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Food Chemistry 77 (2002) 343–347

Food Chemistry

www.elsevier.com/locate/foodchem

Physical–chemical changes in early dwarf cashew pseudofruits during development and maturation

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Received 19 June 2001; received in revised form 12 October 2001; accepted 12 October 2001

Abstract

Cashews (nut + apple) were harvested in July 1997 from clones of early dwarf cashew trees installed under irrigation at MAISA's (Mossoró Agroindustrial S.A.) property, in Mossoró-Rio Grande do Norte state, Brazil, and sorted according to the apple size and skin colour, into seven development and maturity stages. The following characteristics were analysed in the apples: weight, length, upper and lower diameters, pulp firmness, pH, soluble solids (SS), titratable acidity (TA), SS/TA ratio, vitamin C, tannins, total carotenoids, total chlorophyll, total pectin, total calcium, anthocyanins, starch, soluble calcium and reducing sugars. Pseudofruits increased significantly in size after the full development of the nuts. The peak of consumption quality, i.e. highest soluble solids, reducing sugars content, and highest SS/TA ratio was reached at the end of stage seven. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: *Annarcadium occidentale* L.; Development and maturation; Eating quality

1. Introduction

Cashew production has been an important economic activity for many tropical countries, providing a variety of food and industrial products. The fleshy cashew apple, or pseudofruit can be eaten raw or processed into a variety of products. Pseudofruit contributes to human nutrition by supplying vitamin C, averaging 200 mg/100g of juice, four times that of orange juice (Menezes & Alves, 1995)

The early dwarf cashew has an increasing role in Brazilian cashew production and contributes to the rational development of the crop. Even though Brazil is among the most important cashew-producing countries, the commercial exploitation of the crop is limited almost exclusively to the production of nuts for the industrial processing of the kernel (Menezes, 1992).

Information generated by postharvest research on cashew apple has already produced an increase in the commercialisation of fresh cashew apples (Menezes, 1992; Menezes & Alves, 1995). Until very recently, cashew apples were sold exclusively in local street fairs. Today they reach supermarkets in other parts of the country located up to 4000 km from the production area (Pinto, Alves, Mosca, Filgueiras, & Moura, 1997).

According to Filgueiras, Mosca, Alves, and Menezes (1999) there are several indices that can be used to determine the optimal harvest stage of cashew apple, notably colour, firmness, composition and specific gravity.

However, from a practical stand-point, cashew is ready to be harvested when the apple is fully developed, firm, without any shade of green colour and easily detachable from the plant. It is at this stage that flavour, aroma and sugar concentrations are maximum, and acidity and astringency are minimum. For the fresh market, cashew apple must be free from physical injury and not misshapen. For processing it can be misshapen but must be free from disease and insects.

Cashew apples are generally classified according to their colours, namely red and yellow (Sondhi & Pruthi, 1980).There are many different combinations of colour

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0308-8146/02/$ - see front matter
PII: S0308-8146(01)00358-2

and shape, with many gradations between red and yellow, spherical and cylindrical (Johnson, 1973). The clone CCP-76 is an example of plant that produces apple with a deep orange, very attractive colour and taste, which also achieves a size and shape adequate for the fresh fruit market, as well as for the juice industry (Alves, Bezerra, Abreu, & Filguerias, 1999).

The purposes of this study are to describe the physical–chemical changes of pseudofruits of the early dwarf cashew clone CCP-76 at seven different stages of development and maturation, in order to establish criteria for defining harvest maturity as well as providing guidelines for postharvest handling.

2. Materials and methods

The cashews (apple + nut) were harvested in July 1997 from clones of early dwarf cashew trees installed under irrigation at MAISAs (Mossoró Agroindustrial S.A.) property, in Mossoró-Rio Grande do Norte state, Brazil. In the laboratory, the cashews were sorted into seven stages of development and maturation according to external colour of the apple and nut: 1—green with green nut, 2—green with ripe dry nut, 3—light green, 4—yellow colour started, 5—yellow changing to orange, 6—light orange, 7—deep orange. A random design was used for the experiment, with seven treatments (maturation stages) and four repetitions of five fruit samples. Results were submitted to analysis of variance and the means compared through the Tukey test at $P < 0.05$.

The following characteristics: weight, length, upper and lower diameters, pulp firmness, pH, total soluble solids (SS), total titrable acidity (TA), SS/TA ratio, were determined in the apples.

The apples were then frozen and stored at −20 °C for later evaluations of vitamin C, tannins (polymeric, dimeric and oligomeric), total carotenoids, total chlorophyll, total pectin, calcium (total and soluble), anthocyanins, starch and reducing sugars. The following methodology was used: size—measurements were taken for length, upper and lower diameters, according to Almeida, Barros, Lopes, and Araújo (1987); weight—whole cashew (apple + nut), apple and nut were weighed in a semi-analytical electronic balance; pulp firmness—measured in the whole apples with a hand penetrometer FT011 (0–5 kg) with 8 mm diameter plunger; pH—measured by potentiometry, using a glass electrode, according to AOAC (1992); SS—measured with a refractometer and expressed in °Brix as recommended by AOAC (1992); TA—determined by titration with NaOH, as recommended by IAL (1985); SS/TA ratio—calculated as the quotient between the two characteristics; vitamin C—determined by a spectrometric technique according to Pearson (1976); tannins (polymeric, dimeric and oligomeric) extracted according to Swain and Hillis (1959) and analysed as recommended by Reicher, Sierakowski, and Correa (1981); total carotenoids—determined according to Higby (1962); total chlorophyll—extracted from the peel in acetone according to Bruinsma (1963) and calculated as mg/100 g according to the equation given by Engel and Poggiani (1991), after measuring absorbancy at 652 nm; total pectin—determined by the m-hydroxybiphenyl method according Blumenkrantz and Asboe-Hansen (1973); anthocyanins—extracted from the peel according to Francis (1982); total and soluble calcium—determined by atomic absorption spectrometry after nitroperchloric digestion, according to Sarruge and Haag (1974) for total calcium and Siddiqui and Bangerth (1995a, 1995b), for soluble calcium.

3. Results

After the development of cashew nut is completed (Stage 1), the apple begins to grow and develop, with significant changes in physical characteristics (Table 1). The increase in size dimensions of the apple from stage 1 to stage 7 is approximately five-fold for weight, two-fold for diameters and 1.5-fold for length. Table 1

Table 1
Physical changes during development and maturation of cashew apples from clone CCP-76

Maturity stage	Whole weight (g)	Nut weight (g)	Apple weight (g)	Apex diameter (cm)	Base diameter (cm)	Length (cm)	Texture (N)
1	46.58 e*	14.35 a	32.23 e	2.66 e	3.31 e	6.60 c	45.61 a
2	64.23 d	9.50 b	54.73 d	3.25 d	4.25 d	6.61 c	33.83 b
3	77.13 d	9.48 b	67.95 d	3.62 cd	4.71 c	6.63 c	24.12 c
4	95.23 c	9.00 b	88.93 c	3.82 c	5.26 b	7.21 bc	16.77 cd
5	108.97 c	8.32 b	100.65 c	4.05 bc	5.51 b	7.49 b	15.00 de
6	142.36 b	8.84 b	133.52 b	4.48 ab	6.05 a	7.83 ab	11.87 de
7	178.64 a	8.84 b	169.80 a	4.90 a	6.41 a	8.24 a	8.53 e
Coefficient of variation	6.95	7.33	7.94	5.95	3.26	3.78	13.91

* Means followed by same letters in the columns do not differ significantly according to Tukey's test ($P < 0.05$).

Table 2
Chemical and physico-chemical changes during development and maturation of cashew apples from clone CCP-76

Determinations	Maturity stage							
	1	2	3	4	5	6	7	CV
SS (°Brix)	6.49 e*	7.41 de	8.35 cd	9.72 bc	11.11 ab	12.22 a	12.44 a	6.50
TA (%)	0.23 c	0.27 abc	0.26 bc	0.30 ab	0.31 a	0.29 ab	0.29 ab	6.86
SS/TA	28.3 c	27.8 c	32.5 bc	32.4 bc	36.4 ab	42.6 a	43. 6 a	9.54
PH	4.94 a	4.77 b	4.65 bc	4.55 cd	4.36 e	4.50 d	4.53 d	1.13
Vitamin C (mg/100 g)	36.4 d	73.8 c	110.4 b	185. b	204 ab	228 a	229 a	10.6
Reducing sugars (%)	4.07 c	5.06 c	6.74 b	7.88 ab	8.25 ab	8.52 a	9.23 a	10.23
Starch (%)	5.43 a	4.22 b	3.39 bc	2.89 cd	2.24 de	1.79 e	1.50 e	12.13
Tannins (%)								
Poymeric	0.07 f	0.09 e	0.11 d	0.19 c	0.22 b	0.23 b	0.24 a	2.29
Dimeric	0.29 b	0.24 d	0.24 d	0.26 c	0.29 ab	0.30 ab	0.30 a	1.82
Oligomeric	0.32 a	0.29 bc	0.28 d	0.30 b	0.29 cd	0.30 b	0.29 cd	1.16
Anthocyanins (mg/100 g)	4.49 d	4.80 d	8.78 c	16.0 b	20.3 a	20.3 a	21.5 a	8.19
Total carotenoids (mg/100 g)	1.20 d	2.50 d	14.0 c	22.0 b	30.1 a	32.0 a	32.0 a	12.5
Total chlorophyll (mg/100 g)	53.3 a	37.0 b	28.6 bc	18.8 cd	13.8 d	7.97 d	6.52 d	23.5
Total pectin (%)	0.16 a	0.15 ab	0.14 bc	0.13 de	0.11 e	0.13 cd	0.12 de	4.85
Total calcium (mg/100 g)[a]	28.3 a	21.0 b	16.8 c	12.7 d	12.4 d	10.9 d	10.8 d	10.6
Soluble calcium (mg/100 g)[a]	7.34 a	6.31 a	6.55 a	6.28 a	6.81 a	6.02 a	6.52 a	14.6

SS, Soluble solids; TA, titratable acidity.
* Means followed by same letters in the columns do not differ significantly according to Tukey's test ($P < 0.05$).
[a] Dry matter

shows that the most accentuated increase in apple weight occurred between stages 6 and 7. After the apple begins to increase in size, the nut loses weight. From stage 1 to stage 7 pulp firmness of the apple is reduced by approximately 80%.

Anthocyanins, total carotenoids, SS, SS/TA, polymeric tannins, vitamin C, and reducing sugars increase continuously during maturation of the apples. Total chlorophyll, total calcium, total pectin and starch decrease as maturation evolves towards stage 7. There were no significant changes in pH, TA, dimeric and oligomeric tannins and soluble calcium from stage 1 to stage 7 (Table 2).

4. Discussion

Cashew nut and apple appear to grow independently of one another (Pratt & Mendonza Jr., 1980). There is an initial phase in the development of cashew when there is a rapid growth of the nut with little development of embryo and apple, a second phase when both nut and apple grow rapidly and a final phase in which, after the nut has achieved its maximum size, it starts to lose water (and consequently weight) and the apple continues to grow (Thompson, 1968). The results reported here show that the behaviour of clone CCP-76 is not different from what should be expected.

The mean total weights found by Alves et al. (1999), Moura (1998) and Pinto et al. (1997), for cashews from clone CCP-76 at stage 7, respectively 145.65, 150.80 and 172.19 g, were lower than the 178.64 g figure found in our experiment. This variation, according to Moura (1998), can be ascribed to several factors such as the season of harvest and the water availability in the field.

Cashew grading, for the fresh fruit market in Brazil, is based on the number of cashews per tray (550–600 g), which usually varies from 4 to 8. Considering that the consumer's preference is for cashew types 4–6, the most adequate fruits are those weighing on average, 100 g (Filgueiras et al., 1999). The physical characteristics found (Table 1) in this experiment demonstrate that clone CCP-76 produces cashews of type 4 on average.

Cashew pulp firmness decreases gradually doing its development and maturation, with the sharpest decline happening between stages 1 and 4. This softening is probably due to starch degradation and consequent increase in soluble sugar content as well as to the action of pectinolytic enzymes.

Cashew apple reaches good palatability at stage 7 due to the equilibrium of its aroma and flavour characteristics. Sondhi and Pruthi (1980) reported that total sugars, present in cashew apple during maturation, mostly comprise reducing sugars, glucose and frutose, with sucrose occurring only in traces. The results reported here were similar, as can be deduced from the fact that reducing sugars are the main constituents of SS.

Loss of chlorophyll (from 53.3 to 6.82 mg/100 g) was paralleled by gradual increase in carotenoid pigments

(from 1.25 to 32.0 mg/100 g) and anthocyanins (from 4.49 to 21.5 mg/100 g) during maturation of cashew apples. These data support the fact reported by Filgueiras et al. (1999) that the changes in colour of cashew apple during maturation are caused by chlorophyll loss as well as synthesis of other pigments.

The trend for tannin content during maturation was a few significant changes except in the polymeric fraction, for which a gradual increase was observed up to stage 7.

Alves et al. (1999) reported a stable tannin content during maturation of CCP-76 cashew apple, although they did not comment on dimeric and oligomeric fractions. Sondhi and Pruthi (1980) and Augustin and Unnithan (1981) reported a tendency to significant decrease in tannin content during the development of cashew. Despite previous reports, the present experiment shows changes in tannin contents during maturation as follows: increase in polymeric fraction from 0.07 to 0.24% and slight decrease in oligomeric fraction from 0.32 to 0.29%. This is in part agreement with what has been reported by Ozawa, Lilley, and Haslam (1987), that the astringency of unripe or immature fruits is a consequence of the presence of intermediate molecular weight tannins, but the content of these compounds is reduced during ripening due to complexation and polymerisation processes.

It is important to point out that the results of this research have made evident that, even though no marked reduction in oligomeric tannin content was found, the increase in the polymerisation degree of tannins, during maturation, makes them less reactive and contributes to the palatability of fully ripe cashew apple.

The changes in vitamin C content, seen in Table 2, show that the highest value is reached at the end of ripening. As noted by Chempakam (1983), the rise in ascorbic acid level during the last phase of cashew apple development may be attributed to a fall in activity of ascorbic oxidase, the enzyme involved in its degradation. Alternatively, according to the same author, the enlargement of the apple during the final phase may have lowered the concentration of the enzyme itself or the amount of $Cu++$ which is a cofactor for ascorbic acid oxidase.

Little changes were noticed in pH and TA (Table 2) during maturation, whereas SS content increased gradually and reached a maximum at stage 7. Total pectin and calcium contents were reduced, which probably explains part of the loss of pulp firmness.

The highest contents of anthocyanins and total carotenoids and the lowest of chlorophyll are characteristics of fully ripe and edible quality fruit, associated with the highest SS and lowest TA contents. Consequently highest palatability (SS/TA) was reached at stage 7, indicating that this is the ideal harvest stage for CCP-76 cashew apples, both for fresh consumption and juice processing.

References

Almeida, J. I. L., Barros, L. M., Lopes, S. G. V., & Araújo, E. A. (1987). Study on the growth of early dwarf type cashew (*Anarcadium occidentale* L.) nut and apple. *Revista Brasileira de Fruticultura, Cruz das Almas*, *9*(3), 21–30 (Portuguese).

Alves, R. E., Bezerra, F. C., Abreu, F. A. P., & Filgueiras, H. A. C. (1999). Development and maturation of the apple of early dwarf cashew tree CCP-76. *Acta Horticulturae, Leuven*, *485*, 225–230.

Association of Official Analytical Chemists. 1992. *Official methods of analyses of the Association of Official Analytical Chemists Washington* (11th ed.).

Augustin, A., & Unnithan, V. K. G. (1981). An attempt on maturity of cashew apple. *Indian Cashew*, *14*(4), 9–11.

Blumenkrantz, N., & Asboe-Hansen, G. (1973). New method for quantitative determination of uronic acids. *Analytical Biochemistry, New York*, *54*, 484–489.

Bruinsma, J. (1963). The quantitative analysis of chlorophyll A and B in plant extracts. *Photochemistry and Photobiology*, *2*, 241–249.

Chempakam, B. (1983). Distribution of ascorbic acid and ascorbic acid oxidase activity in developing cashew apple (*Anarcadium occidentale*, L.). *Journal of Horticultural Science*, *58*(3), 447–448.

Engel, V. L., & Poggiani, F. (1991). Study on chlorophyll concentration on the leaves in function of shadowing in seedlings of four forestry species. *Revista Brasileira de Fisiologia Vegetal*, *3*(1), 39–45 (Portuguese).

Filgueiras, H. A. C., Mosca, J. L., Alves, R. E., & Menezes, J. E. (1999). Cashew apple for fresh consumption: research and postharvest handling technology in Brazil. *Acta Horticulturae, Leuven*, *485*, 155–160.

Francis, F. J. (1982). Analysis of anthocyanins. In: MAR Kakis, P. (Ed.) Anthocyanins as food colors. New York, Academic Press, 181–207.

Higby, W. K. (1962). A simplified seethed for determination of some the carotenoid distribution in natural and carotene-fortified orange juice. *Journal of Food Science, Chicago*, *27*, 42–49.

Instituto Adolpho Lutz. (1985). *Analytical norms of the Adolfo Lutz Institute: chemical and physical methods for food analysis*. São Paulo: IAL (Portuguese).

Johnson, D. (1973). The botany, orig., and spread of cashew *Anacardium occidentale* L. *The Journal of Plantation Crops*, *2*, 1–7.

Menezes, J. B. (1992). *Refrigerated storage of cashew (*Anacardium occidentale *L.) apples under ambient and modified atmospheres*. MSc Thesis, ESAL, Lavras (Portuguese).

Menezes, J. B., & Alves, R. E. (1995). *Physiology and postharvest technology of cashew apple*. Fortaleza: EMBRAPA-CNPAT [Documents, 17] (Portuguese).

Moura, C. F. H. (1998). *Quality of apples of early dwarf cashew clones (*Anacadium occidentale *L.) under irrigation*. MSc Thesis, UFC, Fortaleza (Portuguese).

Ozawa, T., Lilley, T. H., & Haslam, E. (1987). Polyphenol interactions: astringency and the loss of astringency is ripening fruit. *Phytochemistry, Elmosford*, *26*(11), 2937–2942.

Pearson, D. (1976). *The chemical analysis of foods*. Acríbia Zanegoza (Spanish).

Pinto, S. A. A., Alves, R. E., Mosca, J. L., Filgueiras, H. A. C., & Moura, C. F. H. (1997). Fresh consumption quality of the apple of some Brazilian early dwarf cashew clones (*Anacardium ocidentale* L.). *Proc. Interamer, Soc. Trop. Hort.*, *41*, 189–193.

Pratt, H. K., & Mendoza, D. B. Jr. (1980). Influence of nut removal on growth and ripening of the cashew-apple. *Journal of the American Society for Horticultural Science*, *105*(4), 540–542.

Reicher, F., Sierakowski, M. R., & Correa, J. B. C. (1981). Spectrophotometric determination of tannins by fosfotungstic-fosfomolibolic reactive. *Technology and Biology Archives. Curitiba*, *24*(4), 407–411 (Portuguese).

Sarruge, J. R., & Haag, H. P. (1974). *Chemical analysis in plant*. Piracicaba: ESALQ-USP (Portuguese).

Siddiqui, S., & Bangerth, F. (1995a). Differential affect of calcium and strontium on flesh firmness and properties of cell wall in apples. *Journal of Horticultural Science, United Kingdom*, *70*(6), 949–953.

Siddiqui, S., & Bangerth, F. (1995b). Effect of pre-harvest of calcium on flesh firmness and cell-wall composition of apples—influence of fruit size. *Journal of Horticultural Science, United Kingdom*, *70*(2), 263–269.

Sondhi, S. P., & Pruthi, J. S. (1980). Effect of variety/strain and stage of maturity on the quality of cashew apples. *Indian Journal of Horticulture*, *37*(3), 270–275.

Swain, T., & Hillis, E. E. (1959). The phenolic constituents of Prunus domestica. II. The analysis of tissues of the "Victoria" Plum tree. *J. Sci. Food Agric.*, *10*(2), 135–144.

Thompson, A. K. (1968). Stages of development of the fruit of cashew (*Anacardium occidentale* L.). *Proc. Trop. Region. Amer. Soc. Hort. Sci.*, 209–215.