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Comparative evaluation of the quality characteristics of the osmo-dehydrated star fruit slices using hot air, solar and sun drying

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Abstract
The star fruit (*Averrhoa carambola*) belonging to family Oxalidaceae is one of the earliest known tribal fruit being grown in abundance in India. It is a multipurpose, drought resistant evergreen tree which is gaining lot of importance for its therapeutic potentials. Due to lack of technical knowledge most of these fruits are not effectively utilised. The present study was an effort to perform a quality characteristics evaluation of osmo-dehydrated star fruit slices subjected to hot air drying (HAD), Solar drying (SOD) and sun drying (SD). The star fruit slices were subjected to microwave blanching, Osmo-dehydrated and the process was optimized. Final samples were prepared at that optimum conditions and subjected to hot air drying, solar drying and sun drying. Quality analysis of the dried sample was done for ascorbic acid (AA), oxalic acid (OA), rehydration ratio (RR). The sensory (colour and shape) analysis was also carried out. Drying time taken was 6-13 hrs, 7-11 hrs and 11-18 hrs for HAD, SOD and SD. The solar dryer achieved considerable reduction of 75% in drying time as compared to that of conventional sun drying. The samples undergone microwave blanching and osmo-dehydration lost part of AA and OA during heat treatments. The sun dried samples showed very low sensory score (5 to 6) which was much lower than those of HAD and solar dried samples. Osmo-solar process may be recommended to be practiced at rural level for dehydration of star fruit slices as a compromise method between HAD and SD considering both the quality parameters of finished product and from energy consumption point of view.

Keywords: Solar drying, sun drying, rehydration ratio, ascorbic acid, oxalic acid

1. Introduction

The star fruit (*Averrhoa carambola*) belonging to family Oxalidaceae is popularly known as tribal fruit of India. The evergreen tree can be used for multipurpose and is very much resistant to drought. Though the fruits and plant parts are traditionally used for various diseases, the fruit is the most usable part of the plant. Due to lack of technical knowledge most of these fruits are not effectively utilised. The fruit contains vitamin C, total phenolics, antioxidants, dietary fibres and mineral in a huge amount which helps in health promoting [1, 2]. Fruit contains soft, fleshy, yellow and edible pulp, with the flavor of a green, sour apple [3]. The fruit is used for preparation of jelly, jam and beverages. And sometimes, it is also used in curry to give a sour taste. The presence of moisture above 90% wb makes the fruit perishable and the utilization becomes limited due to the seasonal availability. Therefore, it is necessary to preserve this nature's gift by doing proper processing with efficient nutrition retention. The fruit has a very unique star shape and market potential is very high due to the ripen golden colour. It is used for garnishing of salads and other products prepared by value addition [4, 5]. A huge portion of this fruit is getting wasted at production point due to lack of transpiration facilities, storage and processing. Keeping in view of the above stated problem, development of in-expensive processing methods is necessary for storage of this nutritious fruit.

Dehydration is the process of removal of water from agricultural products and essential methods for storing this fruit with minimum spoilage [6]. Finding the standard optimum processing parameters is also very much essential for producing product with highest quality and with efficient nutrition. The standardized processing parameter can be directly used by the rural farmers and industries [7]. Different types of methods are being constantly used for drying different products having their own benefits and limitations. Conventional hot air drying is more efficient compared to sun drying; gives uniformly dried with better quality product. With all these advantages, the hot air dryer is costly and it is not affordable by rural farmers. The renewable energy sources can be used for this purpose for saving the major processing cost. Solar energy is the abundantly available energy source which generally used for drying operations of agricultural commodities [8]. Solar drying reduces the drying time considerably and improves the product quality with better taste, colour and texture compared to open sun drying. In open sun drying, the major losses are due to birds, rodents, insects, rain and microorganisms because of direct exposure of the product into open sun and dust. This causes the product quality degradation and the loss of market value of the particular product. Therefore, keeping in view of the above stated problem and the advantages of solar drying, the present research was carried out with aim to have a comparative evaluation of the quality characteristics of the osmo-dehydrated star fruit slices subjected to hot air drying, solar drying and sun drying.

2. Materials and Methods
2.1 Sample Preparation
The golden verities [9] of star fruit were collected from the local market of Bhubaneswar. It was washed thoroughly with tap water, wiped with a towel for removal of surface moisture and stored at -4 °C for the whole experiments. The moisture content of the sample was measured in hot air oven at 105 °C [10]. The initial moisture was found to be 909.14% d.b.

2.2 Drying experiment
The star fruit was cut into 5, 10 and 15 mm thick slices by a hand operated stra fruit slicer which is published elsewhere [11]. Then the slices were subjected optimized conditions of microwave blanching [12]. The blanched slices were osmo-dehydrated under optimized conditions [13]. Osmo-dehydration process was responsible for partial removal of water for which it was required to be followed by other drying methods. In the present investigation, a comparative evaluation was made among hot air drying at two temperatures of 50 ˚C (HAD50) and 60 ˚C (HAD60), solar drying (SOD) and sun drying (SD). In order to assess the effect of blanching and osmo-dehydration, the samples were subjected to these treatments under previously designed optimum conditions. Therefore, three lots of samples i.e. microwave blanching with osmo-dehydration; only osmo-dehydration and control (no treatments) were prepared and evaluated for all the drying methods as mentioned above. The untreated samples were also dried under the same drying conditions. Moisture loss was recorded at 15 min intervals initially, then onwards at 30-min and one hour intervals during the drying process using a digital weighing balance with an accuracy of 1±0.0001g. The drying process was stopped up to the weight of the star fruit became constant and it was assumed to be the equilibrium stage. For all the drying methods the drying operation was started with an initial moisture content of about 900.14% (db) and continued until no further changes in their mass was observed i.e. to the final moisture content of about 8% (db) which was taken as the equilibrium moisture content. The drying rate and the moisture ratio were calculated from the experimental data and the curves were plotted accordingly.

2.3 Drying methods
2.3.1 Hot air drying: Thin-layer drying experiments for slices under controlled conditions were conducted for star fruit slices in a hot air dryer at 50 and 60 °C (40-60% relative humidity). A convective cabinet dryer (IIC, Model TD-12) was used in this investigation (Figure 1). The tray dryer consists of an air heating section, a centrifugal blower, sensors for measurement of parameters and one displaying unit. A heavy duty door was provided in the front side for keeping and removal of the tray. Before starting of the experiment, the dryer was switched on for 30 min to reach the desired temperature of drying. An anemometer (Lutron AM-4201) was used continuously to measure and to monitor the air velocity inside the drying chamber. After the desired temperature was reached, the fruit slices of about 1 to 2.5 kg/m^2 were kept in a single layer above the tray. All the experiments were conducted at 1.2 m/s air velocity.

Fig 1: Hot air dryer

2.3.2 Solar drying: The system consists of single glazed (2 mm thickness) solar cabinet drier mounted on a metal frame (Figure 2). The cross-sectional area covered by the solar drier is 1.24m^2. The top glass surface is inclined at an angle of 15^{O}with horizontal to maximize the capture of solar radiation at Bhubaneswar (latitude 22^{O}15'N) during the test period. The solar collector cum drying unit was a box kept in glass covered enclosure under which the drying chamber is placed. Three drying trays (Perforated stain less steel) kept inside the drying chamber and the area coverage of each tray was 0.091m^2. Two air vents were located at the rear panel of the dryer measuring 0.125 m diameter. A hinged door was placed at the front side of the dryer for accessing to inside the chamber and also for loading and unloading of the fruit slices. The inlet air was passing from the bottom of the chamber and the outlet air was sucked by the upper part of drying chamber which was fitted with an air vent with a fan. The solar dryer was provided with 6-watt DC fan and 8-watt photovoltaic module to operate the fan.

2.3.3 Working principle of the solar dryer
The inner wall of the drying chamber was painted with black colour to absorbed the solar energy through the top glass surface and it increases the drying air temperature inside the chamber. This process maintains the temperature different between drying chamber and the ambient air. Inside the drying chamber, the heated air goes upward and pick up the moisture from the fruit slices and comes out through the top air vent. This action decreases the air pressure inside the drying chamber and fresh ambient air was drawn into the cabinet from the inlet holes. A continuous flow of air from below is thus established. All the experiment was conducted from 9.00 AM to 5 P.M which was 8 hrs duration each day. After each experiment (after 5.00 PM), the samples were tempered in an ambient condition and again kept in the dryer at 9.00 AM in the next day. The experiment was continued up to the desired moisture content (8% db, for star fruit slices) was achieved. A temperature sensor (Testo model 945 accuracy ±0.3 ^{O}C) was fitted inside the drying chamber to continuously measure the drying air temperature. The relative humidity and the air velocity was measured with a digital humidity meter (accuracy±2.5% and ±0.01 ºC) and an anemometer 9Lutron AM-4201). The relative humidity was measured at both inside and outside of the drying chamber.

After completion of drying, the dried slices were collected, cooled in a shade to the ambient temperature and then sealed it in the plastic bag for storage and further quality analysis.

Fig 2: Samples inside the Solar dryer

Sun drying: The optimized osmo-dehydrated slices, which had already lost some of its moisture, were subjected to sun drying on single layers over a clean polythene sheet. After first day the samples were kept for tempering and in the second day the same procedure was repeated. Ambient temperature and RH was measured as described earlier.

2.4 Drying calculation

2.4.1 Drying rate: The time and temperature were noted down from the individual drying experiments. The removal of water with time as mentioned against each drying temperature was observed regularly. The drying rate for each time interval for each drying temperature was calculated by considering the water removed per unit time for the particular interval [14].

$$\text{Drying Rate} = \frac{\text{Weight of water removed}}{\text{Time} * \text{weight of bone dry material}} * 100 \quad (1)$$

Moisture ratio: The moisture ratio was calculated by the following formula:

$$MR = \frac{(W_t - W_e)}{(W_0 - W_e)} \quad (2)$$

Where, W_t is the % db moisture content at time t, W_0 is the % db moisture at initial, W_e is the % db moisture at equilibrium. W_e is quite small as compared to W_t and W_o and RH of drying air is continuously fluctuating. Here the moisture ratio W_t/W_0 has been calculated and plotted against drying time for different drying conditions and the moisture ratio (MR) can be given as below:

$$\text{Moisture ratio} = \frac{W_t}{W_0} \quad (3)$$

2.5 Quality Analysis

2.5.1 Determination of Ascorbic Acid: The standard procedure given by Ranganna [15] was followed in the investigation for estimation of ascorbic acid content. The standard method of based on the reduction of 2,6-diclorophenol indophenols dye by ascorbic acid. The dried sample of 10 g was taken, grounded by adding 10 ml of 3% metaphosphoric acid in a mortar pestle. 40 ml of metaphosphoric acid was added to the grounded sample and the whole lot was filtered and centrifuged for separation of the supernatant fluid. The supernatant was taken in a volumetric flask and titration was done with 2, 6-diclorophenol indophenol solution until a rose pink colour appears. The ascorbic acid content was estimated using the standard formula.

2.5.2 Determination of oxalic acid: The standard procedure given by Archer *et al.*, [16] has been standardized and modified for star fruit and used in the present research. 3g of sample was mixed with 60 ml of distilled water, boiled and it was added with 0.3 g of calcium chloride. Then the mixture was left undisturbed for 16 h at room temperature. The calcium oxalate was precipitated in the bottom and it was separated by centrifuging. The precipitate was washed with dilute ammonia (20%, 20ml per each sample) solution two times. 1N sulphuric acid was used for dissolving the precipitate and the solution was titrated with 0.1N $KMnO_4$ at 60-70 °C. (1ml of 0.1N $KMnO_4$ is equivalent to 4.5 mg of anhydrous oxalic acid).

2.6 Sensory evaluation

Sensory evaluation was carried out by a trained panel of 12 judges of different age groups, having different eating habits. Sensory characteristics of the dehydrated samples were determined as composite score of the 12-member consumer panel using 9-point Hedonic scale following the procedure of ISI (1997) [17]. The sensory evaluation was conducted for colour and shape i.e. like extremely 9, like very much 8, like moderately 7, like slightly 6, neither like nor dislike 5, dislike slightly 4, dislike moderately 3, dislike very much 2 and dislike extremely 1. The comparison was performed among all the dehydrated samples prepared. The flow chart of the whole experimental plan is given in the Figure 3.

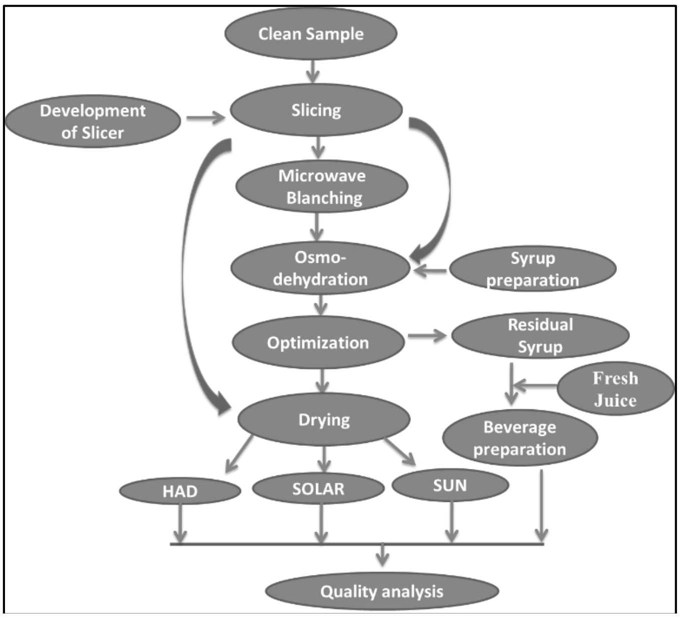

Fig 3: Flowchart of the experimental plan

3. Results and Discussion

3.1 Comparison of Temperature of the solar dryer with ambient

The inside temperature of the solar dryer with the ambient air for a whole day is shown in Figure 4. The maximum drying air temperature was found to be 71.44 °C at 1.30 PM of the day inside the chamber against 41.4 °C outside the chamber. The variation of the drying air temperature was due to the variation in solar radiation and relative humidity of the air. The dryer performance was affected by the solar radiation, temperature of the collector and the drying tray, relative humidity of the inlet and exit air and air velocity. The temperature was different in the different trays during whole day. The temperature was highest in the top tray compared to the bottom tray. Therefore, the fruit slices kept in the top tray dried faster compared to the bottom tray (Preliminary trials). However, in the present experiment all the analysis of solar drying with respect to quality characteristics of the product was reported for top tray only.

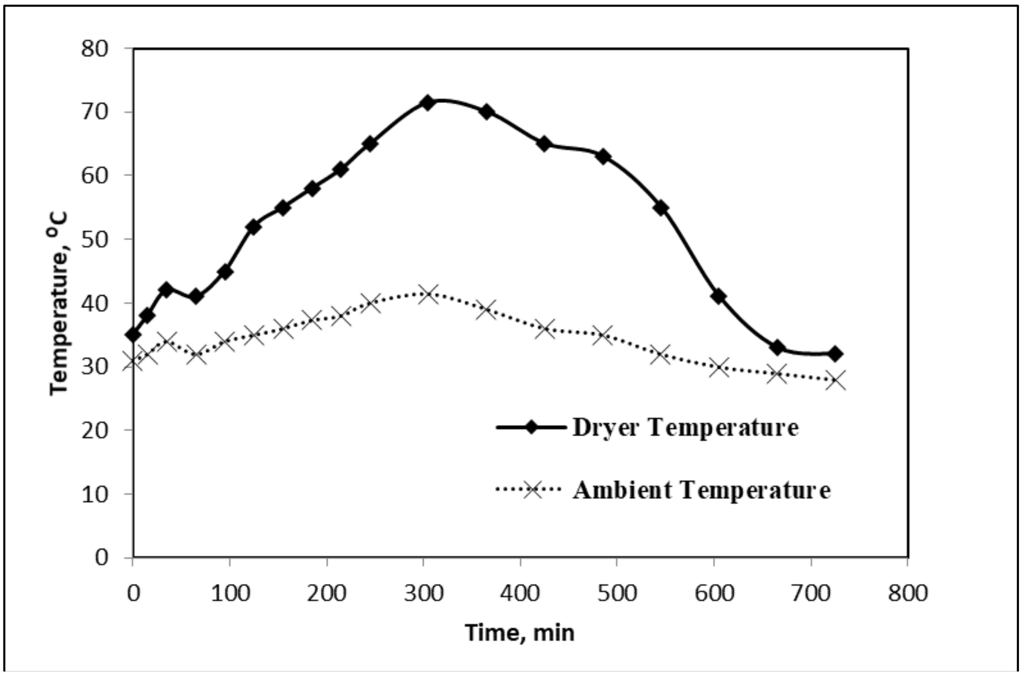

Fig 4: Variation of solar dryer and ambient temperature with time

3.2 Details drying yield and time

The initial moisture content of the sample was 909.14% db and the final moisture content of samples was ranged from 8.26 to 9.03% db. The sample drying data for HAD50 and solar drying is given in Table 1 and 2. The drying time requirement for the star fruit slices varied (7-18 h) with drying methods. This variation was remarkably higher in case of sun drying (>11h). HAD60 required minimum drying time among all the methods. However, drying time requirement in solar drying was less than that by HAD50. This was due to the attainment of very high temperature (>60 ^{O}C) by solar dryer for few hours in the day of experiment.

Samples treated with both microwave blanching and osmo-dehydration required minimum drying time irrespective of drying methods. This is due to obvious reason of moisture loss during both the operation. Methods requiring a drying time of more than 8h, were subjected to tempering overnight for a period of about 15 hr (5 PM to 8 AM). The drying time with different drying methods is shown in Figure 5. One sample graph for moisture ration with drying time is shown in Figure 6.

Table 1: Experimental data for hot air drying at 50 °C for control and microwave blanched-osmo sample

	HAD50 for Control sample			HAD50 for MWB with OD sample		
Drying time, min	MC (% db)	Drying rate	MR	MC (% db)	Drying rate	MR
0	909.08		1	242.642		1
15	832.30	5.118	0.915	221.808	1.388	0.914
30	751.23	5.404	0.826	203.434	1.224	0.838
60	595.72	5.183	0.655	165.417	1.267	0.681
90	450.35	4.845	0.495	134.522	1.029	0.554
120	354.84	3.183	0.390	110.398	0.804	0.454
150	291.79	2.101	0.320	87.635	0.758	0.361
180	199.33	3.081	0.219	64.703	0.764	0.266
240	153.62	0.761	0.168	34.349	0.505	0.141
300	116.82	0.613	0.128	14.835	0.325	0.061
360	88.63	0.469	0.097	9.993	0.080	0.041
420	61.76	0.447	0.067	8.681	0.021	0.035
480	35.97	0.429	0.039	8.585	0.001	0.035
540	19.82	0.260	0.021			
600	13.31	0.110	0.014			
660	10.35	0.049	0.011			
720	9.034	0.020	0.009			
780	8.75	0.005	0.009			

*MWD is microwave blanched

Table 2: Experimental data for solar drying for control and microwave blanched-osmo sample

	Drying data of solar drying for control sample			solar drying for MVB with OD sample		
Drying time, min	**MC (% db)**	**Drying rate**	**MR**	**MC (% db)**	**Drying rate**	**MR**
0	910.25		1	193.43		1
15	864.64	3.041	0.951	185.42	0.748	0.958
30	795.13	4.633	0.874	173.71	1.093	0.898
60	685.11	3.667	0.753	151.99	1.013	0.785
90	574.08	3.701	0.631	130.42	1.007	0.674
120	457.27	3.893	0.503	109.80	0.962	0.567
150	324.54	4.424	0.357	87.38	1.046	0.451
180	213.43	3.703	0.234	54.24	1.547	0.280
240	125.83	1.459	0.138	15.28	0.909	0.079
300	104.93	0.348	0.115	11.32	0.092	0.058
360	56.72	0.803	0.062	9.18	0.049	0.047
420	34.04	0.377	0.037	8.87	0.007	0.045
480	16.17	0.297	0.017			
540	10.07	0.101	0.011			
600	8.82	0.029	0.009			
660	8.52	0.004	0.005			

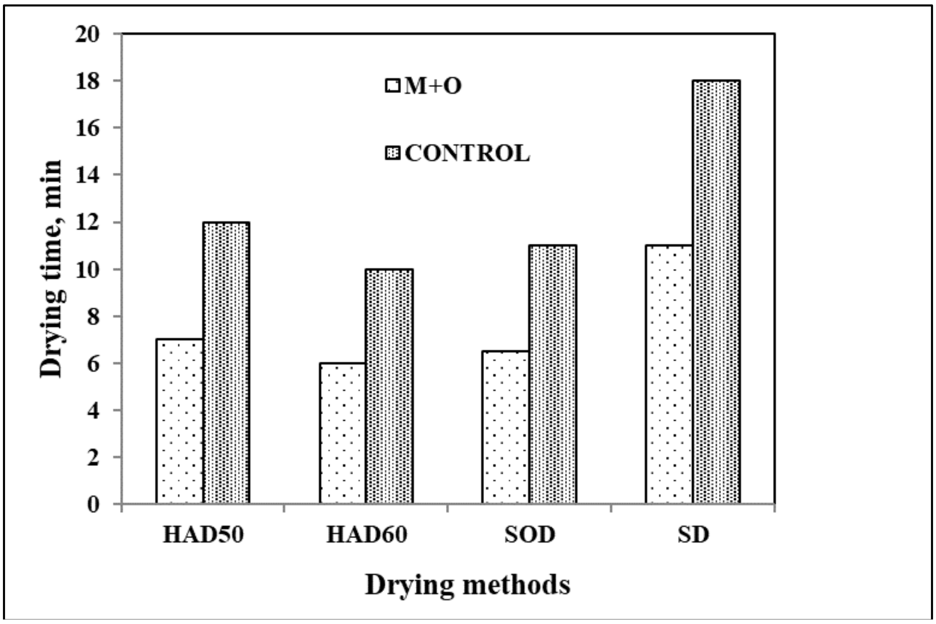

Fig 5: Variation of drying time with drying methods

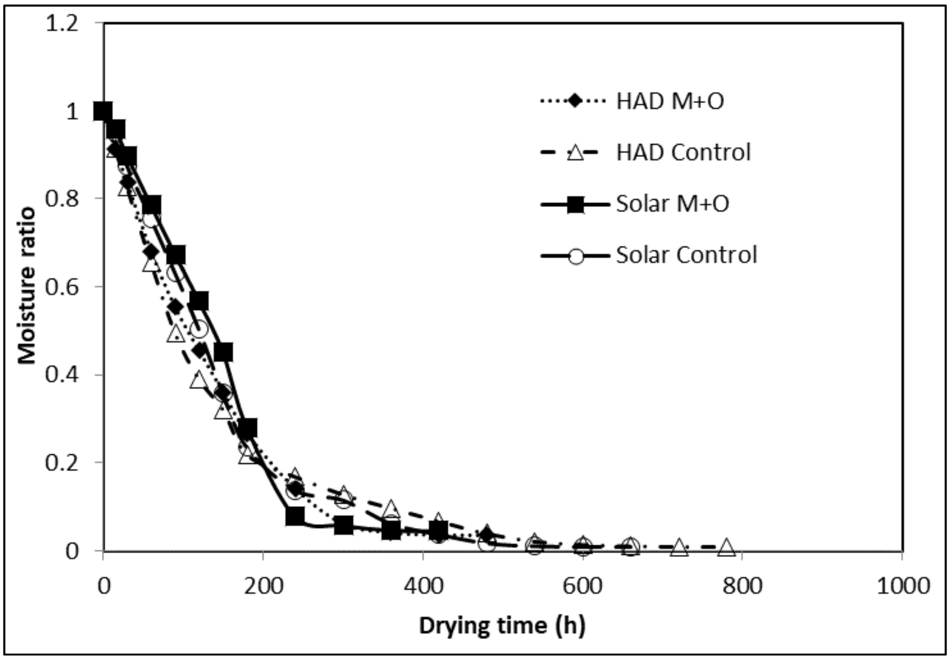

Fig 6: Variation of moisture ratio with drying time (HAD50 vs Solar)

The experimental result of quality characteristics of star fruit slices undergone different drying methods and treatments are presented in Table 3. The rehydration ratio varied from 1.58 to a maximum value of 2.82. This ratio was minimum for sun dried samples and maximum for HAD60 samples irrespective of the treatments. HAD50 samples showed a very close rehydration property (1.95-2.82) to that of HAD60 (2.02-2.76). Solar dried samples were found to have low rehydration ratio than HAD samples but was much better than sundried samples. Among the treatments, the control samples showed highest rehydration ratio than rest two. This is due to the fact of solid gain during osmosis for which less pore space is available per given weight for absorption of moisture.

In order to study the effect of drying methods on AA & OA, a comparison may be made with reference to initial values of fresh sample (743.67mg/100g DM and 28.04 mg/g DM respectively). The samples undergone microwave blanching and osmo-dehydration lost part of these sensitive (AA and OA) during heat treatments and leaching through osmosis to residual syrup. This is the reason why AA values were highest for all control samples in all the drying methods. However, a considerable amount was still preserved in microwave treated samples. Sun drying could not preserve much AA, may be due to longer drying period. On the other hand, HAD60 dried samples and solar dried samples had lower AA than HAD50 dried samples though these were significantly higher than those of sundried samples. This could be due to degradation of AA at higher temperature (more than 60 ^{O}C) in both these methods. Similar trend has been observed for OA in all the samples. Here, it may be mentioned that the loss in both AA and OA during osmosis may not be considered as a loss if the residual syrup is recovered for useful product preparation. Previous study has also shown promise for use of residual syrup in beverage preparation [17, 18].

Table 3: Effect of drying methods on quality characteristics of dried slices

Drying Methods	Treatment	FMC (% db)	Drying time required	RR	AA	OA	Sensory	
							color	shape
HAD50	MWB+O	8.58	8	2.26	305	6.5	8.2	8
	CONTROL	8.75	13	2.82	520	22	6.2	6
HAD60	MWB+O	8.42	6	2.16	296	5.9	7.5	8
	CONTROL	8.3	10	2.76	496	18	5.8	6.1
SOD	MWB+O	8.87	7	1.96	288	6.1	7.3	7.8
	CONTROL	8.53	11	2.44	482	16.5	5.2	5.8
SD	MWB+O	8.4	11	1.75	192	4.2	6.1	7.1
	CONTROL	8.26	18	2.16	320	13.6	5.1	5.4

*IMC (% db) = 909.138, Fresh Ascorbic acid (mg/100g DM) = 743.67, Fresh Oxalic acid (mg/g DM) = 8.04, MWB is microwave blanched, O is osmo-dehydration

3.3 Sensory properties

Colour and shape of the dried slices are the two sensory properties which have been considered in this investigation. Likeness for colour was the closeness to natural fruit colour and that for shape was minimum shrinkage. Preliminary studies indicated no noticeable difference in colour of the samples subjected to microwave blanching and osmo-dehydration. The difference was observed only after these were subjected to final stage of drying and finished products were obtained. Table 3 showed very low sensory score (5 to 6) for sundried samples which is much lower than those of HAD and solar dried samples. Sundried samples became reddish in colour which was quite away from natural yellowish colour. This is probably due to degration of colour pigments under sun and conversion of some chemical compounds which needs further research. Rudra (2008) found that the high temperature could lead to replacement of magnesium in chlorophyll by hydrogen, thereby converting chlorophyll to pheophytin. The sensory score for solar dried samples were intermediate between HAD and sundried samples. The microwave blanching with osmo-dehydration samples gave highest result which may be due to enzymatic inactivation for further degradation at a later stage. Sensory evaluation for shape also depicted similar trend as those of colour. Shape of all the control samples were distorted with abrupt shrinkage and therefore were unacceptable. Sundried samples also scored relatively low values which might have been due to long drying time. The samples subjected to microwave blanching maintained the contour of slices to a greater extent and fetched significantly higher sensory scores.

Overall analysis indicated that sun drying of star fruit slices may be ruled out because of high drying time and rapid loss of quality characteristics. Though HAD60 required less drying time and preserved more AA and OA, it fetched low sensory acceptance in comparison to HAD50. Therefore, HAD50 may be considered as the best drying conditioned among the methods considered under experiment. Though RR, AA and OA were observed to be better in HAD samples as compared to solar dried samples, the sensory characteristics obtained in solar dried samples were at par with HAD samples. So samples had better overall acceptability particularly with microwave blanched osmo-dehydrated samples. The samples subjected to osmo-dehydration without undergoing blanching could also be considered for value addition process as the quality parameters were quite close, even though less than that of blanched samples.

4. Conclusions

Drying time taken was 6-13 hrs, 7-11 hrs and 11-18 hrs for HAD, SOD and SD. The developed natural convection solar dryer was capable of producing the air temperature between 50 and 60 °C, that was optimum for dehydration of star fruit slices. The solar dryer achieved considerable reduction of 75% in drying time as compared to that of conventional sun drying. The quality of product was better maintained solar dryer than that by open sun drying. On the basis of present design, the temperature fluctuation was high in the solar dryer and the maximum temperature was above the requirement (>70 ^{O}C). Hence, it may be suggested to have temperature control provision in commercial solar dryers for better performance. Osmo-solar process may be recommended to be practiced at rural level for dehydration of star fruit slices as a compromise method between HAD and sun drying considering both the quality parameters of finished product and keeping a view point on energy consumption during drying. It is concluded that this dryer may prove to be beneficial for rural area where conventional power is a major constraint.

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