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Research Article

Quality Aspects of Pre-Treated Potato Tubers (*Solanum tuberosum* L.) After Boiling and Warm-Holding

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Abstract

The preparation of steam-cooked potatoes in large-scale food service systems is challenging since it requires high flexibility and handling large volumes. To increase efficiency, potato tubers are industrially pre-treated, which includes peeling and chemical pre-treatments to avoid enzymatic browning. In large-scale food service systems, potatoes are often warm-held before serving. Industrial pre-treatment and Warm-Holding (WH) might, however, contribute to reduced eating quality in terms of subsurface hardening. This study investigates the impact of chemical pre-treatment (dipping in water (Ref sample), Organic Acid (OA), sodium metabisulfite (SMS), and OA+SMS) and varying Relative Humidity (RH) during WH. The textural evaluation revealed that hardness increased for WH with decreased RH due to evaporation as well as chemical pre-treatment, with a significant impact from OA+SMS. A visual evaluation showed a distinct layer on the surface of those samples treated with SMS and OA+SMS, while Light Microscopy (LM) images showed changes in cellular structure, with the formation of bricklike cells at the surface occurring to a greater extent in samples treated with OA or OA+SMS. The results showed that reduced eating quality due to subsurface hardening can be caused by these three different mechanisms.

Keywords: Eating Quality; Industrial Pre-Treatment; Large-Scale Food Service System; Potatoes; *Solanum tuberosum* L.; Subsurface Hardening; Warm-Holding

Abbreviations: WH: Warm-Holding; Ref-reference sampl: dipped in water; OA: Organic Acid; SMS: Sodium Metabisulfite; DM: Dry Matter

Introduction

Potatoes (*Solanum tuberosum* L.) are commonly served in large-scale food service systems, such as those found at schools or hospitals. To manage the logistical challenges in preparing and serving the required quantities, potatoes are usually industrially pre-treated, steam-cooked, and warm-held before serving. Those steps contribute to efficiency but reduce the quality of the tubers [1-3]. During industrial pre-treatment, the tubers are peeled with methods that have a high mechanical impact, which causes reactions as well as physically broken cells, contributing to increased enzymatic browning [4-6]. Since industrially pre-treated potatoes are cooked on average 5 days after peeling, actions to prevent enzymatic browning must be considered. One common method is chemical preservation. Chemical preservation is performed by immersing the peeled tubers in solutions of, e.g., Organic Acids (OA) or Sodium Metabisulfite (SMS). OA act as a reducing agent in combination with pH reduction below the optimum of the enzyme, while SMS inhibits PPO in combination with a bleaching effect on the anthocyanins, the substrate that causes the dark colour [7]. Chemical preservation is cheap and easy to implement in the process line. However, side effects such as the formation of a tough layer (subsurface hardening) on the surface of the tubers and off-flavours have been reported [8-10]. To evaluate the extent of subsurface hardening, the texture can be analyzed by penetrating the surface [11]. Several studies have been conducted to explain the phenomena that contribute to the physio-chemical changes that give rise to subsurface hardening. Conclusions in the literature mainly explain the phenomena by pectin, but there is disagreement regarding the details. Some conclude that PME activity causes subsurface hardening [12], while others found correlations between it and the presence of Ca^{2+} [13]. Others point to suberization as a possible explanation, which is shown as a formation of bricklike cells at the surface of the tuber [5].

Potatoes in large-scale food service systems are usually prepared by steam-cooking. It is not unusual for some tuber batches to be cooked ahead of time or transported from the large-scale food service system to another facility before being served. To achieve a good eating quality with a pleasant eating temperature, the tubers are warm-held. In Sweden, the recommendation used to be a minimum temperature of 72 ˚C for a maximum of 2 h, which is a standard still applied in most large-scale food service systems. The aim is to keep the relative humidity at 100%. However, due to the handling and properties of the facilities, this is not always the case.

Differential Scanning Calorimetry (DSC) is used to measure the heat flow through the sample at different temperatures. Starch can be analyzed by DSC, for instance, to determine gelatinization and retrogradation [14]. Reactions analyzed by DSC in starch mostly give rise to endothermic reactions, but some phenomena cause exothermic reactions that might be of interest. These include starch granule swelling at around 25 ˚C, the organisation of polymer chains (i.e., starch and pectin) during cooling for starch varieties with a high amylose:amylopectin ratio after repeated heating >120 ˚C, and polymer degradation at >120 ˚C for potato tubers, including 200-280 ˚C for pectin [15-17].

Retrogradation of starch generally contributes to more structure of the food item. Gelatinized starch retrogrades continuously. Nakazawa, et al. [18] reported retrogradation of starch at 50 ˚C when stored for 5 days, while retrogradation at 5 ˚C was initiated after 12 h. It is important to achieve a pleasant eating temperature when serving a hot meal; nevertheless, for logistical reasons, the temperature likely drops to regions where starch gelatinization is initiated before consumption. Although Kaaber, et al. [19] investigated the contribution of gelatinized starch for increased hardness after cooking, but no correlation was found.

This study aims to understand the underlying effects that cause the reduced eating quality of potatoes prepared in large-scale food service systems and connect these to chemical preservation and Warm-Holding (WH) set-up.

Material and Methods

Potato characteristics

Two varieties of tubers with different characteristics were chosen: Bintje, which is considered mealy/firm, and Fakse, which is considered firm. Both varieties have been grown in Southern Sweden. Tubers in the weight range of 70-110 g were chosen. These were peeled by hand and exposed to one out of four chemical pre-treatments: Ref (dipping in water), OA (0.5% ascorbic acid + 0.5% citric acid for 60 min, pH 2.4), SMS (5% Sodium metabisulfite for 20 min, pH 4.1) or OA+SMS (OA followed by SMS).

Cooking

The tubers were steam-cooked in a combi-steamer (SCC WE 61, RATIONAL AG, Germany) until the core of the tuber had reached 94 ˚C. The core temperature was monitored by thermocouples Type K (diameter of 0.5 mm), connected to a Thermocouple Data Logger USB TC-08, Pico Technology LTD, UK. After cooking, a Warm-Holding (WH) step was added. The tubers were held at 72 ˚C for 2 h with an RH of 10% and 100%, respectively. For Ref, an additional RH of 60% was investigated. A control sample without WH was also included.

Texture analysis

To evaluate how the textural properties were affected, instrumental texture analysis was performed similar to that found in Sjölin, et al. [20], but with a few adjustments. A TVT-300XP (Perten Instruments AB, Sweden) equipped with a 7 kg load cell was used, with the sample placed in a stand to fix its position. Tubers were analyzed by puncture analysis, using a cylinder probe with a diameter of 5 mm, with 5 replicates for each probe type. Whole tubers were used in each analysis. The probe speed was set to 1 mm/s for all measurements. The weight and height of each sample were recorded by the texture analyzer.

Light microscopy

Histological analyses were conducted using a light microscope (Elipse Ti-U, Nikon, Japan) at 4-, 10- and 20-times magnification. Samples were cut with a scalpel, and samples from the surface of the peeled tuber as well as parenchyma cells were analyzed. The sample images were taken with a digital camera (digital sight DS-Qi1Mc, Nikon Co., Japan).

Different scanning calorimetry

The different scanning calorimetry was performed in a manner similar to that found in Karlsson and Eliasson [14], but with a few adjustments. A sample was taken from the surface of the tuber and placed in pre-weighed, coated aluminium pans (TA Instruments, New Castle, USA), which were hermetically sealed and reweighed. The analyses were performed on a DSC 6200 from Seiko Instruments, Inc. (Shizuoka, Japan) over a temperature range of 8–120 ˚C with a scanning rate of 10 ˚C min^{-1}. The instrument was calibrated using Indium, and an empty pan was used as reference. The dry matter (dm) content at the surface of the tuber was determined by puncturing the pans containing the sample and drying them in an oven at 105 ˚C for 24 h after the DSC scan. The analyses were performed in triplicates.

Results and Discussion

Potato tuber characteristics

During cooking and WH, tubers undergo physical changes that affect eating quality. The dm of the tuber was affected by RH during WH where a lower RH led to an increased dm independent of variety and pre-treatment (Table 1). This behaviour was seen both in the average of the whole tuber and on the surface, with a larger difference on the surface. When warm-held at RH100, dm was constant or increased slightly compared to no WH for most samples. At RH60, the dm for Ref Bintje and Fakse were 42.6±1.3% and 44.2±1.8, respectively.

	Bintje				**Fakse**			
	Ref	OA	SMS	OA+SMS	Ref	OA	SMS	OA+SMS
No WH	39.3±2.9	33.9±3.2	40.5±2.1	39.4±2.2	39.1±2.1	27.7±6.4	38.4±7.4	39.3±5.9
WH100	36.9±3.4	36.0±1.9	35.0±4.5	37.7±0.9	36.7±3.3	34.6±4.5	34.5±1.8	36.1±4.4
WH10	60.3±0.8	48.9±5.9	55.3±3.3	48.9±2.6	51.7±3.5	47.0±1.0	47.1±5.0	56.8±3.3

Table 1: Average dry matter (dm) as w/w% ± standard deviation at the surface of the tubers for untreated tubers (Ref) and tubers pre-treated with OA (0.5% ascorbic acid + 0.5% citric acid for 60 min, pH 2.4), SMS (5% Sodium metabisulfite for 20 min, pH 4.1) or OA+SMS (OA followed by SMS) for warm-holding at different relative humidities (RH).

The weight and volume changes that occurred during WH were also affected by RH and decreased more when warm-held at a lower RH (Figures 1 and 2). Since the weight hardly changed at RH100, it can be assumed that evaporation of water is the only contributing factor, with the difference in relative humidity on the tuber surface and ambient air as the driving forces. The dehydration was a second-order polynomial kinetics.

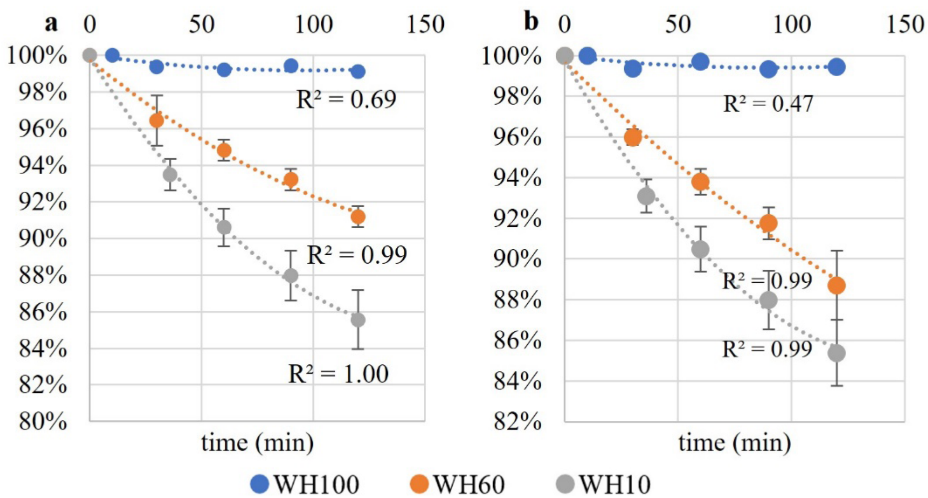

Figure 1: Weight loss (% based on the weight of the raw tuber) during WH for a) Bintje (B) and b) Fakse (F) at different RH.

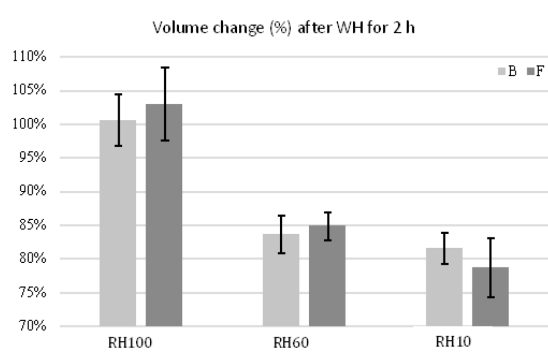

Figure 2: Volume change during WH at different RH for Bintje and Fakse.

An important part of determining the quality of a meal is its visual appearance. Table 2 compares the visual appearance of half tubers for different pre-treatments and RH during WH. In general, Bintje has a brighter appearance compared to Fakse, which is yellower. Samples pre-treated with SMS or OA+SMS showed the creation of a layer at the surface that had separated from the core. This agrees very well with the texture results presented in Figures 1 and 2, showing that increased chemical pre-treatment increased the hardness. The outer layer probably separated since the increased hardness hindered the outer layer from following the soft, inner part of the tuber. The separated layer was more pronounced for Bintje than for Fakse and appeared to a higher extent in warm-held samples compared to noWH. It has previously been reported that sloughing appears more frequently for mealy varieties compared to waxy varieties, indicating that internal structures cause this difference [21,22]. For WH at RH10, the tough, outer layer separated from the inner part of the tuber was detected independent of pre-treatment, but with a thinner and tougher layer for Ref and OA. A curly appearance was also detected, which was probably caused by dehydration.

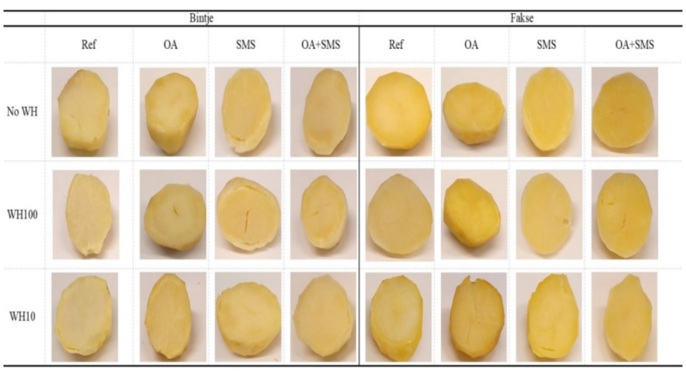

Table 2: Visual appearance of tubers with different pre-treatments and WH at different RH.

For Bintje, and to some extent also for Fakse, WH at RH100 caused cracks in the core of the tuber. Those cracks indicated that the cooking procedure had continued during the WH. Since heat travels through the tubers from the surface towards the core during cooking, the outer regions of the tuber had probably been affected to a higher extent than the core, meaning that the continuation of the cooking process during WH affected the core more than the surface.

Texture

The hardness of the tubers depended mainly on the RH during WH (Figures 3 and 4), but also on the pre-treatment. The hardest tubers were obtained for WH at RH10 for both Bintje and Fakse, with a significant difference between no WH and WH at RH100 for samples with the same pre-treatment. No significant difference was observed between no WH and WH at RH100 for samples with the same pre-treatment. The WH temperature was set to 72°C to minimize the continuation of cooking, and the results confirm that the cooking degree at the surface of the tubers was not caused by additional WH. However, the appearance of cracks at the core of the tuber shown in Table 2 indicates that the cooking of the core proceeded during the WH. During steam-cooking, heat is transported from the ambient air to the surface of the tuber, as well as towards the core. The surface will be exposed to a higher temperature for a longer time compared to the core and will then reach a higher cooking degree than the core. Therefore, the cooking process in the core continues to a higher extent compared to the surface. The surface and core will have different appearances when cooked to the same cooking degree due to different dm content in different positions of the tuber.

Even though RH during WH had the largest impact, pre-treatments also affected the texture of the tubers. There was a trend of increased hardness with increased pre-treatment, with SMS affecting the hardness more than OA. Fakse tended to have a slightly harder surface than Bintje, especially when pre-treated with OA+SMS. The hardening effect caused by pre-treatments tended to be reduced by WH at RH100, probably due to softening caused by continued cooking. WH at RH60 resulted in a texture harder than WH at RH100 but softer than RH10 (Figure 4). These results show that there is a risk of quality losses even if RH deviates only a little from the optimal 100%. Large-scale food service systems aim to keep WH at RH100; however, due to equipment limitations or logistical issues, this is not always possible.

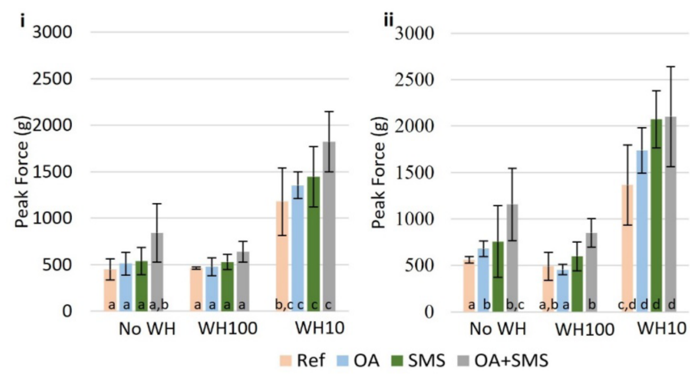

Figure 3: Peak force of i) Bintje and ii) Fakse for different pre-treatments and RH during warm-holding (WH). Error bars show standard deviation and letters grouping based on significant differences (α=0.05).

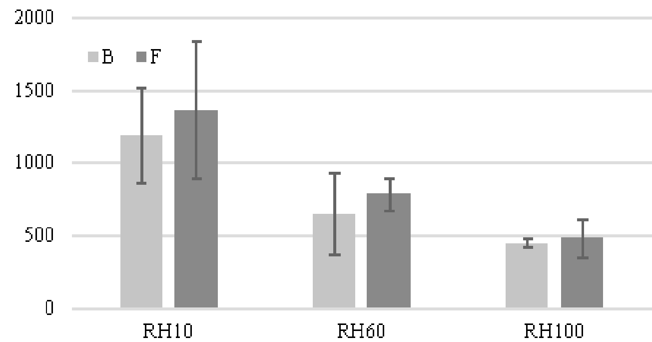

Figure 4: Peak force for reference samples of Bintje (B) and Fakse (F) at RH10, RH60, and RH100 during WH.

Light microscopy

Imaging with Light Microscopy (LM) revealed the cellular structure and how it was affected by the different pre-treatments and WH set-ups. For some of the samples, bricklike cells were identified close to the surface of the tuber, consisting of 1 to 11 cell layers (Figure 5). The bricklike cells appeared more frequently in samples pre-treated with OA or OA+SMS, and to a slightly higher extent in warm-held samples. Similar observations have previously been made by Kaack, Larsen, Thybo and Kaaber [5], for tubers vacuum packed for 6 days without chemical preservation. The appearance was explained by suberization. PME activity has often been related to subsurface hardening. However, Shomer and Kaaber [13] did not see any relation between PME and subsurface hardening for tubers chemically treated with OA. This might depend on the fact that subsurface hardening is caused by suberization. Interestingly, the thick subsurface hardened layer caused by SMS, identified by both visual examination and texture analysis, does not consist of bricklike cells. This means that industrially pre-treated tubers treated with both OA and SMS might develop two different types of protective layers, arising independently from each other and caused by different phenomena.

WH at RH10 had a hardening effect on the cell walls, as confirmed by both visual examination and texture analysis. When imaged by LM, it was seen that the entire cell became rough, which probably depends on dehydration (Figure 6). Even though dehydration does not cause the same elasticity as subsurface hardening, it still contributes to an overall hardness of the tuber that feels unpleasant during consumption.

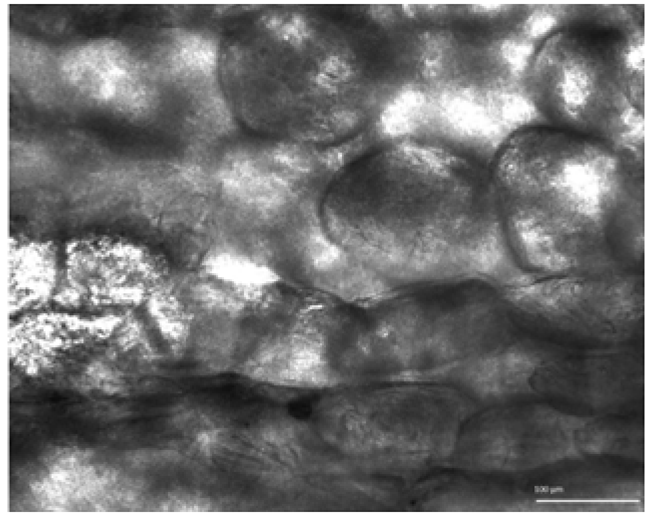

Figure 5: The formation of bricklike cells can be seen in the lower part of the picture, towards the surface of the sample for Bintje pre-treated with OA and WH at RH100.

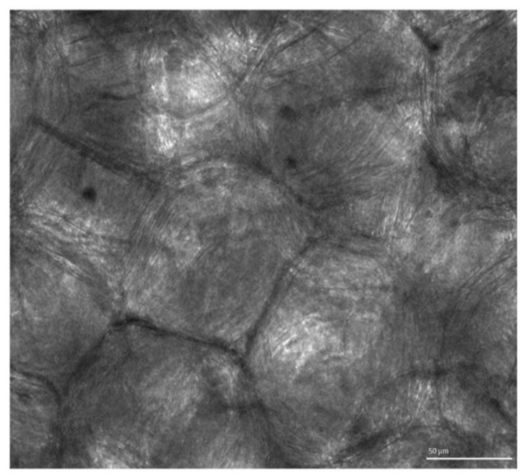

Figure 6: Fakse was pre-treated with OA+SMS and WH at WH10. The cell walls show a rough pattern, probably caused by dehydration.

Differential scanning calorimetry

DSC was performed to identify the extent of retrograded starch initiated before consumption. No endothermic peaks, indicating retrogradation, appeared. However, some unexpected exothermic peaks appeared in the range of 17-60 ˚C for some samples, see example in Figure 7. This is of great interest since exothermic and endothermic reactions usually imply changes that affect the physical appearance and sensorial attributes during consumption, altering eating quality. No correlations between the exothermic peaks and other analyzed variables were seen. However, it would be of significant interest to investigate these phenomena further, especially with focus on the organization of starch and pectin polymers after repeated heating.

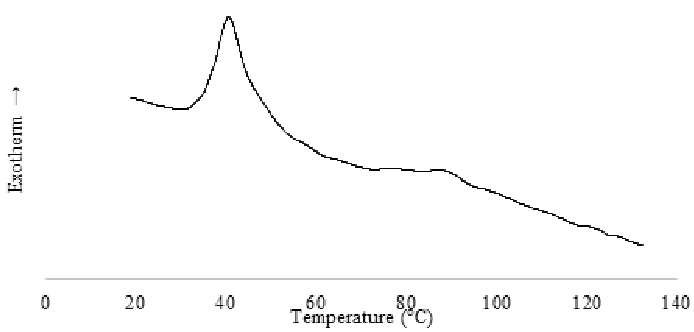

Figure 7: Example of exothermic peak for Bintje pre-treated with OA+SMS and WH10, with enthalpy 5.17 J/g.

Conclusion

Potato tubers are highly affected by both chemical pre-treatment and warm-holding (WH), with WH in the studied region having a larger impact. The pre-treatments were evaluated by comparing differences in hardness, and these showed significantly increased hardness when pre-treated with organic acids and sodium metabisulfite (OA+SMS). The visual examination in combination with LM imaging reveals that two different phenomena cause the textural changes that result from OA compared to SMS. Increased hardness was also observed for WH at RH below 100%, caused by evaporation, which is a third phenomenon contributing to reduced eating quality. To understand and prevent subsurface hardening in large-scale food service systems, it is important to know the underlying reason for subsurface hardening in each logistical chain and adapt preventative actions.

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