Studii şi Cercetări Ştiinţifice
Chimie şi Inginerie Chimică, Biotehnologii, Industrie Alimentară

2022, **23** (3), pp. 197 – 206

Scientific Study & Research
Chemistry & Chemical Engineering, Biotechnology, Food Industry

ISSN 1582-540X

ORIGINAL RESEARCH PAPER

PROCESS OPTIMISATION AND MICRONUTRIENTS RETENTION IN THE PRODUCTION OF OVEN-DRIED ORANGE FLESHED SWEET POTATO FLOUR: TIME STUDY AND VALUE STREAM MAPPING APPROACH

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Received: September, 25, 2021
Accepted: September, 08, 2022

Abstract: Orange Fleshed Sweet Potato (OFSP) is a highly nutritious tuber, rich in vitamins, and a major source of micronutrients (beta-carotene, ascorbic acid and phenolic acid). The retention of these micronutrients during the conversion of OFSP to flour is limited by the choice of drying methods. There is a dearth of information for ascorbic acid and phenolic acid retention levels. Therefore, this study was designed to optimise the OFSP processing methods so that appreciable quantities of the micronutrients are retained in the conversion of OFSP to flour. Time study and Value stream mapping methods were used to establish a standard time for each operation and process improvement, respectively. Using the traditional methods, production time for the process was 2 days, 2 hrs, 44 mins. For the optimised process, the production time was 9 hrs, 5 min, 15 s. The processed OFSP flour had the following nutrient densities: beta-carotene (0.00011 mg·g^{-1}), ascorbic acid (1.76120 mg·g^{-1}), and phenolic acid (0.24321 mg·g^{-1}) at optimised conditions. Based on these results, it can be concluded that nutrients were retained in good measure for the OFSP (Mother's Delight Variety) through improved drying and production times.

Keywords: *drying methods, nutrient yield, process improvements, sweet potato*

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L) Lam) is a root crop widely cultivated in Sub-Saharan Africa. The crop has a global annual production rate of 107.3 million tons with Nigeria producing about 2.5 % of the world's supply [1]. It is rich in carbohydrates, fibre, vitamins, micronutrients (beta-carotene, ascorbic acid, phenolic acid), and antioxidants [2]. The crop can mitigate against diseases and environmental problems [3, 4]. In terms of economic value, it is ranked 5th among other crops in developing nations [5]. Sweet Potato can be classified into three varieties namely: (i) White or cream skin (ii) Red or purple Skin and (iii) Orange flesh. A large proportion of orange colour in the crop is an indication of a high concentration of carotenoids [5, 6]. Due to its short shelf-life, processing of Orange Fleshed Sweet Potato (OFSP) to stable products is encouraged. Therefore, in the processing of sweet potatoes, it is necessary to choose conditions that will simultaneously retain maximum nutrient content, while reducing microbial contamination, discoloration and organoleptic changes [7]. To enhance packaging, storage and minimise loss of nutrients (beta-carotene, ascorbic and phenolic acid), various drying methods have been proposed. This includes sun-drying, microwaving, freeze-drying, hot-air drying, and oven-drying. Although drying extends the shelf life of sweet potatoes, the quantum of energy consumption and its associated costs is high [8]. Hence, the choice of drying methods is important in the determination of nutrient density, residual moisture, microbial load, and colour of sweet potato flour. For instance, beta-carotene retention in sweet potato following freeze, oven, sun, microwave, and hot air drying were (91 - 97 %), (89 - 96 %), (63 - 73 %), (35 %), and (47 - 50 %), respectively [9, 10]. Although, less expensive; sun, microwave, and hot-air drying techniques do not retain high levels of nutrients.

While previous studies have considered issues on OFSP product formulations, production methods, nutritional quality, and comparison of different types of drying methods [11 – 13]. However, literature is sparse on optimum drying conditions for the maximum nutrient yield of beta-carotene, phenolic acid, and ascorbic acid in OFSP through oven-drying. Therefore, this study was designed to optimize the processing method in the conversion of OFSP (Mother's Delight Variety) into flour so that appreciable quantities of beta-carotene, ascorbic and phenolic acid can be retained.

Drying process

For sun-drying, the sweet potatoes are exposed to direct heat from the sun between 1 - 3 days. Although sun-drying is relatively cheap, it may be difficult to regulate the heat and avoid contamination. In the case of oven-drying, the raw OFSP is protected from dust and insects because the procedure is conducted in a closed chamber. However, oven-drying can result in scorching if not regulated [8]. In solar drying, airflow and climatic conditions can be regulated. Using industrial drying entails series of unit operations capable of maintaining the quality of the potatoes.

Time study

Time study is one of the principal techniques in work measurement, the aim is to record the time and work execution rate of a qualified worker at a pre-determined level of performance [14]. A qualified worker should have the physical attributes, intelligence, education, skills, and knowledge required to carry out a task to a stated level of safety, quantity and quality [15]. Due to the unstable nature of the work environment, rest allowances are created for workers to recover lost strength.

Lean concepts and value stream mapping

The elimination of wasteful practices and behavior to enhance productivity improvements constitute lean concepts [16]. Lean manufacturing involves the systematic elimination of waste to increase the productivity of a system. Some topics in lean philosophy include just-in-time, quality systems and value stream mapping. Value Stream Mapping (VSM) usage in process optimization can assist managers to identify non-value adding activities and opportunities for improvements among supply chain components.

MATERIALS AND METHODS

Raw materials

OFSP samples (Mother's Delight Variety) harvested on 23rd October 2018 was purchased from Agricultural and Management Training Institute, Ilorin, North-Central of Nigeria. The raw roots were washed and stored for 8 days without curing.

Processing of OFSP

The sweet potato processing method proposed by Hal [14] was adopted in this study. To start the process, the roots were trimmed and washed with water to remove dirt. After washing, the potatoes were manually peeled due to the irregular shape of the roots. Thereafter, using a lever-type slicer with a capacity of 130 $kg \cdot h^{-1}$ (Figure 1), the roots were sliced into chip size (length: 5 cm; thickness: 1.5 mm) and soaked into 0.1 % sodium metabisulfite solution at 3 different time durations (1, 2 and 3 mins). Following the solution treatment, the chip-size OFSP (Figure 2) were dried using a convection drying oven (Thermo Scientific Herather- OMH 750) at 3 levels of temperature (55, 60 and 65 ºC) and airflow (7, 7.5 and 8 $m \cdot s^{-1}$), respectively. The drying process was carried out at the International Institute of Tropical Agriculture, Ibadan, Nigeria. After the OFSP chip size was dried, it was milled using a blender and grinder model QASA (QBL-1841) at a moisture content of 6 - 8 % and sieved through an 80-mesh screen to get the flour (Figure 3).

Figure 1*. Lever Type Slicer*

Figure 2. *Dried OFSP Chip size*

Figure *3. OFSP Flour*

Time study of OFSP process

A time study was conducted on the sorting, washing, peeling, and slicing processes. The following steps were followed to measure the basic time (BT), standard time (ST), and standard man-hours (SMH): (i) The work environment was observed; (ii) The different operations were split into simple activity and a stopwatch was used to obtain activity processing time; (iii) The normal speed of work for each worker was defined and compared with the work rate of other operators to obtain the performance rating. Performance rating (PR) is the most critical and criticized step in work measurement because it is based on the experience and expertise of the analyst [14]. In this study, to determine PR, speed rating which considers the rate of work accomplished concerning time was adopted.

In work measurements, the observed, basic, and standard time must be identified before the completion time of a job can be calculated. The observed time is the time spent on a task. The basic time is the product of PR and observed time. The time required to complete a unit of work in addition to relaxation allowance with relaxation allowances is the standard time.

Value stream mapping of OFSP process

The following steps were taken to identify value and non-value activities in the OFSP process: (i) Create a flow chart of the production process; (ii) Add metrics and observations; (iii)Verify the current state map of the process; (iv) Develop a future state map; and (v) Set a work plan [17]. A pictorial representation of the process was developed to understand the information and material flow necessary to obtain the lead-time. The following parameters were obtained during VSM: (i) cycle time (C/T), (ii) change over time (CH/T), and (iii) batch size (B/S) in kilogram.

Determination of optimal drying conditions

Response surface methodology was used to determine the optimal drying conditions required to retain micronutrients in the processing of OFSP to flour at temperature, airflow and soaking times of 55, 60 and 65 ºC; 7, 7.5 and 8 $m \cdot s^{-1}$; 60, 120 and 180 s, respectively. The parameters (temperature, airflow and soaking time) were varied at these 3 levels to determine individual and combined responses.

Determination of beta- carotene, ascorbic acid and phenolic contents

The determination of beta-carotene, ascorbic acid and phenolic contents were conducted using Association of Official Analytical Chemists standards (AOAC, 1980) [18].

Beta- carotene

A 50 mL mixture of 95 % ethanol, 10 g of the macerated sample was placed in a conical flask and maintained for 20 minutes inside a water bath between 70 - 80 ºC with periodic shaking. The supernatant was decanted, allowed to cool, and the reading was taken as initial volume. To reduce the concentration of ethanol in the mixture to 85 %, 15 mL of distilled water was added, and further cooled using iced water in a container for about 5 minutes. Thereafter, 25 mL of petroleum ether (pet-ether) was added into the mixture obtained inside a separating funnel with cooled ethanol poured over it. A homogenous was obtained when the funnel was gently swirled and in an upright position, 2 layers of the solution were obtained. The top layer was inserted in a 250 mL conical flask and the bottom layer into a beaker. The bottom layer was re-extracted with 10 mL pet-ether up to 5 - 6 times after it was transferred into the funnel and yellow color was visible. The pet-ether was re-extracted with 50 mL of 80 % ethanol after it was collected and transferred into a 250 mL conical flask. For further analysis, the extract was poured and measured in a sample bottle.

Thereafter, with a spectrophotometer (Spectrumlab 731) at a wavelength of 436 nm, the absorbance of the extracts was obtained. To calibrate the spectrophotometer to a zero-point, a cuvette containing pet-ether (blank) was used. After a steady-state of the display window of the cuvettes was obtained, readings of the samples of each extract were taken. This process was repeated between five to six times before average readings were recorded. The Bear-Lamberts Law provided the calculation to obtain the concentration of β-carotene.

Assay of ascorbic acid (by iodimetry)

For the determination of ascorbic acid content, 2 g of the sample was weighed using an analytic weighing balance and soaked in 50 mL of distilled water (ascorbic acid is soluble in water) for about 3 hours. Whatman filter paper (11 cm) was used to filter the sample. Thereafter, 25 mL of 1M H_2SO_4 was added to the filtrate followed by 3 mL of starch mucilage solution. The new solution was titrated against 0.05 M iodine solution until a persistent violet-blue color was observed. The percentage w/v of ascorbic acid in the sample was recorded.

Phenolic acid

The concentration of phenolic was determined using the spectrophotometric method. To determine the total phenol content in the flour, the Folin-Ciocalteu assay method was used. In a volumetric flask (25 mL), 1 mL of extract and 9 mL of distilled water was mixed to obtain the reaction mixture. Thereafter, the mixture was treated with 1 milliliter of Folin-Ciocalteu phenol reagent and shaken. After 5 minutes, 10 mL of 7 % Sodium carbonate (Na_2CO_3) solution was added to the mixture. In the same manner, a set of standard solutions of gallic acid in the proportion of 20, 40, 40, 60, 80 and 100 $\mu g \cdot mL^{-1}$; was prepared, and incubated for 90 minutes at room temperature. Against the reagent blank at 550 nm with an Ultraviolet (UV) / Visible spectrophotometer. The absorbance for the test and standard solutions were determined. The total phenol content in the mixture was expressed in mg of GAE/g of extract.

RESULTS AND DISCUSSION

Time study of OFSP process

The time study of the sorting, washing, peeling and slicing processes for 10 sweet potatoes is presented in Table 1, 2, 3 and 4, respectively.
In Table 1, the best performance rating (100 %) required 6 seconds (Worker no: 5 and 8). This value represents the observer's concept of standard performance (i.e. what is expected from the worker). Although, the performance rating of workers 1, 2, 6 and 10 is above 100 %. This does not mean better performance, it is an indication that the worker is performing at a speed of 66.6, 16.6, 25.0 and 16.6 %, respectively, than normal. From the average value, the basic, relaxation allowance and standard time for the sorting process were 7.0, 0.2 and 7.2 seconds, respectively.

Table 1. *Time study for the sorting process*

Worker No	Sorting observed Time [s]	Performance Rating (PR) [%]	Basic time (BT) = Sorting observed time *Performance Rating /100	Relaxation allowance (RA) = 3 % of the basic time	Standard Time (ST) = Basic + Relaxation allowance(s)
1	10.0	166.6	16.7	0.5	17.2
2	7.0	116.6	8.2	0.2	8.4
3	5.0	83.3	4.2	0.1	4.3
4	4.5	75.0	3.4	0.1	3.5
5	6.0	100.0	6.0	0.2	6.2
6	7.5	125.0	9.4	0.3	9.7
7	5.5	91.6	5.0	0.2	5.2
8	6.0	100.0	6.0	0.2	6.2
9	4.5	75.0	3.4	0.1	3.5
10	7.0	116.6	8.2	0.2	8.4
Average	6.3	105.0	7.0	0.2	7.2

The result of the time study for the washing process using a basin (manual) and running tap is presented in Table 2. In this process, the best performance rating for the basin and tap occurred at 16 and 7 seconds (Worker No: 3), respectively. The relaxation allowance time was set at 15 and 14.3 % of the basic time for basin and tap activities, respectively. The basic, relaxation allowance and standard time for the basin and tap activities were (20, 3 and 23) and (7.9, 1.1, 9.0) seconds, respectively.

Table 2. *Time study for washing process*

	Washing observed time [s]		**PR**		**BT**	**RA**	**ST**	**BT**	**RA**	**ST**
Worker No	**Basin**	**Tap**	**Basin**	**Tap**	**Basin**			**Tap**		
1	24	10	150.0	142.6	36.0	5.4	41.4	14.3	2.0	16.3
2	22	5	137.5	71.4	30.3	4.5	34.8	3.6	0.5	4.1
3	16	7	100.0	100.0	16.0	2.4	18.4	7.0	1.0	8.0
4	14	6	87.5	85.7	12.3	1.8	14.1	5.1	0.7	5.9
5	18	5	112.5	71.4	20.3	3.0	23.3	3.6	0.5	4.1
6	17	4	106.0	57.1	18.0	2.7	20.7	2.3	0.3	2.6
7	14	8	87.5	114.3	12.3	1.8	14.1	9.1	1.3	10.5
8	20	6	125.0	85.7	25.0	3.8	28.8	5.1	0.7	5.9
9	16	11	100.0	157.1	16.0	2.4	18.4	17.3	2.5	19.8
10	15	9	93.8	128.6	14.1	2.1	16.2	11.6	1.7	13.2
Average	17.6	7.1	110.0	101	20.0	3.0	23.0	7.9	1.1	9.0

In Table 3, the time study for the peeling process using 2 different methods (knife and peeler) is presented. In this process, the best performance rating using the knife and peeler occurred at 47 seconds (Worker No: 4) for knife usage and 40 seconds (Worker No: 5) for the peeler. A relaxation allowance of 8.5 % of the basic time was assumed. The average standard time for the peeling process using a knife and peeler were 59.5 and 54.2 seconds, respectively.

Table 3. *Time study for the peeling process*

	Observed Time [s]		**PR**		**BT**	**RA**	**ST**	**BT**	**RA**	**ST**
Worker No	**Knife**	**Peeler**	**Knife**	**Peeler**	**Knife**			**Peeler**		
1	56	63	119.1	157.5	66.7	5.7	72.4	99.2	8.4	107.7
2	40	62	85.1	155.0	34.0	2.9	36.9	96.1	8.2	104.3
3	62	45	131.9	112.5	81.8	7.0	88.7	50.6	4.3	54.9
4	47	46	100.0	115.0	47.0	4.0	51.0	52.9	4.5	57.4
5	63	40	134.0	100.0	84.4	7.2	91.6	40.0	3.4	43.4
6	57	30	121.3	75.0	69.1	5.9	75.0	22.5	1.9	24.4
7	60	35	127.7	87.5	76.6	6.5	83.1	30.6	2.6	33.2
8	55	48	11.0	120.0	6.1	0.5	6.6	57.6	4.9	62.5
9	45	33	95.7	82.5	43.1	3.7	46.7	27.2	2.3	29.5
10	43	30	91.5	75.0	39.3	3.3	42.7	22.5	1.9	24.4
Average	53	43	112.0	108.0	54.8	4.7	59.5	49.9	4.2	54.2

The time study for the slicing process using a knife and slicer is presented in Table 4. In this process, the best performance rating using the knife and slicer occurred at 110 seconds (Worker No: 5) and 5 seconds (Worker No: 6), respectively. The relaxation allowance time was set to 9 and 3 % of the basic time of knife and slicer activities, respectively. The average standard time using a knife and slicer during the process was 167.4 and 4.1 seconds, respectively.

Table 4. *Time study for slicing process*

	Observed Time [s]		PR		BT	RA	ST	BT	RA	ST
Worker No	**Knife**	**Slicer**	**Knife**	**Slicer**	**Knife**			**Slicer**		
1	81	3	73.6	60.0	59.6	5.4	65.0	1.8	0.1	1.9
2	113	2	102.7	40.0	116.1	10.4	126.5	0.8	0.02	0.82
3	170	5	154.5	100.0	262.7	23.6	286.3	5.0	0.2	5.2
4	180	7	163.6	140.0	294.5	26.5	321.0	9.8	0.3	10.1
5	110	3	100.0	60.0	110.0	9.9	119.9	1.8	0.1	1.9
6	104	5	94.5	100.0	98.3	8.8	107.1	5.0	0.2	5.2
7	133	4	120.9	80.0	160.8	14.5	175.3	3.2	0.1	3.3
8	74	6	67.3	120.0	49.8	4.5	54.3	7.2	0.2	7.4
9	155	4	140.9	80.0	218.4	19.7	238.1	3.2	0.1	3.3
10	135	3	122.7	60.0	165.6	14.9	180.6	1.8	0.1	1.9
Average	125.5	4.2	114.1	84.0	153.6	13.8	167.4	4.0	0.1	4.1

Value stream map of OFSP process

In Table 5, the VSM characteristics of the traditional and optimized production process of OFSP to flour is presented.

Table 5. *Value stream map for process improvement*

VSM No.	Map Definition	Characteristics
1	Traditional or Local process	i. Use of Knives ii. Sun Drying
2	Proposed Process	i. Use of slicer ii. Oven-drying

From visual observation and recording, the traditional process to convert OFSP to flour has a total production time (TPT) of 2 days, 2 hrs, 44 mins for a batch. For the proposed process, the value stream map in Figure 4 shows a pictorial representation of the process indicating information flow, material flow and lead times. The traditional process uses manual labor and sun-drying methods, while the optimized process involved the use of rushing water for washing, a peeler and handheld slicer, and oven-drying. The optimized process has a TPT of 9 hrs, 5 mins, 15 s.

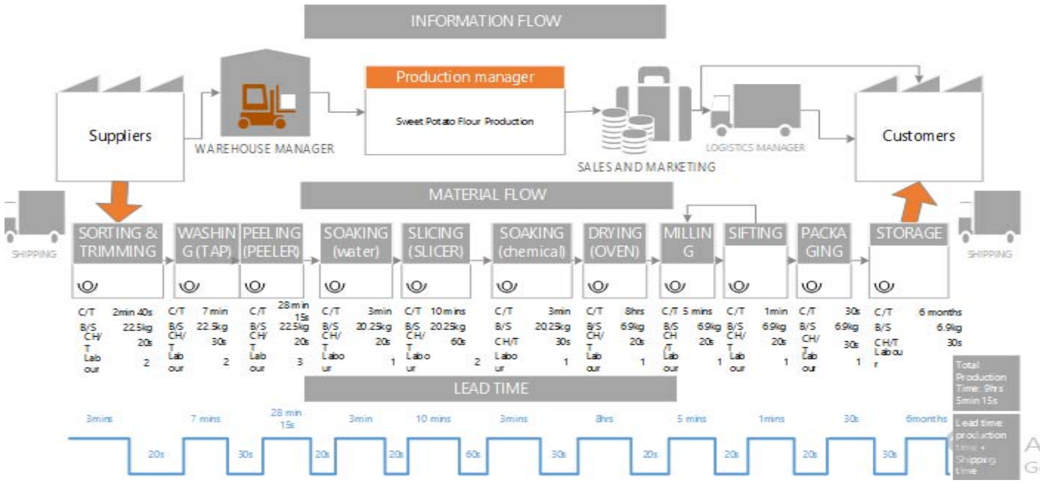

Figure. 4. *VSM information for the proposed process*

Impact of drying condition on OFSP

In Table 6, the optimum drying conditions to determine a trade-off between drying time and nutrient retention are presented.

Table 6. *Summary of micronutrients retention after oven-drying*

Response	Optimum				Experimental Values [mg·g^{-1}]
	Temperature [ºC]	Soaking Time [s]	Airflow [m·s^{-1}]	Predicted Value [mg·g^{-1}]	
Beta-Carotene	65	91.58	7.67	0.000128	0.000112
Ascorbic Acid	65	91.58	7.67	1.83251	1.7612
Phenolic Acid	65	91.58	7.67	0.231301	0.24321

At temperatures above 65 ºC, beta-carotene and ascorbic acid were affected by drying temperature and airflow, while soaking time had the least effect. However, phenolic acid was affected mostly by the soaking time. These conditions resulted in 0.000112 mg/g retention of beta carotene; 1.7612 mg·g^{-1} retention of Ascorbic acid; and 0.24321 mg/g retention of Phenolic acid; with a drying time of 6hrs 30mins. These results are similar to Ahmed [12] on Yellow fleshed sweet potato (sinhwangmi variety) with 0.0001461 mg·g^{-1}, 1.753 mg·g^{-1} and 0.4000 mg·g^{-1} retention of beta-carotene, ascorbic acid, and phenolic acid, respectively.

CONCLUSIONS

In this study, optimization of the processing methods used in the conversion of Orange Fleshed Sweet Potato (Mother's Delight Variety) to flour was achieved. The optimum oven-drying conditions for beta-carotene, ascorbic and phenolic acid maximum micronutrients retention were obtained at temperature, soaking time and airflow of 65 ºC, 1 min 31 secs, and 7.67 m·s^{-1}. At these conditions, 0.000112, 1.7612 and 0.24321 mg·g^{-1} of Beta-carotene, Ascorbic acid, and Phenolic acid were retained. The optimized process offers an effective method of OFSP production, which can be adopted by a flour mill. Further studies can consider a wider airflow effect range and investigate the effect of varying relaxation allowance time on the standard time.

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