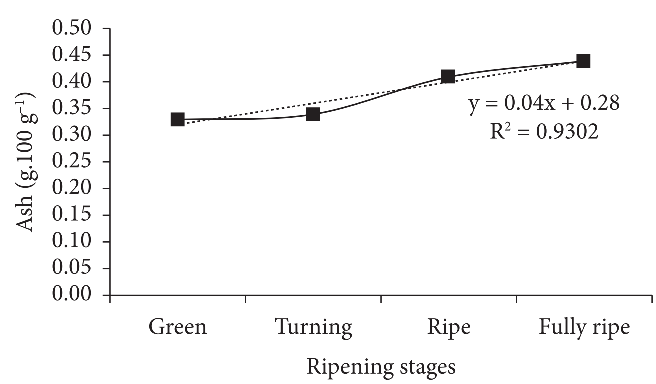

Figure 5. Changes in ash of cubiu fruits at four ripening stages.

at the fully ripe stage (0.44 g.100 g^{-1}) (Figure 5). Moreover, when compared to other ripe solanaceous fruits aforementioned, ripe (or fully ripe) cubiu fruits presented similar ash content (UNICAMP, 2006).

Fruits are complementary sources of macronutrients and micronutrients and therefore are essential for a balanced diet. With regard to micronutrients specifically, cubiu fruits may provide the mineral increment needed for a healthy diet at all ripening stages investigated.

4 Conclusions

With the exception of weight and moisture, all physicochemical indexes exhibited the same general behavior, i.e. they increased as the fruits ripened at the four investigated stages. In comparison to other solanaceous fruits widely consumed in Brazil at the ripe stage, ripe (or fully ripe) cubiu fruits were relatively poor in macronutrients such as proteins and lipids, but rather rich in secondary metabolites such as total carotenoids. The knowledge about the physicochemical changes in cubiu fruits allows greater suitability for dietetic use by the Brazilian population.

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