NaCl-induced changes in structure and water mobility in potato tissue as determined by CLSM and LF-NMR

Ida Krestine Straadt, Anette Kistrup Thybo*, Hanne Christine Bertram

Faculty of Agricultural Sciences, Department of Food Science, University of Aarhus, P.O. Box 50, DK-8830 Tjele, Denmark

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Abstract

This study for the first time reports the combined use of low-field nuclear magnetic resonance (LF-NMR) and confocal laser scanning microscopy (CLSM) in the study of the effects of salting on low and high dry matter (DM) potato tissue. The simultaneous use of CLSM and NMR resulted in important information in relation to the interpretation of the origin of the NMR water populations. Salting caused the raw potato cells to lose weight, which in the microscopic images was observed as loss of turgor pressure still further away from the edges of the samples with increased salting time. The total water loss after salting was lowest for high DM potatoes. The LF-NMR analyses revealed that this could be ascribed to a faster $T_2$ relaxation time of the cytoplasmatic and extracellular water and thus to water being more restricted in high DM potatoes. In addition, a tendency to a faster $T_2$ relaxation time was observed for both low and high DM potatoes with increasing salting time, which reveals a salt-induced restriction of the cytoplasmatic and extracellular water population. The paper illustrates the aptitude of NMR and CLSM to determine and elucidate structural changes and associated changes in water mobility in potato tissue.

Keywords: Salting; Potato; NMR; $T_2$ relaxation; Confocal microscopy

1. Introduction

Texture is of utmost importance for the quality of cooked potatoes as it concerns one of the most essential technological quality attributes in processed potatoes. Texture is affected by raw material properties and processing conditions including salting of potatoes and cooking conditions. Industrially processed, pre-cooked potatoes are salted in a concentrated salt solution for less than 1 min prior to cooking. However, often the potatoes are present in the salt solution for a longer time, and the texture is affected in different ways depending on the properties of the raw material, storage, etc. Therefore the industry requests more knowledge about the influence of salting on the texture of different raw material properties of potatoes and the underlying mechanisms in order to optimize the salting process and the final product quality.

In studies of raw and cooked potatoes, it has been found that the texture is affected by dry matter (DM) content, starch composition and by the cell wall structures (Barrios, Newsom, & Miller, 1963; Burton, 1989; Mccomber, Horner, Chamberlin, & Cox, 1994; Ng & Waldron, 1997; van Marle, Clerkx, & Boekestein, 1992; van Marle, Devries, Wilkinson, & Yuksel, 1997). Microscopic methods have also been used to provide information about differences in texture (Alvarez, Saunders, & Vincent, 2000; Kalab, Allanwojtas, & Miller, 1995; Khan & Vincent, 1990; Mccomber et al., 1994; Ramana, Stengel, Wolf, & Spiess, 1997; Thybo, Martens, & Lyshede, 1998). However, there has been an increased interest in using non-invasive methods such as low-field nuclear magnetic resonance (LF-NMR) and near infrared (NIR) spectroscopy as tools in texture studies in potato research, and their non-destructive nature and potential of becoming future on-line methods reinforced this interest (Mortensen & Thybo, 2000; Mortensen, Thybo, Bertram, Andersen, & Engelsen, 2005; Thybo, Andersen, Karlsson, Donstrup, &
LF-NMR has been shown to be a very successful technique in the characterization of water distribution of foods and texture (Berendsen, 1992; Cornillon, 1998; Thybo et al., 2004). As one of the first studies, Hills & Le Floch (1994) demonstrated that NMR is an excellent tool for studying spatial distribution of water in potato tissue. Later studies have revealed that NMR is highly correlated to DM content and to potatoes texture determined by sensory analysis (Povlsen, Rinnan, van den Berg, Andersen, & Thybo, 2003; Thybo et al., 2003; Thygesen et al., 2001). Determination of water mobility and distribution by LF-NMR has been used to elucidate cured pork of different qualities (Andersen, Andersen, & Bertram, 2006). The study showed that salt-induced swelling and the mean relaxation times of one water population were highly correlated, and the water mobility was very much dependent on the quality of the pork. However, to the author’s knowledge NMR has not previously been used in studies of salted vegetables. When vegetables are soaked in a salt solution, it affects the turgor pressure of the cells. Mannitol solutions have frequently been used to manipulate the turgor pressure of potato tissue (Alvarez et al., 2000; Brusewitz, Pitt, & Gao, 1989; Lin & Pitt, 1986; Ramana et al., 1997). In a hypotonic solution, a swelling of the cells is observed, and conversely in a hypertonic solution, distention and contraction of the cell walls is apparent (Alvarez et al., 2000; Lin & Pitt, 1986). Differences in turgor pressure have been found to cause changes in structure and also in textural attributes such as firmness in vegetables, which can be observed with microscopic methods (Alvarez et al., 2000; Hiller & Jeronimidis, 1996; Lin & Pitt, 1986; Ramana et al., 1997; Ramana & Taylor, 1994).

As salting of potatoes is an important issue for industrially processed potatoes, the aim of the present study is to investigate the influence of salting on changes in texture, microstructure and water mobility and distribution in two raw material qualities of potatoes presented by two DM fractions within one variety.

## 2. Materials and methods

### 2.1. Potato sampling

Potatoes of the Savva variety with low (16–17 g/100 g fw) and high (20–21 g/100 g fw) DM contents sorted out from the same batch were used in the experiments. Twelve tubers (replicates) with a low DM and 10 tubers (replicates) with a high DM were investigated for each salting time. The two groups of DM bins were selected by grading tubers from the same batch on specific gravity (SG) level, which was recalculated into DM content. The SG of each tuber was non-destructively determined according to $SG = \frac{w_w}{w_w - w_a}$, where $w_a = $ weight in air and $w_w = $ weight in water and recalculated to DM content $= 214(SG-0.988)$ (Nissen, 1954).

Cylindrical samples were cut with a metal cork bore (diameter 10 mm) from the storage parenchyma in the bud end. The samples were cut to a length of 25 mm, dried and weighed (weight 1). The cylinders were salted for periods of 0, 1/2, 1, 2, 4 or 6 min in a 100% NaCl solution (370 g/l) at room temperature. Subsequently the samples were dried with a tissue to remove surface water, weighed (weight 2), attached with strings to a glass container and cooked for 6 min at 100 °C in 100 ml of water. The samples were cooled for 10 min at room temperature, dried on the surface and weighed (weight 3). Loss in weight after salting was determined as the difference in weight of the samples before salting (weight 1) and the weight after salting (weight 2). Cooking loss was determined as the difference in weight of the samples before cooking (weight 2) and the weight after cooking (weight 3).

The following procedures were carried out after salting: (i) confocal microscopic examination of raw samples, (ii) confocal microscopic examination of cooked samples, (iii) LF-NMR relaxation measurements of cooked samples, (iv) texture analysis of cooked samples and (v) determination of the salt content of raw and cooked samples. (iii) was determined on all 10 (high DM) or 12 (low DM) tuber replicates, and after this measurement, three of the replicates were subjected to (i) and (ii), and seven (high DM) or nine (low DM) of the replicates to (iv). (v) was determined on 25 g potato to have enough material for a chemical analysis.

### 2.2. Confocal microscopy

Potato samples with a low DM and a high DM for each of the six different salting periods were examined with confocal microscopy. Two cylindrical samples were cut from each tuber, one was examined before cooking, and one was examined after cooking. 1 cm of the cylinder was cut off, and thin sections of raw and cooked potato samples (slice thickness ~2 mm) were sliced free-hand with a scalpel. The samples were placed in a 24-well microtiter frame and covered with an aqueous solution of Congo Red (0.01%) for minimum 30 min.

The samples were mounted on microscopic glass slides and covered with coverslips. The specimens were examined with a laser scanning confocal fluorescence microscope (Bio-Rad Radiance 2100, AGR-3Q AOTF, Hertfordshire, UK), attached to a Nikon Eclipse E800 upright microscope. A green He–Ne laser beam was set at 543 nm excitation and 570 nm longpass emission filter.

The images were acquired with $10 \times (0.45$ NA, Nikon Plan Apo) and $60 \times (1.20$ NA, WI Plan Apo, water immersion) objectives. Images of representative areas of each sample were recorded using the software LaserSharp2000 (Bio-Rad, Hermel Hempstead, UK). The images were further processed with the software LaserPix 2000 (Bio-Rad, Hermel Hempstead, UK).
2.3. NMR transverse relaxation (T2) measurements

After cooking the samples were placed in glass tubes (14 mm in diameter) with lids, which in turn were placed in NMR probe glass tubes after thermostating the samples in a 25°C water bath for 15 min.

The proton T2 relaxation measurements were performed on a Maran Benchtop Pulsed NMR analyzer (Resonance Instruments, Witney, UK) operating at a resonance frequency of 23.2 MHz. Transverse relaxation, T2, was measured using the Carr– Purcell–Meiboom–Gill (CPMG) sequence. The T2 measurements were performed with a τ-value (time between 90° and 180° pulse) of 500 μs. Data from 4096 echoes were acquired as 16 scan repetitions. The repetition time between the scans was 5 s.

The obtained T2 data were analyzed using distributed exponential fitting analysis according to the regularization algorithm by Butler, Reeds and Dawson (1981) and carried out in MatLab (The Mathworks Inc., Natick, MA, USA) version 6.5 using in-house scripts. Distributed exponential fitting results in a plot of relaxation amplitude versus relaxation time over a predefined range of characteristic relaxation times. In this study we fitted 256 logarithmically distributed relaxation times from 0.5 to 3000 ms. T2 relaxation times, T2 areas and T2 widths of the found relaxation populations were calculated. The width was calculated as the width at half height (i.e. standard deviation).

2.4. Tissue strength

A 10 mm sample from the middle of the potato cylinder was cut out for texture analysis. The cylinders were compressed 50% at a constant deformation rate of 20 mm/min. From the force–displacement curve, fracture stress (σ, force at fracture per unit cross-sectional area) and fracture strain (ε, percent deformation at fracture) were determined. The analysis was performed with a TA.Hdi Texture Analyzer with a max load of 100 kg (Stable Micro Systems, Surrey, UK).

2.5. NaCl content

The samples were extracted with a hot basic buffer solution, which precipitated the proteins, and the solution was filtrated. Nitric acid was added, and the content of chloride was determined by potentiometric end point titration with silver nitrate (ABU 901 autoburette and TIM 900 titration manager, Radiometer, Copenhagen) and calculated into percentage of sample weight (raw or cooked).

2.6. Statistical analysis

Statistical analyses were carried out using the Statistical Analysis System (SAS, V8, Cary, USA). The effect of salting periods and DM content was studied by the PROC GLM procedure.

3. Results

3.1. Microstructure of salted raw and cooked potato samples

Fig. 1 and 2 show the microstructure of unsalted and salted raw and cooked potato samples with a low DM content using confocal laser scanning microscopy (CLSM). In the raw potato samples (Fig. 1A, C, E and Fig. 2A, D), the cell walls are visible mostly as bright lines outlined by the fluorochrome Congo Red. Unlike conventional light microscopy, a 3D structure is often apparent where the cell bottoms and sides of the polygonal cells are visible. Even at 60 × magnification the 3D structure is occasionally

![Fig. 1. CLSM images from the edges of sections of raw and cooked potato samples with low DM content at 10 × magnification. (A), (C) and (E) raw potato samples which are unsalted, salted for 1/2 and 6 min, respectively. (B), (D) and (F) cooked potato samples which are unsalted, salted for 1/2 and 6 min, respectively. Scale bar: 200 μm.](image-url)
apparent (Fig. 2A, D). A strong cell adhesion is apparent, the cells are seen to be in close contact and hardly any intercellular spaces can be observed at 10× magnification. Congo Red is not specific for the cell walls, and starch grains are also visible in some samples (e.g. Fig. 1C).

Fig. 1C shows the microstructure of a raw potato sample after salting for 1/2 min in a saturated sodium chloride solution. It is apparent for most cells that cell walls with many facets are visible. However, on the edge of the sample, cells appear with undulated cell walls. With increasing salting time, cells with a buckled appearance are apparent further and further away from the edge. After 6 min of salting, cells several cell layers from the edge are undulated (Fig. 1E). However, in the center of samples, cells with many facets unaffected by the salt are still seen (not shown).

After cooking of the potato samples, the cell wall facets are still visible, but the cells are generally more rounded off, and the 3D appearance is even more visible (Fig. 1B, D, F and 2B, E) than in the raw samples. A reduction in cell-to-cell adhesion is visible, the cells are more separated and consequently more intercellular spaces are observed than in the raw samples (Fig. 1B). In the unsalted samples very few folds and wrinkles are apparent (Fig. 1B and Fig. 2B). When focusing inside the cell the presence of gelatinized starch is apparent (Fig. 2C), which can also be visualized with conventional light microscopy.

After 1/2 min of salting and subsequent cooking, the cells are rounded off, and most of the cells are without wrinkles like the unsalted samples. However, some of the cells are seen to be much wrinkled (Fig. 1D and 2E), but unlike the raw samples, cells with a different appearance are not solely visible along the edges but also in the middle of the sample (not shown). With increasing salting time there is a higher number of cells which have folds and wrinkles, both at the edges (Fig. 1F) and in the center of the samples.

For the potato samples with a high DM content, the same pattern is observed as for samples with a low DM content, except that generally more starch granules are visible within the raw samples with a high DM content (not shown).

### 3.2. NaCl content in raw and cooked potato samples

The salt content in both the raw and the cooked potato samples increased with increasing salting time (Table 1).

<table>
<thead>
<tr>
<th>Salting time (min)</th>
<th>Salt content (g/100 g fresh weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
</tr>
<tr>
<td>0</td>
<td>0.05±0.09</td>
</tr>
<tr>
<td>1/2</td>
<td>1.32±0.09</td>
</tr>
<tr>
<td>1</td>
<td>1.37±0.09</td>
</tr>
<tr>
<td>2</td>
<td>1.91±0.09</td>
</tr>
<tr>
<td>4</td>
<td>2.04±0.09</td>
</tr>
<tr>
<td>6</td>
<td>2.23±0.09</td>
</tr>
</tbody>
</table>

Mean values and standard deviations are given.
When comparing raw and cooked potatoes for each salting time a significant reduction around 75% in salt content is observed.

3.3. Change in weight after salting and cooking of potato samples

For raw potato samples with both a low (Fig. 3A) and a high (Fig. 3B) DM content, a significant increase in total weight loss is observed with increasing salting time (●). After cooking varying degrees of weight loss or weight gain are apparent, strongly depending on DM content (○). For potatoes with a low DM content large weight loss are observed after cooking at low salting times. For potatoes with a high DM content, a weight gain is observed after cooking, which may be an effect of that the removable water already is lost during salting and the high DM potato therefore acts as a sponge absorbing water.

Nevertheless a total weight loss after salting and cooking is observed for both low and high DM for all salting times (▼). Low DM potatoes loose 7–10% water in total whereas high DM potatoes looses between 2% and 7% water. No significant differences in total weight loss between the different salting times are observed, except for 1 min of salting for low DM content and for 6 min of salting for high DM content.

3.4. Tissue strength of salted and cooked potato samples

With increasing salting time a significant increase in the fracture strain is observed for potato samples with low and high DM contents (Fig. 4). Stain values are higher for high DM potatoes. The same tendency is observed for fracture stress, however, no significant differences are seen (data not shown).

3.5. NMR measurements of cooked potato samples

The distributed $T_2$ relaxation times for the cooked potato samples with low and high DM content at three different salting times are shown in Fig. 5A and B, respectively. For high DM potatoes (Fig. 5B), the distributed $T_2$ relaxation times are characterized by three relaxation populations; two minor components around 1–10 and 10–40 ms, respectively, and a major component around ~200 ms ($T_{22}$), while in the low DM potatoes (Fig. 5A) the minor component around 1–10 ms is very weak.

Table 2 presents the mean $T_2$ relaxation time constants, widths, and areas of the major $T_{22}$ population for the cooked potato samples at different salting times. For all the parameters significant differences between low and high DM content are observed indicated by x and y letters.

Significant differences between salting times are indicated by a, b and c letters. For all salting times the relaxation times of the $T_{22}$ population are lower in high DM potato samples compared with low DM potato samples, which corresponds to a faster relaxation of the $T_{22}$ population in potatoes with high DM content (Fig. 5A, 5B).
For both low and high DM content, a tendency to faster $T_{22}$ relaxation times with increasing salting time is observed as the $T_{22}$ peak moves to lower relaxation times with increasing salting times (Fig. 5A, B and Table 2). For potato samples with high DM content, the $T_{22}$ width is significantly lower in salted compared with unsalted samples (Table 2). No significant effect of salting time on the population areas is observed.

4. Discussion

The combined LF-NMR and CLSM investigation has for the first time been used to study potato structure and the effect of salting. The present results clearly indicate that salting time and DM content have a significant effect on structure, texture and water mobility in potato tissue.

As expected, increasing salting time increased the amount of salt in the potato tissues (Table 1). Hence, longer exposure to the saturated salt solution causes an increased uptake of salt. The microscopic images demonstrated that this was associated with the appearance of wrinkled cells, caused by osmotic loss of water, which is observed further and further away from the edges with increasing salting time (Fig. 1C, E). For both low and high DM contents, salting causes the raw potato material to lose weight (Fig. 3A, B). This is not surprising since the saturated salt solution is hypertonic and hence causes water to flow from the cells to the salt solution (Alvarez et al., 2000; Lin & Pitt, 1986). This is observed as a decrease in turgor pressure of the cells, apparent as a distension of the cell walls, at the edges of the potato samples (Fig. 1C, E). With increasing salting time, loss of turgor pressure is seen further and further away from the edges of the samples (Fig. 1E). These results are in line with the study of Alvarez et al. (2000) and of Lin and Pitt (1986) who found a decreased sample volume and a decreased turgor pressure in potato and apple tissue, respectively, treated in increased concentrations of a mannitol. The undulated cell walls (Fig. 2E) might be a result of a decreased cell turgor.

Table 2

<table>
<thead>
<tr>
<th>Salting time (min)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{22}$ mean time (ms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low DM</td>
<td>272 ± 31^{ax}</td>
<td>253 ± 31^{ax}</td>
<td>283 ± 31^{bc}</td>
<td>248 ± 31^{abc}</td>
<td>230 ± 31^{c}</td>
</tr>
<tr>
<td>High DM</td>
<td>228 ± 31^{xy}</td>
<td>197 ± 31^{xy}</td>
<td>190 ± 31^{xy}</td>
<td>189 ± 31^{y}</td>
<td>180 ± 31^{y}</td>
</tr>
<tr>
<td>$T_{22}$ width</td>
<td>72.1 ± 18^{ax}</td>
<td>75.1 ± 18^{ax}</td>
<td>75.1 ± 18^{ax}</td>
<td>68.9 ± 18^{a}</td>
<td>68.3 ± 18^{a}</td>
</tr>
<tr>
<td>Low DM</td>
<td>86.2 ± 18^{xy}</td>
<td>68.0 ± 18^{xy}</td>
<td>58.1 ± 18^{xy}</td>
<td>52.6 ± 18^{y}</td>
<td>55.2 ± 18^{y}</td>
</tr>
<tr>
<td>High DM</td>
<td>94.2 ± 0.9^{ax}</td>
<td>94.2 ± 0.9^{ax}</td>
<td>94.4 ± 0.9^{ax}</td>
<td>93.9 ± 0.9^{ax}</td>
<td>94.2 ± 0.9^{ax}</td>
</tr>
<tr>
<td>$T_{22}$ area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low DM</td>
<td>89.9 ± 0.9^{xy}</td>
<td>89.9 ± 0.9^{xy}</td>
<td>90.0 ± 0.9^{xy}</td>
<td>89.6 ± 0.9^{xy}</td>
<td>90.1 ± 0.9^{xy}</td>
</tr>
<tr>
<td>High DM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LS mean values and standard errors are given. Letters a–c indicate significant differences ($P < 0.05$) between different salting times, and letters x and y indicate significant differences ($P < 0.05$) between low and high DM content in the cooked potato samples.
pressure with a varying degree of plasmolysis (Alvarez et al., 2000).

After cooking the salt content in potato tissue is reduced for all salting times (Table 1), which means that salt leaches into the solution in a reversible osmosis process with excess of water outside the potatoes. Furthermore, the cooking process with softening of cell walls and starch gelatinization may also enhance an equilibrium state for NaCl. From the microscopic images it is furthermore evident that after cooking the salt is no longer just present at the edge, but is evenly distributed to the entire potato sample.

After salting and cooking, high loss of weight was seen for potato samples with low DM content (Fig. 3A). However, the loss in weight after cooking was decreasing with increasing salting time. This means that if salted samples have not already lost high levels of water due to salting, the samples will loose much water after cooking. This causes the total loss of water to be nearly constant for all salting times. In contrast a very little loss of water after cooking was recorded for the unsalted samples. A large difference in water loss was therefore evident between 0 and 1/2 min of salting. Hence, even a short salting time has a significant effect on water loss (Fig. 3A) and NaCl content of cooked potatoes (Table 1) as cell wall permeability may be affected even by short salting times, which leads to loss of water in subsequent cooking. This is very important knowledge for the potato industry, as water loss affects texture.

In potato samples with high DM content, various degrees of loss or gain of water were observed after salting and cooking (Fig. 3B). This can possibly be ascribed to the fact that higher DM content results in less mobile water. This is supported by the NMR data as the T22 relaxation time is faster, and thus the water is more restricted probably by the higher DM content (Fig. 5, Table 2). However, for the total loss of water, a trend similar to that for low DM potatoes was seen. Hence, as for low DM, in total a loss of water for high DM samples was observed, similar for all salting times except for 6 min of salting. However, the total loss of water was lower than the loss for low DM potatoes. This is again supported by the fact that the water is less mobile in the potato samples with low DM content. Mortensen et al. (2005) also found faster relaxation times (T21 and T22) for potato samples with high DM content compared with samples with low DM content.

Besides the fact that NMR showed significant differences in the relaxation times of the T22 populations between potatoes with low and high DM content, it was also possible to determine the structural differences occurring in the salting process with NMR. With increasing salting time a tendency to a faster T22 relaxation time is observed for both low and high DM potatoes (Fig. 5, Table 2), which must be a result of a higher restriction of the mobile T22 water population by the salt, which previously has been assigned relatively free bulk water as cytoplasmatic and extracellular water (Hills & Le Floc’h, 1994; Mortensen et al., 2005).

The fastest relaxation population as the one appearing at 1–10 ms has previously been assigned to water on the surface of or inside starch granules (Hills & Le Floc’h, 1994; Mortensen et al., 2005). It is noteworthy that this population was significantly more pronounced in high DM potatoes compared with low DM potatoes, which is in agreement with the CLSM examinations, which revealed fewer starch granules in the low DM potatoes compared with high DM potatoes. Accordingly, the combination of LF-NMR and CLSM has provided further evidence for the assignment of this population to water interacting with starch granules. Understanding the origin of the different water populations detected by NMR is a prerequisite for extracting a high level of information from NMR measurements, and therefore the present result must be considered important.

It should be noted that for high DM samples, the width of the T22 population decreased with increasing salting times (Table 2). Most probably this decrease in the width of the T2 population reflects the increase in the exchange rate of cytoplasmatic and extracellular water, which can be ascribed to a salt-induced effect on the cell wall permeability. This hypothesis is also supported by the microscopic examinations, which revealed undulated cell walls as function of salting.

For the low DM samples, no decrease in the width of the T22 population as function of salting time was observed. The reason for this difference between high and low DM samples may be ascribed to the fact that high DM samples contrarily to low DM samples had a salt-induced water uptake after cooking (Fig. 3A, B) causing a more homogenous distribution of the salt and thereby a stronger effect of salt.

No significant effects of salting on the area of T22 were found, which indicates that no relative water exchange between intra- and extracellular water is seen, thus this ratio is constant.

Differences in the salt content in the cooked potato samples also had an effect on the firmness of the tissue. From the uniaxial compression analysis, it is apparent that the salted samples had a higher fracture strain and fracture stress than the unsalted samples. The observed increase in firmness or stiffness can be explained by a loss in turgor pressure and an increase in elasticity due to osmosis, which is in accordance with findings by Alvarez et al. (2000), Brusewitz et al. (1989), and Ramana et al. (1997). The folded cell walls may also cause more elasticity and higher strain.

To summarize the effect of salting on changes in structure, texture, and water mobility and compartmentalization, an extended salting time significantly increased the firmness of the samples and the NaCl content, and the extracellular and cytoplasmatic water T22 became more restricted and more homogenous, and the cells appeared with more folded cell wall structures. The combination of microscopic and NMR investigations resulted in important
information in relation to the interpretation of the origin of the NMR water populations.

5. Conclusion

The present paper shows that salting of potatoes prior to cooking changes the final texture. The study also showed that changes in texture as a function of salting time can be determined by a conventional compression test combined with a microstructural investigation and NMR, which gave a deeper insight in water loss, water restriction and cell surface changes. Hereby the paper illustrates the aptitude of NMR and CLSM to determine and elucidate structural changes during salting, which emphasizes the challenge to control the salting time in industrial production of potatoes with various raw material properties.

Acknowledgments

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