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Development of Osmotically Dehydrated Sweet Potato (*Ipomoea batatas* (L.) Lam.) Slices Incorporated with Pineapple Juice and Evaluation of its Chemical and Nutritional Properties

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Abstract: Sweet potato (Ipomoea batatas (L.) Lam.) is a relatively underutilised root crop with numerous health and nutritional benefits. It can potentially serve as the primary source of nutrition in many underdeveloped countries. Osmotic dehydration is a food processing technique employed to lower foods' water content, thereby improving their shelf life. The process may also render the product with an enhanced appearance and sensorial properties. The present study analysed sweet potatoes for their physicochemical properties. The process parameters for the development of osmotically dehydrated sweet potato slices incorporated with pineapple juice were optimised based on sensory evaluation. The optimum process parameters were found to be an osmotic solution concertation of 55 °Brix with 20% pineapple juice (v/v) and 1.5% citric acid (w/v) over a drying time of 6.75 hrs. The developed product was analysed for its physicochemical properties. The samples prepared at the optimised conditions were found to be shelf stable over a period of 6 months.

Keywords: Sweet potato, osmotic dehydration, pineapple, optimisation, storage

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1. Introduction

Sweet potatoes (*Ipomoea batatas* (L.) Lam.) are dicotyledonous plants belonging to the family Convolvulaceae. Their edible root is covered with a thin, smooth skin whose colour may range from red, purple, or brown to white even. The colour of its flesh may be white, yellow, orange or purple (Camire *et al*. 2009). It is the only known hexaploid morning glory (6n = 90) (Jones, 1965). It is a nutritious vegetable that is rich in vitamin A precursor, calories, and fibre and contains a

small amount of protein. Sweet potatoes contain about 70% of carbohydrates on a dry basis, mostly starch, that could potentially be utilized for their functional properties like controlling the rate of heating during cooking (Hoover, 2001). Sweet potatoes made up roughly 20% of the total world production of root and tuber crops (FAO, 1999). Owing to its high nutritional value and high β-carotene content, the National Aeronautics and Space Administration (NASA) has selected it as a candidate crop for space missions.

Despite its nutritional properties and ability to grow in a range of environmental conditions, sweet potatoes have been a somewhat underutilized food crop globally (Woolfe, 1992; Bovell-Benjamin, 2007). As it can be harvested sequentially, it ensures continuous food availability, an important aspect of food security (Motsa *et al.* 2015). About 25% of the total annual yield loss can be attributed to drought stress for sweet potatoes, as opposed to over 50% or complete failure in staple crops like maize (Earl and Davis, 2003).

Osmotic dehydration is a process by which water is removed by immersing the water-containing solid in a concentrated aqueous solution (Ponting, 1973). A simultaneous mass transfer between an osmotically active solution and the food product is observed (Ramya and Jain, 2016). Eliminating moisture from the product reduces the total amount of water available for spoilage microorganisms, fungi and other pathogens. Osmotic dehydration is a great way to increase the shelf life of perishable food products (Yadav and Singh, 2014).

In the present study, the process of osmotic dehydration was optimised along with the incorporation of pineapple juice and the shelf life was evaluated for 6 months.

2. Materials and Methods

2.1. Materials

Fresh pineapples and sweet potatoes were sourced from Devaraja Market, Mysore, Karnataka. Sugar was sourced from the local market whereas all chemicals were procured from Hi-media Laboratories, Mumbai and Merck India, Bangalore, India.

2.2. Methods

2.2.1. Selection and Pre-processing of Fruits and Vegetables

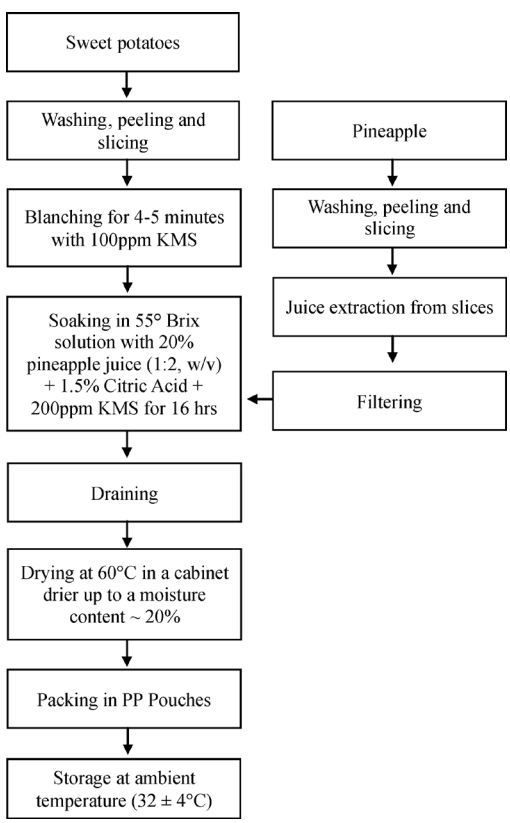
Sweet potatoes and pineapples that showed any signs of mechanical damage or spoilage were discarded. They were then washed thoroughly in running water until they were free from any adhering dirt particles. The sweet potatoes were peeled, sliced and diced into pieces roughly 0.5 cm thick and then blanched

with 100 ppm of KMS for 4-5 minutes. The pineapples were cut into moderately sized pieces and blended. The filtrate was simmered on a low flame and the froth was skimmed off the top. The juice obtained was re-filtered.

2.2.2. Osmotic Treatment and Drying with Varying Conditions

Osmotically active solutions of varying concentrations were prepared by dissolving an appropriate amount of sugar in water and boiling the solution. The solutions were continuously monitored for their Brix value by using a refractometer. The prepared solutions were allowed to cool. A varying amount of citric acid (0.5 – 2%), pineapple juice (10 – 25%) and 200 ppm of KMS was added to the solutions. The slices were then dipped in the osmotic solutions in the ratio of 1:2 (w/v) with varying amounts of soaking time. The slices were drained off completely and dried in a cross-flow cabinet drier at 60°C until the moisture content reached approximately 20%. The slices were packed and sealed in a PP pouch and stored at ambient temperature (32 ± 4°C).

Osmotic dehydration of sweet potatoes incorporated with pineapple juice



2.2.3. Optimization

The optimisation was carried out based on trial and error coupled with the sensory evaluation of the trials run to find the best combination of process parameters.

2.2.4. Physicochemical Analysis

All samples were ground/macerated accordingly prior to analyses for uniformity. All analyses were carried out in duplicates.

2.2.4.1 Proximate Analysis: Moisture content was determined by the AOAC (1997) Method. The samples were dried at 105 ± 2°C until a constant weight was obtained. Total ash content was estimated by the AOAC (1984) Method. The total ash value was represented by the weight of the inorganic matter post burning the organic matter in a muffle furnace at 560 ± 10°C. Total protein content was estimated by Kjeldahl Method (AOAC, 1997). Approximately 1g of the sample was digested with 25 ml of concentrated sulphuric acid and a pinch of digestion mixture until the mixture was completely clear. The solution made up to 100 ml was distilled on a Kjeldahl steam distillation system (Kelplus Classic DX Vats (E), Pelican Equipment's, Chennai, India) with 25ml of 40% sodium hydroxide and 10ml of 2% boric acid solution containing 2 drops of mixed indicator. About 75-100ml of distillate was obtained, which was then titrated against standardised 0.1N hydrochloric acid until an end point marked by a change of colour to pale pink was observed. Total nitrogen and protein content was expressed as a percentage by application of suitable equations. Fat estimation was carried out on a Soxhlet apparatus (AOAC, 1997). Moisture-free samples were placed in a reflux condenser with petroleum ether (boiling point 80 - 100°C) as the solvent. The apparatus was allowed to run for 16 hours, post which the amount of fat was estimated by the increase in weight of the round bottom flask. Reducing and total sugars were estimated by the DNSA method described by Miller, 1959. A standard glucose solution (1mg/ml) was prepared and the sample was extracted with distilled water. The standard solution was pipetted in test tubes ranging from 0 to 1 ml and 1 ml of the sample solution was pipetted. The tubes were placed in a boiling water bath for 5 minutes after the addition of 2 ml of DNSA. 1 ml of sodium potassium tartrate was added and the volumes made up to 10 ml. The absorbance was read on a UV-Visible Spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) at 560nm against a reagent blank. 20 ml of the sample solution was left overnight for inversion after the addition of 5 ml concentrated hydrochloric acid which was neutralised with 1N sodium hydroxide using phenolphthalein as the indicator.

The neutralised solution was made up to 100 ml. Total sugars were estimated by following the steps followed for reducing sugar estimation. Crude fibre was estimated by the acid-alkali hydrolysis method (AOAC, 1995). About 3-4g of fat-free samples were digested with 0.255N sulphuric acid and 0.313N sodium hydroxide in a fibre analyser (Fibretherm FT12, Gerhardt, Germany) for 3 hours. The amount of crude fibre was estimated by the loss in weight after burning the residue obtained in a muffle furnace. Carbohydrate content was estimated by the difference, that is, by subtracting the sum of the values of moisture, ash, protein, fat and crude fibre from 100 (per 100 g). Energy content was estimated by adding the values for carbohydrate, fat, and protein using the factors – 16.736 kJ, 37.656 kJ and 16.736 kJ, respectively.

2.2.4.2. Vitamin Assay: Ascorbic acid was estimated by the titrimetric method using 2,6-dichlorophenol-indophenol dye (AOVC, 1966; Johnson, 1948). An ascorbic acid standard (0.1mg/ml) and the 2,6-dichlorophenol-indophenol dye were prepared. The dye was standardised against a mixture of 3% metaphosphoric acid and the prepared ascorbic acid solution until a persistent pale pink colour appeared. The dye factor, i.e., mg of ascorbic acid per ml of the dye was calculated. The value of ascorbic acid was estimated by titrating the sample solution against the dye for the appearance of a persistent pale pink colour.

2.2.4.3 Chemical Analysis: Titratable acidity was determined by titrimetric estimation (AOAC, 1984). The pH was determined by using a pH meter (Century, Model CP 931, Bangalore, India). Total phenolic content was estimated by the method described by Singleton and Rossi (1965).The sample was macerated with 50% methanol and left overnight in a dark environment. A gallic acid standard (0.1mg/ml) was prepared. The standard was pipetted in test tubes ranging from 0.5 to 2.5 ml. 1 ml of Folin-Ciocalteu reagent was added to all tubes and left for 6 minutes. At the seventh minute, 10ml of 7% sodium carbonate was added. The volumes were made up to 25 ml and left for 90 minutes in a dark environment. The absorbance was read on a UV-Visible Spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) at 750nm against a reagent blank. Total flavonoid content was estimated by the method described by Zhi-shen *et al.* (1999). The sample was macerated with 50% methanol and left overnight in a dark environment. A catechin standard (0.1mg/ml) was prepared. The standard was pipetted in test tubes in the range of 0.5 to 2.5 ml. 0.3ml of 5% sodium nitrite was added to all the tubes and allowed to stand for 5 minutes. At the sixth minute, 0.3ml of 10% aluminium chloride was added and allowed to stand for 6 minutes. At the seventh minute, 2ml of 1N sodium

hydroxide was added and the volumes were made up to 10ml by adding 2.4ml of distilled water. The absorbance was read on a UV-Visible Spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) at 510nm against a reagent blank. Water activity was measured on a digital water activity meter (Aqua Lab, Model 3T E, Decagon Devices, Pullman, USA). The water activity meter was calibrated using standard solutions of water activity levels of 0.250, 0.500, 0.760, and 0.984 provided by the original manufacturers (Decagon, Pullman WA, USA). CIE colour coordinates (L*, a*, b* values) were measured using a D-65 illuminant and a 10° observer. The equipment (Mini Scan XE Plus, Model No. 45/0-S, Hunter Associates Laboratory Inc., Reston, VA, USA). The colourimeter was calibrated using blank and white ceramic tiles provided by the original manufacturers (Hunter Associates Laboratory Inc., Reston, VA, USA). The colour coordinate readings were recorded using the inbuilt software Easy Match QC (Hunter Associates Laboratory Inc., Reston, VA, USA).

2.2.4.4. Texture Analysis: Firmness was evaluated using a texture analyser (TAHDi, Stable Microsystems, London, UK) loaded with Texture Expert Software (Version 1.22, Stable Microsystems, London, UK). The texture analyser was equipped with a 100kg load cell. The firmness readings were recorded with a Warner–Bratzler Blade shearing through the sample at 1 mm/s with automatic return. The downward distance was set to 100% of the sample width, and the pre-test and post-test speeds were set to 2 mm/s and 5mm/s, respectively. The samples were positioned so that the probe penetrated their geometric centre. The firmness results were expressed as the maximum force (N) required for shearing the sample.

2.2.4.5. Enzyme Activity Assay: Polyphenol oxidase activity was estimated by the procedure described by González *et al.* (2000). A 0.1M sodium phosphate buffer (pH 7.0) and a 5 mM catechol standard were prepared. The sample was homogenised in 20 ml of the buffer in ice-cold conditions which was then filtered and centrifuged at 3,500 RPM for 25 minutes. The supernatant was suitably diluted with the buffer. The sample for spectrophotometric analysis was prepared by taking 4ml buffer, 0.8ml catechol, 6.2ml distilled water and 1ml of the diluted supernatant obtained post centrifugation. The absorbance was measured on a UV-Visible Spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) against a reagent blank. Peroxidase activity was estimated by the procedure described by González et. al (2000). A 1M dipotassium hydrogen phosphate buffer (6.5 pH) and a substrate solution were prepared by mixing 0.1ml guaiacol (99.5%), 0.1ml hydrogen peroxide (30%) and 99.8ml of the 1M buffer solution. The sample was homogenised in 20 ml of the buffer in ice-cold

conditions which was then filtered and centrifuged at 0°C at 12,000 RPM for 15 minutes. The supernatant was suitably diluted with the buffer. The sample for spectrophotometric analysis was prepared by mixing 3.48ml of the substrate solution and 0.12ml of the diluted supernatant obtained post centrifugation which was then vortexed prior to analysis. The absorbance was measured on a UV-Visible Spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) against a reagent blank.

2.2.4.6 Sensory Evaluation: The sensory attributes of the Osmodehydrated sweet potato slices were evaluated for their texture, mouthfeel, colour, taste and overall acceptability by a trained panel of 12 members of the scientific staff of the laboratory with knowledge of consumer preferences using a 9-point hedonic scale.

2.2.4.7 Storage Analysis: Storage studies were conducted for the osmotically dehydrated sweet potato slices stored at ambient temperature (32 ± 4°C) for their quality parameters.

2.3. Statistical Analysis

Statistical analysis was carried out on Microsoft Excel 2016. Results were expressed as mean ± SD of the data obtained from duplicates.

3. Results and Discussion

3.1. Physicochemical Analysis of Fresh Sweet Potato vs Developed Product

The physicochemical properties, proximate composition and enzyme activity (polyphenol oxidase and peroxidase) of fresh sweet potatoes were recorded and reported on a fresh-weight basis.

3.1.1. Proximate Analysis

A stark contrast between the moisture content levels was observed. Fresh sweet potatoes were estimated to contain 76 ± 0.49% of moisture, while the osmotically dehydrated product was estimated to contain a much lower 18.07 ± 0.11%. This was due to the loss of moisture as a result of osmotic dehydration coupled with conventional drying. The reported values for fresh sweet potatoes were higher than those reported by Rose and Vasanthakaalam (2011): 62.58 ± 0.70% to 64.34 ± 0.42% but in line with those reported by Aina et al (2009): 62.9% to 83.8%. Protein content was found to be comparable between the two. The developed product showed a marginally higher percentage of protein content. This may

be attributed to the addition of pineapple juice to the osmo-active solution. The effect of osmosis was most evident from the values of reducing and total sugars. The difference can be attributed to the influx of sucrose molecules, thereby increasing the sugar content in the developed product. Crude ash and crude fibre content were found to be comparable between the two. Fat content was relatively low, at 0.89 ± 0.1% which remained unchanged post-processing. Carbohydrate content was estimated to be 20.04% in fresh sweet potatoes as opposed to a much higher 73.83% in the developed product. This could certainly be a result of osmotic treatment in the sucrose solution leading to the uptake of sucrose molecules. Energy content was substantially higher in the developed product at 1,340.594 kJ/100g as opposed to fresh sweet potato with a value of 388.315 kJ/100g. This could be largely attributed to the osmotic treatment leading to the uptake of sucrose molecules (Table 1).

Table 1: Comparison of the proximate composition of fresh sweet potato and osmotically dehydrated sweet potato slices

Parameter	*Quantity*	
	Fresh sweet potato	*Osmotically dehydrated sweet potato slices*
Proximate		
Moisture	76 ± 0.49%	18.07 ± 0.11%
Protein	1.16 ± 0.08%	2.56 ± 0.08%
Reducing Sugars	37.878 ±0.36 mg/100g	134 ± 0.56 mg/100g
Total Sugars	50.052 ±1.01 mg/100g	482.23 ± 1.73 mg/100g
Fat	0.89 ± 0.1%	1.65 ± 0.46%
Crude Ash	0.63 ± 0.02%	1.28 ± 0.01%
Crude Fibre	1.28 ± 0.42%	2.61 ± 0.03%
Carbohydrate	20.04%	73.83%
Energy Content	388.315 kJ/100g	1,340.594 kJ/100g

3.1.2. Vitamin Content and Chemical Analysis

A sharp decline in Vitamin C content was observed in the osmotically dehydrated sweet potato slices. This was a73.65% drop from 15.26 mg/100g to 4.02 mg/100g due to the heat treatment of the sweet potatoes while blanching and subsequent hot air drying. Ikanone and Oyekan (2014) reported a substantial 72.37% reduction in vitamin C content upon boiling: down from 70.69 mg/100ml to 19.53 mg/100ml.

There was a noticeable reduction in the pH and titratable acidity (expressed as % citric acid). pH was estimated at 4.75 ± 0.01, a reduction from

the original 5.13 ± 0.01. Titratable acidity, on the other hand, showed a decrease from 0.094% to 0.414%. These results may be attributed to the incorporation of pineapple juice and citric acid in the osmo-active solution, leading to the increase in acidity.

Water activity showed a decline from the original 0.952 ± 0.02 to 0.685 ± 0.03 due to osmotic coupled with conventional air dehydration. The lowered water activity would form the basis of the product's extended shelf life.

Total phenolic and total flavonoid content was relatively unchanged between fresh sweet potatoes and the developed product. This could imply that the attributes were unaffected by blanching, osmotic treatment and hot air drying (Table 2) The total phenolic values obtained for fresh sweet potatoes were comparable to those estimated by Rumbaoa et al, between 50.1 ± 4.1 to 362.8 ± 10.3 mg GAE/100g of sample on a wet basis.

Table 2: Comparison of the vitamin and chemical composition of fresh sweet potato and osmotically dehydrated sweet potato slices

Parameter	*Quantity*	
	Fresh sweet potato	*Osmotically dehydrated sweet potato slices*
Vitamins		
Vitamin C, total ascorbic acid	15.26 mg/100g	4.02 mg/100g
Chemical Composition		
pH	5.13 ± 0.01	4.75 ± 0.01
Titratable Acidity (% Citric Acid)	0.094%	0.414%
Water Activity	0.952 ± 0.02	0.685 ± 0.03
Total Phenolic Content	81.59 ± 0.63 mg GAE/100g FW	134.52 ± 0.18 mg GAE/100g FW
Total Flavonoid Content	32.76 mg CE/100g FW	65.37 ± 0 mg CE/100g FW

3.1.3. Texture Analysis

Fresh sweet potatoes and the developed product were tested for their firmness using a Warner-Bratzler blade shearing through the samples. The maximum force required for the sample to be sheared was found to be 68.13 ± 4.62 N for the fresh sweet potatoes whereas it was found to be 37.97 ± 5.38 N for the product. This reduction in firmness was due to the water loss upon osmotic treatment followed by conventional drying that led to the slices becoming softer, thereby requiring a lower amount of shearing force to be cut.

3.1.4. Enzyme Activity Assay

The polyphenol oxidase and peroxidase activities for fresh sweet potatoes were reported to be 128.27 ± 2.04 units/g/min and 527.13 ± 14 units/g/min,

respectively. These results pointed toward high enzymatic activity potentially leading to faster browning of the root tissues. The osmotically dehydrated product on the other hand reported a significant decrease in its enzyme activity. Polyphenol oxidase activity was found to be non-detectable. Peroxidase activity was lowered to 50.14 ± 8.21 units/g/min. This drop could be due to a loss in activity rendered by the heat treatment during blanching and conventional hot air drying.

3.1.5. CIE Colour Coordinates

The CIE colour coordinates represented a shift from a brighter, lighter colour of the fresh sweet potatoes to a darker, deeper shade of yellow post-processing (Table 3). A reduction in the L* value represented a drop in lightness. The a* values were comparable, indicating a minor shift in the green hues. On the other hand, the b* values dropped considerably from 20.97 to 8.27 representing a drop in yellow hues to a darker shade.

Table 3: CIE colour coordinates of sweet potato and osmotically dehydrated sweet potato slices

CIE Colour Coordinates	*Fresh Sweet Potato*	*Osmotically Dehydrated Sweet Potato Slices*
L*	60.62	30.58
a*	0.85	2.15
b*	20.97	8.27

3.2. Optimization of Osmotic Solution Concentration, Percentage of Pineapple Juice and Citric Acid, and Drying Time

Optimisation of the variables was carried out based on trial and error coupled with sensory evaluation to arrive at the best possible combination of process parameters. There were five sets of process variable combinations. The preferred combination was selected based on the overall acceptability of the product developed in each case.

3.3. Effect of Osmotic Solution Concentration, Percentage of Pineapple Juice and Citric Acid on Weight Reduction and Overall Acceptability

An increase in osmotic concentration generally resulted in an increased degree of weight reduction post-drying. The reduction in weight post-drying was found to be the highest in trial 2 at 50.02%, whereas the least in trial 1, being

32.41%, respectively. In terms of overall acceptability, trial 5 delivered the best results, scoring 8 on the 9-point hedonic scale, whereas trial 3 yielded the least satisfactory results, scoring 6.8 (Table 4).

Table 4: Effect of process parameters on yield and overall acceptability

Trial No.	*Osmotic Solution Concentration (°Brix)*	*Citric Acid (%)*	*Pineapple Juice (%)*	*Yield (%)*	*Overall Acceptability*
1	55	0.5	10	32.41	7.4
2	60	1.0	25	50.02	7
3	55	1.0	20	45.20	6.8
4	55	2.0	20	37.05	7.7
5	55	1.5	20	36.80	8

The optimum process parameters were found to be an osmotic solution concertation of 55 °Brix with 20% pineapple juice (v/v) and 1.5% citric acid (w/v) over a drying time of 6.75 hours. These conditions yielded a product with an appealing appearance and a good sugar-acid balance. The product had a soft, chewy texture.

Sweet potatoes after osmotic treatment

Sweet potatoes after osmotic treatment and conventional drying

3.4. Sensory Evaluation

The developed product was found to possess good sensorial attributes, scoring 8.42 ± 0.19 in terms of overall acceptability (Table 5).

Table 5: Sensory attributes of osmotically dehydrated sweet potato slices

Texture	*Mouthfeel*	*Colour*	*Taste*	*Overall Acceptability*
8.17 ± 0.33	8.33 ± 0.33	8.42 ± 0.19	8.46 ± 0.33	8.42 ± 0.19

Note: Data reported as a mean of 12 values ± SD.

3.5. Storage Analysis

Post a storage period of 6months under ambient conditions (32 ± 4°C), the water activity was found to have increased from 0.685 ± 0.03 when fresh to 0.743 ± 0.01 (Table 6). The CIE colour coordinates were expressed in terms of L*, a* and b*. They were held to be 23.49, 2.56 and 10.86, respectively (Table 7). Upon visual inspection, the slices showed some scattered areas of white discolouration. However, no mould growth was observed (Figure 3.1).

Table 6: Effect of storage on water activity of osmotically dehydrated sweet potato slices

Parameter	*Storage Period*	
	0 Days	*180 Days*
Water Activity	0.685 ± 0.03	0.743 ± 0.01

Table 7: Effect of storage on colour coordinates of osmotically dehydrated sweet potato slices

Colour Coordinate	*Storage Period*	
	0 Days	*180 Days*
L*	30.58	23.49
a*	2.15	2.56
b*	8.27	10.86

4. Conclusion

A good quality osmotically dehydrated product could be made from sweet potatoes by immersing the slices in sugar solution and pineapple juice. The product was found to have excellent sensory attributes and could be stored for 6 months under packed conditions at room temperature.

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