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Process Optimisation of Sweet Potato (*Ipomoea batatas*) Puree as an Ingredient in a Formulation of Weaning Food

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ABSTRACT

Sweet potato, a tuber crop widely spread across the World (Africa, Asia, America, Caribbean and Europe) and very affordable, supplies the body with major and vital nutrients (carbohydrates, fat, proteins and vitamins) needed for good body development can be used as an ingredient in weaning food for babies. For this purpose it needs to be boiled and mashed into a paste before being served to babies. The cooking conditions of the *Lira* variety from a Portuguese region (Aljezur) were studied over a temperature range of 80 to 95°C during 10 to 180 min to evaluate its effects on the physico-chemical properties (texture, non-enzymatic browning and ascorbic acid). From the kinetics modelling study, it was concluded that a fractional conversion first order model fitted well the experimental data for these properties and the kinetic parameters estimated were: texture, (k_{ref}= 0.1611 ± 0.015 min^{-1}, Ea = 101.13 ± 14.22 KJ/mol with R^2_{adj} = 0.9719), non-enzymatic browning (k_{ref} = 0.0331 ± 0.004 min^{-1}, Ea = 389.27 ± 26.86 KJ/mol with R^2adj = 0.9971) and ascorbic acid (k_{ref} = 0.0244 ± 0.023 min^{-1}, Ea = 101.70 ± 14.66 KJ/mol with R^2_{adj} = 0.9905). Based on these findings, the optimization of the cooking conditions to obtain a high quality puree was determined as 90% colour retention, 70% ascorbic acid retention and moderately cooked at 90°C, 7 min; this result was further validated. The team that developed this work was composed by Nigerian and Portuguese researchers and though performed in Portugal and with a Portuguese variety of sweet potato; the goal was to use these results in the industrial development of a weaning food product in Africa, more specifically in Nigeria.

Keywords: ascorbic acid, β-carotene, kinetics mathematical modeling, non-enzymic browning, physico-chemical properties, texture and thermal degradation
Abbreviations: AA, ascorbic acid; **Ea**, activation energy; **fwb**, fresh weight basis; $\mathbf{k_{ref}}$, rate constant; $\mathbf{R^2}$, determination coefficient; $\mathbf{R^2_{adj}}$, adjusted determination coefficient

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INTRODUCTION

Origin, varieties and distribution

Over 95% of the global sweet potato crop is produced in developing countries, where it is the fifth most important food crop. China is the largest grower of sweet potatoes, providing about 80% of the world's supply, followed by Nigeria and Uganda which produce each about 2.5% of the world's supply, as can be observed in **Table 1**. Europe has only a very small sweet potato production, mostly in Portugal, which is the only European country that produces sizeable quantities of sweet potato, at 23,000 tons (International Potato Centre (CIP) 2006). This tuber is very affordable, mainly in Africa as it can be observed in **Fig. 1**, but exceptionally it can reach high prices such as the Portuguese one (**Fig. 2**), due to its special characteristics which deserved a highlight in this review.

Nutritional quality of sweet potatoes

Depending upon the variety, of which there are about 400, the skin and flesh of the sweet potato may range from almost white through cream, yellow, orange, and pink to a very deep purple, although white and yellow-orange flesh are most common. Sweet potatoes are grouped into two different categories depending upon the texture they have when cooked: 1st Group - Firm, dry, and mealy; 2nd Group - Soft and moist. In both types, the taste is starchy and sweet, with different varieties having different unique tastes. Usually sweet potatoes are high in carbohydrates and vitamin A and can produce more edible energy per hectare per day than wheat, rice or cassava (Baybutt *et al.* 2000). The yellow-orange flesh varieties also provide vitamins A and C. The plant's green leaves can also be consumed, providing additional protein, vitamins and minerals (Woolfe 1992). Besides simple starches, sweet potatoes are rich in complex

Received: 30 June, 2010. Accepted: 12 March, 2011.

Invited Review

Table 1 Ranking of the top 20 countries that produce sweet potato in the World.

Ranking	Yearly production (tonnes)								
	2007			2008			2009		
1	China	75800197		China	80522926	*	China	81212926	F
2	Uganda	2602000		Nigeria	3318000		Uganda	2766000	
3	Nigeria	2432000		Uganda	2707000		Indonesia	2057913	
4	Indonesia	1886852		Indonesia	1876944		India	1120000	
5	Viet Nam	1437600		Viet Nam	1323900		Angola	982588	
6	United Republic of Tanzania	1322000		United Republic of Tanzania	1322000	F	Kenya	930784	
7	India	1067200		India	1094000		U.S.A.	883099	
8	Angola	949104		Kenya	894781		Rwanda	850000	F
9	Madagascar	890000	F	Madagascar	890000	F	Philippines	600000	F
10	Mozambique	875216		Mozambique	890000	F	Cuba	437100	
11	Burundi	873663		Burundi	873663	F	Ethiopia	262854	*
12	Rwanda	841000		U.S.A.	836560		South Africa	62688	
13	U.S.A.	819641		Rwanda	826000		Senegal	40000	F
14	Kenya	811531		Angola	819772		Portugal	27000	F
15	Papua New Guinea	580000	F	Papua New Guinea	580000	F	Argentina		M
16	Philippines	573734		Philippines	572655		Burundi		M
17	Cuba	414000		Ethiopia	526487		Guinea-Bissau		
18	Ethiopia	388814		Cuba	375000		Madagascar		M
19	Republic of Korea	352269		Argentina	340000	F	Morocco		M
20	Argentina	340000	F	Republic of Korea	329351		Mozambique		M

[*]: Official data,F :FAO estimate * = Unofficial figure | [ ] = Official data | F = FAO estimate | M = Data not available
Source: FAOSTAT database, 2011

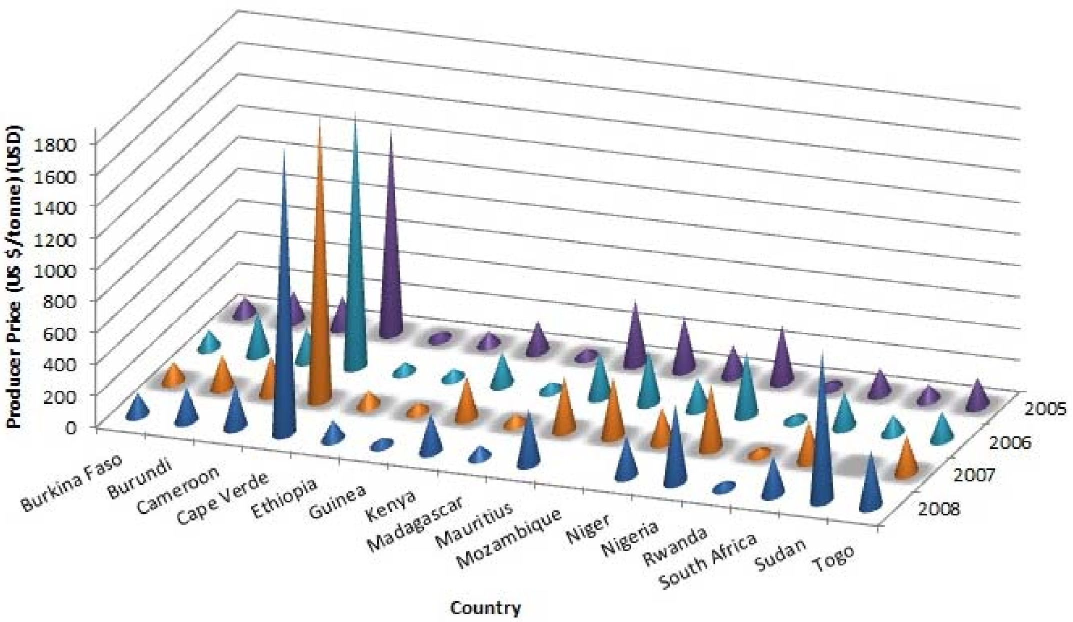

Fig. 1 Prices of sweet potato in African countries for the period of 2004-2007. Source: FAOSTAT database, 2010.

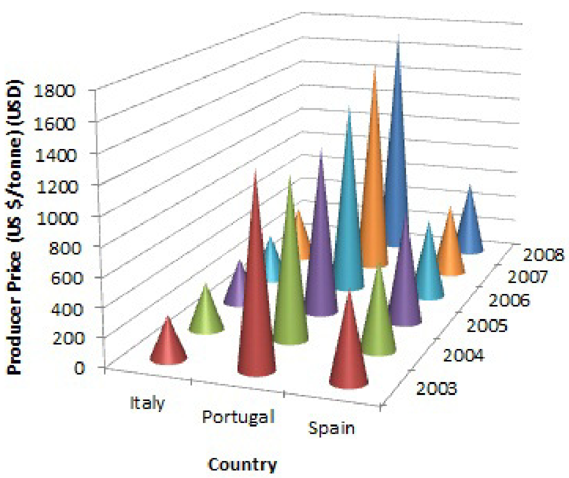

Fig. 2 Prices of sweet potato in European countries for the period of 2002-2007. Source: FAOSTAT database, 2010.

carbohydrates, dietary fiber, β-carotene (a vitamin A equivalent precursor), vitamin C, and vitamin B6 (CIP 2006). In 1992, the Center for Science in the Public Interest, USA compared the nutritional value of sweet potatoes to other vegetables. Considering fiber content, complex carbohydrates, protein, vitamins A and C, iron, and calcium, the sweet potato ranked highest in nutritional value. According to these criteria, sweet potatoes earned 184 points, 100 points over the next on the list, the common potato, as reported by the North Carolina Sweet Potato Commission (NCSPC) (2006). Sweet potato varieties with dark orange flesh have more β-carotene than those with light colored flesh and their increased cultivation is being encouraged in Africa, where vitamin A deficiency is a serious health problem (Baybutt *et al.* 2000).

Despite the name "sweet", it may be a beneficial food for diabetics, as preliminary studies on animals have revealed that it helps to stabilize blood sugar levels and to lower insulin resistance (Baybutt *et al.* 2000). Sweet potatoes have been used in Africa to fight a widespread vitamin A deficiency that results in blindness and even death for

Table 2 Nutritional composition of raw sweet potato (per 100 g).

Parameter	Amount
Energy	360 KJ/86 Kcal
Carbohydrates	20.1 g
Starch	12.7 g
Sugars	4.2 g
Protein	1.6 g
Vitamins	
Vitamin B6	0.2 mg (15%*)
β-carotene	8509 µg (79%*)
Thiamine (vitamin B1)	0.1 mg (8%*)
Riboflavin (vitamin B2)	0.1 mg (7%*)
Niacin (vitamin B3)	0.61 mg (4%*)
Panthotenic acid (vitamin B5)	0.8 mg (16%*)
Folate (vitamin B9)	11 µg (3%*)

Source: *% of RDA, USDA National Nutrient Database (2009)

African children (Bengtsson *et al.* 2008; Nandutu and Howell 2009). About two-thirds of the children developing xerophthalmia, the blindness-inducing disease resulting from lack of vitamin A, die within a year of losing their sight (FAO/WHO 1988; Aguayo and Baker 2005). Sweet potato has been proved to be an excellent source of vitamin A (in the form of β-carotene) and a very good source of vitamin C; it also has healing properties as an antioxidant food. Both β-carotene and total vitamin C (**Table 2**) are very powerful antioxidants that work in the body to eliminate free radicals (Grabowsky *et al.* 2008). Free radicals are chemicals that damage cells and cell membranes and are associated with the development of conditions like atherosclerosis, diabetic heart disease, and colon cancer (Grabowsky *et al*. 2008). This may explain why β-carotene and vitamin C have both been shown to be helpful for preventing these conditions (Agarwal 2000). The human body needs energy to work and play. Energy comes from the nutrients in foods. The main nutrients that provide energy are carbohydrates, protein and fat. Energy is measured in kilocalories (kcal), calories or kilojoules (kJ), and 1 kcal = 4.2 kJ. With the exception of cassava (590 kJ/100 g), sweet potato (465 kJ/100 g) is a higher source of energy than other root and tuber staples including potato (335 kJ/100 g), yam (434 kJ/100 g) and taro (432 kJ/100 g) (United States Department of Agriculture (USDA) 2009). The starch making up sweet potato dry matter is easily digestible and therefore a useful ingredient in the preparation of good weaning meals (Hamilton *et al.* 1986).

Sweet potato roots are valuable sources of ascorbic acid. They may contain more than 30 mg/100 g (fwb) (Haytowitz and Matthews 1984). As little as 100 g of boiled sweet potato can supply 85% of a child's recommended daily intake of ascorbic acid and over 50% of that of an adult (Woolfe 1992).

SWEET POTATO FROM ALJEZUR (PORTUGAL)

History of Aljezur

The town of Aljezur was founded in the tenth century by Arabs and later seized from the Moors in 1249. According to legend (although this clashes with history and the date of the sweet potato's introduction into Europe), the Knights of the Order of St James of the Sword, led by Paio Peres Correia, drank a potion made from sweet potato before every important battle. The force of the invasion and the speed with which they took the castle of Aljezur stunned the Moors, who were unable to react to such a sudden charge. The conquest took place in 1249 and, according to the legend, the potion that was the determining factor in the victory was no other than the famous 'feijoada de batata doce de Aljezur' (the Aljezur sweet potato bean stew). Whatever the truth of this story, the sweet potato's origins in Aljezur have been lost over time, which serves to illustrate that it has a long tradition in the region and in the diet of the local people (Ministério da Agricultura do Desenvolvimento Rural e das Pescas (MADRP) 2007).

Description and production and uniqueness of Batata Doce de Aljezur

The 'Batata doce de Aljezur' (Aljezur sweet potato) is the adventitious, fleshy, tuberous root of the plant *Ipomoea batatas* L. (syn. Batatas edulis) of the *Lira* variety and Convolvulaceae family. Elongated and pear shaped, its skin is purple or reddish brown and its flesh yellow. Its size varies between 8.5 × 4.0 cm and 16.5 × 7.1 cm and it reaches a weight of between 50 and 450 g (**Fig. 3**). It has a sweet taste and its texture is not very fibrous. When eaten raw, its taste is similar to that of chestnuts (MADRP 2007). The product's physical, chemical and organoleptic characteristics stem from the farmers' cultivation practices (expertise) and the natural conditions present in the region (**Fig. 4**): the land and sandy coverings that have an underlying layer of clay, and the particularly oceanic climate affecting the narrow coastal strip, which is irrigated by the Mira River. These conditions are found only within the boundaries of the production area. Even in neighboring areas, the climate and the

Fig. 3 Sweet potatoes from the Aljezur region right after harvesting. Available online: http://www.barlavento.online.pt

Fig. 4 Location of Aljezur, in the Southeastern Atlantic Coast of Portugal. Available online: http://www.cm-aljezur.pt

type of soil are significantly different. Aljezur has an outstanding reputation as far as the sweet potato is concerned, which is reflected by the price that this product reaches on the market, the attempts to infringe on the name and abuse it, the numerous references to it in literature and the many events dedicated to the product. The sweet potato's reputation in Aljezur is not a recent trend, resulting from sporadic and dubious demand for the product. It is still eaten today because consumers of this type of product recognize that these sweet potatoes have unique characteristics (sweet, smooth and not particularly fibrous) and prefer sweet potatoes of the *Lira* variety produced in this region to those imported from other parts of the world (MADRP 2007).

Cultivation

The soil is lightly tilled and harrowed and organic fertilizer is put down. The nursery area is set up in February, when roots are planted 10-15 cm deep in the ground, each one in an area 50 × 60 cm. The move to the final growing area takes place in April/May when a piece of the stem measuring 25 cm in length is planted. Each one is planted in an area 20 × 65 cm and lightly watered. Weed control is carried out by weeding. In most cases, watering is not necessary. The plant remains in the ground for about four months. Most of the harvesting is done in October, when the roots have reached maturity and there is not too much moisture in the soil. After harvesting, the sweet potatoes are dried above ground for around eight days, to allow suberisation and so that any cuts can heal. The sweet potatoes are then washed to remove excess soil and other impurities and are stored in a cool, ventilated area with an average temperature of 13-14°C. Selection and packaging takes place in the region of origin, which is justified not only by reduced production costs and more effective and efficient quality control and product traceability, but also and mainly because the product is extremely sensitive to handling/ transport: sweet potatoes develop necrosis easily and this has a significant impact on preserving the product and on its quality and appearance.

Comparison of nutritional and functional properties of sweet potatoes (*Ipomoea batatas*) and regular potato (*Solanum tuberosum*)

Although partly sharing a common denomination, potatoes and sweet potatoes are biologically unrelated plants. In fact, while there are over 200 species of wild potato that differ in size, shape, colour, starch content and flavor, the sweet potato is not one of them (Navarre *et al.* 2009; KLICK educação). Most cultivated potato varieties belong to the *Solanum tuberosum* species (Burlingame *et al.* 2009; Olson *et al.* 2010a). Other vegetable crops belonging to the *Solanaceae* family include tomato, pepper, eggplant and tomatillo (KLICK educação; Olson *et al.* 2010a). The sweet potato (*Ipomoea batatas* L. Lam) is a member of the *Convolvulaceae* family, which includes other species, such as water spinach, water convolvulus and kangkong (Roesler *et al.* 2008; Olson *et al.* 2010b).

The weight, length and width of potato and sweet potato tubers also vary (**Table 3**), with the latter reaching considerably higher sizes and weights (Tabatabaeefar 2002; Aina *et al.* 2009). Visual flesh colours of potato pulps usually range from white to yellow shades, whilst sweet potato pulps show colours from white to yellow, orange, or orange-red (**Table 4**) (Aina *et al.* 2009; Cabezas-Serrano *et al.* 2009). The chemical composition of potatoes and sweet potatoes is presented in **Table 5**. Sweet potatoes show higher fat, ash, fructose, glucose, sucrose, total soluble sugars and amylase contents, when compared to common potatoes (Lisińska and Leszczyński 1989; Takahata *et al.* 1996; Aina *et al.* 2009; Burlingame *et al.* 2009; Cabezas-Serrano *et al.* 2009). Total phenols, antioxidant capacities and selected vitamin contents are shown in **Table 6**. Again, sweet potatoes present higher values, for most of the parameters, when compared to potatoes.

Table 3 Physical properties of potato and sweet potato tubers.

	Width (cm)	Length (cm)	Weight (g)
Potato	2.6 - 15.8	2.2 - 7.8	9.0 - 445.0
Sweet potato	11.1 - 22.3	17.2 - 29.3	1100 -3100

Sources: Tabatabaeefar (2002); Aina *et al.* (2009)

Table 5 Proximate composition of potato and sweet potato tubers.

Parameter	Potato	Sweet potato
Moisture (%)	62.68 – 87.0**	64.1 – 83.8
Protein (%)	0.85 – 4.2**	1.9 – 4.4
Fat (%)	0.05 – 0.51**	0.2 – 1.8
Ash (%)	0.44 – 1.87****	1.9 – 4.4
Fructose (mg/g)	0.00 – 0.18**	0.420 – 12.2***
Glucose (mg/g)	0.015 – 0.34**	0.090 – 11.6***
Sucrose (mg/g)	0.08 – 1.39**	11.7 – 37.2***
Total soluble sugars (%)	1.4 – 2.3 *fw**	1.8 – 4.7
Amylose (%)	3.5 – 4.3**	15.3 – 30.2

Sources: Aina *et al.* (2009); * Cabezas-Serrano *et al.* (2009); ** Burlingame *et al.* (2009); *** Takahata *et al.* (1996); **** Lisińska and Leszczyński (1989).

SWEET POTATO PURÉE PROCESSING OPTIMIZATION

As already mentioned sweet potatoes (*Ipomea batatas*) are an economical and healthy food crop containing high β-carotene, substantial amounts of ascorbic acid and minerals (Woolfe 1992). Globally, the sweet potato is an important staple food or base material for a variety of food and industrial applications (Tian *et al.* 1991; Ravi *et al.* 1996). In many developing countries, infant foods are prepared from locally available sources, mainly cereals, roots and tubers, which are served as a thick porridge (Sanni *et al.* 1999). There is obviously a need for nutritionally balanced, energy

Table 4 CIE Tristimulus *L*, *a*, *b* and other colour parameters of the pulp of potato and sweet potato.

	L	*a*	*b*	Hue angle	Chroma
Potato	65.0 - 71.3	- 5.1 - (- 3.7)	16.7 - 30.5	1.72 - 1.79	17.1 - 31.0
Sweet potato	60.8 - 84.0	- 2.4 - 27.8	9.9 - 28.8	- 89.0 - 85.3	5.9 - 40.0

Sources: Aina *et al.* (2009); Cabezas-Serrano *et al.* (2009)

Table 6 Total phenolic content, antioxidant activities and vitamin concentrations in potatoes and sweet potatoes.

Parameter	Potato	Sweet potato
Total phenolics (mg/g dw)	4.0 – 6.5 ****	1.4 – 4.7
Antioxidant activity (mg/g dw) Trolox equivalent	0.43 – 0.892 ***	1.0 – 4.6
Chlorogenic acid (μg/g dw)	0.00 – 1446.0 ***	25.9 – 422.4
Caffeic acid (μg/g dw)	0.10 – 1570.0***	0.5 – 20.5
Ascorbic acid (mg/100 g)	16.1 – 34.8 *fw**	5.2 – 31.2
Folate (μg/g dw)	0.46 – 1.37****	0.11 ****
β-Carotene (μg/g fw)	0.00 – 1.11*****	0.60 – 231.1******

Sources: Aina *et al.* (2009); * Cabezas-Serrano *et al.* (2009); ** Padda and Picha (2008); *** Burlingame *et al.* (2009); **** Navarre *et al.* (2009); ***** Wu *et al.* (2008); ****** Bengtsson *et al.* (2008).

dense, easily digestible weaning foods, especially for the first six months, in the case of infants who cannot be breast-fed or when breast-feeding alone becomes insufficient (Hansen *et al.* 1981). Weaning from the breast is a process during which mothers gradually introduce their babies to culturally assigned foods as they continue to breastfeed. Weaning begins with the introduction of sources of food other than breast milk and ends with the last breastfeeding (Riordan 2005). Weaning is also described as the transition from suckling to eating of non-milk food, occurring during the first year of life - based on cultural beliefs and practices, physicians' beliefs, mothers' perceptions of their infants' needs and economic realities (Chao *et al.* 2007). Because weaning typically occurs during a period of rapid growth, attention to both nutritional and developmental issues during this period is warranted. Weaning practise can affect infant health, particularly in developing countries like Africa, or in inner city areas in which weaning diarrhoea is prevalent (Slome 1960; Riordan 2005).

Pureeing of sweet potato is carried out on a large scale in the United States with most of it being utilized to manufacture baby foods (Woolfe 1992). A sweet potato-processing plant in Snow Hill, N.C., USA produces aseptic sweet potato puree using a continuous-flow microwave heating technology developed by Coronel *et al.* (2005).

During thermal treatment, carbohydrates undergo a series of physical transitions and chemical transformations that are manifested by changes in their physical properties, including heat capacity, enthalpy and crystalinity (Biliaderis 1990). The objective of this study was to determine the best time-temperature combination that gives rise to high quality sweet potato puree for weaning food formulation by a optimization procedure and consequent validation.

PHYSICAL AND CHEMICAL CHARACTERIZATION OF FRESH PRODUCT

Mathematical modelling of experimental data can accurately predict the progress of a chemical reaction taking place in a homogeneous liquid or semi-solid during thermal processing and/or storage, being very useful in many engineering applications, including process optimization. Therefore, experimental studies and application of various simplified models to predict and interpret kinetic parameters (reaction order, rate constant, and activation energy) are needed. The kinetic parameters for a reaction should be independent of the process and instrument used. Most food quality attributes' changes during thermal preservation or during storage follow a first order reaction model (**Eq. 1**).

$$\ln\frac{C}{C_0} = kt \tag{1}$$

where C_0 is the initial concentration, C the concentration at time t and k the reaction rate constant (min^{-1}). However, for the so called psychophysical attributes such as colour or texture, the attribute doesn't disappear totally; instead often it decreases just to a certain extent, reaching a plateau. If the fraction reactant that has been converted to yield a product at a given time, f is used (**Eq. 2**), a convenient variable often used in place of concentration (Levenspiel 1974; Zimerri and Tong 1999) and a modified version of **Eq. 1** is obtained, a fractional conversion first order reaction (**Eq. 3**). For irreversible first-order reaction kinetics, this model also applies.

$$f = \frac{(C_0 - C)}{(C_0 - C_\infty)} \tag{2}$$

$$(1-f) \;\; or \;\; \ln\left[\frac{(C - C_\infty)}{(C_0 - C_\infty)}\right] = kt \tag{3}$$

with C_∞ the measured non-zero equilibrium parameter value(s) at infinite time. The dependence of the rate constant on temperature is defined by the Arrhenius equation (**Eq. 4**):

$$k = k_o \;\exp\left(-\frac{Ea}{RT}\right) \tag{4}$$

with $k_{0,}$ the frequency factor (min^{-1}), Ea, the activation energy (kJ/mol), R, the universal gas constant (8.314 J/mol K) and T, the absolute temperature (Kelvin, K).

Due to the large difference in magnitude between the k_0 value and the Ea value, a reference temperature, T_{ref} was introduced to rescale the parameters (Nunes *et al.* 1993) (**Eq. 5**). This transformation not only brings stability to the numerical integration and parameter estimation, but also, by using a reference rate constant, k_{ref}, it is enhanced that the equation can be applied in the most interesting range of temperatures including the reference temperature, T_{ref}.

$$k = k_{ref}\exp\left(-\frac{Ea}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \tag{5}$$

where k_{ref}, is the reaction rate at the reference temperature, T_{ref}, the reference temperature and the other parameters, Ea, k and R, same as defined above.

MATERIALS AND METHODS

Sample preparation

Fresh samples of sweet potatoes (*Ipomoea batatas*, var. *Lira*) from Aljezur were analysed. The sweet potatoes were purchased from the market and washed thoroughly. The skin was removed and washed again thoroughly to expose the yellow fleshed skin. This was followed by cutting the washed tuber into cylindrical discs of 2 cm in diameter and 0.5 cm in thickness.

Thermal treatment

The isothermal temperatures of the sweet potatoes were first determined to ensure the uniform heat circulation in the samples. This was done by inserting a thermocouple connected to a data logger (Delta logger), in the geometrical centre of each cylindrical disc of the samples and fixed on a basket support placed inside the water bath. Next, the sweet potato samples were placed inside a beaker containing 100 mL of water at each study temperature, and placed in a Thermostat water bath (model-Grant W 38) set at the same temperature and exposure times ranging from 0 to 180 min. Right after the heating time was reached the samples were transferred to a beaker for each experiment and immediately cooled in a beaker with ice water, for 2 min. Triplicates were used for each time-temperature combination.

Ascorbic acid

Reagents: The extracting solution was 0.4% oxalic acid containing 20% acetone. To a solution of 4 g oxalic acid dissolved in 500 mL distilled water, 200 mL acetone was added and diluted to 1 L with distilled water. A stock solution of 2,6-dichloroindophenol (DCIP) was prepared by dissolving 100 mg of dye in 100 mL warm water, and adding 84 mg $NaHCO_3$. This was diluted to 500 mL with water and filtered. The DCIP stock solution was further diluted with water such that when 1 mL of extracting solution and 9 mL of DCIP solution were reacted and an absorbance value (at 520 nm) of 0.300 to 0.350 was obtained.

Ascorbic acid standard curve: 100 mg of anhydrous ascorbic acid (AA) was dissolved in 100 mL of extracting solution. Appropriate aliquots of the stock AA solution (1.0 to 5.0 mL) were pipetted into 100 mL volumetric flasks containing extracting solution, yielding concentrations of 10.0 to 50.0 µg/mL. One millilitre aliquots of these dilutions were then reacted with 9 mL DCIP and the reaction read at 520 nm.

Sampling procedure

Ascorbic acid concentrations were evaluated by the spectrophotometric method of Egoville *et al.* (1988). The method is based on the ability of AA to reduce the dye 2,6- DCIP. 15 g of fresh or boiled sweet potatoes were extracted with an oxalic acid and acetone solution (0.4 and 20%, respectively) by homogenizing in a Ultra-turrax T25 (Janke & Kunkel Ika-Labortechnik, Germany) during 5 min at 4000 rpm. The extract was filtered under vacuum through a filter paper Whatman no. 2 (Whatman International Ltd., Maidstone, UK) and brought to 100 mL with the same extracting solution. One milliliter of the extract was reacted with 9 mL of 2,6-dichloroindophenol (1.6%) during 1 min and read at 520 nm on a Hitachi U-2000 spectrophotometer (Hitachi Ltd., Tokyo, Japan). The AA concentration was quantified through comparison with a standard curve of L-AA (Riedel-de-Haen 33034).

Non-enzymatic browning

Browning measurements were carried out using the method described by Baloch *et al.* (1973). Raw and cooked sweet potato samples (2.5 g) were homogenized for 5 min in 50 mL acetic acid-formaldehyde aqueous solution (2-1%, v/v) . The slurry was filtered and 0.5% lead acetate was added to the filtrate. Then, the slurry was collected in a volumetric flask, made up to 100 mL with acetic acid-formaldehyde solution. After mixing, the extract was centrifuged at 2500 rpm for 5 min and the supernatant was mixed with an equal volume of ethyl alcohol. The mixture was centrifuged again and absorbance measurements were taken at 420 nm and 600 nm by using a Hitachi U-2000 spectrophotometer. Browning was calculated from the difference between the two absorbance values.

Texture determination

Texture measurements were performed in a Texture Analyser Instron Model (1011) using a 50 N load cell and equipped with a 8 mm diameter probe at a speed of 50 mm/min. Force–distance curves were recorded and firmness (maximum peak force, N) and energy (area under force–distance curve, J) were used as indicators of textural parameters. Four measurements were done for each conditions tested.

Modeling of the kinetics of thermal degradation of relevant parameters during heat preservation

From the observation of the trend of degradation of ascorbic acid, texture and non-enzymatic browning (**Figs. 5-7**), it can be seen that the behavior of thermal degradation clearly deviates from simple first order levelling off after a certain time. Due to this fact, a fractional conversion model (**Eq. 3**) was attempted to model the data (Levenspiel 1974). The use of the fractional conversion model for determining the effects of heat processing on sweet potatoes have been previously reported (Rizvi and Tong 1997; Stoneham *et al.* 2000) and first order kinetic model reported by other authors (Nisha *et al.* 2006). The kinetic parameters were then estimated based on the Arrhenius law (**Eq. 4**) using a two-step analysis and the adequacy of the models studied. A one step non-linear regression was next performed through all the data points in order to calculate the activation energy, Ea, and rate constant at reference temperature, k_{ref}, from the original data (Lund 1983; Arabshahi and Lund 1985).

In all this study, the statistical software STATA, version 4.0 (STATA Corp. 1995) was used. The parameter property presented as the fraction of property change for fractional conversion, f, at any time t, is defined as (**Eq. 3**): The use of the fractional conversion model for determining the effects of heat processing on sweet potatoes have been previously reported (Rizvi and Tong 1997; Stoneham *et al.* 2000).

The reference temperature used was the average value of the range considered (i.e. T_{ref} = 87.5°C). Parameters' precisions were evaluated by confidence intervals at 95%, and the quality of the regression was assessed by the coefficient of determination (R^2) by checking the randomness and normality of residuals, thus allowing best model selection.

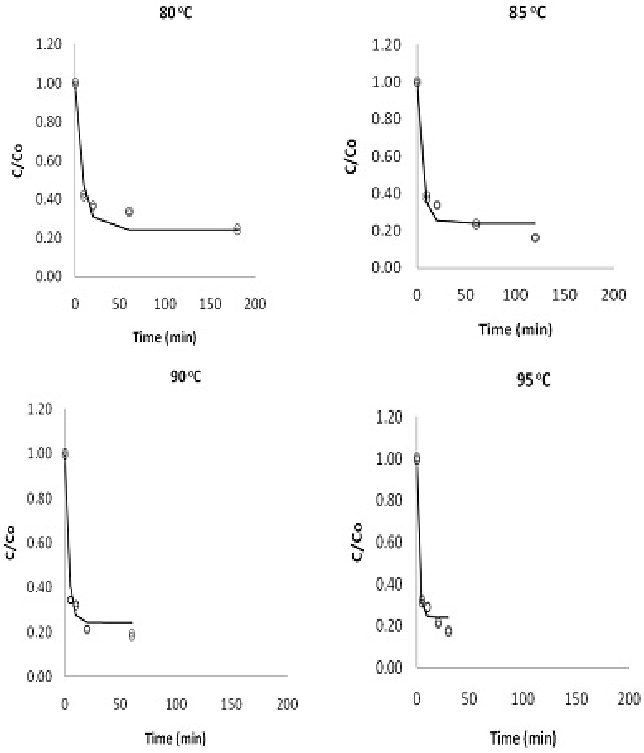

Fig. 5 Effect of temperature and time on ascorbic acid degradation in sweet potatoes, at the temperature range of 80–95°C. (○) experimental values with heating processes; (–) model predicted values for heating processes.

RESULTS AND DISCUSSION

Effects of heating on the ascorbic acid content and its degradation

Raw sweet potatoes contain between 17 and 35 mg/100 g of ascorbic acid on a fwb (Bradbury and Singh 1986; Woolfe 1992). However, these levels are significantly reduced by thermal processing (Bradbury and Singh 1986). The ascorbic acid values reported for the raw sweet potatoes in this current study are much lower than the previously reported values; this may be as a result of type of variety used and/or some oxidation and hydrolysis over storage time before analysis. Zee *et al.* (1991) have previously reported the effect of storage on ascorbic acid in raw sweet potatoes and they concluded that AA is sensitive to air, heat and water, and can easily be destroyed by prolonged storage. Cooking losses of L-ascorbic acid depend on the degree of heating, leaching into the cooking medium, surface area exposed to water and oxygen, pH, presence of transition metals, and any other factors that facilitate oxidation (Eitenmiller and Laden 1999).

The kinetic parameters of AA during heating at different temperatures and processing times are shown in **Table 6**. The reaction mechanism of ascorbic acid decomposition in foods has been studied extensively (Archer and Tannenbaum 1979; Liao and Seib 1987). It should be emphasized that different pathways, which give origin to different breakdown products, exist for the degradation of ascorbic acid. As many parameters will influence the kinetics of vitamin decomposition, it is difficult to establish a precise precursor-product relationship. Various mechanism of deterioration might operate simultaneously.

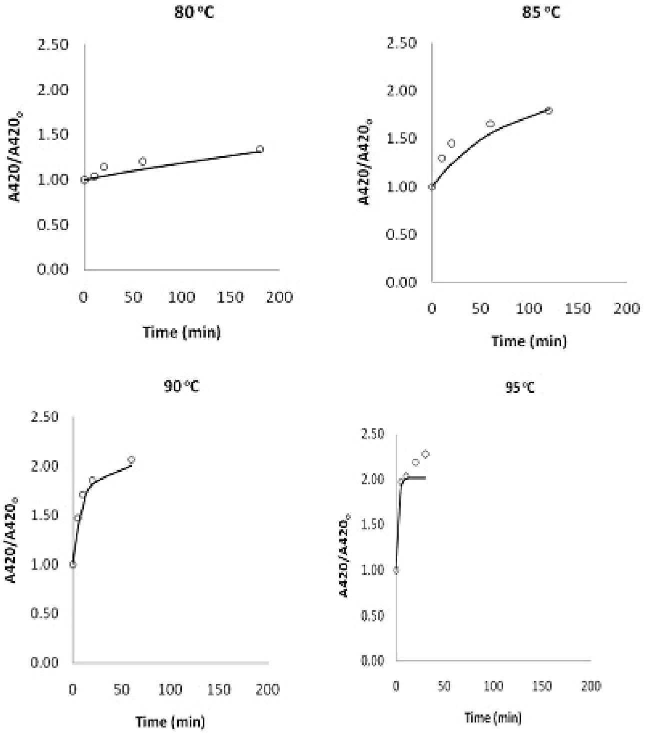

Fig. 6 Effect of temperature and time on the degree of non-enzymic browning in sweet potatoes, at the temperature range of 80–95°C. (○) experimental values with heating processes; (–) model predicted values for heating processes.

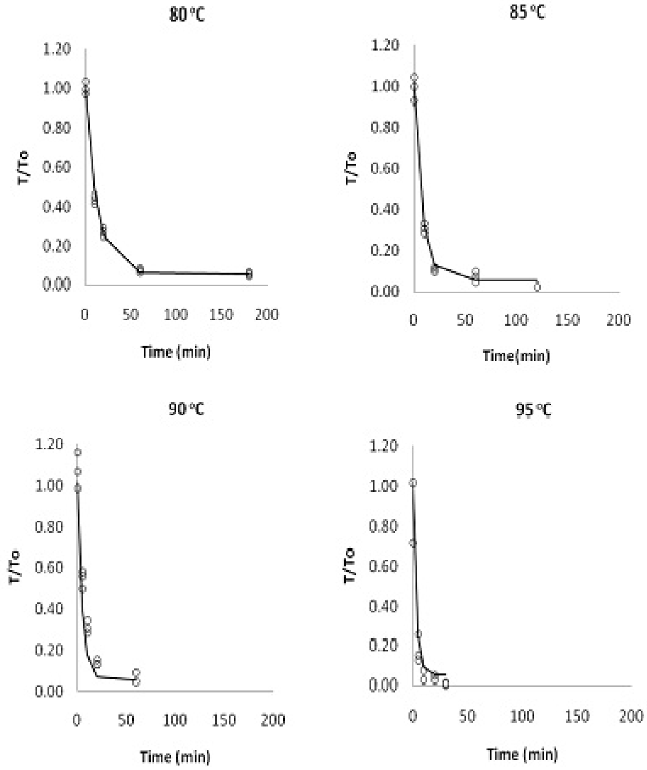

Fig. 7 Effect of temperature and time on peak load/firmness of sweet potatoes, in the temperature range of 80–95°C. (○) experimental values with heating processes; (–) model predicted values for heating processes.

Non-enzymatic browning

Non-enzymatic browning is the formation of dark-colored pigments in foods during processing and storage, which results from reactions between reducing sugars such as fructose and glucose on one hand, and protein and its derivatives (amino acids and amides) on the other (Maillard 1912). As the sugar concentration decreased, an increase in the degree of non-enzymatic browning was seen across the time-temperature combinations studied. At an initial sugar concentration of 17.35 ± 0.057 g/100 g of sweet potato, the non-enzymatic browning value was 0.007 (absorbance value at 420 nm) and gradually increased at increasing temperatures and times of exposure (**Fig. 6**). The sucrose hydrolysis observed at increasing temperatures caused an increase in fructose and glucose contents and hence the consumption of these reducing sugars, which was attributable to the browning reactions. Therefore, the obtained increase of the browning rate at high amplitudes can be attributed to the decrease of sugar content (Yuan *et al.* 2009).

Texture degradation kinetics

Thermal texture degradation of sweet potatoes was investigated over a varying time and temperature periods. Long heating times were included in this study in order to estimate C_∞ correctly. In **Fig. 7**, the relative firmness (*i.e.* firmness of the sample divided by the firmness of the time-zero samples) is plotted as a function of the heating time. The data was modelled using a fractional conversion kinetic model (**Eq. 3**). This figure indicates that the fractional conversion kinetic model is suitable for modelling thermal degradation of sweet potato texture (R^2_{adj} = 0.9719) (**Table 7**). Rapid texture degradation was observed with increasing temperature and heating times, followed by a saturation phase where texture degradation rate slows down, until an equilibrium texture property is achieved. Similar results have been reported by Abu-Ghannam (1998) when modelling the textural changes of legumes and red kidney beans. The texture degradation of sweet potatoes had an Ea of 101.13 ± 14.22 KJ/mol which is close to the values reported by Vu *et al.* (2004) as 117.56 ± 10.55 KJ/mol for texture degradation in carrots. However Cunningham *et al.* (2008) reported for common potatoes soaked in water in the temperature range of 20-80°C a lower value of 41.12 kJ/mol.

Table 7 Kinetic parameters of properties utilized for optimization.

Kinetic parameters	Ascorbic acid	Non-enzymic Browning	Texture
C0	0.9966 ± 0.017	1.0550 ± 0.032	1.0202 ± 0.029
C∞	0.2412 ± 0.011	2.1261 ± 0.043	0.0509 ± 0.0020
Ea (KJ/mol)	101.70 ± 14.66	389.27 ± 26.86	101.13 ± 14.22
Kref (min^{-1})	0.2444 ± 0.023	0.0331 ± 0.004	0.1611 ± 0.015
R^2adj	0.9905	0.9971	0.9719

Optimization of time-temperature conditions for the puree

The objective function of this optimization is to maximize the retention of ascorbic acid, while reducing non-enzymatic browning and obtaining good firmness, necessary for the weaning puree. The mathematical models previously obtained and the respective kinetic parameters, activation energy, *Ea* and rate constant k_{ref} (at a reference temperature of 87.5°C) obtained for texture, non-enzymatic browning and ascorbic acid (**Table 6**) were utilized in **Equation 6**. These equations were derived from the fractional conversion model to obtain time (t) at different temperatures that will correspond to different percentage retentions (X) limiting it to ≤ 60%.

$$t = \frac{\ln X}{K} \qquad (6)$$

Fig. 8 shows the graph of time (t), obtained plotted against temperature. The coarse line represents the vitamin C concentration at different retentions (60, 70, 80 and 90%), the dash line representing non-enzymatic at different colour retentions (60, 70, 80 and 90%) and the round dots representing texture at different levels of cooking; A (well-cooked), B (moderately cooked) and C (not cooked). Therefore, a point was reached and determined to obtain a time

Table 8 Validation of the optimized processing conditions.

Temperature (90°C)	Processing time (min)	Texture (firmness)	Non-enzymic browning (%)	Vitamin C
% retention (validation)	7	54 ± 6	80.8 ± 3	70.2 ± 5
% retention (predicted)	7	60 ± 0.02	90 ± 0.015	60 ± 0.31

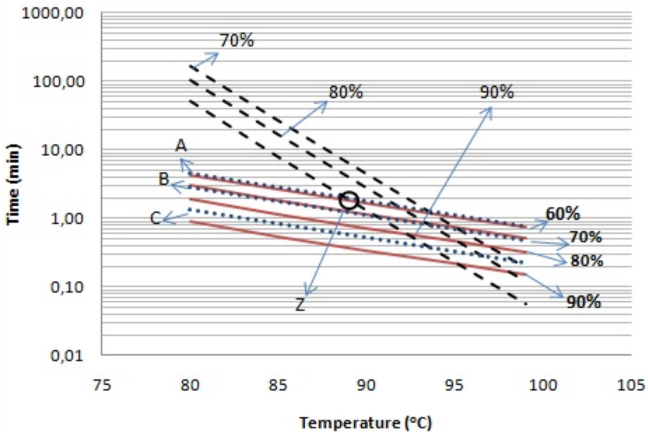

Fig. 8 Graphical optimization of the cooking conditions (time-temperature profile) of sweet potato puree. Coarse line represents the optimization of ascorbic acid retention; corresponding to 60, 70, 80 and 90% retentions, the dashed line for the non-enzymic browning; corresponding to 70, 80 and 90% retentions and the round dots for the texture; A (well-cooked), B (moderately cooked), C (not-cooked) corresponding to 60, 70 and 80% firmness lost. The interception of the three lines, presented by point Z, gave a 'sweet spot'; a time and temperature combination (90°C and 7 min) where a maximum firmness lost, colour and ascorbic acid retention are reached.

and temperature combination where there is maximum retention of ascorbic acid, high colour retention and good firmness, this point represents Z as can be seen in **Fig. 8** and this point corresponded to 90°C and 7 min.

Validation of optimized conditions of the puree

The firmness, non-enzymatic browning and ascorbic acid were tested for at the optimized conditions obtained (90°C for 7 min) and the values obtained and its percentage retention compared with the predicted values are presented in **Table 8**. It can be seen that at a temperature of 90°C, the sweet potato sample is well cooked (54 ± 6% firmness loss), enough to allow for easy mashing to obtain the puree during the weaning food preparation, although slightly lower than the predicted (60 ± 0.02%), also the percentage of ascorbic acid retention (70.2 ± 5%) obtained was slightly higher than the predicted (60 ± 0.31%) and a good colour retention (80.8 ± 3%) was observed, which is also slightly lower than the predicted (90 ± 0.015%).

Potential use of sweet potato purée in baby food in developing countries

Based on the result obtained from the optimization, the best cooking conditions were found (a time and temperature combination) minimizing therefore the degradation of the main ingredient in a weaning food, the sweet potato puree. According to USDA (2002), the recommended daily allowance (RDA) of vitamins and proteins for adequate growth and development of babies are vitamin A – 800 µg, vitamin B1 – 1.4 mg, vitamin B2 – 1.6 mg, vitamin B6 – 2 mg, vitamin B12 – 1 µg, vitamin C – 60 mg, vitamin D – 5 µg, vitamin E – 10 mg. In order to meet these requirements, the necessary ingredients which will fortify and supplement some nutrients that might be lost despite the use of the optimized cooking conditions of the sweet potatoes puree will be: the addition of coconut milk, soy milk and orange juice, which are rich in vitamin A, C and E to a formulation would fulfill these requirements with an additional protein supplementation by soy milk. The vitamin C derived from the addition of orange juice, apart from making up for the RDA required of vitamin C for babies, also served to improve the flavor and colour of the puree, to give it an attractive and appealing look. In addition, it also served as an anti-oxidant to reduce the risk of microbial contamination of the finished product, whilst the fructose acted as a sweetener to make it more enjoyable. To complement this recipe, it is very important to use boiling/warm water to mix the formulae composition, before feeding the babies with it, so as to reduce or maintain the microbial load to the minimum limits specified for their body system. In **Fig. 9** a flowsheet for a production line of a dried weaning porridge that includes sweet potato is proposed.

CONCLUSION

The optimized cooking conditions for the puree, which are a temperature of 90°C and a duration of 7 min, obtained from this study for a weaning food formulation was efficient for the control of the firmness, colour retention and ascorbic acid. The consumer acceptability and market survey of this formulation will be a major area for future research.

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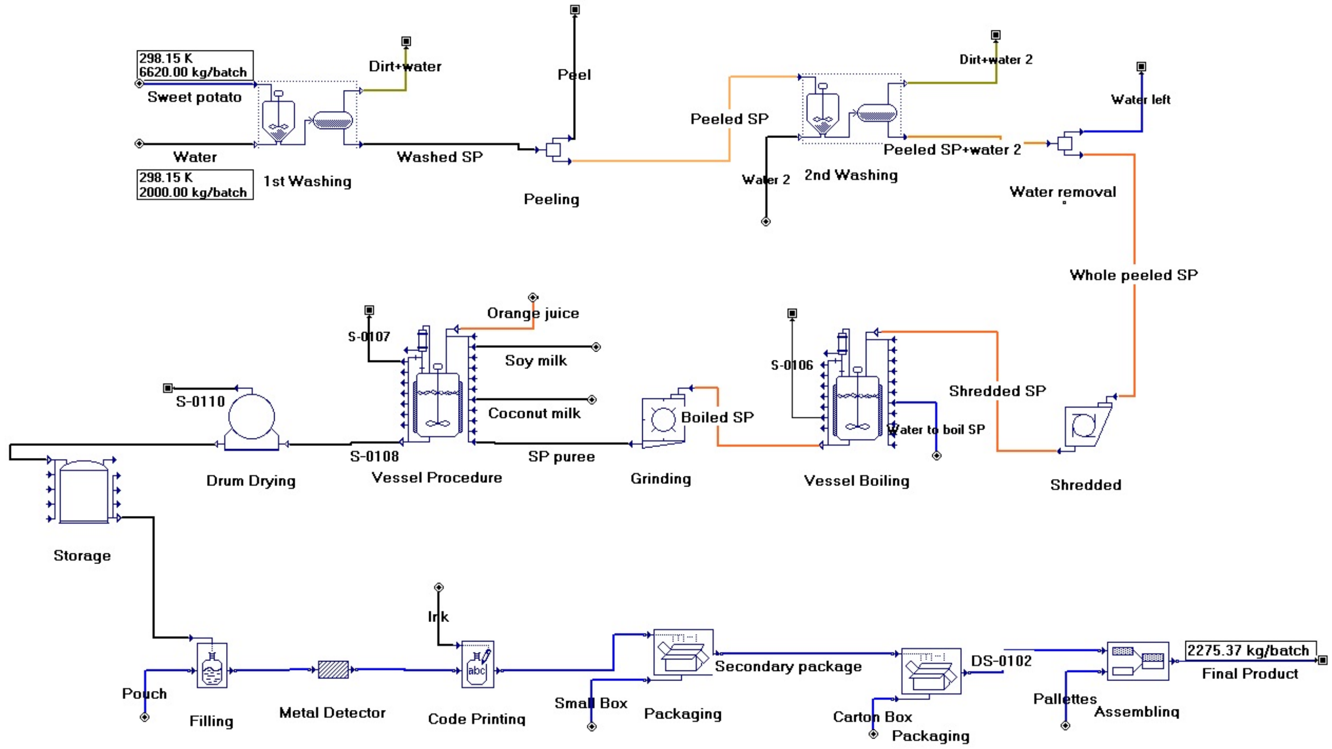

Fig. 9 Proposed production line of the sweet potato.

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