

PREPARATION OF SAPOTA POWDER BY OSMO-FREEZE DRYING

¹CHOLERA, S. P. AND ²PATEL, N. C.

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH – 362 001, GUJARAT, INDIA

**EMAIL: spcholera@jau.in*

¹Assistant Professor, Deptt. of Processing & Food Engineering, CAET, JAU, Junagadh

²Vice Chancellor, Anand Agricultural University, Anand

ABSTRACT

Osmotic dehydration of 4 mm sapota slices was carried out at different osmotic variables, viz., osmotic solution concentration (60⁰ and 70⁰Brix), immersion time (5 and 10 h), process temperature (30⁰, 40⁰ and 50 C) and sample to solution ratio (1:5). Osmotically dehydrated sapota slices were freeze dried at -20 and -40⁰C temperature at a constant vacuum pressure of 1 torr using freeze dryer. The powder was prepared by grinding sapota slices and sieved using 100 μ sieve size. The highest water loss to solid gain ratio (6.02 %) of sapota slice after osmotic dehydration as well as overall quality of osmo-freeze dried sapota powder revealed that the highest values of rehydration ratio (4.56), water solubility index (89.15 %), water absorption index (701.82 %), titratable acidity (0.26 %), ascorbic acid content (54.66 mg/100 g), overall acceptability (8.33) as well as lowest non-enzymatic browning (0.040 OD) were obtained in treatment having 60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature which required 34 h freeze drying time. It could be concluded that treatment having 60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature, was found to be the best among all the treatments on the basis of physical, biochemical and sensory characteristics of osmo-freeze dried sapota powder.

KEY WORDS: *Osmotic dehydration, osmo-freeze drying*

INTRODUCTION

Sapota is a highly perishable fruit, it has very short shelf life and marketing of fresh fruits to different places is very difficult. Therefore, it is necessary to convert it into value added products which retain colour, flavour and nutrients with longer shelf life. So to increase the shelf life of sapota, the fruit is converted into various processed products like powder, dried slices, pulp, juice, RTS, beverages, etc. Sapota powder is used

in ice-cream, flavoured milk, shrikhand, chocolates, etc.

Among others, a fundamental factor affecting the quality of the dried product when conventional procedures i.e., hot air drying methods are used is the thermal damage to the minerals, and other volatile compounds and poor reconstitution properties. These negative effects on the quality of the final products can be eliminated by adopting freeze drying method. Freeze drying is a method of dehydrating

frozen material by a process of sublimation under vacuum, usually for the purpose of preservation. Sapota powder by freeze drying is a very interesting alternative to recombine the fruit with practically all the properties of the natural product. Preparation of good quality sapota powder by osmo-freeze drying method is the novel concept because of the final product will get the combined benefits of these two valuable processes. Osmotic dehydration prior to freeze drying will retain the colour, flavour, aroma, texture and taste in the final product. Osmotic dehydration prior to freeze drying will also reduce the moisture content, drying time and energy consumption. Subsequent freeze drying will give the dried product of the same size and shape as the original one with an excellent quality, stability and convenient reconstitution when placed in water. Freeze dried products will maintain nutrients, colour, flavour, and texture often indistinguishable from the original product.

MATERIALS AND METHODS

Physical and biochemical parameters of fresh sapota fruits

The physical parameters viz., fruit weight, maximum and minimum diameter, pulp to peel (plus seed) ratio, firmness and cutting force of fresh sapota fruits were measured. Firmness and cutting force were measured using texture analyzer (Stable Micro Systems – UK, Model: TA-XT2i) using 50 kg load cell. The biochemical parameters viz., titratable acidity, total sugar, ascorbic acid as well as moisture content of fresh sapota fruits were also measured as per standard methods reported in following sections.

Osmotic dehydration of sapota slices

Osmotic dehydration of 4 mm sapota slices was carried out at

different osmotic variables, viz., osmotic solution concentration (60⁰ and 70⁰Brix), immersion time (5 and 10 h), process temperature (30⁰, 40⁰ and 50⁰C) and sample to solution ratio (1:5). Osmotic solution was prepared using sucrose and maltodextrine as an osmotic agent in 2:1 proportion. Addition of cryo-protectant maltodextrine in osmotic solution would prevent the damage of intercellular structure of sapota slices at low freeze drying temperature. After completion of osmotic dehydration, the sapota slices were removed and spread on blotting paper to remove surface moisture. The solid gain (SG), water loss (WL), water loss to solid gain ratio (WL/SG) and weight loss were measured as per the method reported by Islam and Flink (1982). Moisture content and titratable acidity were measured as per Ranganna (2000) method, whereas ascorbic acid and total sugar were measured per method suggested by Sadasivam and Manickam (1996). Osmotic dehydration of fresh sapota slices was carried out considering three factors Completely Randomized Design with three replications.

Osmo-freeze drying of sapota slices

The samples of twelve different treatments of osmotically dehydrated sapota slices were freeze dried by freeze dryer (lyophilizer- model FDU-7003) at -20 and -40⁰C temperature with a constant vacuum pressure of 1 torr (1 mm Hg) was maintained throughout the experiments (Plate 1). The freeze drying of these samples was carried out till it attained desired moisture content i.e., 3 to 4 % (db). The freeze drying characteristics of sapota slices were determined during freeze drying process in terms of variation in weight loss, moisture content, drying rate and moisture ratio with respect to drying time. The

rehydration ratio of the osmo-freeze dried sapota slices was determined as per the method suggested by Ranganna (2000). The powder was prepared by grinding freeze dried sapota slices and sieved using 100 μ sieve size. The osmo-freeze dried powder prepared by different treatments was light creamish in colour, free flowing in crispness, crystalline in consistency and highly hygroscopic in nature. Osmo-freeze drying of sapota slices was carried out considering Factorial Completely Randomized Design with three repetitions.

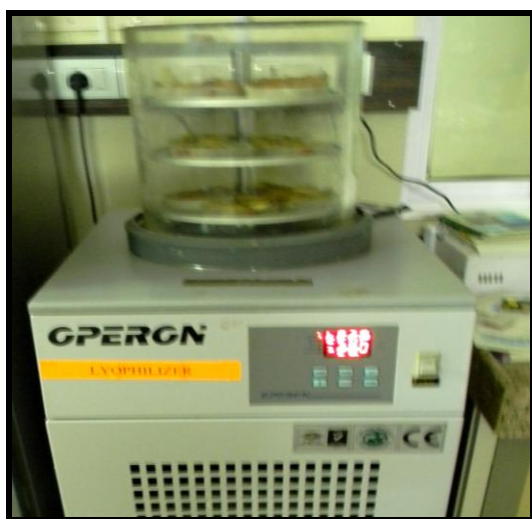


Plate 1: Freeze dryer (FDU-7003)

Quality evaluation of sapota powder prepared by different treatments

The quality evaluation of sapota powder obtained by 25 treatment samples (i.e., 24 osmo-freeze drying treatments + control treatment) was carried out on the basis of physical, biochemical and sensory characteristics. The physical parameters viz., per cent recovery, water solubility index (WSI) and water absorption index were measured using Eq. 1, 2 and 3, respectively. The biochemical parameters viz., titratable acidity, total sugar, ascorbic acid and non-enzymatic browning (NEB) were

Hot air drying of fresh sapota slices

The hot air drying of fresh sapota slices was carried out at 60⁰C air temperature and 1.25 m/s air velocity using laboratory scale tray dryer as a control treatment for comparative studies (Plate 2). Hot air dried sapota slices were of dark cream colour. Wrinkles and dark spots were appeared on surface of dried slices. Stiff and brittle in nature as well as shrinkage from its original volume was also observed.



Plate 2: Laboratory scale tray dryer

also measured. The sensory evaluation based on colour, flavour, taste and odour was carried as per the method suggested by Ranganna (2000).

$$\text{Recovery (\%)} = \left(\frac{\text{Weight of powder}}{\text{Weight of fresh slice}} \right) \times 100 \quad (1)$$

$$\text{WSI (\%)} = \left(\frac{\text{Weight of dissolve solid in supernatant}}{\text{Weight of dry solid powder}} \right) \times 100 \quad (2)$$

$$\text{WSI (\%)} = \left(\frac{\text{Weight of sediments}}{\text{Weight of dry solid powder}} \right) \times 100 \quad (3)$$

RESULTS AND DISCUSSION

Physical and biochemical parameters of fresh sapota fruits

The mean value of fruit weight, maximum and minimum diameter, pulp to peel ratio, cutting force and firmness was found to be 69.75 ± 1.78 g, 51.40 ± 1.47 mm and 43.70 ± 0.97 mm, 5.49 ± 0.22 , 5.01 ± 0.90 kg and 1.44 ± 0.27 kg, respectively. The mean value of titratable acidity, total sugar, ascorbic acid and moisture content was found 0.16 ± 0.04 %, 18.08 ± 0.70 %, 19.90 ± 1.80 mg/100g and 74.15 ± 0.78 % (wb), respectively. The results of physical and biochemical parameters of fresh sapota fruits are in agreement with the results reported by Ganjyal *et al.* (2005) and Pawar *et al.* (2011).

Osmotic dehydration of sapota slices ***Effect of osmotic variables on solid gain, water loss, WL/SG and weight loss***

The mean values of solid gain, water loss and weight loss increased with increased in concentration of osmotic solution, immersion time and process temperature (Table 1). The lowest values of solid gain (4.62 %), water loss (26.15 %) and weight loss (21.53 %) were obtained in treatment O₁ (60⁰Brix osmotic solution + 5 h immersion time + 30⁰C process temperature), while the highest solid gain (10.07 %), water loss (38.72 %) and weight loss (28.65 %) were obtained in treatment O₁₂ (70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature). The results of similar pattern for different osmotic characteristics were reported by Kshirsagar (2006) for sapota slices, Sagar and Kumar (2009) for mango slices and Kumar and Devi (2011) for pineapple slices.

Water loss to solid gain ratio (WL/SG) decreased with increased in concentration of osmotic solution and

immersion time, whereas WL/SG was not much varied with the change in process temperature. The highest water loss to solid gain ratio (WL/SG) of 6.02 % was obtained in treatment O₃ (60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature) and the lowest water loss to solid gain ratio (WL/SG) of 3.84 % was obtained in treatment O₁₂ (70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature). The ratio of water loss to solid gain is the indication of an efficient process, as process of osmotic dehydration always aims to minimum uptake of solid (sugar) with maximum release of water. So, high value of water to solid gain ratio for treatment O₃ (60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature) indicated that there was intensive water removal from the sapota slices accompanied with minimal solid gain.

The increase of solid gain, water loss and weight loss in the sapota slices with increase in osmotic solution concentration during osmosis may be due to the increase in pressure gradient of osmotic solution, which may accelerate the mass transfer process of water and solid diffusion. The influence of process temperature may be attributed to decrease in the external resistance to mass transport from the surface of sapota slices and also decreased in viscosity of osmotic medium and facilitating the outflow of water through cellular membranes structure of sapota slices favoured when immersion time of sapota slices was extended.

The statistically analyzed values revealed that the effect of osmotic solution concentration (S) and immersions time (I) on solid gain, water loss, WL/SG, weight loss and moisture content was found significant (Table 2). However, effect of process

temperature on solid gain, weight loss and moisture content was found significant. The effect of only few interactions, i.e., S x T, I x T, S x I x T on weight loss and I x T, S x I x T were found significant, whereas effects of other interactions were found non-significant. This might be due to inherent nature of the factors. When interactions are non-significant, it means that levels of one factor are consistent over various levels of another factor.

Effect of osmotic variables on titratable acidity, total sugar and ascorbic acid

The mean value of total sugar and ascorbic acid content was increased and of titratable acidity was decreased after osmotic dehydration for all the treatments (Table 3). The highest retention of ascorbic acid (22.52 mg/100g) and titratable acidity (0.15 %) was obtained in treatment O₃ (S₁I₁T₁), i.e., 60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature, whereas the lowest retention of ascorbic acid (19.50 mg/100g) and titratable acidity (0.10 %) was found in treatment O₁₂ (S₂I₂T₃) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature. The mean values of total sugar showed that the highest value of total sugar of 24.19 % was found in treatment O₁₂ (S₂I₂T₃) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature, whereas the lowest value of 21.87 % was found in treatment O₁ (S₁I₁T₁) i.e., 60⁰Brix osmotic solution + 5 h immersion time + 30⁰C process temperature. The results are accordance with Azoubel and Murr (2003) for cashew apple, Sagar and Kumar (2009) for mango slices and Kumar and Devi (2011) for pineapple slices.

The statistical analysis of data on the effect of osmotic solution concentration (S) and immersion time (I) on titratable acidity, total sugar and ascorbic acid presented in Table 4 revealed that the effect of process temperature (T) on was found significant on ascorbic acid, whereas it was non-significant on titratable acidity and total sugar content of the sapota slices after osmotic dehydration. However, the interaction effect between S x I, I x T, S x T and S x I x T on titratable acidity, total sugar and ascorbic acid content was found non-significant. It showed that individual effect of levels of factor was found dominant, but effect their interaction was not dominant over all the biochemical parameter of sapota slices after osmotic dehydration.

From the present investigation, on the basis of osmotic and biochemical characteristics of sapota slices, it was found that the treatment O₃ (i.e., 60⁰Brix sucrose solution + 5 h immersion time + 50⁰C temperature) was found to be the best among all the treatments after considering highest value of water loss to solid gain ratio (6.02 %), titratable acidity (0.15 %) and ascorbic acid content (22.52 mg/100g) as well as reasonably lower gain of sugar (22.40 %) during osmotic dehydration of sapota slices.

Osmo-freeze drying of sapota slices

Effect of freeze drying temperature on drying time and drying constant

The results presented in Table 5 revealed that the treatments with -20⁰C freeze drying temperature required more freeze drying time (4 to 6 hour) as compared to treatments with -40⁰C freeze drying temperature to reduce the almost similar initial moisture content of osmotically dehydrated sapota slices to 3 to 4 % (db) (i.e., 2.91 to 3.85 % (wb)). While comparing all 24 treatments, the highest freeze drying

time of 42 h in treatment D₁ (S₁I₁T₁F₁), i.e., 60⁰B osmotic solution + 5 h immersion time + 30⁰C process temperature – 20⁰C freeze drying temperature, whereas lowest of 26 h in treatments D₂₄ (S₂I₂T₃F₂), i.e., 70⁰B osmotic solution + 5 h immersion time + 50⁰C process temperature – 40⁰C freeze drying temperature, showing a wide difference of 16 h in freeze drying time. The higher value of drying constant was obtained in treatments with -40⁰C freeze drying temperature as compared to treatment with -20⁰C freeze drying temperature (Table 6). The results obtained are in conformity with the results reported by Oliveira *et al.* (2011) for lyophilization of sapota pulp and Koroishi *et al.* (2009) freeze drying of orange juice.

Rehydration ratio of osmo-freeze dried sapota slices

The higher value of rehydration ratio was observed (Table 6) in sapota slices at -40⁰C freeze drying temperature as compared to -20⁰C freeze drying temperature, while remarkably the lowest rehydration ratio of 1.88 was obtained in hot air dried sapota slices at 60⁰C air temperature and 1.25 m/s air velocity. The excellent rehydration capacity with highest value of rehydration ratio (4.56) was obtained in sapota slices dehydrated at 60⁰Brix osmotic solution, 5 h immersion time, 50⁰C process temperature and -40⁰C freeze drying temperature. Cui *et al.* (2008) reported the highest rehydration ratio of 5.61 for freeze dried apple slice, whereas lowest rehydration ratio of 4.81 obtained in hot air drying.

Physical parameters of osmo-freeze sapota powder

Recovery

The highest recovery of 29.86 % was obtained in treatment D₂₄ (S₂I₂T₃F₂) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C

process temperature - 40⁰C freeze drying temperature, whereas the lowest recovery of 20.65 % was obtained in treatment D₁ (S₁I₁T₁F₁), i.e., 60⁰Brix osmotic solution + 5 h immersion time + 30⁰C process temperature - 20⁰C freeze drying temperature (Table 6). This indicated that the powder recovery of osmo-freeze dried sapota slices increased with increased in solid gain, as treatment D₁ (S₁I₁T₁F₁) and D₂₄ (S₂I₂T₃F₂) obtained the lowest (4.62 %) and the highest (10.07 %) value of solid gain, respectively.

Water solubility index (WAI) and water absorption index (WAI)

The highest value of WSI (89.15 %) and WAI (701.82 %) of osmo-freeze dried sapota powder was obtained in treatment D₆ (S₁I₁T₃F₂) i.e., 60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature, whereas the lowest of WSI (67.11 %) and WAI (436.22 %) was obtained in treatment D₂₃ (S₂I₂T₃F₁) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 20⁰C freeze drying temperature (Table 6).

Biochemical characteristics of osmo-freeze powder

It was noticed that titratable acidity, total sugar and ascorbic acid content of osmosed sapota slices increased after freeze drying at -20⁰C and -40⁰C for all 24 treatments. This might be attributed to reduction of water accompanied with higher concentration of biochemical characters in osmo-freeze dried sapota powder. The highest retention of titratable acidity (0.26 %) and ascorbic acid (54.66 mg/100 g) were obtained in treatment D₆ (S₁I₁T₃F₂), i.e., 60⁰Brix osmotic solution + 5 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature, whereas the lowest retention of titratable acidity

(0.11 %) and ascorbic acid (35.84 mg/100 g) were found in treatment D₂₃ (S₂I₂T₃F₁) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 20⁰C freeze drying temperature (Table 6). This might be attributed to influence of quick freezing (- 40⁰C) process over slow freezing (-20⁰C) process found in better retention of titratable acidity and ascorbic acid after freeze drying.

The highest value of total sugar was obtained in treatment D₂₄ (S₂I₂T₃F₂) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature. This might be attributed to higher sugar uptake at higher osmotic solution concentration (70⁰Brix), immersion time (10 h) and process temperature (50⁰C) resulted in higher total sugar content of sapota powder after freeze drying at - 40⁰C temperature (Table 6). Thus, highest value of WSI and WAI in treatment D₆ (S₁I₁T₃F₂) shows excellent water dissolving and water absorbing characteristics of osmo-freeze dried sapota powder.

The lowest value of non-enzymatic browning (NEB) of 0.040 OD was obtained in treatment D₆ (S₁I₁T₃F₂) i.e., 60⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature, whereas the highest of 0.13 OD was obtained in treatment D₂₃ (S₂I₂T₃F₁) i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 20⁰C freeze drying temperature (Table 6). The lowest value non-enzymatic browning is an indication of lower degradation of ascorbic acid as degradation of ascorbic acid deteriorates the colour of the product. In addition to this, higher sugar gain also darkens the colour of the product.

The results of present investigation are in accordance to that reported by Oliveira *et al.* (2011) for freeze drying of sapota pulp using laboratory level bench top freeze dryer at -18⁰C. They reported the total freeze drying time of 24 h was required to reduce the initial moisture content of sapota pulp of 75.04 % (wb) to 12.30 % (wb). The initial values of titratable acidity (0.083 %), total sugar (11.17 %) and ascorbic acid (8.45 mg/100 g) was remarkably increased in lyophilized sapota powder to 0.247 %, 51.99 % and 9.84 mg/100 g, respectively. The results are also in agreement to the results reported by Jangam *et al.* (2008) for sapota pulp. They found a remarkable increase of total sugar content of fresh sapota pulp from 16 to 20 % to about 40 to 60 % after drying by different methods.

The statistical analysis of data (Table 7) revealed that the effect of osmotic solution concentration (S), immersion time (I) and freeze drying temperature (F) on recovery, WSI, WAI, titratable acidity, total sugar, ascorbic acid and NEB were found significant. The effect of process temperature (T) on recovery, WSI, titratable acidity, total sugar and ascorbic acid was found significant, whereas effect of process temperature on WAI and NEB was found non-significant. The effect of four factor interaction i.e., S x I x T x F on WSI, titratable acidity, total sugar and NEB was found significant.

Sensory characteristics of osmo-freeze powder

It was noticed that that the highest sensory score on the basis of colour, flavour, taste and odour of sapota powder of 8.33 was obtained in treatment D₆ (S₁I₁T₃F₂) i.e., 60⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature,

whereas, the lowest sensory score of 5.42 in treatment D₂₄ (S₂I₂T₃F₂), i.e., 70⁰Brix osmotic solution + 10 h immersion time + 50⁰C process temperature - 40⁰C freeze drying temperature.

Hot air dried sapota powder

The powder recovery (19.48 %), WSI (58.82 %), WAI (412.30 %), titratable acidity (0.12 %), total sugar (40.32 %), ascorbic acid (28.76 mg/100), NEB (0.145 OD) and sensory score (4.90) were obtained in sapota slices dried at 60⁰C air temperature and 1.25 m/s air velocity i.e. treatment D₂₅ (control). The values of recovery, WSI, WAI, titratable acidity, total sugar, ascorbic acid and sensory score of hot air dried sapota powder were very lower as compared to osmo-freeze dried sapota powder. The value of NEB of hot air dried sapota powder was higher than that of the osmo-freeze dried powder obtained by different treatments. Furthermore, the hot air dried sapota powder was of dark cream colour. Lumping and sticking of powder was also observed. The osmo-freeze dried powder prepared by different treatments was light creamish in colour, free flowing, crystalline in consistency, and highly hygroscopic in nature. These might be attributed to highly sophisticated freeze drying method, could be able to reconstitute the fruit with its natural substances. This might not be possible in hot air dried powder due to loss of natural substances at higher temperature (i.e., 60⁰C). The results are in accordance to that reported by Antal (2010) for vacuum freeze drying and hot air drying of apple cubes.

CONCLUSION

From the results and discussion, it was summarized that osmotic dehydration of sapota slices (4 mm) at 60⁰Brix osmotic solution

concentration, 5 hour immersion time, 50⁰C process temperature and 1:5 sample to solution ratio was found to be the best among all the treatments on the basis of highest water loss to solid gain ratio (6.02 %), ascorbic acid content (22.52 mg/100g), titratable acidity (0.15 %) as well as reasonably lower sugar gain. The treatments with -20⁰C freeze drying temperature required more freeze drying time (4 to 6 hour) as compared to treatments with -40⁰C freeze drying temperature to reduce the same initial moisture content of sapota slices to desired level (i.e., 3 to 4 % (db)). On the basis of physical parameters of osmo-freeze dried powder, highest value of rehydration ratio (4.56), water solubility index (89.15 %), and water absorption index (701.82 %) were obtained in treatment with 60⁰Brix osmotic solution concentration, 5 hour immersion time, 50⁰C process temperature and -40⁰C freeze drying temperature. On the basis of biochemical parameters of osmo-freeze dried powder, highest retention of titratable acidity (0.26 %) and ascorbic acid content (54.66 mg/100 g) as well as the lowest level of non-enzymatic browning were obtained in treatment with 60⁰Brix osmotic solution concentration, 5 hour immersion time, 50⁰C process temperature and -40⁰C freeze drying temperature. On the basis of sensory characteristics of osmo-freeze dried powder, highest sensory score of 8.33 in terms of colour, flavour, taste, odour and overall acceptability was obtained in treatment with 60⁰Brix osmotic solution concentration, 5 hour immersion time, 50⁰C process temperature and -40⁰C freeze drying temperature. Osmo-freeze drying of 4 mm thick sapota slices at 60⁰Brix osmotic solution concentration, 5 hour immersion time, 50⁰C process temperature, 1:5 sample

to solution ratio and - 40 °C freeze drying temperature was found to be the best on the basis of physical, biochemical and sensory characteristics of osmo-freeze dried powder.

REFERENCES

- Antal, T. (2010). Inspection of the technological characteristics influencing the quality of dried fruits and vegetables. Ph. D. thesis (Unpublished) Submitted to University of Debrecen, Kalman Kerpely Doctoral School.
- Azoubel, P. M. and Murr, F. E. X. (2003). Optimization of osmotic dehydration of cashew apple (*Anacardium occidentale* L.) in sugar solutions. *Food Sci. Tech. Int.*, **9**(6): 427-433.
- Cui, Z. W.; Li, C. Y.; Song, C. F. and Song, Y. (2008). Combined microwave vacuum and freeze drying of carrot and apple chips, *Drying Technol.*, **26**(12): 1517-1523.
- Ganjyal, G. M.; Hanna, M. A. and Devadattam, D. S. K. (2005). Processing of Sapota (Sapodilla), Powdering. *J. Food Technol.*, **3**(3): 326-330.
- Islam, M. N. and Flink, J. M. (1982). Dehydration of potato. II. Osmotic concentration and its effect on air-drying behaviour. *J. Food Technol.*, **17**: 387-403.
- Jangam, S. V.; Joshi, V. S.; Mujumdar, A. S. and Thorat, B. N. (2008). Studies on dehydration of sapota (*Achras zapota*). *Drying Technol.*, **26**(3): 369-377.
- Koroishi, E. T.; Boss, E. A.; Maciel, M. R. W. and Filho, R. M. (2009). Process development and optimization for freeze-drying of natural orange juice. *J. Food Process Engg.*, **32**(3): 425-441.
- Kshirsagar, V. A. (2006). Studies on osmotic air drying characteristics of sapota slices. M.Tech. Thesis (Unpublished) submitted to Junagadh Agricultural University Junagadh.
- Kumar, P. and Devi, P. (2011). Optimization of some process variables in mass transfer kinetics of osmotic dehydration of pineapple slices. *Int. Food Res. J.*, **18**: 221-238.
- Oliveira, V. S.; Afonso, M. R. A. and Costa, J. M. C. (2011). Physico chemical and hygroscopic behavior of sapodilla lyophilized. *Rev. Ciênc. Agron.* [online]., **42**(2): 342-348.
- Pawar, C. D.; Patil, A. A. and Joshi, G. D. (2011). Physico-chemical parameters of sapota fruits at different maturity stages. *Karnataka J. Agric. Sci.* **24**(3): 420-421.
- Ranganna, S. (2000). Handbook of Analysis and Quality Control for Fruits and Vegetable Products. Tata McGraw Hill Publishing Co. Ltd., New Delhi.
- Sadasivam, S. and Manickam, A. (1996). Biochemical Methods. 2nd Ed. New Age International Private Ltd. Publishers, Coimbatore, India.
- Sagar, V. R. and Kumar, P. S. (2009). Involvement of some process variables in mass transfer kinetics of osmotic dehydration of mango slices and storage stability. *J. Sci. Ind. Res.*, **68**: 1043-1048.

Table 1: Mean values of osmotic characteristics of sapota slices during osmotic dehydration

Treatments	Solid Gain (SG) (%)	Water Loss (WL) (%)	WL /SG	Weight Loss (%)	Moisture Content (%) (wb)
O ₁ (S ₁ I ₁ T ₁)	4.62	26.15	5.656	21.53	61.13
O ₂ (S ₁ I ₁ T ₂)	5.19	29.22	5.626	24.03	59.10
O ₃ (S ₁ I ₁ T ₃)	5.22	31.43	6.019	26.21	57.85
O ₄ (S ₁ I ₂ T ₁)	5.56	31.26	5.620	25.70	58.60
O ₅ (S ₁ I ₂ T ₂)	7.22	32.17	4.455	24.95	56.80
O ₆ (S ₁ I ₂ T ₃)	8.72	36.32	4.165	27.60	53.15
O ₇ (S ₂ I ₁ T ₁)	5.99	30.16	5.033	24.17	57.30
O ₈ (S ₂ I ₁ T ₂)	7.19	33.50	4.661	26.32	54.43
O ₉ (S ₂ I ₁ T ₃)	7.85	35.16	4.480	27.31	52.90
O ₁₀ (S ₂ I ₂ T ₁)	8.48	36.30	4.283	27.82	51.60
O ₁₁ (S ₂ I ₂ T ₂)	8.80	36.84	4.185	28.04	51.00
O ₁₂ (S ₂ I ₂ T ₃)	10.07	38.72	3.844	28.65	48.80

(S₁, S₂=60 °B, 70 °B ; I₁, I₂=5 h, 10 h ; T₁, T₂, T₃ = 30 °C, 40 °C, 50 °C)

Table 2: Statistically analyzed data on effect of osmosis on osmotic characteristics

Treatments	Solid Gain (SG) (%)	Water Loss (WL) (%)	WL /SG	Weight Loss (%)	Moisture Content (%) (wb)
Osmotic Solution Concentration (S)					
S ₁ (60 °Brix)	6.08	29.15	5.01	25.00	57.79
S ₂ (70 °Brix)	8.22	32.59	4.06	27.05	52.44
SEm	0.23	1.03	0.19	0.06	0.25
CD at 5%	0.67	2.99	0.56	0.18	0.72
Immersion Time (I)					
I ₁ (5 h)	6.20	29.16	4.89	24.92	56.87
I ₂ (10 h)	8.10	32.58	4.17	27.12	53.37
SEm	0.23	1.03	0.19	0.06	0.25
CD at 5%	0.67	2.99	0.56	0.18	0.72
Process Temperature (T)					
T ₁ (30 °C)	6.15	29.06	4.96	24.80	57.17
T ₂ (40 °C)	7.37	30.83	4.32	25.83	54.97
T ₃ (50 °C)	7.93	32.73	4.32	27.44	53.22
SEm	0.28	1.26	0.23	0.08	0.30
CD at 5%	0.82	NS	NS	0.23	0.89
CV, %	13.62	14.09	17.85	1.03	1.91
S x I					
SEm	0.32	1.45	0.27	0.09	0.35
CD at 5%	NS	NS	NS	NS	NS
S x T					
SEm	0.40	1.78	0.33	0.11	0.43
CD at 5%	NS	NS	NS	0.32	NS
I x T					
SEm	0.40	1.78	0.33	0.11	0.43
CD at 5%	NS	NS	NS	0.32	1.26
S x I x T					
SEm	0.56	2.51	0.47	0.15	0.61
CD at 5%	NS	NS	NS	0.45	NS

(S₁, S₂=60 °B, 70 °B ; I₁, I₂ =5 h, 10 h ; T₁, T₂, T₃ = 30 °C, 40 °C, 50 °C)

Table 3: Mean values of osmotic characteristics of sapota slices during osmotic dehydration

Sr. No.	Treatment	Initial Values Before Osmotic Dehydration			Mean Values After Osmotic Dehydration		
		Titratable Acidity (%)	Total Sugar (%)	Ascorbic Acid (mg/100 g)	Titratable Acidity (%)	Total Sugar (%)	Ascorbic Acid (mg/100 g)
1	O ₁ (S ₁ I ₁ T ₁)	0.16	19.50	18.40	0.14	21.87	20.79
2	O ₂ (S ₁ I ₁ T ₂)	0.16	19.50	18.40	0.15	22.19	21.71
3	O ₃ (S ₁ I ₁ T ₃)	0.16	19.50	18.40	0.15	22.40	22.52
4	O ₄ (S ₁ I ₂ T ₁)	0.16	19.50	18.40	0.13	22.06	19.82
5	O ₅ (S ₁ I ₂ T ₂)	0.16	19.50	18.40	0.14	22.60	20.58
6	O ₆ (S ₁ I ₂ T ₃)	0.16	19.50	18.40	0.14	23.10	21.54
7	O ₇ (S ₂ I ₁ T ₁)	0.17	20.20	18.20	0.11	22.94	19.12
8	O ₈ (S ₂ I ₁ T ₂)	0.17	20.20	18.20	0.12	23.39	20.18
9	O ₉ (S ₂ I ₁ T ₃)	0.17	20.20	18.20	0.13	23.73	21.33
10	O ₁₀ (S ₂ I ₂ T ₁)	0.17	20.20	18.20	0.10	23.46	18.47
11	O ₁₁ (S ₂ I ₂ T ₂)	0.17	20.20	18.20	0.08	23.73	18.95
12	O ₁₂ (S ₂ I ₂ T ₃)	0.17	20.20	18.20	0.07	24.19	19.50

(S₁, S₂=60 °B, 70 °B; I₁, I₂=5 h, 10 h; T₁, T₂, T₃= 30 °C, 40 °C, 50 °C)

Table 4: Statistically analyzed data on effect on osmotic characteristics of sapota slices during osmotic dehydration

Treatment Details	Titrateable Acidity (%)	Total Sugar (%)	Ascorbic Acid (mg/100 g)
Osmotic solution concentration (S)			
S ₁ (60 °Brix)	0.140	22.37	21.16
S ₂ (70 °Brix)	0.117	23.58	19.59
S.Em.±	0.002	0.18	0.27
C.D. at 5 %	0.006	0.53	0.78
Immersion Time (I)			
I ₁ (5 h)	0.138	22.75	20.94
I ₂ (10 h)	0.120	23.20	19.81
S.Em.±	0.002	0.18	0.27
C.D. at 5 %	0.006	NS	0.78
Process Time (T)			
T ₁ (30 °C)	0.126	22.60	19.55
T ₂ (40 °C)	0.127	22.97	20.35
T ₃ (50 °C)	0.133	23.35	21.22
S.Em.±	0.002	0.22	0.33
C.D. at 5 %	NS	NS	0.96
C.V. %	6.481	3.36	5.58
S x I			
S.Em.±	0.003	0.26	0.38
C.D. at 5 %	NS	NS	NS
S x T			
S.Em.±	0.003	0.32	0.46
C.D. at 5 %	NS	NS	NS
I x T			
S.Em.±	0.003	0.32	0.46
C.D. at 5 %	NS	NS	NS
S x I x T			
S.Em.±	0.005	0.45	0.66
C.D. at 5 %	NS	NS	NS

(S₁, S₂=60 °B, 70 °B ; I₁, I₂=5 h, 10 h ; T₁, T₂, T₃ = 30 °C, 40 °C, 50 °C)

Table 5: Values of freeze drying time, regression co-efficient and freeze drying constant for different osmo-freeze drying treatments

Sr. No.	Treatments	MC After Osmotic Dehydration (% (db))	Drying Time (h)	Relationship	Regression Coefficient, (R^2)	Freeze Drying Constant (h^{-1})
1	D ₁ (S ₁ I ₁ T ₁ F ₁)	152.65	42	MR=2.186e ^{-0.21x}	0.878	0.21
2	D ₂ (S ₁ I ₁ T ₁ F ₂)	157.27	36	MR= 2.189e ^{-0.24x}	0.900	0.24
3	D ₃ (S ₁ I ₁ T ₂ F ₁)	145.28	40	MR= 2.351e ^{-0.23x}	0.870	0.23
4	D ₄ (S ₁ I ₁ T ₂ F ₂)	144.50	34	MR= 2.002e ^{-0.23x}	0.909	0.23
5	D ₅ (S ₁ I ₁ T ₃ F ₁)	137.25	38	MR=1.923e ^{-0.20x}	0.907	0.20
6	D ₆ (S ₁ I ₁ T ₃ F ₂)	137.25	34	MR =1.883e ^{-0.23x}	0.940	0.23
7	D ₇ (S ₁ I ₂ T ₁ F ₁)	142.25	38	MR=1.952e ^{-0.21x}	0.906	0.21
8	D ₈ (S ₁ I ₂ T ₁ F ₂)	141.55	34	MR=1.965e ^{-0.24x}	0.908	0.24
9	D ₉ (S ₁ I ₂ T ₂ F ₁)	131.21	36	MR=1.926e ^{-0.21x}	0.908	0.21
10	D ₁₀ (S ₁ I ₂ T ₂ F ₂)	131.48	32	MR= 1.853e ^{-0.24x}	0.923	0.24
11	D ₁₁ (S ₁ I ₂ T ₃ F ₁)	113.77	34	MR=1.938e ^{-0.23x}	0.920	0.23
12	D ₁₂ (S ₁ I ₂ T ₃ F ₂)	113.22	30	MR=2.090e ^{-0.29x}	0.963	0.29
13	D ₁₃ (S ₂ I ₁ T ₁ F ₁)	133.86	36	MR=1.948e ^{-0.21x}	0.913	0.21
14	D ₁₄ (S ₂ I ₁ T ₁ F ₂)	134.19	32	MR=1.771e ^{-0.23x}	0.917	0.23
15	D ₁₅ (S ₂ I ₁ T ₂ F ₁)	119.11	34	MR=1.911e ^{-0.23x}	0.926	0.23
16	D ₁₆ (S ₂ I ₁ T ₂ F ₂)	119.44	30	MR=1.704e ^{-0.25x}	0.961	0.25
17	D ₁₇ (S ₂ I ₁ T ₃ F ₁)	112.63	34	MR=1.921e ^{-0.23x}	0.914	0.23
18	D ₁₈ (S ₂ I ₁ T ₃ F ₂)	112.31	28	MR=1.848e ^{-0.28x}	0.944	0.28
19	D ₁₉ (S ₂ I ₂ T ₁ F ₁)	111.24	34	MR=1.943e ^{-0.23x}	0.908	0.23
20	D ₂₀ (S ₂ I ₂ T ₁ F ₂)	110.97	28	MR=1.827e ^{-0.28x}	0.948	0.28
21	D ₂₁ (S ₂ I ₂ T ₂ F ₁)	104.79	32	MR=2.029e ^{-0.26x}	0.917	0.26
22	D ₂₂ (S ₂ I ₂ T ₂ F ₂)	104.92	26	MR=1.791e ^{-0.29x}	0.967	0.29
23	D ₂₃ (S ₂ I ₂ T ₃ F ₁)	95.66	30	MR=2.177e ^{-0.28x}	0.897	0.28
24	D ₂₄ (S ₂ I ₂ T ₃ F ₂)	96.85	26	MR=1.830e ^{-0.29x}	0.945	0.29

(S₁, S₂=60 °B, 70 °B ; I₁, I₂ =5 h, 10 h ; T₁, T₂, T₃ = 30 °C, 40 °C, 50 °C ; F₁, F₂ = - 20 °C, - 40 °C)

Table 6: Mean values of physical and biochemical parameters of osmo-freeze dried sapota powder prepared by different treatments

Sr. No.	Treatments	Rehyd-ration ratio	Recov-ery (%)	WSI (%)	WAI (%)	Titrata-ble Acidity (%)	Total Sugar (%)	Ascorbic Acid (mg/100 g)	NEB (OD)
1	D ₁ (S ₁ I ₁ T ₁ F ₁)	3.79	20.65	78.35	607.21	0.20	52.63	44.57	0.053
2	D ₂ (S ₁ I ₁ T ₁ F ₂)	4.31	23.18	82.45	647.23	0.23	58.95	48.83	0.047
3	D ₃ (S ₁ I ₁ T ₂ F ₁)	3.86	21.81	82.88	642.32	0.22	55.53	47.48	0.046
4	D ₄ (S ₁ I ₁ T ₂ F ₂)	4.33	24.05	86.79	673.45	0.24	61.13	53.48	0.041
5	D ₅ (S ₁ I ₁ T ₃ F ₁)	3.96	23.37	84.42	654.26	0.23	59.43	52.13	0.049
6	D ₆ (S ₁ I ₁ T ₃ F ₂)	4.56	24.86	89.15	701.82	0.26	61.15	54.66	0.040
7	D ₇ (S ₁ I ₂ T ₁ F ₁)	3.34	23.82	76.75	548.76	0.18	60.55	47.60	0.074
8	D ₈ (S ₁ I ₂ T ₁ F ₂)	4.06	25.91	78.23	559.34	0.20	65.78	49.09	0.068
9	D ₉ (S ₁ I ₂ T ₂ F ₁)	3.45	24.95	77.12	551.41	0.19	63.38	46.63	0.071
10	D ₁₀ (S ₁ I ₂ T ₂ F ₂)	4.11	26.82	79.58	569.00	0.22	68.05	47.53	0.066
11	D ₁₁ (S ₁ I ₂ T ₃ F ₁)	3.49	25.18	78.41	560.63	0.19	63.95	44.36	0.072
12	D ₁₂ (S ₁ I ₂ T ₃ F ₂)	4.16	27.24	80.65	576.65	0.22	69.10	45.10	0.062
13	D ₁₃ (S ₂ I ₁ T ₁ F ₁)	3.14	22.20	73.44	495.72	0.16	56.51	40.69	0.099
14	D ₁₄ (S ₂ I ₁ T ₁ F ₂)	3.56	24.93	74.85	505.24	0.17	63.34	44.65	0.093
15	D ₁₅ (S ₂ I ₁ T ₂ F ₁)	3.20	23.45	74.21	500.92	0.17	59.64	43.39	0.091
16	D ₁₆ (S ₂ I ₁ T ₂ F ₂)	3.57	25.87	75.08	506.79	0.18	65.69	48.97	0.086
17	D ₁₇ (S ₂ I ₁ T ₃ F ₁)	3.28	25.14	74.53	503.08	0.17	63.85	47.72	0.091
18	D ₁₈ (S ₂ I ₁ T ₃ F ₂)	3.76	26.75	76.15	514.01	0.19	67.87	50.07	0.082
19	D ₁₉ (S ₂ I ₂ T ₁ F ₁)	2.65	26.10	71.08	462.02	0.13	66.26	38.74	0.102
20	D ₂₀ (S ₂ I ₂ T ₁ F ₂)	3.25	28.40	71.89	467.29	0.15	72.00	40.07	0.097
21	D ₂₁ (S ₂ I ₂ T ₂ F ₁)	2.73	27.35	69.32	450.58	0.11	69.36	37.87	0.120
22	D ₂₂ (S ₂ I ₂ T ₂ F ₂)	3.31	29.40	69.92	454.48	0.13	74.51	38.67	0.100
23	D ₂₃ (S ₂ I ₂ T ₃ F ₁)	2.81	27.60	67.11	436.22	0.11	70.00	35.84	0.130
24	D ₂₄ (S ₂ I ₂ T ₃ F ₂)	3.39	29.86	67.91	441.42	0.12	75.66	36.50	0.111

(S₁, S₂=60 °B, 70 °B ; I₁, I₂=5 h, 10 h ; T₁, T₂, T₃ = 30 °C, 40 °C, 50 °C ; F₁, F₂ = - 20 °C, - 40 °C)

Table 7: Statistically analyzed data on effect of osmo-freeze drying on physical and biochemical characteristics of sapota life

Treatment	Recovery (%)	WSI (%)	WAI (%)	Titratable Acidity (%)	Total Sugar (%)	Ascorbic Acid (mg/100 g)	NEB (OD)
Osmotic Solution Concentration (S)							
S ₁ (60 Brix)	24.32	81.23	607.67	0.22	61.64	48.46	0.06
S ₂ (70 ⁰ Brix)	26.42	72.12	478.15	0.15	67.06	41.93	0.10
S.Em.±	0.04	0.05	2.93	0.0003	0.05	0.05	0.0003
C.D. at 5 %	0.12	0.13	8.33	0.001	0.13	0.13	0.0009
Immersion Time (I)							
I ₁ (5 h)	23.86	79.36	579.34	0.20	60.48	48.05	0.07
I ₂ (10 h)	26.89	74.00	506.48	0.16	68.22	42.34	0.09
S.Em.±	0.04	0.05	2.93	0.0004	0.05	0.05	0.0003
C.D. at 5 %	0.12	0.13	8.33	0.001	0.13	0.13	0.0009
Process Temperature (T)							
T ₁ (30 °C)	24.40	75.88	536.60	0.18	62.00	44.28	0.08
T ₂ (40 °C)	25.46	76.86	543.62	0.18	64.66	45.51	0.08
T ₃ (50 °C)	26.25	77.29	548.51	0.186	66.38	45.80	0.0788
S.Em.±	0.05	0.06	3.59	0.0003	0.06	0.06	0.0004
C.D. at 5 %	0.14	0.16	NS	0.001	0.16	0.16	NS
Freeze Drying Temperature (F)							
F ₁ (-20 °C)	24.30	75.64	534.43	0.17	61.76	43.92	0.08
F ₂ (-40 °C)	26.44	77.72	551.39	0.19	66.94	46.47	0.07
S.Em.±	0.04	0.05	2.93	0.0005	0.05	0.05	0.0003
C.D. at 5 %	0.12	0.13	8.33	0.001	0.13	0.13	0.0009
C.V. %	0.96	0.36	3.24	1.073	0.43	0.62	2.4829
S x I							
S.Em.±	0.06	0.07	4.14	0.0005	0.07	0.07	0.0005
C.D. at 5 %	0.16	0.19	11.78	0.001	0.19	0.19	NS
S x T							
S.Em.±	0.07	0.08	5.07	0.001	0.08	0.08	0.0006
C.D. at 5 %	NS	0.23	14.43	0.002	0.23	NS	0.0016
SxF							
S.Em.±	0.06	0.07	4.14	0.0005	0.07	0.07	0.0005
C.D. at 5 %	NS	0.19	11.78	0.001	0.19	NS	0.0013

Table 7 Continue....

I x T							
S.Em.±	0.07	0.08	5.07	0.001	0.08	0.08	0.0006
C.D. at 5 %	0.20	0.23	14.43	0.002	0.23	0.23	0.0016
IxF							
S.Em.±	0.06	0.07	4.14	0.0005	0.07	0.07	0.0005
C.D. at 5 %	NS	0.19	NS	NS	NS	0.19	0.0013
T x F							
S.Em.±	0.07	0.08	5.07	0.001	0.08	0.08	0.0006
C.D. at 5 %	0.20	0.23	NS	NS	0.23	0.23	0.0016
SxIxT							
S.Em.±	0.10	0.11	7.17	0.001	0.11	0.11	0.0008
C.D. at 5 %	NS	0.32	NS	0.002	0.32	0.32	0.0023
S x T x F							
S.Em.±	0.10	0.11	7.17	0.001	0.11	0.11	0.0008
C.D. at 5 %	NS	NS	NS	0.002	0.32	NS	0.0023
I x T x F							
S.Em.±	0.10	0.11	7.17	0.001	0.11	0.11	0.0008
C.D. at 5 %	0.28	0.32	NS	0.002	0.32	0.32	0.0023
S x I x T x F							
S.Em.±	0.14	0.16	10.15	0.001	0.16	0.16	0.0011
C.D. at 5 %	NS	0.46	NS	0.003	0.46	NS	0.0032

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