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Biochemical Changes in Cream and Orange-fleshed Cured Sweet Potatoes Cooked under Different Modes

Jyothi G. Krishnan[1], G. Padmaja[1], S. N. Moorthy[1], G. Suja[1] and J. Sreekumar[2]

[1]Division of Crop Utilization, Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram-695 017, Kerala, India

[2]Section of Extension and Social Sciences, Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram-695 017, Kerala, India

Corresponding author: G. Padmaja, email: padmajabn@yahoo.com

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Abstract

The importance of sweet potato (*Ipomoea batatas* L.) as a health food, contributed by carotenoids, anti-oxidants, phenolics, dietary fiber and anthocyanins is increasingly recognized in several countries. Browning, resulting from enzymatic and non-enzymatic reactions is a major problem for processed sweet potato. With a view to developing functional foods from sweet potatoes, the biochemical changes during curing of cream and orange-fleshed sweet potatoes and during cooking under different modes like boiling, microwave baking and hydro-thermal cooking were studied at Central Tuber Crops Research Institute, Thiruvananthapuram, India. Decrease in starch and increase in sugars during curing were more in the orange-fleshed variety, while total free amino acids and phenols did not change during curing. Citric acid/ascorbic acid and sodium sulfite promoted more leaching of starch during boiling, especially from cream-fleshed variety. Microwave baking (900 W; 5 min) of fresh and cured sweet potatoes, resulted in a sharp decrease in starch and increase in sugars. Retention of amino acids was maximum in hydro-thermally cooked roots. Total phenolics increased in whole roots with peel during boiling/hydro-thermal cooking, while microwave baking resulted in lower phenol levels. Microwave baking of cured sliced sweet potato roots was the best technique to reduce starch and increase soluble solids, with very low levels of total phenols.

Key words: Sweet potato, cooking, microwave baking, phenols, amino acids

Introduction

Sweet potato (*Ipomoea batatas* Lam) ranks seventh among the food crops of the world and is important in the subsistence farming systems of Asia and Africa. Approximately 90% of the world production is from the developing nations, with China topping the list. The roots as well as leaves are used as animal feed in China, Papua New Guinea, India and Vietnam (Woolfe, 1992), while several value added food products are made from sweet potato roots in China, Japan, New Zealand and Southern United States. Nutritionally, the roots are rich in starch, vitamins and minerals (Bouwkamp, 1985; Padmaja, 2009; Woolfe, 1992). Besides the major nutrients, sweet potatoes are a rich source of phytonutrients like dietary fiber (Philpott et al., 2003) and anti-oxidants (Hayase and Kato, 1984). Sweet potatoes are processed into several products like canned roots, puree, flakes and dehydrated powders to ensure round-the-year availability and to reduce the post harvest losses (Woolfe, 1992). The quality of the roots and the

resultant products are reported to be improved, when the harvested roots are cured for 7-10 days at 28-30° C and relative humidity of 80-85% (Hamann et al., 1980). Curing is practiced to rapidly heal the damaged surface so that further weight loss and pathogen attack during storage could be prevented (Heinze and Appleman, 1943; Kushman et al., 1977; Walter, 1987). Cured sweet potatoes are reported as most suitable for making flakes due to the high soluble solids content that could be achieved in the puree (Scott and Matthews, 1957; Spadaro et al., 1967). Cooking is an invariable step in the production of processed products like puree and flakes, besides direct consumption as food and several reports are available on the process modifications during cooking for obtaining the desired quality of products (Spadaro et al., 1967; Wadsworth et al., 1966; Deobald et al., 1969). Purcell and Walter (1982) reported the comparative loss of amino acids during baking, canning and flake manufacture. Changes in total phenolics during steam cooking (peeled or whole) of three cultivars of sweet potato were reported by Troung et al. (2007), who found that the phenolics increased on cooking. Microwave processing is practiced in various unit operations in many industries, although non-uniform distribution of heat in the material is reported to result in hot and cold spots in the product (Cha-um et al., 2009; Vadivambal and Jayas, 2009). The present study was designed to compare the biochemical changes occurring during curing of two sweet potato varieties as well as during cooking the roots (fresh vs. cured) under different modes like boiling, microwave baking and hydrothermal cooking and to understand how the varietal differences affect the biochemical changes among cream and orange-fleshed sweet potatoes during cooking.

Materials and Methods

Materials

Two released varieties of sweet potato from Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram, Kerala, India, *viz.*, Sree Arun (pale cream-fleshed) and Sree Kanaka (orange-fleshed) grown under identical management conditions at the Institute Farm, CTCRI were utilized for the study.

Processing of roots

The freshly harvested un-damaged roots of the two sweet potato varieties were divided into two parts and one part was used for the cooking experiments on fresh roots. The other part was kept for curing in a plastic bucket with removable loose lid at 27° C and relative humidity of 80-82% for 10 days.

Fresh as well as cured roots were cooked in three methods/forms such as whole roots with peel (M1), whole roots without peel (M2) and sliced (M3; 1.0 cm thick round discs) roots. These three forms were cooked in boiling water (1:4 w/v) (T1) or in solutions of citric acid (T2) or ascorbic acid (T3) (1.0%) or sodium sulfite (T4) (0.5%). Whole roots were cooked for 25 min while the sliced roots were cooked for only 20 min. The three forms of roots were also baked in a microwave oven (T5) (900 W; 5 min) or hydro-thermally cooked (T6) in a vegetable steam cooker (M/s TTK Prestige India Ltd., India) for 30 min. The three types of roots were separately kept over the porous plate in the cooker and exposed to steam from boiling water at 100°C.

Biochemical analyses

The fresh as well as cured roots were analysed for dry matter (DM), starch, total and reducing sugars, total phenols and total free amino acids. These parameters were also monitored in the roots cooked by the various modes. In the case of cooked/baked roots, the whole roots with peel after each processing operation were peeled and sliced for sampling, while the whole roots without peel were sliced and sampled. The DM content of the various samples was determined by the oven drying method (AOAC, 1995). The starch and sugars (total and reducing) were determined in the sweet potato root samples by the titrimetric method of Moorthy and Padmaja (2002). Total phenolics were extracted overnight using methanol (80 percent) and assayed using Folin-Ciocalteau reagent (Swain and Hillis, 1955). Total free amino acids were extracted using ethanol (80 percent) and quantified using ninhydrin reagent (Moore and Stein, 1948).

Statistical analysis

The experiments were conducted in a factorial mode in

Completely Randomized Block Design with four factors viz., treatments at six levels (water, citric acid, ascorbic acid, sodium sulfate, microwave baking, hydrothermal cooking), two varieties (Sree Kanaka and Sree Arun), methods or product form at three levels (whole roots with peel, whole roots without peel and sliced) and types of curing at two levels (fresh/no curing and cured). All the treatment combinations were compared with analysis results of fresh samples. The experiment was carried out according to four way factorial experiment with four replications. Statistical analyses were done for all parameters using One way Analysis of Variance and least significant difference test for comparing the means using the package Genstat DE (Genstat, 2008).

Results

Biochemical changes in cured sweet potato roots

The initial starch content in Sree Arun [73.77% dry weight basis (dwb)] decreased to 69.0% after the curing period. The decrease was however more in Sree Kanaka

Table 1. Effect of treatments, varieties, types and methods of cooking of sweet potato roots on the starch content (g 100g $^{-1}$ dry basis)

Treatments	Methods	Varieties			
		Sree Kanaka (V1)		Sree Arun (V2)	
		Type		Type	
		Fresh	Cured	Fresh	Cured
Fresh (untreated)		74.78±0.93	62.78±0.44	73.77±0.94	68.99±1.14
Water (T1)	Whole roots with peel (M1)	59.95±0.11	54.70±0.66	66.78±0.52	61.97±1.12
	Whole roots without peel(M2)	59.44±0.66	52.97±0.07	62.45±0.53	60.42±0.68
	Sliced roots (M3)	60.85±1.08	55.21±0.92	64.89±0.13	61.33±0.47
	Mean	60.08±0.61	54.25±0.55	64.71±0.39	61.24±0.76
Citric acid (1.0%; T2)	M1	58.62±1.12	55.06±0.13	61.30±1.45	54.14±0.86
	M2	57.37±0.76	52.57±0.67	61.70±1.71	56.19±0.55
	M3	57.68±1.04	53.05±0.54	60.76±0.28	54.51±0.59
	Mean	57.89±0.98	53.56±0.45	61.25±1.15	54.95±0.67
Ascorbic acid (1.0%; T3)	M1	56.23±0.52	52.04±0.09	56.92±0.78	51.04±0.82
	M2	56.75±0.50	57.95±0.82	59.20±0.54	50.13±0.85
	M3	53.12±1.03	55.82±1.29	60.80±0.91	52.61±0.72
	Mean	55.37±0.68	55.27±0.73	58.98±0.74	51.25±0.80
Sodium sulfite (0.5%; T4)	M1	57.61±1.13	51.05±0.82	61.40±1.07	53.69±0.86
	M2	57.04±1.11	54.92±1.07	61.25±0.50	56.76±0.51
	M3	53.96±0.09	53.68±1.50	60.49±1.00	54.25±0.95
	Mean	56.20±0.78	53.21±1.13	61.05±0.86	54.90±0.77
Microwave baking (T5)	M1	47.78±0.65	43.28±0.00	49.77±0.52	41.52±0.59
	M2	48.43±0.65	42.71±0.66	52.33±0.05	40.78±0.52
	M3	50.64±1.22	40.17±1.43	49.88±0.13	40.88±0.25
	Mean	48.95±0.84	42.05±0.70	50.66±0.23	41.06±0.45
Hydrothermal cooking (T6)	M1	57.36±0.47	51.24±0.95	67.00±1.46	61.29±0.00
	M2	57.87±0.27	52.87±1.02	67.71±0.86	60.84±0.61
	M3	56.47±0.54	53.52±0.99	66.06±0.93	59.78±0.00
	Mean	57.23±0.43	51.54±0.99	66.92±1.08	60.64±0.20
Treatment Mean		55.95±0.73	51.65±0.74	60.59±0.75	54.01±0.63

Each value is Mean ± SD from four replications; C.D (0.05) (Treatments): 0.3264; C.D (0.05) (Treatments and variety): 0.4616; C.D (0.05) (Method and type): 0. 3264; C.D (0.05) (Treatments, variety, method and type): 1.1308

and the cured roots had only 63.0% starch compared to 74.8% in the fresh roots (Table 1). The total sugar content was higher in the fresh roots of Sree Kanaka (16.2%) than Sree Arun (13.8%) and curing led to a sharp increase in the total sugar content to 26.40% and 20.09% respectively in the two varieties. Nevertheless, the increase in reducing sugar was only from 9.8% to 11.0% in Sree Arun, indicating that part of the glucose formed as a result of the amylolytic activity on starch may be getting converted *in situ* to sucrose. The increase in reducing sugar was more in Sree Kanaka (12.4% to 19.0%) and out of a decrease of approximately 10.0% starch during curing, only 6.7% could be accounted by the increase in reducing sugars, which again showed that there was sucrose formation during curing of sweet potatoes (Table 2). Total free amino acids (TFA) were slightly higher for Sree Arun (0.86 g 100 g^{-1} dwb) than Sree Kanaka (0.75 g 100 g^{-1} dwb) and curing did not

Table 2. Effect of treatments, varieties, types and methods of cooking of sweet potato roots on the total sugar content (g 100g^{-1} dry basis)

Treatments	Methods	Varieties			
		Sree Kanaka (V1)		Sree Arun (V2)	
		Type		Type	
		Fresh	Cured	Fresh	Cured
Fresh (untreated)		16.17±0.45	26.40±0.67	13.77±0.89	20.09±0.81
Water (T1)	Whole roots with peel (M1)	32.56±0.65	35.33±0.65	25.05±0.09	31.29±0.48
	Whole roots without peel(M2)	30.20±0.39	36.43±0.30	25.29±0.48	31.29±0.48
	Sliced roots (M3)	32.71±0.48	35.90±0.21	24.18±0.56	29.88±0.24
	Mean	31.82±0.51	35.88±0.39	24.84±0.38	30.82±0.40
Citric acid (1.0%; T2)	M1	27.04±0.82	34.33±0.00	21.57±0.51	25.34±0.94
	M2	27.83±0.34	35.60±0.00	21.92±0.15	28.09±0.19
	M3	26.17±0.88	34.92±0.00	22.91±0.17	25.03±0.05
	Mean	27.01±0.68	34.94±0.00	22.14±0.28	26.15±0.39
Ascorbic acid (1.0%; T3)	M1	29.85±0.30	34.95±0.47	22.41±0.50	25.34±0.94
	M2	28.44±0.52	34.68±1.36	20.60±0.49	27.14±0.27
	M3	28.76±0.51	35.49±0.42	20.91±0.67	26.24±0.49
	Mean	29.02±0.44	35.04±0.75	21.31±0.55	26.24±0.57
Sodium sulfite (0.5%; T4)	M1	24.59±0.69	34.83±0.57	23.08±0.83	25.13±0.86
	M2	27.02±0.82	34.17±0.20	22.83±1.10	26.48±0.55
	M3	27.33±0.47	34.00±0.53	24.53±0.62	26.05±0.82
	Mean	26.32±0.66	34.33±0.43	23.49±0.85	25.89±0.74
Microwave baking (T5)	M1	37.22±0.26	47.64±0.77	30.45±0.53	36.78±0.53
	M2	37.13±0.26	47.59±1.35	30.09±0.64	38.04±0.09
	M3	35.89±0.44	48.07±0.83	30.00±0.00	39.91±0.84
	Mean	36.75±0.32	47.77±0.98	30.18±0.59	38.25±0.48
Hydrothermal cooking (T6)	M1	30.37±0.37	38.34±1.25	23.96±0.08	31.54±0.54
	M2	30.01±0.23	39.06±0.83	24.34±0.94	33.95±0.75
	M3	30.68±0.47	39.26±0.77	24.12±0.63	32.93±1.38
	Mean	30.35±0.36	38.89±0.95	24.14±0.55	32.82±0.89
Treatment Mean		30.21±0.51	37.81±0.59	24.35±0.50	30.03±0.58

Each value is Mean ± SD from four replications; C.D (0.05) (Treatments): 0.2539; C.D (0.05) (Treatments and variety): 0.3590; CD(0.05) (Method and type): 0.2539; CD(0.05) (Treatments, variety, method and type): 0.8794

produce any significant change in the TFA levels (Table 3). Total phenol content in sweetpotato roots increased nominally during curing from 0.30% to 0.33% in Sree Arun and 0.41% to 0.48% in Sree Kanaka (Table 4). Among the two varieties, the orange-fleshed variety, Sree Kanaka had higher phenol content in the flesh (on dry weight basis).

Starch and sugar changes under various modes of cooking

Three forms of fresh and cured sweet potatoes like M1, M2 and M3 were cooked in water and other solutions (section 2.2), microwave baked or hydro-thermally cooked. Even though the initial starch content in fresh

Table 3. Effect of treatments, varieties, types and methods of cooking of sweet potato roots on the reducing sugar content (g $100g^{-1}$ dry basis)

Treatments	Methods	Varieties			
		Sree Kanaka (V1)		Sree Arun (V2)	
		Type		Type	
		Fresh	Cured	Fresh	Cured
Fresh (untreated)		12.36±0.70	19.00±0.90	9.80±0.46	11.00±0.73
Water (T1)	Whole roots with peel (M1)	18.95±0.74	25.09±0.11	16.02±0.77	21.00±1.00
	Whole roots without peel(M2)	19.75±0.38	25.29±1.05	15.95±0.65	19.97±0.44
	Sliced roots (M3)	18.94±0.17	24.30±2.00	15.10±0.84	19.00±0.52
	Mean	19.21±0.44	24.90±1.35	15.69±0.74	20.00±0.36
Citric acid (1.0%; T2)	M1	16.08±0.83	21.67±0.58	13.88±1.64	19.09±0.87
	M2	15.22±0.51	21.87±0.15	15.09±0.87	20.06±0.91
	M3	15.31±0.88	22.92±0.14	4.90±1.15	21.07±0.89
	Mean	15.54±0.74	22.15±0.29	14.62±1.22	20.07±0.89
Ascorbic acid (1.0%; T3)	M1	14.24±0.00	22.50±0.50	14.67±1.53	20.14±0.80
	M2	16.53±0.00	20.56±0.49	15.07±0.60	9.94±0.69
	M3	15.66±0.00	20.77±0.68	14.03±0.55	21.02±0.47
	Mean	15.48±0.00	21.28±0.56	14.59±0.89	20.37±0.65
Sodium sulfite (0.5%; T4)	M1	18.24±1.25	23.07±0.90	14.03±1.00	0.07±0.60
	M2	18.00±0.00	22.83±1.13	15.02±1.03	20.09±0.65
	M3	18.78±2.10	24.33±0.58	15.02±0.97	0.13±0.81
	Mean	18.34±1.12	23.41±0.87	14.68±1.00	20.10±0.69
Microwave baking (T5)	M1	21.04±1.07	31.93±0.90	22.50±3.77	25.13±0.71
	M2	21.06±0.73	30.80±1.31	20.67±3.06	26.03±0.55
	M3	20.70±0.49	31.76±1.18	21.90±2.85	26.07±0.14
	Mean	20.93±0.76	31.50±1.13	21.69±3.23	25.75±0.47
Hydrothermal cooking (T6)	M1	17.80±0.35	24.15±0.35	15.05±0.93	21.75±0.99
	M2	18.96±0.75	23.23±0.68	14.90±1.85	21.19±0.33
	M3	18.88±0.76	23.94±0.58	15.17±0.34	21.33±0.59
	Mean	18.55±0.48	23.77±0.54	15.04±1.18	21.43±0.63
Treatment Mean		18.01±0.63	24.50±0.63	16.05±1.30	21.28±0.79

Each value is Mean ± SD from four replications; C.D (0.05) (Treatments): 0.4995; C.D (0.05) (Treatments and variety): 0.7064; C.D (0.05) (Method and type): 0.4995; C.D (0.05)(Treatments, variety, method and type): 1.7304

roots was almost similar for the two varieties, it was found that a larger decrease occurred during curing for the orange fleshed variety, Sree Kanaka. Decrease in starch content when the fresh roots were boiled in water or the chemical solutions, was also more for Sree Kanaka (Table 1). Statistical analysis showed significant difference between the treatments ($p<0.001$). Microwave baking gave roots with significantly lower starch content than the other treatments. Starch content decreased from 74.8% in the initial sample to 63.0% in cured roots in the case of Sree Kanaka and this further decreased during boiling. The extent of decrease was however more for fresh roots than cured roots. The cured roots of Sree Kanaka had a total sugar content of 26.4%, which sharply increased to 34.0-36.0 % during boiling, indicating that appreciable starch hydrolysis takes place during boiling (Table 2).

The starch content in the water boiled samples from fresh roots was higher for Sree Arun than Sree Kanaka, although the extent of decrease on cooking of cured roots was similar for both the varieties. Cooking the roots in citric acid, ascorbic acid and sodium sulfite led to greater loss of starch from both the varieties, with more loss from Sree Arun. The total and reducing sugar contents were low in the boiled roots, when the two varieties were cooked in the chemical solutions as compared to water cooking (Tables 2 and 3). The pattern of starch retention in the three forms of roots was ambiguous (no definite pattern) for both the varieties as well as the cooking solutions, indicating that the form of root (whole with or without peel or sliced) does not influence starch reduction. The reduction in starch content coupled with the increase in total as well as reducing sugars was highly significant in the microwave baked roots. Starch content ranged from 47.8% to 50.6% when the three forms of fresh roots of Sree Kanaka were baked, compared to 74.8% in fresh roots. The values were in the range of 40.2-43.3% in the cured baked roots in comparison to 63% in the cured roots. The starch content in Sree Arun after microwave baking was 49.8-52.3%, which was significantly higher than Sree Kanaka. Cured roots of Sree Arun also had higher starch (69%) than Sree Kanaka and after microwave baking also, the cured roots of Sree Arun contained more starch (44.4-46.2%) than Sree Kanaka. The total and reducing sugars in microwave baked roots were also much higher in Sree Kanaka than Sree Arun (Tables 2 and 3). Starch content in the hydro-thermally cooked roots of sweet potato was almost similar to the boiled (water) roots. Differences could not be noticed between the three forms of roots such as whole root with peel or without peel and sliced roots. Accordingly, the increase in total and reducing sugars in the hydro-thermally cooked roots of the two varieties was also similar to the boiled (water) roots of the respective samples (Tables 2 and 3). Percentage retention of starch was higher for Sree Arun than Sree Kanaka, as in the other boiling methods or microwave baking. There was a significant difference in the values of both total sugar ($p<0.001$) and reducing sugar ($p<0.001$) in various treatments. Significantly higher values were observed in the microwave baking for both total and reducing sugars.

Total free amino acids

Total free amino acids (TFA) decreased in both the varieties on cooking, as compared to the fresh and cured roots. The cured roots of Sree Arun retained less TFA than fresh roots, (Table 4), while the cured roots of Sree Kanaka also had lower free amino acid content in all the boiling treatments, except the sodium sulfite treatment, where a greater decrease was observed in the fresh roots.

The microwave baked roots from fresh as well as cured samples of Sree Arun had TFA in the range of 0.61-0.64% (fresh) and 0.56-0.60% (cured) as compared to 0.86% in the fresh or cured roots. The decrease was slightly less in Sree Kanaka (0.61-0.65%) when compared to the initial value (0.75%) (Table 4). Nevertheless, in the case of hydro-thermal cooking, higher levels of TFA were observed in Sree Arun that the microwave baked roots. Cured roots of Sree Kanaka also had higher TFA levels than the respective microwave baked roots. The three forms of roots used for baking or hydrothermal cooking had no effect on the retention of TFA (Table 4).

Total phenolics

The total phenol content in the roots cooked in water or other media when whole roots with peel were used was higher than the fresh or cured samples. Higher values were observed for both the varieties during hydrothermal cooking of whole roots with peel. Boiling slices or whole

Table 4. Effect of treatments, varieties, types and methods of cooking of sweet potato roots on the content of total free amino acids. (g $100g^{-1}$ dry basis)

Treatments	Methods	Varieties			
		Sree Kanaka (V1)		Sree Arun (V2)	
		Type		Type	
		Fresh	Cured	Fresh	Cured
Fresh (untreated)		0.75±0.00	0.77±0.03	0.86±0.00	0.87±0.01
Water (T1)	Whole roots with peel (M1)	0.61±0.00	0.56±0.00	0.64±0.00	0.66±0.01
	Whole roots without peel(M2)	0.62±0.01	0.56±0.01	0.66±0.00	0.63±0.01
	Sliced roots (M3)	0.60±0.03	0.53±0.05	0.76±0.03	0.56±0.04
	Mean	0.61±0.01	0.55±0.02	0.69±0.01	0.62±0.02
Citric acid (1.0%; T2)	M1	0.63±0.03	0.64±0.04	0.70±0.05	0.65±0.03
	M2	0.64±0.02	0.57±0.02	0.69±0.02	0.67±0.02
	M3	0.63±0.03	0.56±0.01	0.72±0.02	0.61±0.05
	Mean	0.64±0.02	0.59±0.02	0.70±0.03	0.64±0.03
Ascorbic acid (1.0%; T3)	M1	0.68±0.02	0.58±0.03	0.71±0.03	0.60±0.00
	M2	0.68±0.02	0.56±0.03	0.73±0.02	0.64±0.01
	M3	0.72±0.02	0.54±0.04	0.65±0.03	0.60±0.01
	Mean	0.69±0.02	0.56±0.04	0.70±0.03	0.61±0.01
Sodium sulfite (0.5%; T4)	M1	0.55±0.04	0.63±0.02	0.60±0.01	0.57±0.06
	M2	0.52±0.02	0.62±0.03	0.69±0.01	0.56±0.00
	M3	0.53±0.02	0.65±0.03	0.62±0.03	0.54±0.04
	Mean	0.53±0.03	0.63±0.03	0.63±0.02	0.56±0.03
Microwave baking (T5)	M1	0.64±0.00	0.65±0.00	0.64±0.03	0.60±0.01
	M2	0.61±0.02	0.62±0.02	0.61±0.01	0.56±0.01
	M3	0.61±0.02	0.65±0.01	0.61±0.02	0.59±0.00
	Mean	0.62±0.02	0.64±0.01	0.62±0.02	0.58±0.00
Hydrothermal cooking (T6)	M1	0.62±0.00	0.77±0.02	0.79±0.04	0.79±0.03
	M2	0.61±0.02	0.79±0.01	0.74±0.04	0.73±0.01
	M3	0.63±0.01	0.78±0.01	0.73±0.02	0.74±0.01
	Mean	0.62±0.01	0.78±0.01	0.75±0.03	0.75±0.02
Treatment Mean		0.62±0.02	0.0.62±0.02	0.68±0.02	0.63±0.02

Each value is Mean ± SD from four replications; C.D (0.05) (Treatments): 0.00971; C.D (0.05) (Treatments and variety): 0.01373; C.D (0.05) (Method and type): 0.00971; C.D (0.05) (Treatments, variety, method and type): 0.03363

roots of Sree Arun without peel, or microwave baking and hydro-thermal cooking resulted in low phenol levels in the cooked roots (Table 5). However, varietal differences were noticed for Sree Kanaka, which retained high levels of phenols when whole roots with peel were boiled in water or other media or during microwave baking or hydro-thermal cooking. The three forms of roots had high phenol levels when cooked in the ascorbic acid medium, while in all other cases, lower levels were observed (Table 5). Based on ANOVA, there was significant difference between the three methods ($p<0.001$) and treatments ($p<0.001$). Microwave baking resulted in significantly lower phenol values than the other treatments.

Table 5. Effect of treatments, varieties, types and methods of cooking of sweet potato roots on the total phenol content (g $100g^{-1}$dry basis)

Treatments	Methods	Varieties			
		Sree Kanaka (V1)		Sree Arun (V2)	
		Type		Type	
		Fresh	Cured	Fresh	Cured
Fresh (untreated)		0.41±0.02	0.48±0.01	0.30±0.01	0.33±0.02
Water (T1)	Whole roots with peel (M1)	0.63±0.01	0.95±0.01	0.52±0.02	1.33±0.04
	Whole roots without peel(M2)	0.40±0.02	0.45±0.02	0.23±0.03	0.39±0.01
	Sliced roots (M3)	0.40±0.01	0.43±0.01	0.22±0.04	0.38±0.02
	Mean	0.48±0.01	0.61±0.01	0.32±0.03	0.70±0.02
Citric acid (1.0%; T2)	M1	0.53±0.02	0.79±0.02	0.64±0.01	0.65±0.00
	M2	0.34±0.01	0.39±0.01	0.26±0.00	0.31±0.01
	M3	0.37±0.02	0.32±0.02	0.25±0.01	0.31±0.01
	Mean	0.41±0.02	0.50±0.02	0.38±0.01	0.43±0.01
Ascorbic acid (1.0%; T3)	M1	1.67±0.06	1.17±0.03	0.61±0.02	1.11±0.02
	M2	1.09±0.01	0.63±0.02	0.34±0.06	0.40±0.01
	M3	1.25±0.02	0.71±0.04	0.32±0.01	0.39±0.00
	Mean	1.34±0.03	0.84±0.03	0.42±0.03	0.63±0.01
Sodium sulfite (0.5%; T4)	M1	0.67±0.03	1.11±0.05	0.55±0.03	0.86±0.02
	M2	0.38±0.03	0.33±0.00	0.29±0.01	0.31±0.05
	M3	0.36±0.03	0.32±0.02	0.27±0.00	0.30±0.03
	Mean	0.47±0.03	0.59±0.03	0.37±0.01	0.49±0.03
Microwave baking (T5)	M1	0.53±0.05	0.43±0.04	0.44±0.05	0.22±0.05
	M2	0.38±0.00	0.37±0.02	0.29±0.02	0.10±0.03
	M3	0.39±0.01	0.37±0.02	0.29±0.00	0.15±0.00
	Mean	0.43±0.02	0.39±0.03	0.34±0.02	0.16±0.02
Hydrothermal cooking (T6)	M1	0.80±0.06	1.07±0.06	0.65±0.04	0.70±0.04
	M2	0.33±0.01	0.27±0.05	0.32±0.06	0.22±0.01
	M3	0.33±0.03	0.28±0.00	0.30±0.02	0.22±0.04
	Mean	0.49±0.03	0.54±0.04	0.42±0.04	0.38±0.03
Treatment Mean		0.61±0.02	0.58±0.02	0.37±0.02	0.47±0.02

Each value is Mean ± SD from four replications; C.D (0.05) (Treatments): 0.01166; C.D (0.05) (Treatments and variety): 0.01649; C.D (0.05) (Method and type): 0.01166; C.D (0.05) (Treatments, variety, method and type): 0.040

Discussion

The changes in the major biochemical constituents such as starch and total and reducing sugars and the two parameters viz., total free amino acids and total phenols associated with the browning problems during processing of sweet potato were studied during cooking in water or other media, microwave baking or hydrothermal cooking. Curing the harvested roots resulted in a greater conversion of starch to reducing sugars in Sree Kanaka than Sree Arun. Nevertheless, out of the 12.0 units of starch that was hydrolysed during curing, only 6.7 units could be accounted by the reducing sugar increase in Sree Kanaka, indicating that part of the reducing sugars may be getting converted to non-reducing sucrose, due

to the sucrose synthetic activity. Takahata et al. (1996) reported that the acid invertase activity in sweet potato roots played a major role in the varietal differences in the hexose content of roots. Huang et al. (1999) also found that the reducing sugar content in cured and stored roots increased significantly and this could be correlated with the acid invertase activity. Storage of sweet potato roots at 32°, 15.6° and 7°C was reported to result in increased sucrose, glucose and fructose (Picha, 1986). Increases were observed in total and reducing sugars during curing in our study also, although the differences were not uniform for the two varieties studied. Edmund and Ammerman (1971) also reported increases in amylolytic activity and sugars during curing of sweet potato, which gave a 'moist' mouthfeel to baked sweet potatoes from cured roots. The small increase in reducing sugars in Sree Arun resulted from its rapid conversion to the non reducing sucrose during curing. Such carbohydrate conversions were reported in sweet potato by other workers as well (Edmund and Ammerman, 1971; Walter et al., 1975).

There are several reports about the involvement of phenols and polyphenol oxidase in the wound response of sweet potatoes (Hyodo and Uritani, 1967; Tanaka and Uritani, 1977). Walter and Schadel (1981) showed that about 78% of the phenols were localized in the skin and outer 5 mm tissue of sweet potatoes. In our study, only the healthy, undamaged roots were kept for curing which may be the reason for the small rise in phenols observed in cured roots. Truong et al. (2007) reported a range of 57.1 to 78.6 mg of total phenolics per 100 g fresh weight (f.w) of flesh in three cured sweet potato varieties. Higher values up to 94.9 mg 100 g^{-1} f.w have been reported by Walter et al. (1979), which were similar to that obtained by us for the cream-fleshed variety Sree Arun (~ 90 mg 100 g^{-1} f.w). Very high values of 945 mg 100 g^{-1} f.w have been reported in orange-fleshed varieties (Cevallos and Cisneros, 2003).

Organic acids as well as sodium sulfite promoted greater leaching of starch from both fresh and cured roots of Sree Arun than boiling in water, while in the case of Sree Kanaka, leaching in chemical solutions was more from fresh roots. The increase in total and reducing sugars during boiling the three forms of sweet potato, indicated that considerable hydrolysis of starch takes place during cooking. The increase was more in the roots cooked in water and the lower starch coupled with the low sugar content in roots cooked in other media in comparison to water indicates that such media may be promoting more leaching of both starch and sugars into water. However, the cured roots of Sree Kanaka were found to retain a higher percentage of total sugars than Sree Arun on cooking in chemical solutions. Walter et al. (1976) reported that the alpha-amylase of sweet potato had an optimum activity at 70-75°C and contributed to the hydrolysis of starch to sugars in cooked sweet potatoes.

As compared to boiling, sharp increase in total and reducing sugars was observed in microwave baked roots of the two varieties. Curing has been reported to increase the levels of the native amylolytic enzymes in sweet potato (Scott and Matthews, 1957; Sistrunk et al., 1954) and this could have contributed to a rapid rise of sugars in the initial few seconds. Jenkins and Gieger (1957) reported that the major conversion of starch to reducing sugars, dextrins or maltose occurred during the first 30 min of conventional baking at a temperature of below 70°C. Microwave baking at 900 W for 5 min, immediately raises the temperature inside the roots and hence the observed increase in sugars and decrease in starch in our study might have occurred from the thermo-chemical cleavage of starch rather than enzymatic cleavage. There are reports that combining infrared with microwaves could increase the degree of starch gelatinization (Sakiyan et al., 2009). Lewthwaite et al. (1997) also observed very high total sugar values in microwave baked (750 W for 3 min) unpeeled sweet potato roots (> 150-200% increase over raw roots), and the samples were reported to reach 100° C within 1-1.5 min itself, indicating that the amylase-mediated maltose formation may be taking place only till the temperature is below 80° C and hence the high sugar content is also contributed by the thermo-chemical cleavage of starch. Thickness, geometry and dielectric properties of food are reported to affect the heat transfer behaviour in microwave baking (Vadivambal and Jayas, 2009). Nevertheless, we found that the decrease in starch and increase in sugars did not differ significantly between the three types of roots. Hydrothermal cooking of sweet potatoes also elevated the sugar content to levels similar to boiling when fresh roots were used and slightly higher levels than boiling, when cured roots were used. Hoover and Harmon (1967) also reported activation of

saccharifying enzymes and higher sugar levels in ground sweet potato exposed to steam heating. They found that more than 90% of the increase in maltose occurred during the initial 10 min of heating and changes in sucrose and hexose levels were insignificant. Takahata et al. (1992) reported varietal differences in the reducing sugar formation during steaming (40-60 min) of unpeeled sweet potato roots who found that while maltose production was very high in six varieties, it was negligible in three other varieties and correlated it with the lack of ß- amylase activity in the three varieties. We found that the degree of rise in reducing sugars during hydro-thermal cooking was double in cured roots of Sree Arun (11.0 to 21.0%) than Sree Kanaka (19.0 to 24.0%). This is contrary to the pattern of rise in reducing sugars during curing of both the varieties, indicating that conversion to non-reducing sugars occurring at the curing stage of Sree Arun might be getting reversed at the hydrothermal cooking process. The lower starch content coupled with higher levels of total and reducing sugars in hydrothermally cooked or boiled samples from fresh roots of Sree Kanaka indicates that there is a higher rate of hydrolysis of starch in this variety. This is further substantiated by the fact that the fresh roots of Sree Kanaka had much higher amylase activity than Sree Arun (662 Units vs. 179 Units; 1 Unit = mg reducing groups h^{-1} 100 g^{-1} fresh roots under the assay conditions) (unpublished data).

Among the various modes of cooking, higher retention of total free amino acids (TFA) was observed in the hydro-thermally cooked roots. Loss of amino acids during boiling may be predominantly through leaching, while the decrease observed in microwave baked roots might have occurred from the thermal destruction of amino acids. Purcell and Walter (1982) reported that the major loss was for lysine during canning and dehydration and less loss occurred during conventional baking for 90 min at 190° C. Tryptophan and total sulfur containing amino acids were also reported to be lost during processing of sweet potatoes (Purcell and Walter, 1982).

Total phenolics in the samples were higher when whole sweet potato roots with peel were boiled or hydro-thermally cooked than the respective values from sliced roots or from whole roots without peel. Roots of Sree Kanaka (sliced or whole roots without peel) also had higher levels of phenols, when cooked in ascorbic acid. Phenolics were reported to play a major role in the darkening of sweet potato during processing (Walter and Purcell, 1980). Greying of canned sweet potatoes has been attributed to the interaction between polyphenol oxidases (PPO) and phenolics at the lye-peeling step (Scott and Kattan, 1957). Walter and Schadel (1981) observed that the level of phenolics in sweet potato was maximum in the outer cambium, followed by skin and the inner cambium. This might have led to the higher levels of total phenols observed when whole roots with peel were cooked in our study. Truong et al. (2007) also reported that in three sweet potato varieties, the whole raw roots had higher phenolic content than the flesh part and in each case, cooking resulted in increase in phenolics, with a greater rise in the whole raw roots. Higher retention of phenols, resulting from the inactivation of polyphenol oxidase was reported in 15 min lye-peeled sweet potatoes (Walter and Giesbrecht, 1982). The higher levels of phenolics observed in our study in the whole roots with peel might also be due to the rapid destruction of PPO, which is reported to be localized in the phellogen and phelloderm regions and in the latex of laticifers (Schadel and Walter, 1981). Also, there exists the possibility of release of free phenols from their complexes with proteins during high temperature cooking. Microwave baking of sliced roots was found to be the best technique to yield processed roots having the lowest phenol content, coupled with high reducing sugar content. Although, of late, phenolics have been categorized under nutraceuticals, the disadvantage of its association with browning in processed foods has also to be taken care, while designing processing technologies. The unique advantage of rapid decrease of starch with very high increase in soluble solids (sugars) and low retention of phenols leading to less chances of discoloration, observed in our study shall be economically advantageous for sweet potato processing for manufacture of flakes.

Conclusion

Major curing-associated changes in sweet potatoes were the conversion of starch to sugars and varietal differences were noticed in the extent of hydrolysis of starch, with a higher hydrolysis in the orange-fleshed sweet potato variety, Sree Kanaka. The build-up of reducing sugars during curing was not proportionate to the amount of

starch hydrolyzed, which coupled with the elevated total sugar levels, indicate that part of the reducing sugars are getting converted to sucrose as well during the curing process. Organic acids such as citric acid or ascorbic acid and sodium sulfite promoted more leaching of starch to the cooking medium than water, with a greater leaching from Sree Arun. Very high decrease in starch and increase in total and reducing sugars were observed in fresh and cured sweet potato roots subjected to microwave baking, resulting probably from the thermo-chemical cleavage of starch. Maximum retention of amino acids was observed in hydrothermal cooking. High levels of total phenolics were observed when whole sweet potato roots were boiled or hydro-thermally cooked, while roots subjected to microwave baking retained lower levels of phenols. Curing followed by microwave baking (900 W; 5 min) of whole roots without peel or sliced roots was found to be the best method to rapidly decrease the starch and elevate the soluble solids in sweet potato, without causing a rise in phenol levels, so that the roots could be further pureed without discoloration and used for product development.

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