Drying kinetics and physical changes of osmotically pretreated potato (*Solanum tuberosum* L.) slice

**L C Hawa, F L Khoirunnida and S H Sumarlan**

Department of Agricultural Engineering, Faculty of Agricultural Technology, Universitas Brawijaya, Malang, Indonesia

Email: la_choviya@ub.ac.id

**Abstract.** Potato (*Solanum tuberosum* L.) is world’s main crops that owing poor storability characteristic in unprocessed state due to high water content. One of most widely used preservation method for vegetables such as potato is drying process with steam blanching and osmotic dehydration as pretreatment. Blanching and osmotic dehydration pretreatment are used for reducing water content as well as enhance dried product quality by immersing the product into hypertonic solution. In present study, potato slice blanched by steam for 3 min then soaked into three different type of salt as osmotic agent, i.e. NaCl, KCl and CaCl2 with different concentration (10, 15, and 20% (v/v)). The drying process was conducted using hot air dryer at 40°C for 4 h. The results indicated that higher concentration of hypertonic solution give greater water loss and solid gain value. The initial water content of pretreated potato slice was significantly decreased due to osmotic dehydration compared to non pretreated slices. The final potato slice water content with 10% KCl of pretreatment was slightly lower than other pretreatment combination. The drying rate of potato slices with 10 and 20% of CaCl2 were the lowest rate with almost similar pattern. Pretreatment with 10% CaCl2 was considered as the most effective pretreatment in terms of better surface color and minimum shrinkage of potato slice. The microscopy image showed that starch granules of potato were spread and invisible due to starch gelatinization. The appearance of cell wall was not clear with less shrinkage of potato microstructure.

1. **Introduction**

The drying process with hot air-drying systems has been widely performed by food industry players due to its numerous advantages such as less costly and applicable for almost all food products. Among these advantages, there are several shortcomings related to the quality of the product from drying; therefore, the pre-treatment before drying is absolutely considered necessary. One of them is the treatment of blanching and osmotic dehydration.

Blanching becomes one of the processes of applying heat with a temperature (mild heat treatment) on food with water or steaming media. Blanching on agricultural materials generally aims to stop enzyme activity leading to browning and oxidation. The effectiveness of the pre-drying treatment is to inactivate enzymes such as peroxidase in vegetables and fruits causing browning and oxidation, to maintain material quality, to reduce drying time, to release air from intracellular tissue, to store ascorbic acid, to increase drying diffusivity, to soften tissue and to reduce contamination of microorganisms harmful, to obtain the expected products with certain quality standards. Technically, pre-blanching treatment is usually followed by osmotic dehydration [1].
Osmotic dehydration is performed to reduce the water content of cell tissues in ingredients such as vegetables and fruits soaked in hypertonic solutions. The combination of water and solute will push water out of food ingredient. The advantages of osmotic dehydration are: reducing drying time, saving energy use, and maintaining the sensory properties of a material. With this method, the water content of potatoes can be minimized to a fairly low level without changing the texture of potatoes; and the protein content is not denatured [2]. The main factor affecting osmotic dehydration is a type of osmotic agent. Types of solutes which commonly are employed including sugar and salt. The commonly applied salts are NaCl, KCl, and CaCl₂ [3]. Salt solution as an osmotic medium has the advantage in terms of low viscosity and the ability to properly diffuse when compared to sugar, due to smaller salt molecules than those in sugar [4].

This study aimed to determine solid gain (SG), water loss (WL), moisture content, drying rate, shrinkage analysis, color analysis, and structural analysis in cells.

2. Materials and Method

2.1. Materials
Potato were purchased from local traditional market in Malang, East Java Province, Indonesia, with the diameter around 7 cm. Fresh potatoes are peeled, washed, cut with thickness 1 mm and diameter of 3 cm and are weighed to find a uniformed size.

2.2. Osmotic dehydration as pretreatment
The steam blanching process is then performed for 3 minutes. Then the potatoes are braked and in 20 ml of osmotic solution using NaCl, KCl, and CaCl₂ for 10 minutes. The potato from osmotic dehydration are weighed and put into an oven at 105 °C for 4 hours, the mass is then weighed to find out the dry matter. The treatment process for osmotic dehydration in this study is accomplished to retrieve data on the value of solid gain (SG) and water loss (WL).

2.3. Drying process
Potatoes are put in the tray dryer at 40 °C for 4 hours. Weighing the shrinkage of the material is conducted every 15 minutes in the first 2 hours and every 30 minutes in the next 2 hours. It is later put in an oven with a temperature of 105 ° C for 4 hours and dry solids of potatoes are then also weighed.

2.4. Color testing
Color testing is performed on dry potato samples by utilizing a black box with dimensions of 30 cm x 30 cm x 44 cm. Nikon DSLR camera is employed to obtain the picture which is then analyzed by using visual basic applications.

2.5. Intracellular structure testing
Cell structure testing is carried out by utilizing an Olympus light microscope with 100x magnification in untreated samples, blanching, and osmotic dehydration blanching combinations. Sample preparation is provided for microscope testing by using potato slice with 1 mm in thickness and 3 cm in diameter.

3. Results and Discussion

3.1. Solid gain (SG)
The SG values of various types of salt and concentration variations are presented in Figure 1. In Figure 1, the highest solid gain is found in NaCl salt with a concentration of 20% which is equal to 20.535% and the lowest is found in CaCl₂ salt with a concentration of 10%, counted for 3.563%. In general, the graph presents an increase in SG values along with increasing concentration of salt solution. SG demonstrates the number of dissolved solids inducing the sample. In the process of
osmotic dehydration, the higher the SG value, the more dissolved solids will induce the sample. In contrast, the lower the SG value, the amount of dissolved solid decreasingly induces the sample [5].

The molecular weight of NaCl is the smallest among the other three salts, which is 58.44 gr / mol. The smaller the molecular weight of a salt, the easier it is to induce the material, resulting in bigger SG value. Whereas, the CaCl₂ salt has the highest molecular weight among the other three salts, which is 110.99 gr / mol. The greater the molecular weight of a salt, the harder the salt will induce an ingredient, resulting in smaller solid gain. This finding is consistent with Sterling's research (1973).

This statement is supported by a journal which states that potato starch produces crystal-like size outcomes, ranging from 0.5 nm to 75 nm. This finding is possible due to size of the crystal which presents the pore size index of the potato [6]. If converted to units of microns, it will be approximately 0.0005 microns to 0.00075 microns. The particle size of NaCl salts based on the Relative Size of Material table is approximately 0.0005 microns to 0.003 microns. Based on the journal, the researcher analyzed that the size of the salt particles is almost the same as the pore size of the potato. However, with the introduction of the blanching treatment, it can enlarge the cell wall and the pores of the potato; thus, the salt solution will be easier to induce the potato.

3.2. Water loss (WL)

WL values in various types of salt and concentration variations are illustrated in Figure 2. In Figure 2, the highest WL value in NaCl salt with a concentration of 20% is equal to 13.114% and the lowest WL value is found in CaCl₂ salt with a concentration of 10% which is equal to 2.385%. WL value increases along with increasing concentration of salt solution. Water loss indicates the amount of water that comes out during osmotic dehydration. Higher concentration of the osmotic solution causes the difference in concentration and greater osmotic pressure between the material and the solution moves more water towards salt solutions [7]. Increasing the WL value in NaCl salt appears due to the small number of molecular weights, allowing the salt to easily induce the material along with the increasing amount of water.

3.3. Water content

Decreasing water content during the drying process at 40°C (in various types of salt with variations in concentration) is depicted in Figure 3, 4 and 5.
Figure 3, 4 and 5 show that the longer the drying time, the water content of the material decreases. At the beginning of the drying process, there is a significant decrease in water content; however, at the end of the drying process the water content less decreases. This finding is in accordance with the opinion of Adiyanto et al. [8] pointing out that the decrease in water content is proportional to the drying time.

In Figure 3, 4 and 5, the lowest decrease in water content is found in the blanching treatment. The decrease in water content in the treatment of osmotic dehydration is slower than that of blanching due to the salt inhibiting the release of water from the material. Water is tightly bound to salt taking longer duration of process. Materials treated with blanching alone have the highest moisture content before drying, compared to untreated materials and materials with a combination treatment of blanching and osmotic dehydration. Materials that are treated with blanching alone can absorb more water than the untreated material. This is in accordance with the literature which states that the existence of a heating process (blanching) first causes starch content in the material to experience swelling resulting in the ability to absorb larger amount of water [9].

The material given the combination treatment of blanching and osmotic dehydration has a low water content value before drying compared to the untreated material and the material which is treated only with blanching. The higher the concentration of osmotic solution, the lower the water content value will be obtained. This proves that the presence of osmotic dehydration can reduce the water content of a material. The results of this study are in accordance with the literature indicating that the
water content decreases along with increasing salt concentration. This is related to the initial driving force of the process of osmotic dehydration. Greater initial concentration of the solution will lead to greater difference in concentration (driving force) between the ingredients and in the osmotic solution. According to Junior et al. [10], it was explained that the effects of osmotic dehydration by utilizing salt resulted in seeping salt into the product during drying would trap water to get out of the product. This occurrence is due to higher salt molecules than water molecules.

3.4 Drying rate

The graph of the drying rate is presented in Figure 6, 7, and 8. The fastest drying rate occurs in the blanching sample. The drying rate of osmotic dehydration samples is slower than blanching samples as the presence of salt as an osmotic agent will inhibit the rate of water transfer from potatoes. The constant drying rate occurs when the result is between 80% and 60%. The drying rate decreases between 60% and 40%. The second descending drying rate occurs when the moisture content is 40% until the end of drying. The results also indicate that the drying rate depends on the temperature of the applied hot air where the drying rate will increase along with the increasing temperature of the hot air [11].

Figure 6. Relation of drying rate with water content towards NaCl salt with temperature of 40°C for 4 hours

Figure 7. Relation of drying rate with water content towards KCl salt with temperature of 40°C for 4 hours

Figure 8. Relation of drying rate with water content towards CaCl₂ salt with temperature of 40°C for 4 hours

When the drying rate decreases (indicated by falling rate) the water bond becomes the secondary water bond (multilayer layer) marked with water presence in the microcapillary. The nature of water in a multilayer layer is bonded stronger than that in free water. When the drying rate decreases (indicated as second falling rate), water bonds to the primary water bond in the active group of food. Water molecules bind to other water molecules containing O atoms and N atoms as in carbohydrates and proteins. Primary water bound in the monolayer is mostly difficult to evaporate with longer time.
evaporation [12]. Previous study by Hawa et al. [13] has also reported the impact of increasing temperature was parallel to a decrease in monolayer water content.

3.5. Shrinkage
The shrinkage of dried potato slices is presented in Figure 9. The untreated samples (a, b, c) appear as blackish brown potatoes, with shrinkage dominant across the surface, rolling irregularly. In the blanching sample (d, e, f) there brownish reaction is not found, with shrinkage appearance in the edges of the potato. Blanching can inhibit browning reactions but cannot inhibit shrinkage. In samples with osmotic dehydration treatment (g, h, i, j, k, l, m, n, and o), browning reactions generally occur and with a little shrinkage at the edges. The use of NaCl salts has a positive influence on shrinkage discoloration. Shrinkage can occur due to the process of: decreasing in treatment, the occurrence of hardening and the effect of the browning reaction [14].

The results of the analysis of potato cell structure in various treatments are demonstrated in Figure 10. In untreated samples (a), starch granules appear as clear, round, and dark in color due to the drying process. According to Jiménez-Hernández et al. [15] potato starch has a smooth surface, round and oval, with the size ranging from 10 microns to 50 microns. In the blanching sample (b), the starch granules are not clearly visible, in brightly colored and with clearly visible cell-wall. This is in accordance with Sjoo et al. [16], who explained that thin lines mark cell walls and dark starch granules. In potatoes, after cooking process the starch granules will break resulting in a spongy structure under the broken cell wall. The cell walls of potatoes in mature conditions are more scattered and swollen compared to raw samples, as proteins are seen as small particles of light. Samples with the treatment from a combination of blanching and osmotic dehydration indicate shrinkage with visible cell walls of potatoes. However, the starch granules are not visible. This is consistent with the statement from Mayor et al. [17], who concluded that the application of hypertonic solution (osmotic dehydration) causes water to leave the cell. As a result of the shrinkage in vacuole and the rest of the protoplasm, the plasma membrane will be pulled away from the cell wall, recognized as plasmolysis. During plasmolysis, osmotic dehydration in potato is accompanied by loss of turgor pressure, shrinkage and cell deformation (consisting of cell wall and plasma membrane).

![Figure 9](image1.png)

**Figure 9.** Potato slices appearance after drying at 40°C for 4 hours. (a-b) untreated; (d-f) blanching; (g) KCl 10%; (h) KCl 15%; (i) KCl 20%; (j) NaCl 10%; (k) NaCl 15%; (l) NaCl 20%; (m) CaCl₂ 10%; (n) CaCl₂ 15%; and (o) CaCl₂ 20%

![Figure 10](image2.png)

**Figure 10.** Result of microscope testing of various treatments. (a) untreated; (b) blanching; (c) NaCl 10%; (d) NaCl 15%; (e) NaCl 20%; (f) KCl 10%; (g) KCl 15%; (h) KCl 20%; (i) CaCl₂ 10%; (j) CaCl₂ 15%; and (k) CaCl₂ 20%
4. Conclusions
The highest solid gain value is found in the concentration of NaCl salt of 20% which is equal to 20.535%. The highest value of water loss is found in the concentration of NaCl salt of 20% which is equal to 2.385%. Decreasing pattern in water content and drying rate (in samples with treatment of osmotic dehydration) is faster than the untreated samples. Brownish color changes can be inhibited by the treatment of osmotic dehydration appeared in the structure of the brightly colored and clearly visible starch cell which.

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