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Mass Transfer Kinetics during Osmotic Dehydration of Pineapple Samples Coated with Pectin

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Abstract

The effect of process conditions on the mass transfer during osmotic dehydration of coated pineapples was studied. Pineapple samples were coated with 0.5 to 5.0% (w/v) pectin solution prior to osmotic dehydration in sucrose solution. The time of dipping in the coating solution was kept at 60 and 120 s followed by oven drying time of 10 and 40 min to solidify the coating. Water loss, solid gain, performance ratio and weight reduction were measured during osmotic dehydration of both coated and uncoated samples. Water loss of coated samples was more than the uncoated samples in coating solution of 0.5 to 3% concentration whereas solid gain of coated samples was less than the uncoated samples at all the concentrations of coating solution. Increase in drying time led to decrease in both water loss and solid gain. PR values increased as the concentration of coating agent increased from 0.5 to 1% and further increase in the concentration above 1% resulted in decreased PR. The highest value of performance ratio of 5.89 was observed in samples dipped in coating solution of 1% concentration for 120 s followed by oven drying for 40 min.

Highlights

- Cut pineapple samples were coated with pectin at different concentrations and then osmotic dehydration was carried out.
- Coating proved to be an effective method to check transfer of solid gain without affecting water removal during osmotic dehydration.
- Highest performance ratio was observed at 1% concentration of pectin as compared to other concentrations.

Keywords: Osmotic dehydration, coatings, pineapple, mass transfer, pectin, performance ratio

Osmotic dehydration (OD) is one of the preservation methods, which is widely used for partial removal of water from food materials. This process mainly deals with the removal of water from food by immersing the food material in an osmotic solution. For osmotic treatment, food material is introduced into an aqueous solution of increased osmotic pressure. During OD, due to difference in concentration of dissolved substances in the cell fluid within the tissue and the osmotic solution, two counter current mass transfers take place: (1) diffusion of water out of the cells into the solution and (2) uptake of solute by cellular tissues from the osmotic solution (Hough *et al*. 1993; Jena and Das 2005; Lazarides *et al*. 1997; Raoult-Wack *et al*. 1994; Singh *et al*. 2010; Waliszewski *et al.* 2002). Pineapple (*Ananas comosus*) is rich in minerals, have high content of vitamins and excellent source of bromelain, an enzyme, used as meat tenderizing agent and as a neutraceutical (Lotz-Winter 1990).

The major limitation of OD is the penetration of large amount of solute into the food material, which brings about the resistance for mass exchange of water in further dehydration processes. It modifies the final product composition and taste and results in the development of concentrated solids layer under the product surface upsetting the osmotic pressure gradient across the product-medium interface and decreasing the driving force for flow of water (Hawkes and Flink 1978; Lazarides, 2001). To overcome the problem of solute intake, application of coating on the fruits can be introduced prior to OD. This will efficiently hinder the penetration of solute inside the food without seriously affecting the rate of water removal (Ishikawa and Nara 1993; Khin *et al*. 2005; Lenart and Dabrowska 1999; Lewicki *et al*. 1984; Singh *et al*. 2011).

Edible coatings are defined as thin layers of edible material applied on the foods by immersing, spraying or wrapping to offer a selective barrier against transmission of gases, vapours and solutes while also offering mechanical protection. The term coating is used when it is applied directly and formed on the surface of the product while the term film is used when it is formed separately as thin sheets and applied on the products (Gennadios and Weller 1990). Aqueous solutions of potato and cornstarches, gelatin, amylopectin, pectin, maltodextrin, wheat gluten, sodium alginate, methylcellulose and chitosan are used for the coating of fruits and vegetables (Camirand *et al*. 1992; Lenart and Dabrowska 1997; Lewicki *et al*. 1984; Wong *et al*. 1994).

The edible coatings should have the following characteristics for the purpose of osmotic dehydration (OSMEMB) process: good mechanical strength, good sensory properties, easy and rapid film formation, high water diffusivity and low solute diffusivity, and maintenance of the coating in an intact state without dissolving into the osmotic solution (Camirand *et al*. 1992). The advantages of OSMEMB process are: high rates of OD as compared to uncoated samples, reduced losses of colourants, flavour compounds and nutrients, allow use of low molecular weight osmotic agents e.g. NaCl, provide physical strength to food pieces to withstand mixing during processing and minimize oxidation activity during storage. The main objective of this study was to determine the effect of pectin as a coating agent on the mass transfer during OD of pineapples with different concentrations of coating solution, time of dipping in coating solution and drying time.

Materials and Methods

Pineapples were procured from the local market, Sangrur for mass transfer studies. Sucrose was used as the osmotic agent. Pectin (Sisco Research Laboratories Private Limited, Mumbai) was used as coating agent. Calcium chloride (Sisco Research Laboratories Private Limited, Mumbai) was used as a cross linking agent.

Coating Prior to Osmotic Dehydration

Pineapples were peeled and cut into cuboids of size 2.0x2.0x0.75 cm^3. Pectin was selected as a coating agent because of its high performance ratio demonstrated in the screening experiments. The different concentrations of pectin solutions were prepared (0.5%, 1%, 2%, 3%, 4% and 5%, w/v) with distilled water. The pineapple samples were weighed and dipped into the solution of coating agent for two different time of 60 s and 120 s. Pineapple samples were taken out from the coating solution, drained to remove adhering solution for 30 s and then dipped into $CaCl_2$ solution (2% w/v), which was used as a cross-linking agent. The cross linking time was 30 s for all the coated samples. The samples were then taken out from the $CaCl_2$ solution and dried in a hot-air oven at 50°C to fix the layer of coating for 10 and 40 min followed by OD, which was carried out at the optimized OD conditions as described below.

Osmotic Dehydration

In the screening experiments, by using different levels of processing parameters in Central Composite Rotatable Design (CCRD), the conditions of OD were optimized. The processing parameters optimized were sucrose concentration of the osmotic solution, temperature during OD, time and fruit-solution ratio, where as the response variables kept were water loss, solid gain and ratio of water loss to solid gain (WL/SG) with desired conditions of maximum water loss, minimum solid gain and maximum WL/SG ratio during the OD. The optimized conditions obtained were 62°Brix sucrose concentration, temperature of 30°C for 6 hours time using 1:6 fruit-solution ratio (Singh *et al*. 2008). After OD, samples were taken out of the osmotic medium, drained, then gently blotted with filter paper to remove adhering solution and weighed. Uncoated samples were also dehydrated osmotically by using sucrose solution for comparison of the mass transfer in coated samples to that in uncoated samples.

Analysis of Moisture Content

Moisture content of pineapple samples was determined by the oven drying method (AOAC 1990). Samples were weighed and placed in an oven set at 70°C. The samples were kept in the oven until a constant weight was reached. The samples were cooled down to room temperature in desiccators and weighed. The moisture content of the samples was then calculated from the weight of the sample before and after drying. The initial moisture content of fresh pineapple samples varied from 90% to 93% wet basis (w.b.).

Mass Transfer Studies

Evaluation of mass exchange between the solution and sample during OD were made by using the parameters such as water loss (WL), solid gain (SG), performance ratio (PR) and weight reduction (WR). In order to compare the mass transfer between the coated and uncoated samples, water loss (WL), solid gain (SG), performance ratio (PR) and weight reduction (WR) were calculated according to the following equations:

$$WL = \frac{m_i z_i - m_f z_f}{m_i} \times 100 \text{ (g/100 g fresh sample)}$$

$$SG = \frac{m_f s_f - m_i s_i}{m_i} \times 100 \text{ (g/100 g fresh sample)}$$

$$PR = \frac{WL}{SG}$$

$$WR = WL - SG \text{ (g/100 g fresh sample)}$$

where m_i and m_f are the initial and final weight (g) of the samples, respectively; z_i and z_f are the initial and final mass fraction of water (g water/g sample), respectively; s_i and s_f are the initial and final mass fraction of total solids (g total solids/g sample), respectively.

Statistical Analysis

All the experiments were carried out in triplicates and the average value was taken for calculations. Composite Rotatable Design (CRD) was used to analyze the results to determine if the differences were significant between the coated and uncoated samples. Factorial Composite Rotatable Design was employed to find out differences among the coated samples at different concentrations of coating solutions, two dipping time (60 and 120 s) and two oven drying time (10 and 40 min).

Results and Discussion

Water loss

The effect of coating on water loss (WL) during OD of coated and uncoated pineapple samples at different concentrations of pectin, and two levels of dipping time and drying time is shown in Figure 1. The highest value (48.86 g/100 g fresh sample) of WL was found during mass transfer process in OD of pineapple samples dipped for 120 s in pectin solution of 2% concentration and later oven dried for 10 min, while the minimum WL (37.50 g/100 g fresh sample) was observed at 5% concentration of pectin solution which were dipped for 120 s followed by oven drying for 40 min to fix the coating on the sample. A difference of 11.36 (g/100 g fresh sample) was noted in the rates of WL between the highest and lowest value of WL.

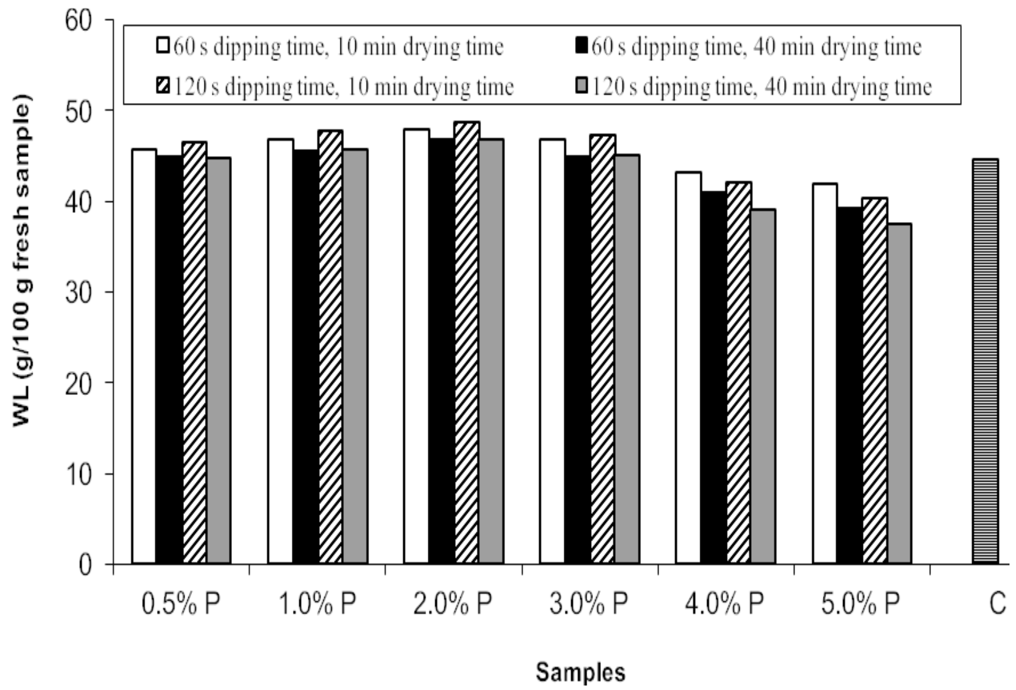

Figure 1. Effect of coating on the water loss (WL) during osmotic dehydration of coated and uncoated pineapple samples at different concentrations of pectin, two levels of dipping time and drying time P, pectin coated pineapple samples; C, control or uncoated pineapple sample

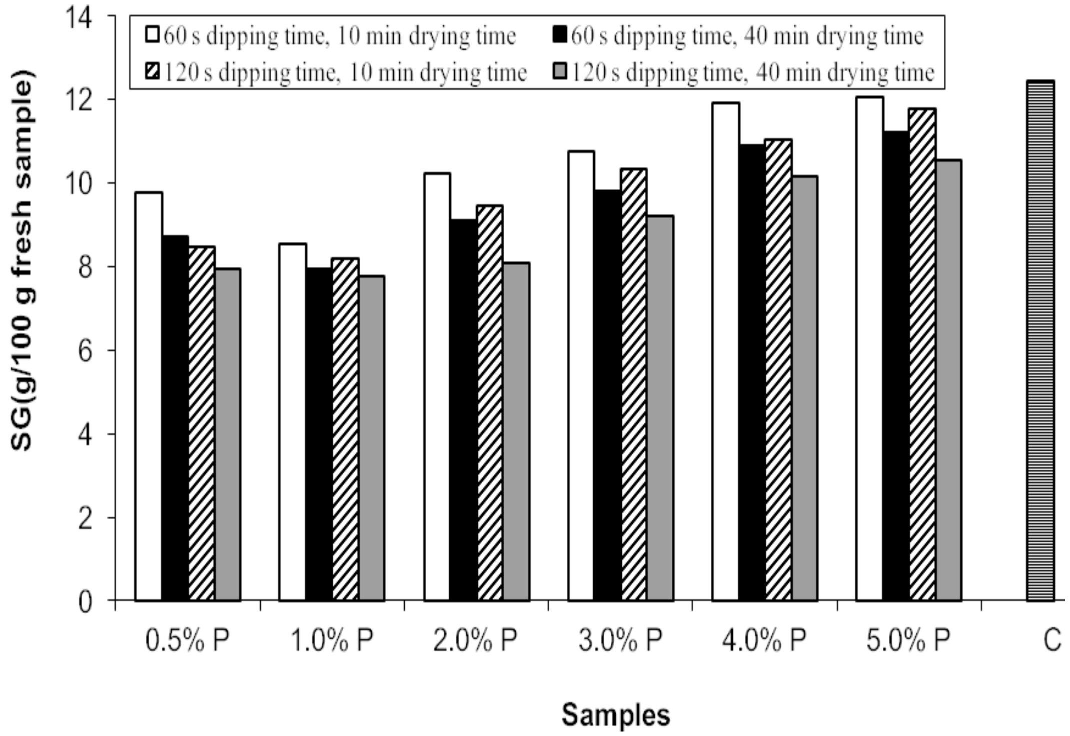

Figure 2. Effect of coating on the solid gain (SG) during osmotic dehydration of coated and uncoated pineapple samples at different concentrations of pectin, two levels of dipping time and drying time P, pectin coated pineapple samples; C, control or uncoated pineapple sample

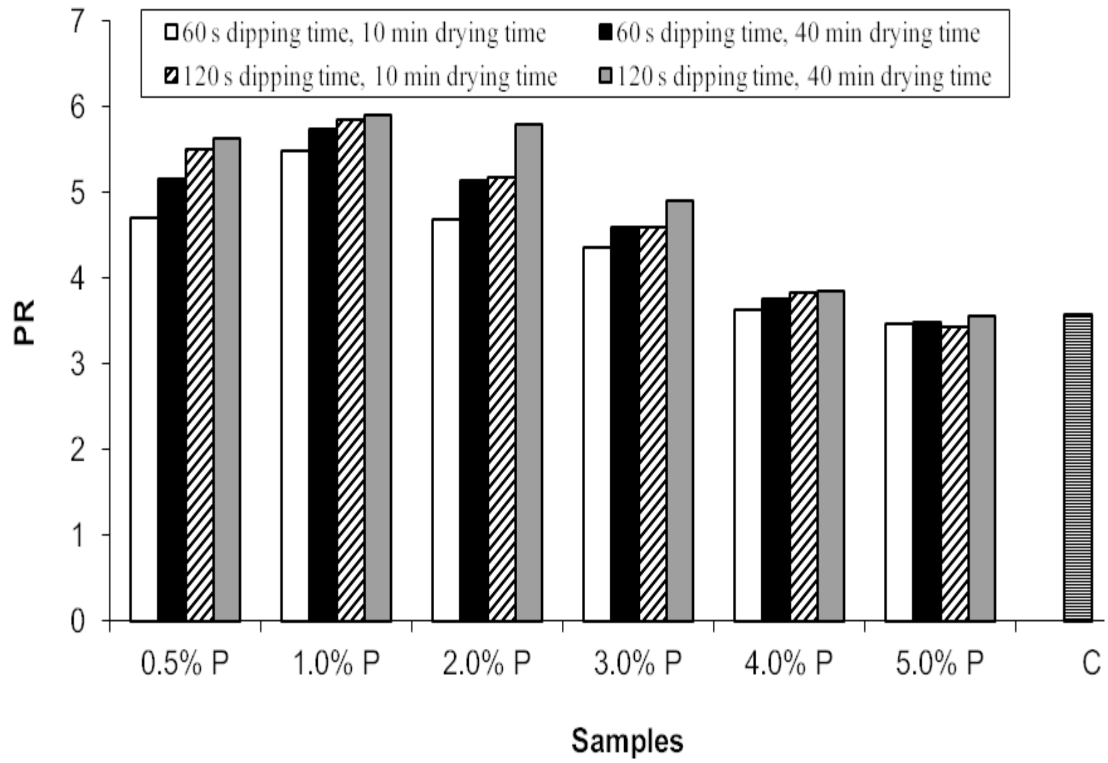

Figure 3. Effect of coating on the performance ratio (PR) during osmotic dehydration of coated and uncoated pineapple samples at different concentrations of pectin, two levels of dipping time and drying time P, pectin coated pineapple samples; C, control or uncoated pineapple sample

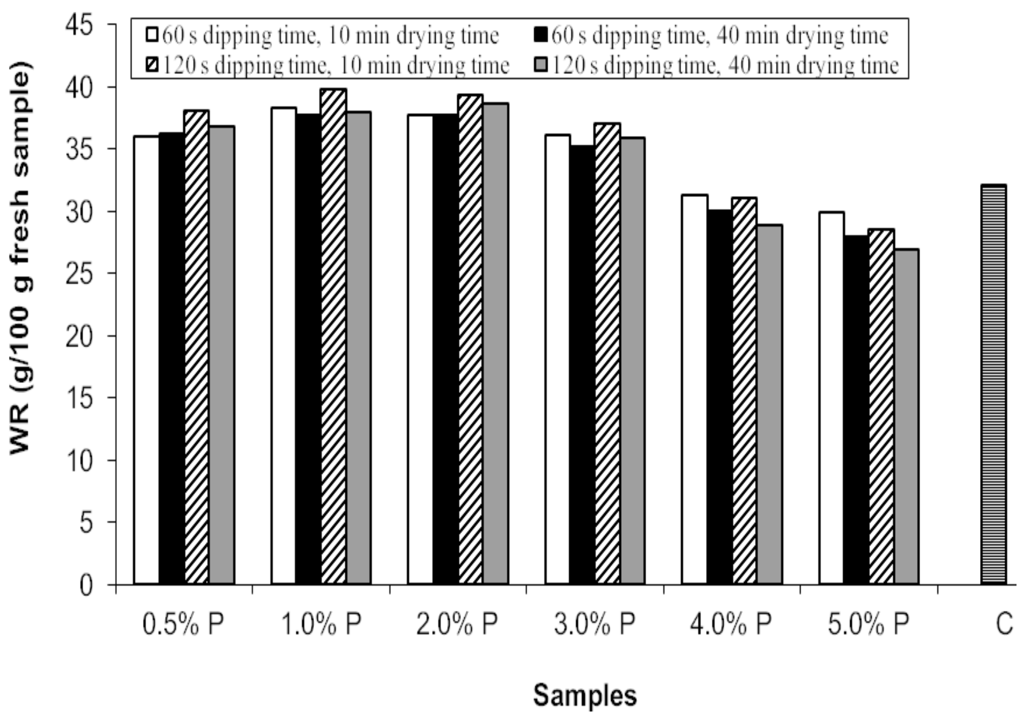

Figure 4. Effect of coating on the weight reduction (WR) during osmotic dehydration of coated and uncoated pineapple samples at different concentrations of pectin, two levels of dipping time and drying time P, pectin coated pineapple samples; C, control or uncoated pineapple sample

WL values increased with increase in the concentration of coating solution from 0.5 to 2%, but with further increase in the concentration up to 5%, WL decreased. This phenomenon was observed when the pineapple samples were dipped in the coating solution at both 60 and 120 s followed by oven drying for both 10 and 40 min. The maximum value of WL was observed at a concentration of 2% irrespective of dipping and drying time. This may be due to the reason that an optimum concentration of coating solution may result into effective coating, which may cause an increased WL. Subsequent increase in the concentration may result in the poor attachment of coating or characteristic changes in the membrane properties. In the results, it was observed that further increase in the concentration above 2% probably led to poor formation of coating, which resulted in decreased WL.

WL values of coated samples treated with coating solution ranging from 0.5 to 3% were more than the uncoated or control sample, where as values of samples coated at 4% and 5% were less than the uncoated samples. This phenomenon was observed at both the dipping time of 60 and 120 s and later oven dried for both 10 and 40 min. Therefore, increasing the concentration to 4% and above resulted lesser WL than the uncoated samples. This may be attributed to the fact that high concentration of coating agent resulted in moisture barrier during OD. Therefore, increasing the concentration of coating solution to 4% or above did not yield any significant results. Coating treatment prior to OD may be considered as a structural modification to food cell membranes due to its ability of endurance during OD. The development of coating would result in higher WL and impediment of sucrose uptake.

Considering the mean values of WL at both the dipping and drying time, there was an increase in WL as the concentration was increased from 0.5 to 2% and then decreased as it was further increased to 5%. At all the concentrations, WL decreased by increasing the oven drying time from 10 to 40 min at both the dipping time of 60 and 120 s. The mean values of WL in coating solution of concentration ranging from 0.5 to 3% were more than the value of uncoated samples. The WL in coated samples was less than the uncoated sample when the sample was dipped in the coating solution of 4% and 5% concentration at both the dipping and drying time. The purpose of increasing the drying time was to develop an effective coating on the fruit sample, but the increase in the drying time did not yield coating to support increase in WL. When the oven drying time was increased from 10 to 40 min, the value of WL varied from 39.18 to 47.91 (g/100 g fresh sample) after dipping the sample for 60 s in the coating solution of concentration ranging from 0.5 to 5%. The WL varied from 37.50 to 48.86 (g/100 g fresh sample) as the dipping time was increased to 120 s. This may be due to the reason that increasing the oven drying time caused decreased WL during OD, due to shrinkage induced by longer drying. The longer oven drying time is generally used for solidifying the coating layer, which may damage the pineapple tissues by changing the cell membrane structure that reduced the mass transfer rate during OD process. The pineapple tissues, dried for 10 min were observed to maintain their firm cell structure during OD. Therefore, increase in the oven drying time from 10 to 40 min led to decrease in WL. This is in agreement with previous research findings on low methoxyl pectinate (LMP) in potatoes (Khin *et al*. 2006a). Lenart and Dabrowska (2001) reported that LMP coated samples have greater WL than uncoated samples with various drying and osmotic time. Lenart and Dabrowska (1999) also reported that LMP as a coating agent in apples could achieve higher or same WL than uncoated samples. Statistical analysis revealed significant differences ($p<0.05$) among the data for uncoated and coated samples over six different concentrations, two dipping time and two oven drying time. The value of WL at both the dipping time (60 and 120 s) and drying time (10 and 40 min) were found statistically different from each other ($p<0.05$). The WL values of the coated samples were statistically different from the uncoated sample.

Solid Gain

The solid gain (SG) in coated and uncoated pineapple samples at various concentrations of pectin and two levels of dipping and drying time is shown in Figure 2. The lowest value (7.76 g/100 g fresh sample) of SG was observed during mass transfer in OD of pineapple samples dipped in coating solution of 1% concentration for 120 s and later on oven dried for 40 min, where as the highest value (12.07 g/100 g fresh sample) of SG was observed in sample dipped for 60 s in 5% solution followed by oven drying for 10 min, indicating a difference of 4.31 (g/100 g fresh sample) in the rates of SG between its highest and lowest value.

Increasing the concentration of the coating solution from 0.5 to 1% led to decrease in the SG and then increased up to 5% concentration. This was observed in all the combinations of concentration, dipping and drying time. This may be due to the reason that selecting the concentration of the coating solution at 0.5% and 1% level resulted in the formation of coating that was strong enough to prevent the entry of solute molecules i.e. sucrose during the process of OD of pineapple samples. At the concentration greater than 1%, SG value increased and was more than the value of SG of coated sample of 0.5% concentration. This was observed in all the values of SG at all the levels of concentration and at both the levels of dipping and drying time under study. There was considerable check in SG by using coating solution of both 0.5% and 1% concentration. The values of SG obtained by using all the combinations of concentrations, dipping time and drying time were less than the SG value of uncoated samples (12.45 g/100 g fresh sample). Therefore, even by increasing the concentration of solution to 5%, the values of SG were less than the uncoated sample. SG was increased as the concentration was increased from 1 to 2% or above which may be due to poor development of coating on the pineapple samples.

Considering the mean values of all the levels of concentration, SG was decreased as the concentration increased from 0.5 to 1% and then increased from further increase in the concentration up to 5%. It was found that maximum decrease in SG was observed in pineapple sample dipped in coating solution of 1% concentration. Comparing the mean values of both the drying time at both the dipping time 60 and 120 s, SG value decreased with increase in the oven drying time from 10 to 40 min. Comparing the mean values of two dipping time, SG value decreased with increase in the dipping time from 60 to 120 s. This may be due to the fact that the development of coating was more appropriate when the sample was dipped for more time and formation of proper coating prevented the gain of solute molecules into the fruit tissue. Therefore, coating developed by dipping the samples into solutions for more time impeded the uptake of solute molecules into the fruit sample. This is in agreement with the findings of Lenart and Dabrowska (1999) in apples using pectin. SG value also decreased when the mean values of drying time were increased from 10 to 40 min. This may be due to the reason that oven drying for long time led to strong attachment or fixation of coating to the pineapple samples, which further reduced the influx of solute molecules into the fruit sample during the OD process. Another explanation for this phenomenon could be that oven-drying step in the coating process caused shrinkage of cells which further caused the reduction of intercellular spaces leading to decrease in the uptake of sucrose into the sample. This is consistent with the findings of Khin *et al.* (2007). Therefore, increase in both dipping and drying time caused decrease in SG.

Overall, coating resulted in substantially decreased solid uptake, thus leading to improved OD process. This fact is consistent with previous findings in potato cubes (Khin *et al.* 2006a), apples (Khin *et al*. 2006b), apples (Lenart and Dabrowska 1999) using low methoxyl pectinate, in strawberries (Matsuka *et al*. 2006) using sodium alginate, carrageenan and guar gum, and in pineapples (Singh *et al*. 2010) using sodium alginate as coating agent. Statistical analysis revealed that the values of SG at all the levels of concentration, both the dipping and drying time differ significantly from one another. The difference in the values of SG of the coated and uncoated sample was statistically significant ($p<0.05$). The values of SG at both the dipping time (60 and 120 s) and drying time (10 and 40 min) were found statistically different from each other.

Performance ratio

Performance ratio (PR) is defined as the ratio of the amount of water removed to the amount of solute uptake. PR (WL/SG) ratio serves as an indicator for process effectiveness (Camirand *et al*. 1968; Khin *et al*. 2006b; Lazarides *et al*. 1995; Singh *et al*. 2010). High PR is indicative of a treatment that aims at extensive dehydration with minimal solid uptake. As coating is aimed at limiting solid uptake and promoting water removal, therefore, PR is an appropriate way to evaluate and finalize the process conditions. In this study, PR is indicative of process efficiency and depends on the concentration of coating solution, time of dipping of sample and drying time to fix the coating.

Figure 3 presents PR in coated and uncoated pineapple samples at various concentrations of pectin at two different dipping and drying time. The highest value of PR (5.89) was observed during mass transfer process in OD of pineapple samples dipped in coating solution of 1% concentration for 120 s followed by oven drying for 40 min, while the lowest value (3.42) was found in samples dipped for 120 s in coating solution of 5% concentration followed by drying for 10 min. PR values increased as the concentration of coating agent increased from 0.5 to 1% and further increase in the concentration above 1% resulted in decreased PR. This trend was observed in both the dipping time of 60 and 120 s and drying time of 10 and 40 min. Therefore, increase in the value of PR by using the coating solution indicated that the purpose of coating the pineapple samples was achieved as the coating was performed to increase the WL and decrease the SG. Increase in PR value verifies the fact that the coating helped to obstruct the entry of sucrose molecules into the pineapple samples, while at the same time ensuring the loss of water from the pineapple sample into the osmotic solution during the OD process. PR values of all the coated samples were more than the uncoated samples (3.57) except the samples, which are coated with coating solution of 5% concentration. The maximum concentration of 5% was unable to increase the value of PR above the PR of uncoated sample. This is due to the reason that both the WL and SG values at 5% concentration were less than the values of uncoated samples. The greater ratio of WL to SG in pectin coated apples was observed in comparison with uncoated apples by Lenart and Dabrowska (1999). Lewicki *et al.* (1984) observed high PR for calcium-low methoxyl pectinate coated apples compared with uncoated apples. Khin *et al.* (2006b) found high PR in low methoxyl pectinate coated apples.

Considering the mean values of the concentration at both the dipping time and drying time, PR value increased from 5.24 to 5.73 with increase in the concentration of coating solution from 0.5 to 1% and then decreased to 3.48 as the concentration was increased to 5%. The maximum difference in the PR value between coated and uncoated sample was found in the samples, which were dipped in the coating solution of 1% concentration for 120 s followed by oven drying for 40 min. Furthermore, with increase in drying time from 10 to 40 min, the PR value varied from 3.47 to 5.73 at dipping time of 60 s and from 3.42 to 5.89 by increasing dipping time to 120 s. Comparing the mean values of two dipping time, PR value increased from 4.51 to 4.82 after increasing dipping time from 60 to 120 s. Similarly, when the mean values of two drying time were considered, PR value was 4.54 at 10 min drying time, which later on increased to 4.78 by increasing drying time to 40 min. Statistical analysis revealed that the PR values at all the six levels of concentration, two dipping time and two drying time differ significantly from one another. The difference in the values of PR of coated and uncoated sample was statistically significant ($p<0.05$).

Weight reduction

The comparison of weight reduction (WR) between coated and uncoated samples at different concentrations of pectin and two levels of dipping time and drying time is presented in Figure 4. The differences in water removal and solid gain rate resulted in significant differences in net WR among coated samples and also between coated and uncoated samples. The highest WR (39.80 g/100 g fresh sample) was observed in pineapple samples dipped in coating solution of 1% concentration for 120 s followed by oven drying for 10 min while the lowest WR (26.97 g/100 g fresh sample) was found in samples dipped for 120 s in coating solution of 5% concentration and later on oven dried for 40 min. The value of WR of uncoated sample was found to be 32.10 (g/100 g fresh sample).

The WR values of all the coated samples, which were dipped in the coating solution of concentration ranging from 0.5 to 3% were more than the uncoated sample. The values of WR of coated samples were less than the uncoated sample when the samples were coated in the solution of 4% concentration or above at both the dipping and drying time. It was desired that WL should be maximum and SG should be minimum during the mass transfer to achieve maximum WR values in the coated samples. Increase in the concentration of coating solution from 0.5 to 1% led to increase in WR values at a drying time of 10 min after dipping the samples for both 60 and 120 s. WR values started decreasing with further increase in concentration to 2% or above. On the other hand, when the drying time was increased to 40 min, the increase in WR values was observed from 0.5 to 2% after dipping the samples for both 60 and 120 s. WR values decreased when the concentration of coating solution was further increased to 3% or above. Therefore, 1% concentration was considered best at a drying time of 10 min and 2% concentration was considered best when the oven drying time was 40 min.

Considering the mean values of all the six concentrations at both the dipping time and drying time, WR value increased from 36.79 to 38.42 (g/100 g fresh sample) with increase in the concentration from 0.5 to 1% and then decreased afterwards to 28.33 (g/100 g fresh sample) when concentration was increased to 5%. Comparing the coated and uncoated sample at both the dipping time and drying time, a maximum difference of 7.70 (g/100 g fresh sample) was observed in samples, which were dipped in coating solution of 1% concentration for 120 s and later on drying for 10 min. Comparing the mean values of dipping time, there was small increase in WR value by increasing the dipping time from 60 to 120 s. Similarly, when the mean values of two drying time were compared, WR value decreased from 35.27 to 34.16 (g/100 g fresh sample) with increase in the drying time from 10 to 40 min. Statistical analysis showed that WR values at all the levels of concentration, two dipping time and two drying time differ significantly from one another. The values of WR of the entire coated samples were statistically different from the uncoated sample ($p<0.05$).

Conclusion

The concentration of coating solution, dipping time and drying time showed significant effect on the WL, SG, PR and WR during OD process. WL increased up to 2% level of concentration of coating solution and then decreased with further increase in the concentration. WL of coated samples was more than the uncoated sample only up to 3% concentration showing high concentration of coating solution resulted in moisture barrier during OD. SG decreased up to 1% concentration and then increased up to 5% concentration, but SG of all the coated samples were less than the uncoated samples. Increase in dipping time led to decrease in WL. SG decreased by increasing both the dipping and drying time. PR was observed highest in those samples, which were dipped for 120 s in coating solution of 1% pectin solution and later oven dried for 40 min. Overall, coating resulted in substantially decreased solid uptake while maintaining the amount of WL.

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