Influence of Passion Fruit Juice on Colour Stability and Sensory Acceptability of Non-Sugar Yacon-Based Pastes

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ABSTRACT

This work was aimed at studying the influence of PFJ and/or sodium disulphite on Yacon pulp colour, and evaluating the sensory attributes of Yacon non-sugar pastes. A colour kinetic evaluation of browning in 11 treatments containing Yacon tubers, yellow passion fruit juice (PFJ) and/or sodium disulphite, over the course of 240 minutes was studied to inactivate the PPOs activity. The evaluation of the colour alterations of Yacon tuber by the addition of variable amounts of PFJ and sodium disulphite enabled identification of efficient treatments for the inhibition of browning: T7 (300 g kg $^{-1}$ PFJ), T8 (400 g kg $^{-1}$ PFJ), and T10 (150 g kg $^{-1}$ PFJ + 0.25 g kg $^{-1}$ sodium disulphite). These treatments presented high colour intensity (C*) and an insignificant (P <0.05) total colour degradation (ΔE). The products elaborated by the cooking of these ingredients were submitted to the acceptability test and data showed that T7 garnered an acceptance index of 78%.

Key words: *Smallanthus sonchifolius;* Diabetes; Passion fruit; Sensory analysis; kinetics; Polyphenol oxidases

INTRODUCTION

Yacon (*Smallanthus sonchifolius, Asteraceae*) is a tuber crop originally cultivated in South America in the Andean highlands (Zardini, 1991). It is a food source as well as an acknowledged medicinal plant for the local population. It has gradually received more attention due to its abundant content of fructooligosaccharides (FOS) and phenolic compounds (Quinteros, 2000).

Until the end of the 1980s, with the exception of Peru and Japan, the scientific community paid only vague attention to this plant. Each Yacon root typically weighs 100 – 2,000 g and mainly stores water (860 – 900 g kg $^{-1}$) and carbohydrates (90 –

130 g kg $^{-1}$) (Hermann et al., 1999). It also contains small amounts of fat, potassium, fructose, glucose, saccharose, vitamin A, some free amino acids such as L-tryptophan, and carotenoids such as β-carotene and neurosporene (Quinteros, 2000; Ohyama et al., 1990). The majority of the carbohydrates (600 to 700 g kg $^{-1}$) are inulin-type oligofructans and β-(2→1)-fructooligosaccharides (Vilhena et al., 2000), which are short fructose polymers with a polymerization degree of 3 – 10 fructans (Goto et al., 1995).

Yacon tubers have various antioxidant (Yan et al., 1999), anti-diabetic (Aybar et al., 2001), antifungal (Inoue et al., 1995), and anticholesteremic properties (Delzenne and Kok,

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2001). Yacon is commonly consumed by diabetics because of its known positive effects on the digestive system (Zardini, 1991). Fructans, especially inulin, can modulate the growth of bacteria in the intestines and boost the immunological system, offering beneficial health effects (Capito, 2001).

The Yacon tuber contains carotenoids that confer its yellow colour (Quinteros, 2000). It also contains chlorogenic acid, ferulic acid, and caffeic acid (Simonovska et al., 2003), which make the tubers susceptible to enzymatic browning reactions caused by polyphenol oxidases (PPOs) (Yoshida et al., 2002). To inhibit these reactions, PPOs are inactivated by the heat or by the use of reducing agents, such as sulphites and organic acids (ascorbic, malic, citric acids) (Yan et al., 1999; Araújo, 2004).

PPOs catalyze the oxidation of o-phenolic substrates to o-quinones, which are subsequently polymerized to dark-colored pigments. These metalloenzymes, which are widely distributed in the plants, are considered to be the main contributor to the browning of fruits and vegetables that occur during the harvesting, handling, processing, and storage of many plant materials (Mayer and Harel, 1979; Mayer and Harel, 1991; Vamos-Vigyazo, 1981; Zawistowski et al., 1991; Ayaz et al., 2008).

Colour is one of the most important sensory attributes of food products, since it is an indicator of the degree of cooking, aesthetics, and freshness (Hutchings, 1999). It is also the first characteristic that attracts consumers' attention, and therefore greatly influences their preferences and demands (Calvo et al., 2001). For these reasons, colour is considered as the major factor in the assessment of food product quality and it is extensively used to characterize the variation of colour in the foods during processing (Ameur et al., 2007). The PPOs contained in Yacon tubers lead to browning, a negative chemical reaction that limits products development. Hence, it is very important to inactivate these enzymes so that the natural colour of the root is preserved.

With the goal of developing new technological products with both physiological functionality and sensory acceptance by the consumers, producers have developed a number of processed Yacon products, such as air-dried tuber slices (Grau and Rea, 1997), unrefined Yacon syrup, which is marketed as a dietetic sweetener (Herman, Freire and Pazos, 1999), sweet pastries, fermented vegetables, and ethanol (Lachman et al., 2003). Yacon juice treated with active carbon powder (Hondo et al., 2000a), Yacon vinegar (Hondo et al., 2000b), chocolate cake (Moscatto et al., 2004), and Yacon juice blended with peach (Silva, 2004), or lemon juice (Granato and Neves, 2005), are some other products that have been developed.

In the same context, passion fruit juice (PFJ) is a relevant species (Souza et al., 2008) that can also be a suitable ingredient to produce other Yacon-based products due to the fact it contains a large quantity of organic acids and carotenoids, recognized compounds that inhibit PPOs activity and confer taste, flavour and a good-looking aspect to the food. For this reason, the current work was aimed to study the influence of PFJ and/or sodium disulphite on the colour of Yacon pulp in order to inhibit the enzymatic browning, and evaluate the sensory attributes of Yacon non-sugar pastes.

MATERIALS AND METHODS

Sample materials

The materials used in this work include Yacon tubers obtained from local market in Curitiba (Brazil), yellow PFJ (500 g kg^{-1} pulp in water, pH = 2.63, ^{o}Brix = 8.20, acidity = 45.5 g kg^{-1} in citric acid), saccharine and sodium cyclamate mixed sweeteners in a 1:1 ratio (Doce menos, São Paulo, SP, Brazil), and disodium disulphite ($Na_2S_2O_5$, Synth, São Paulo, SP, Brazil).

Experimental design

To study the enzymatic inactivation of the blends containing Yacon tubers and PFJ and/or $Na_2S_2O_5$, a totally random experimental design was utilized, in accordance with the treatments indicated in Table 1.

Table 1 - Experimental treatments to study the prevention of browning in paste of Yacon tubers with passion fruit juice.

Treatment	Formulation
1 (control)	Yacon tuber
2	Yacon tuber + 25 g kg^{-1} PFJ
3	Yacon tuber + 50 g kg^{-1} PFJ
4	Yacon tuber + 75 g kg^{-1} PFJ
5	Yacon tuber + 100 g kg^{-1} PFJ
6	Yacon tuber + 150 g kg^{-1} PFJ
7	Yacon tuber + 300 g kg^{-1} PFJ
8	Yacon tuber + 400 g kg^{-1} PFJ
9	Yacon tuber + 0.15 g kg^{-1} Na$_2$S$_2$O$_5$
10	Yacon tuber + 150 g kg^{-1} PFJ + 0.25 g kg^{-1} Na$_2$S$_2$O$_5$
11	Yacon tuber + 0.35 g kg^{-1} Na$_2$S$_2$O$_5$

Note: PFJ = passion fruit juice; Na$_2$S$_2$O$_5$ = disodium disulphite.

Yacon blend processing

The Yacon tubers were washed in flowing water, and then disinfected with a 200 mgL^{-1} chloride solution (Quinteros, 2000). The tubers were manually peeled, weighed, and blended with PFJ and/or Na$_2$S$_2$O$_5$, in accordance with the experimental design. The mixture (950 g), for each treatment, was processed for four minutes using a blender (Wallita, São José dos Pinhais, Brazil) at 9000 r.p.m.

Instrumental colour

The colour degradation study was conducted at 0, 15, 30, 45, 60, 120, 180, and 240 minutes after blending of the Yacon and PFJ mixtures by determining the CIELAB colour parameters - $a*$, $b*$ and $L*$ - as measured by a Hunterlab colour difference meter model D25L-2 (Hunter Assoc. Laboratory, VA, USA), with D65 optical sensor, 0° geometry and 10° angle of vision. $L*$ was the lightness factor, which indicated the degree of lightness or darkness of the sample; $a*$ and $b*$ were the chromaticity coordinates that represented the red(+)/green(-) and yellow(+)/blue(-) colour attributes, respectively. Chroma, $C*$, which indicates the intensity of colour, was calculated by the formula: $C* = (a*^2 + b*^2)^{1/2}$. The total colour difference, ΔE, between the initial and final colour of the blends (Yacon + PFJ and/or Na$_2$S$_2$O$_5$) was calculated using the Hunter-Scotfield's equation: $\Delta E = (\Delta a*^2 + \Delta b*^2 + \Delta L*^2)^{1/2}$, where $\Delta a* = a* - a*_0$; $\Delta b* = b* - b*_0$; $\Delta L* = L* - L*_0$; subscript ''0'' indicate the initial colour at time 0. Prior to measuring the colour of the blended mixtures, the instrument was calibrated using black and white reference standard ceramic plates. The samples were placed in a clear glass Petri dish, and colour measurements were performed six times.

Kinetic models

The data obtained from the instrumental colour were adjusted to describe the change of colour parameters throughout the evaluation. This kind or analysis has been extensively reported in the literature for several fruits (Lee and Chen, 1998; Chutintrasri and Noomhorm, 2007) because it describes the effect of time on colour variation. The reaction rate constants were determined by fitting the experimetnal data to a first-order kinetic model (Tiwari et al., 2008): $C = C_0\,e^{kt}$, where C was the studied parameter at any given reaction time, C_0 was their initial value and k was a rate constant. Data fitting was considered to be significant at a probability level of $\leq 5\%$.

Diet paste design

The treatments with best results in the inhibition of enzymatic browning of Yacon pastes, from colorimetric analyses, were utilized to prepare diet pastes. These diet pastes were further processed to check for their acceptance by potential consumers. The pastes were prepared according to a traditional recipe. Briefly, 3 kg of Yacon and PFJ were cooked for 20 min at 85 °C in an aluminum pan, cooled using an ice bath until it reached 10 °C, and then supplemented with sweetener at a concentration of 3 g kg^{-1}. The products were aseptically placed in a sterile glass container and kept under refrigeration (7 °C) until they were used for sensory analyses.

Sensory assessment

The rating test was applied to analyze the degree of liking of colour, taste, overall liking, and texture using a seven-point hedonic scale, where 1= 'strongly disliked'; 2= 'moderately disliked'; 3= 'slightly disliked'; 4= 'indifferent'; 5= 'slightly liked'; 6= 'moderately liked'; and 7= 'strongly liked' (ABNT, 1998). The non-sugar pastes were presented monadically for each panelist in a random form using a balanced block design. Water and a cream cracker biscuit were used by the panellists to cleanse the palate. A total number of 51 different panellists between the ages of 13 and 43 years evaluated each sample in different sessions, in a total of 153 responses. The samples were placed in disposable plastic cups, each identified with three random digits.

Statistical analyses

All variables had their normality and variance homogeneity tested by dispersion graphs and Hartley's test. Second, repeated measures ANOVA was carried out to determine the existence of any statistical difference ($P < 0.05$) among the samples, by comparing the treatments and the initial and final values for each colour parameter, followed by Tukey's HSD post hoc test (Montgomery, 2000), using the statistical program Statistica version 7.0 (StatSoft Inc., Tulsa, OK, USA). Significance of the results from the sensory data analysis was submitted to two-way ANOVA for the identification of contrasts. Pearson's correlation coefficients (r) were calculated for the determination of associations among the sensory data. The acceptance index of each non-sugar paste was calculated by the percentage of respondets who indicate that they 'slightly liked', 'moderately liked', or 'strongly liked' the product sample (Lawless and Heymann, 1999).

RESULTS AND DISCUSSION

Colour degradation

Previous studies of enzymatic browning on Yacon juice disclosed a rapid change from green to a darker colour during grinding and crushing of the roots (Quinteros, 2000). Similar behaviour was observed in the control treatment in the present study, such that pulp tonality shifted from yellowish to dark brown, due to melanin production came from the reaction between phenols and amino acids naturally present in Yacon tubers.

The data in Table 2 indicated that with the exception of treatments T7, T8, and T10, the amounts of PFJ and/or $Na_2S_2O_5$ utilized in the study did not sufficiently prevent the enzymatic browning of the blends. Browning could be visualized by the reduction of $L*$, increase of $a*$ and decrease of $b*$ coordinate values (Cabello, 2005). As previously stated, yacon tubers contain chlorogenic acid and L-tryptophan, which are substrates used by PPO enzymes to produce melanin (Yan et al., 1999), which dark compounds that negatively affect the sensory acceptance of fruit products (Araújo, 2004).

Table 2 - Variation of colorimetric parameters ($L*$, $a*$, and $b*$) related to passion fruit juice (PFJ) and disodium disulphite addition to yacon blends.

Treatments	$L*$ Initial	$L*$ Final	$a*$ Initial	$a*$ Final	$b*$ Initial	$b*$ Final
T1	$51.27^a \pm 0.91$	$11.23^b \pm 0.31$	$-1.96^a \pm 0.52$	$-1.00^b \pm 0.02$	$20.18^a \pm 0.27$	$5.60^b \pm 0.52$
T2	$75.59^a \pm 0.54$	$32.27^b \pm 0.54$	$3.45^a \pm 0.12$	$7.47^b \pm 0.19$	$22.29^a \pm 0.68$	$16.34^b \pm 0.40$
T3	$77.87^a \pm 1.63$	$35.70^b \pm 0.30$	$3.99^a \pm 0.10$	$9.37^b \pm 0.11$	$24.58^a \pm 0.55$	$22.95^b \pm 0.22$
T4	$75.59^a \pm 0.65$	$40.01^b \pm 0.35$	$4.75^a \pm 1.10$	$6.79^b \pm 0.04$	$25.47^a \pm 0.58$	$20.89^b \pm 0.30$
T5	$73.90^a \pm 0.20$	$41.01^b \pm 1.59$	$5.93^a \pm 0.06$	$6.07^b \pm 0.05$	$28.99^a \pm 0.09$	$22.48^b \pm 0.43$
T6	$71.30^a \pm 0.21$	$48.07^b \pm 0.10$	$7.76^a \pm 0.10$	$7.87^a \pm 0.06$	$35.12^a \pm 0.16$	$26.78^b \pm 0.38$
T7	$66.41^a \pm 4.04$	$48.15^b \pm 0.15$	$4.84^a \pm 0.22$	$3.15^b \pm 0.12$	$31.47^a \pm 3.78$	$31.43^a \pm 0.23$
T8	$66.86^a \pm 0.74$	$53.42^b \pm 0.27$	$1.30^a \pm 0.48$	$7.78^b \pm 0.11$	$42.30^a \pm 3.64$	$40.72^a \pm 0.92$
T9	$60.86^a \pm 1.55$	$22.27^b \pm 0.78$	$3.32^a \pm 0.15$	$4.65^b \pm 0.70$	$23.91^a \pm 1.03$	$14.07^b \pm 1.44$
T10	$67.39^a \pm 1.50$	$50.96^b \pm 0.37$	$5.70^a \pm 0.27$	$3.05^b \pm 0.16$	$31.44^a \pm 1.47$	$29.61^a \pm 0.41$
T11	$65.36^a \pm 4,19$	$44.06^b \pm 0.94$	$3.18^a \pm 0.23$	$1.01^b \pm 0.07$	$22.72^a \pm 0.64$	$14.53^b \pm 0.59$

Note: Mean ± standard deviation. Mean in the same line with different letters are significantly different according to the Tukey's HSD test ($P < 0.05$).

The final $a*$ coordinate ranged from –1.00 to 9.37 for all the treatments, whereas the $b*$ coordinate ranged from 5.60 to 40.72, which indicated that the T6, T7, T8, and T10 treatments presented higher values relative to the other ones. Notwithstanding, the yellow colour ($b*$ coordinate) was significantly stable ($P > 0.05$) throughout the 240 minutes time course for T7, T8, and T10 treatments, probably due to the presence of carotenoids and organic acids in the PFJ that naturally inhibited the PPO activity. Treatment T9 (0.15 g kg^{-1} $Na_2S_2O_5$) presented the worst colour stability with regard to enzymatic browning as there was a great decrease ($P < 0.05$) in the yellowish hue ($b*$), and an increase in the red colour ($a*$ value). On the other hand, T8 kept its colour throughout the entire time course, due to the inhibition of the PPOs. Therefore, T8 was considered the best treatment. It was already been demonstrated that disodium disulphite is an effective inhibitor of PPO enzymes in Yacon tubers (Neves and Silva, 2007). However, the T11 treatment, which consisted of 0.35 g kg^{-1} of disodium disulphite, did not satisfactorily inhibit the browning, whereas the T10 treatment, which contained 150 g kg^{-1} PFJ and 0.25 g kg^{-1} of disodium disulphite, significantly inhibited the browning, as observed by the insignificant ($P > 0.05$) shift from the $b*$ coordinate value.

Colour degradation is a suitable analysis and to assess the enzymatic browning of fruit juices (Mattietto et al., 2007), pulps (Moura et al., 2001), mango pulp (Faraoni et al., 2008) and drink with tropical fruit (Rosso and Mercadante, 2007). Thus, the $a*$ and $b*$ values or some their combination should be used as physical parameters to describe visual colour alteration. The total colour degradation of the blends can also be expressed as a single numerical value, ΔE, which indicates the magnitude of the total colour difference in a food sample over a certain period of time. The total colour difference was lower in the treatments that contained high PFJ concentrations, T7 ($\Delta E = 18.34$), T8 ($\Delta E = 15.00$), and T10 $\Delta E = (16.74)$. Analogous behaviour was observed in the blend T10, which had a relatively lower concentration of PFJ, but included disodium disulphite, as shown in Figure 1. The highest total colour difference of the tested treatments was observed in treatment T2 ($\Delta E = 43.91$).
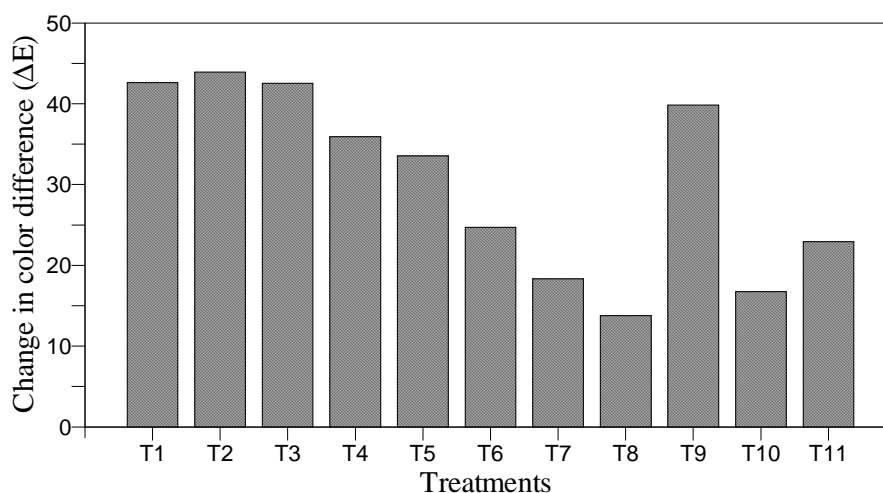

Figure 1 - Change in total colour difference (ΔE) related to passion fruit juice (PFJ) addition and/or disodium disulphite.

The chroma value ($C*$) indicated the degree of colour saturation and was proportional to the colour strength. Treatments T6, T7, T8, and T10 showed higher values of chromaticity in the beginning of the experiment (Fig. 2). However, T6 presented a significant decrease ($P < 0.05$) in its chromaticity over time.

Treatment T8 showed the highest colour intensity (41.46) at the end of the experiment due to the high concentration of PFJ. On the other hand, T1,

the control sample, showed the least intense colour saturation ($C^* = 5.69$) after 240 minutes. Figure 3 indicated that T7, T8, and T10 presented less variation of L^* over the course of the experiment, as these treatments showed better inhibition of enzymatic browning. During the incubation, dark compounds, such as melanin, which mainly resulted from the non-enzymatic browning reactions, oxidation of organic acids or precipitation of pigments (Sandi et al., 2004), might have contributed to a reduction in luminosity of the other treatments.

These compounds likely contributed to the darker appearance of the blends. Significant ($P < 0.05$)

first-order kinetic models for the degradation of lightness for the T7, T8 and T10 treatments were obtained, with determination coefficients above 67% (Fig. 4), aiming to consider the equations suitable as purpose-predictors in the experimental interval studied.

The yellowness (b^* coordinate values) decreased in the following treatments: T1, T2, T3, T4, T5, T6, T9, and T11, as illustrated in Figure 5. The positive Δb^* values observed for T7, T8, and T10 indicated that these blends were more yellow than blue in colour, whereas the Δb^* values were more negative for the other treatments.
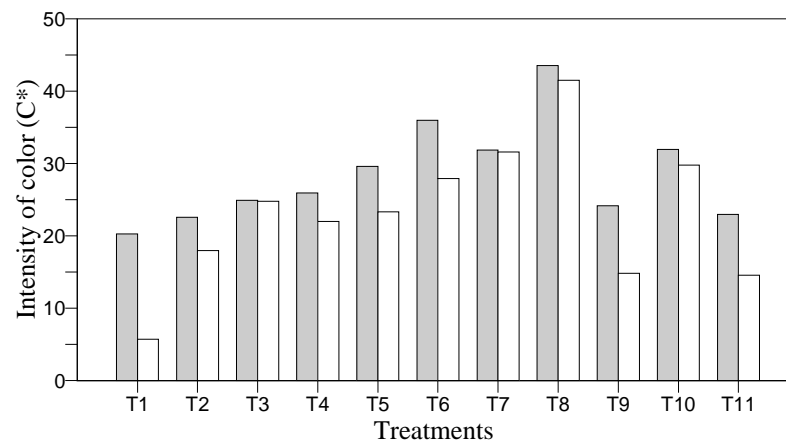

Figure 2 - Initial (full bars) and final (void bars) intensity of colour (C^*) related to passion fruit juice (PFJ) addition and/or disodium disulphite.
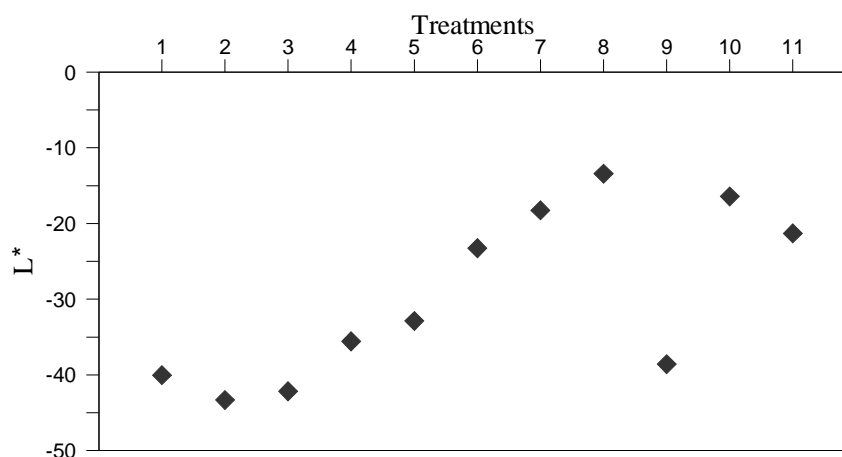

Figure 3 - Kinetic of the ΔL^* values related to passion fruit juice (PFJ) addition and/or disodium disulphite.
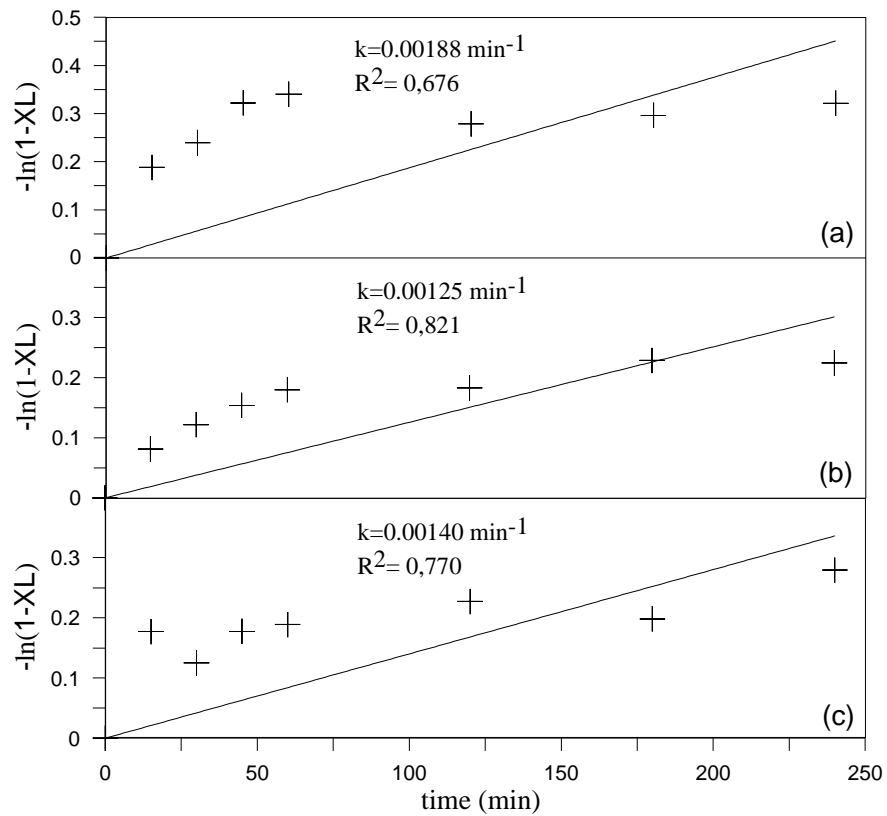
Figure 4 - Kinetic models for degradation of lightness ($L*$) of the blends containing 300 g kg^{-1} PFJ (T7) (a), 400 g kg^{-1} PFJ (T8) (b) and 150 g kg^{-1} PFJ + 0.25 g kg^{-1} $Na_2S_2O_5$ (T10) (c).

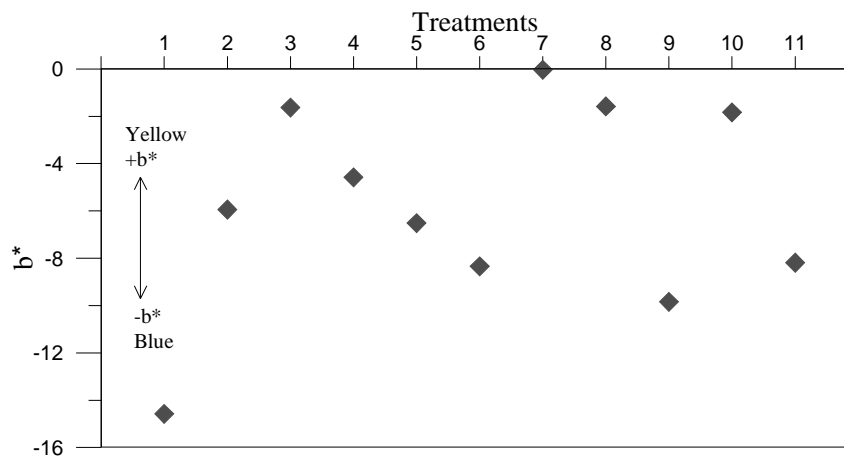**Figure 5** - Kinetic of the $\Delta b*$ values related to passion fruit juice (PFJ) addition and/or disodium disulphite.

A negative Δa^* value indicated that there was more green than red in the juice colour. The Δa^* declined slightly in T7, T8, T10, and T11, while the opposite behaviour was observed in the other formulations (Fig. 6). These data indicated that there was more red than green in the final colour for the other treatments.

Significant ($P < 0.05$) first-order kinetic models for a^* coordinate degradation for the T7, T8 and T10 treatments were obtained, with determination coefficients above 72%, corroborating the idea that colour degradation followed a linear behaviour, as shown in Figure 7.
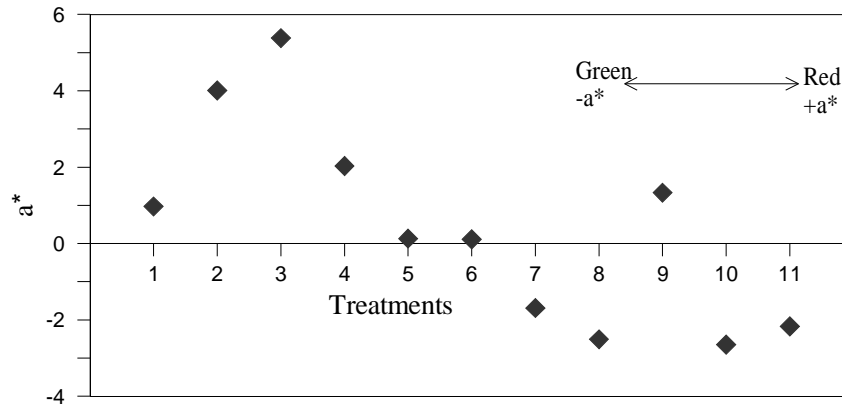

Figure 6 - Kinetic of the Δa^* values related to passion fruit juice (PFJ) addition and/or disodium disulphite.
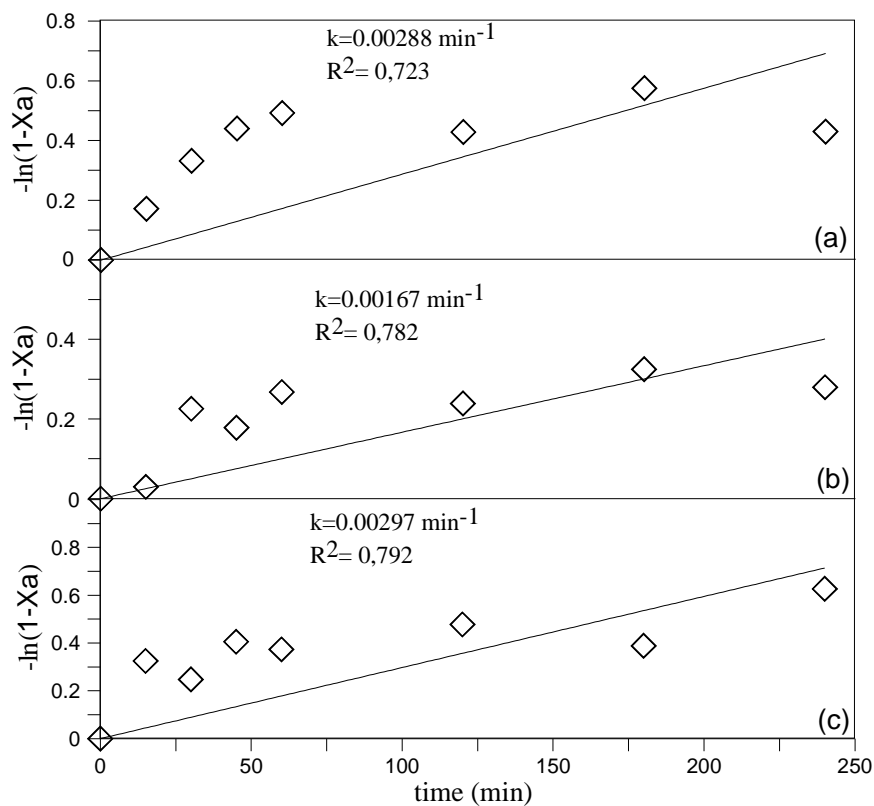

Figure 7 - Kinetic models for degradation of a^* colour coordinate of the blends containing 300 g kg^{-1} PFJ (T7) (a), 400 g kg^{-1} PFJ (T8) (b) and 150 g kg^{-1} PFJ + 0.25 g kg^{-1} Na$_2$S$_2$O$_5$ (T10) (c).

In accordance with Quinteros (2000), products containing Yacon tubers must combine two or more methodologies, such as the use of organic acids, heat or other physical treatments, to inhibit the enzymatic browning in order to obtain the acceptance by potential consumers. However, such processing of Yacon products may hamper their ability to compete in a market with less processed products (Hermann et al., 1999).

Sensory assessment
Since treatments T7, T8, and T10 presented a high colour intensity ($C*$) and an insignificant ($P < 0.05$) colour difference (ΔE) after 240 minutes, they where chosen for the sensory analyses. The sensory assessment produced data that were homogenous ($P > 0.05$) when the Hartley's test was applied and the two-way ANOVA showed that there was no significant statistical difference ($P > 0.05$) among the sensory parameters, as observed in Table 3. The analysis of the panellists' scores indicated that the paste samples presented mean hedonic scores above 'indifferent' (4.00) for the attributes. The overall liking of the products was significantly ($P < 0.001$) correlated to taste (r = 0.866), texture (r = 0.804), and colour (r = 0.874), suggesting that these attributes were the main drivers of the overall liking of non-sugar Yacon-based pastes. The acceptance indices (scores above 'indifferent') for the T7, T8, and T10 were 78, 63, and 55%, respectively. In accordance with Lawless and Heymann (1999), a food product that has been developed must present, at least, 70% of acceptability to be a market potential. Hence, only T7, produced with 300 g kg^{-1} of PFJ would be inside this criterion.

Table 3 - Sensory attributes of non-sugar Yacon pastes.

Samples	Sensory attributes[1]			
	Taste	Texture	Overall liking	Colour
T7	5.00	4.71	5.10	5.55
T8	4.98	4.61	4.80	5.25
T10	4.76	4.63	4.57	5.27
Pooled Standard Deviation	1.54	1.40	1.51	1.29
P_{sample} (Hartley)[2]	0.69	0.59	0.87	0.43
P_{sample} (Anova)[3]	0.40	0.90	0.20	0.14
$P_{panellits}$ (Hartley)[2]	1.00	1.00	0.88	1.00
$P_{panellits}$ (Anova)[3]	0.09	0.38	0.37	0.76

Note: [1]Data expressed as mean (n = 51); [2]Probability values obtained by Hartley test (F max) for homogeneity of variances; [3]Probability values obtained by two-way ANOVA; T7 = 300 g kg^{-1} PFJ; T8 = 400 g kg^{-1}; PFJ; T10 = 150 g kg^{-1} PFJ + 0.25 g kg^{-1} $Na_2S_2O_5$.

CONCLUSION

The present work has demonstrated that the control of alterations in the colour parameters of Yacon pastes by the addition of variable amounts of PFJ and/or $Na_2S_2O_5$ enabled identification of efficient treatments for the inhibition of browning. In this regard, treatments T7 (300 g kg^{-1} PFJ), T8 (400 g kg^{-1} PFJ), and T10 (150 g kg^{-1} PFJ + 0.25 g kg^{-1} $Na_2S_2O_5$) showed potential to prevent the browning in the blends at 240 minutes post-reaction onset. The non-sugar paste developed with 300 g kg^{-1} of PFJ seemed to be the most preferred by the taste panel, with an acceptance index of 78%. These results suggested that a Yacon-PFJ and/or $Na_2S_2O_5$ mixture could have a great potential for industrial production, which might provide a new diet option for diabetics.

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