Analytical Methods to Characterize the Cooking Behaviour of Potatoes

T. Harada* and K. Paulus

Fed. Res. Centre for Nutrition, D-7500 Karlsruhe (Fed. Research Centre for Nutrition, Engesserstrasse 20, D–7500 Karlsruhe (West Germany)
(Received February 18, 1985; Accepted April 5, 1985)

During cooking chemical, physical and microbiological changes occur, and obviously many constituents of the products are involved in these changes. From consumers point of view texture is the property which usually indicates the degree of cooking and this determines acceptance. Texture therefore is an important property to describe the cooking behaviour of foods. From the scientific point of view additional properties and the constituents involved in the reactions and changes are interesting as well in order to characterize the cooking behaviour.
Analytical methods were adapted to the problem of characterizing the cooking behaviour of potatoes, a basic food item for food industry, catering institutions and households. In a first step, constituents possibly important for texture development were selected on the basis of literature data. Then chemical methods were checked, modified and adapted to the evaluation of these constituents. Finally, rapid methods are advised for some of these as starch, soluble amylose, and pectin. Furthermore a method to measure cell size and techniques to evaluate shear force (texture measurement) and the sensory parameters texture and taste were selected or developed and are explained.

Introduction

Evaluation of the rates of changes in a food during the most common thermal process, namely cooking, as a function of temperature and time is called cooking kinetics. Although this very old process of cooking is used daily in households and food industry, the knowledge of cooking kinetics still is very limited.
Texture is the most important quality factor of cooked edible plant tissue. For many products taste is a decisive property as well. To describe and evalute the cooking behaviour, appropriate methods are required. Texture and taste may be evaluated by sensory tests, texture may be determined also by objective measurements. However, to explain changes during cooking, more information on changes in chemical constituents is necessary mainly under the aspect of correlating sensory, physical and chemical results.
Some investigators tried to explain textural differences on the basis of the results of chemical methods. Intercellular adhesion (controlled by pectic substances in the middle lamella of the cell wall), diffusion of amylose into this region and cell size are considered to be the most important factors controlling the firmness of potatoes (1–3).
Other authors have shown that there are at least two essentially independent features of cooked potato texture. They are referred to as "mealiness" and "mouthfeel", and "breakdown" and "sloughing" (4). Several investigators tried to measure mealiness objectively by using different equipment, but it is not in all cases clear whether the methods used are suitable for the evaluation of mealiness and the results were not always convincing. As far as sloughing is concerned, two methods for direct measuring have been proposed, namely the microscope test (5–7) and a test based on the weight retained in a sieve (RWCS test) of ZAEHRINGER *et al.* (8) and LUDWIG (9).

The role of pectic substances in intercellular adhesion is still unknown also for reasons of analytical difficulties.
The dynamics of chemical changes which so far have been rarely been studied systematically, should be in the foreground of studies on cooking kinetics. Main objective of this study therefore was to learn about the kinetics of textural changes by sensory, physical and chemical analysis. Taste, and the changes of taste during cooking were evaluated only by sensory analysis.
To realize this objective the project was divided into three steps. In a first theoretical step, any components of relevance for texture were listed on the basis of literature data (Tab. 1). The first texture property listed is sloughing, which can be evaluated by the microscope and RWCS tests already mentioned. Firmness as part of the objective texture, as listed in **Tab. 1**, can be determined by thin-wire methods (10), the depth of penetration by penetrometer (11), and intercellular adhesion, i. e. the so-called compressive strength, by tenderometer. This objective texture is furthermore characterized by adhesiveness. The third texture property mentioned in **Tab. 1.** is subjective texture. It comprises textural sensations perceived during sensory tests, which can be characterized with firmness and mealiness.
21 components of potatoes are listed in **Tab. 1;** all of them have been related to texture properties in literature. The considerations during the first step of the project were concentrated on ranking these components in order to get a priority list. The last column of **Tab. 1** shows the result, indicating that the list of constituents can be reduced to 6–8 of them, taking also practical aspects of routine analysis into account. As a result of these considerations, total solids, specific gravity, starch content, cell size, surface area of cells, soluble amylose and pectin content were selected as interesting parameters. In addition shear force measurements and sensory tests were included.
The second step of the project comprised testing of the selected analytical methods as to their suitability for the intended purpose. The final step was then to improve and

* Present address: Ajinomoto Co., Inc., Kawasaki, Japan

Tab. 1 Potato components interesting as to texture
(+ = very interesting, ± = still interesting, − = not interesting)

Component	Texture					Priority
	Sloughing	Objective		Subjective		
		Firmness	Adhesiveness	Firmness	Mealiness	
Total Solids	±	+		+	+	+
Specific gravity	±	+		+	+	±
Starch	±	+		+	+	+
Amylose		+	±	+	+	−
Amylopectin						−
Amylose/Amylopectin					+	−
Starch granule size					±	−
Cell size	+		+		+	±
Surface area	+	+	+	+	±	+
Cellwall thickness			+			−
Gelatinized starch					+	−
Soluble amylose		+	+	+	+	±
Starch Retrogradation		±		±	+	−
Pectin	±	+	+	+		±
Pectinase activity			±			−
Pectin esterase act.			+			−
Pectin hydration	+		+			−
Methylation of pectin	+		+			−
Polyvalent cations	+	+	+	+		+
Sugar	±		±		+	−
Protein	±		±		+	−

adapt the analytical procedures to the special aim of evaluating the constituents and properties with sufficient accuracy in a great number of samples. Step 2 and 3 will be described in detail in this paper.

Materials and Methods

Soluble amylose
A modified procedure of NONAKA (13), which was based on various methods described in literature (12–14), was used to determine the amount of soluble amylose leached out from the potato cells during cooking. Potato slices were cooked in boiling water and mashed by hand. To 5.0 g of mashed potatoes, 50 ml water (40 °C) were added and stirred for 2 min. with a magnetic stirrer and subsequently filtered through a 15 cm folded filter paper. 5.0 ml of the filtrate were added to 1.5 ml of 0.02 n KJ_3 solution and then diluted to 50.0 ml. Extinction was measured at 640 nm on a spectrometer.

Starch
Many methods have been described to determine starch in biological materials. Some use the specific glucose oxidase procedure, others employ a non-specific hydrolysate measurement after exposure to mildly acid conditions to extract and hydrolyze the starch.
The glucoamylase method yields low values because of incomplete hydrolysis by the glucoamylase. The mildly acid hydrolysis method, on the other hand, yields high values because small glucose quantities are derived from cellulose and the resulting errors therefore are large for substances with relatively low starch content (15, 16).

Our own experiments were based on the method according to McCREADY *et al.* (17) which we tried to facilitate, however. Potato slices were frozen at -30 °C, broken into pieces in a household mixer and used as samples. To avoid interference of free sugar in the anthrone method, 5.0 g of raw potato slurry were extracted 4 times with 30 ml of 80% ethyl alcohol (60 °C) by centrifugation and decantation. The sugar-free residue was treated by perchloric acid in the usual way. The supernatant of each fraction and the sugar-free residue were examined for anthrone colour development, and a material balance of the total sugar was made.

Pectin
Analysis of pectin contents in plant tissues generally involves extraction of pectic substances (18–20). The uronic content of extracts can be determined colourimetrically (carbazol reaction, titration, decarboxylation, or calcium pectinate formation).
A simple and easy method is described by KEIJBETS and PILNIK (21) who corrected the neutral sugar interference in the carbazole test after extraction of pectic substances with Ultrazym 100. As far as the carbazole test is concerned we applied the method of BITTER and MUIR (22) because it is rapid and quantitative. Neutral sugar was not calculated as galactose but as glucose to avoid the influence of starch in the carbazole test. Preparation of samples was the same as in the case of starch analysis.

Cell size
The raw and cooked potato slices were frozen immediately at -30 °C. Frozen slices were cut into about 150 μm thick sections on a sliding microtome, stained in methylene blue and

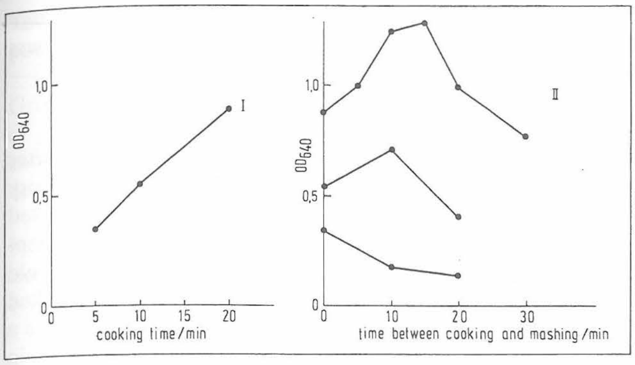

Fig. 1 Influence of cooking time at 100°C (I) and time between cooking and mashing (II) on the extinction value OD_{640} (indicator for the amount of soluble amylose in cooked potatoes)

photographed under the microscope (23). Cell measurements (vertical and horizontal cord lengths) were made in enlarged photographs (about 70 × magnification). Two pictures of each of 3 sections cut from the potato slices were made, corresponding to about 250 cord lengths for any determination. Mean cord lengths were expresses as "cell size".

Texture measurement
For texture measurements, a universal testing machine (Zwick, No. 1442, Germany) was used. Slices of potatoes were taken from the core of tubers. The samples were cooled down to room temperature after thermal treatment and before the measurements were carried out.
For shear force measurements, slices were placed on a steel plate with a hole of 10.05 mm in diameter. A conical plunger of 10.0 mm in diameter at the contact side was moved through the sample at 50 mm/min and the force required was recorded over the time.

Sensory analysis
Sensory tests should provide information of the sensation of overall texture and taste. It was decided to use a method based on descriptive sensory tests, but to apply the method as category test. During a longer period of preliminary experiments, both attributes had been described at very different cooking degrees. These descriptions were used to fix the categories according to relationships established previously (24).

Results and Discussion

Soluble amylose
The first point of interest concerned the effect freezing and thawing have on the amount of soluble amylose in cooked potato material after mashing at different temperatures; OORAIKEL *et al.* (25) reported a substantial decrease in the free starch content after freezing and thawing. In the present experiment no extinction value was found after freezing and thawing, and therefore freezing and thawing have to be avoided before the analysis.
Other points of interest were the influence of time between cooking and mashing, the influence of time between mashing and extraction and the stability of the filtrate.
The results showed that there is a significant effect of time between cooking and mashing **(Fig. 1)**. So samples should be mashed immediately after cooking. There is also an effect of the time between mashing and extraction **(Fig. 2)**, and therefore extraction should be done immediately after mashing. Stability of the filtrate was determined in three samples of

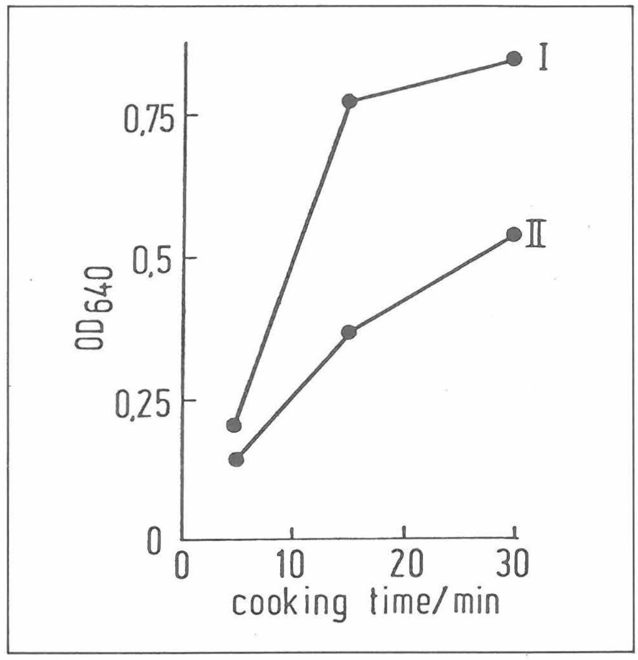

Fig. 2 Influence of time between mashing and water extraction on the extinction value OD_{640} (indicator for the amount of soluble amylose in cooked potatoes)
I = extraction immediately after mashing; II = 5 min allowed to pass between mashing and extraction

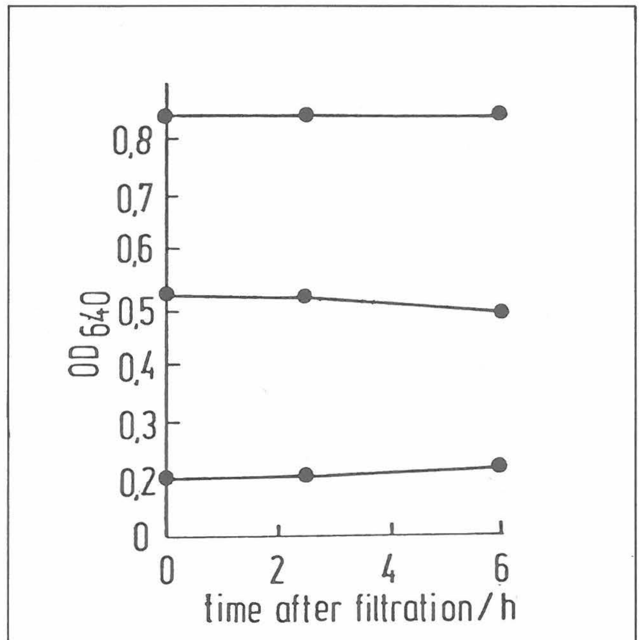

Fig. 3 Stability of the filtrate used for the determination of the extinction value OD_{640} (indicator for the amount of soluble amylose in cooked potatoes)

substantially different extinction values; the samples were allowed to stand up to 6 hours after filtration, but did not change during this time **(Fig. 3)**.

Starch
The time required for the determination of starch is reduced considerably if extraction is simplified. The effect of the number of extractions with hot alcohol on the free sugar content in the supernatant is illustrated in **Fig. 4.** Total sugar

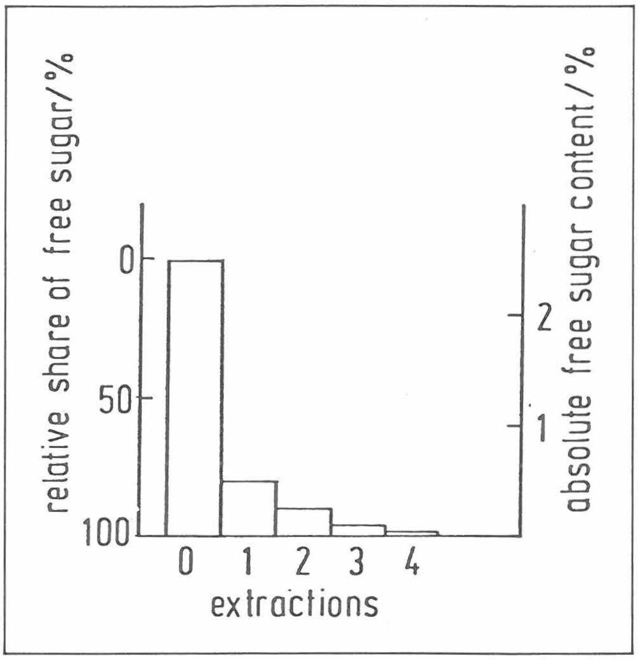

Fig. 4 Influence of the number of extractions (hot alcohol) on the free sugar content in the supernatant during the starch determination in potatoes

content of potatoes lies between about 0.5 and 3% of the starch content. During cooking of sliced potatoes a certain amount of soluble sugars is leached out, so the relationship between starch and total sugar increases.

After the first extraction, about 80% of free sugars are removed. Total sugar content after this treatment is about 0.5% of the starch content or even less. The error in the starch content due to omission of three additional extractions hence is very low and within the accuracy of the method.

Pectin

The pectin content of cooked potatoes could be easily analyzed by using Ultrazym – 100, omitting saponification and EDTA steps according to the method of Keijbets.

The formula to calculate anhydrated galacturonic acid is as follows (n = 19):

Anhydrated galacturonic acid

$(\mu m/ml) = 70.7\ (OD_{530}) - 10.4\ (OD_{490})$

Cell size

Cell size was determined in raw and cooked potatoes. A comparison of cell sizes of raw and cooked slices (3 min/100 °C) of variety Atica yielded the following results based on the average of 5 samples (226 cells measured):

raw 166 µm (± 24 µm)

cooked 195 µm (± 37 µm)

Obviously the cell size increases during cooking. This development, depending upon temperature and time of the treatment, might be an interesting parameter for cooking kinetics.

Texture measurement

Maximum shear force was found to be a good indicator for the hardness of the samples. Shear force values showed differences for slices from different potatoes treated in the same way. For raw slices, values were between 70 and 80 N, for cooked ones values were in the range of a few N. A comparison of these data shows that, apart from differences from slice to slice, there are differences between the shear force values for different thermal treatments which are large enough to describe the kinetics of the changes in firmness and adhesiveness.

Sensory analysis

The descriptions of texture and taste were categorized after defining 3 important categories within the whole category scale, namely texture and taste for optimally cooked potatoes, for raw samples and completely overcooked samples. From the preliminary results of the experiments it could be seen that 4 categories between raw and optimally cooked and optimally cooked and overcooked samples, resp. gave a sufficiently precise description. Finally the schemes shown in **Tab. 2** and **3** were established.

Samples have to be presented and tasted immediately after cooking. The trained panelists received 3 discs and had only to mark the category the description of which corresponded to the sensation perceived. From 8 panelists 24 answers were received on the average. Later on the categories were transferred into numbers by the panel leader in order to obtain data for further mathematical treatment. Number 1 is the value for raw potatoes or the first category, 6 corresponds to optimally cooked potatoes and 11 to overcooked samples.

In conclusion, some analytical methods were tested for, and

Tab. 2 Scheme for the assessment of the cooking degree of potatoes: texture

Groups of cooking degree	Type and intensity of the attributes	Sample 1	Sample 2
Insufficiently cooked	Very hard, completely raw		
	Clearly too hard, to raw, uniform, but clearly too hard to bite		
	Noticeably hard, raw, glassy, crumbly, coarse-grained; non-uniform resistance to biting		
	Slightly hard, raw, glassy, crumbly, coarse-grained; slightly non-uniform resistance to biting		
	Predominantly uniform, smooth, somewhat hard sensation in biting		
Optimally cooked	Uniform, light resistance to biting		
Excessively cooked	Predominantly somewhat too light and too soft a sensation in biting		
	Slightly too light; slightly soft, floury, watery; easy to mash, but still somewhat "al dente"		
	Noticeably too light, noticeably soft, floury, watery; very easy to mash; no longer "al dente"		
	Markedly too soft, too watery, no resistance against mashing		
	Mashily soft, pulpy, wet		

Tab. 3 Scheme for the assessment of the cooking degree of potatoes: taste

Groups of cooking degree	Type and intensity of the attributes	Sample 1	Sample 2
Insufficiently cooked	Completely raw, completely disharmonious		
	Clearly raw, clearly tart (pungent) clearly disharmonious		
	Noticeably raw, noticeably tart (pungent), only weak, disharmonious taste of potato		
	Slightly raw, slightly tart (pungent), slightly disharmonious potato taste of medium intensity		
	Mainly harmonious potato taste of medium intensity		
Optimally cooked	Harmonious, strong taste of potato		
Excessively cooked	Mainly harmonious, slightly flat potato taste		
	Slightly flat-insipid, slightly watery, slightly stale, slightly disharmonious potato taste of medium intensity		
	Noticeably flat, watery, stale; only weak, disharmonious potato taste		
	Distinctly leached out, stale, disharmonious		
	Completely empty, leached out, stale, disharmonious		

adapted to the special purpose of evaluating the cooking kinetics of potatoes. Usually a lot of samples have to be analyzed, and therefore rapid, accurate and reliable methods should be used.

Some factors in the determination of soluble amylose were checked as influence of freezing and thawing of cooked samples, the time between cooking and mashing, the time between mashing and extraction, in order to rationalize the process. But it could be shown that the determination has to be carried out and completed without any break immediately after the experiment to avoid distorting influences. In contrast to soluble amylose, starch determination could be simplified and shortened. One extraction step appeared sufficient without reducing the accuracy of the method. A rapid method for determination of pectin was developed combining analytical procedures described in the literature and the use of Ultrazym 100. Measurement of cell lengths in enlarged photographs of 150 µm thick sections is time-consuming. But determination of cell size increase is an appopriate way to describe the effect of a thermal process on potato tissue.

In addition, a simple texture measurement was introduced to describe the cooking effects objectively. The shear force values obtained are very different for different cooking degrees. Finally methods for the sensory properties texture and taste were evaluated as category tests, in order to describe product changes on the basis of quality parameters detectable by consumers. We finally established scales based on 11 categories between raw and completely overcooked samples. Trained panelists are recommended for these tests.

The described methods and tests have been optimized with regard to such kinetic experiments and provide reliable results. The procedures proposed should facilitate the evaluation of the cooking kinetics of potatoes.

References

1 REEVE, R.M., Pectin starch and texture of potatoes: Some practical and theoretical implications, J. Text. Stud., *8*, 1–17 (1977)
2 LINEHAN, D.J. and HUGHES, J.C., Texture of cooked potato. I. Introduction, J. Sci. Fd. Agric., *20*, 110–112 (1969)
3 LINEHAN, D.J. and HUGHES, J.C., Texture of cooked potato. II. Relationship between intercellular adhesion and chemical composition of the tuber, J. Sci. Fd. Agric., *20*, 113–119 (1969)
4 WARREN, D.S. and WOODMAN, J.S., The texture of cooked potatoes: A Review, J. Sci. Fd. Agric., *25*, 129–138 (1974)
5 STERLING, C. and BETTELHEIM, F.A., Factors associated with potato texture. 3. Physical attributes and general conclusions, Fd. Res., *20*, 130–137 (1955)
6 GINZBURG, B.Z., Evidence for a protein gel structure cross-linked by metal cations in the intercellulose cement of plant tissue, J. exp. Bot., *12*, 85–107 (1961)
7 LETHAM, D.S., The separation of plant cells with ethylenediamine-tetraacetic acid, Exp. Cell. Res., *21*, 353–360 (1960)
8 ZAEHRINGER, M.V., LUDWIG, J.W. and MULLER, F.M., Cooking quality of some Dutch potato varieties, Eur. Potato J., *12*, 225–237 (1969)
9 LUDWIG, J.W., Untersuchungen über das Abkochen von Kartoffeln, Mitt. Inst. Aufbewahr. Verwert. Landw. Erzeugn. (IBVL), *9*, 7 (1972)
10 RATHSACK, K., Der Speisewert der Kartoffel, Verlagsgesellsch. f. Ackerbau, M.B.H. Berlin, 1935.
11 BARMORE, M.A., Potato mealiness and change in softening on cooking, Food Res., *2*, 377–385 (1937)
12 MULLINS, W.R., HARRINGTON, W.O., OLSON, R.L., WOOD, E.R. and NUTTING, M.D., Estimation of free starch in potato granules and its relation to consistency of reconstituted product, Fd. Technol., *9*, 393–395 (1955)
13 NONAKA, M., The textural quality of cooked potatoes. I. The relationship of cooking time to the separation and rupture of potato cells, Am. Potato J., *59*, 141–149 (1980)
14 POTTER, A.L., NEEL, E.M., REEVE, R.M. and HENDEL, C.E., Change in the physical condition of starch of the potato during precooking heating, Am. Potato J., *36*, 444–449 (1959)
15 DEKKER, R.F. and RICHARDS, G.N. Determination of starch in plant material, J. Sci. Fd. Agric., *22*, 441–444 (1971)
16 MAC RAE, J.C., SMITH, D. and McCREADY, R.M., Starch estimation in leaf tissue - a comparison of results using six methods, J. Sci. Fd. Agric., *25*, 1465–1469 (1974)
17 McCREADY, R.M., GUGGOLZ, J., SILVIERA, V. and OWENS, H.S., Determination of starch and amylose in vegetables, Analyt. Chem., *22*, 1156–1158 (1950)
18 KERTESZ, Z.I., The pectic substances, 99–104, Interscience Publ., New York - London, 1951.
19 McCOMB, E.A. and McCREADY, R.M., Calorimetric determination of pectin substances, Analyt. Chem., *24*, 1630–1632 (1952)
20 McCREADY, R.M. and McCOMB, E.A., Extraction and determination of total pectic materials in fruits, Analyt. Chem., *24*, 1986–1988 (1952)
21 KEIJBETS, M.J. and PILNIK, W., Some problems in the analysis of pectin in potato tuber tissue, Potato Res., *17*, 169–177 (1974)
22 BITTER, T. and MUIR, H.M., A modified uronic acid carbazole reaction, Analyt. Biochem., *4*, 330–334 (1962)
23 GRAY, D., Some effects of variety, harvest date and plant spacing on tuber breakdown on canning, tuber dry matter content and cell surface area in the potato, Potato Res., *15*, 317–334 (1972)
24 PAULUS, K. and TIRTOHUSODO, H. Untersuchungen zur Garungskinetik von Kartoffeln, Ern.-Umschau, *29*, 255–259 (1982)
25 OORAIKUL, B., PACKER, G.J.K. and HADZIYER, D., Starch and pectin substances as affected by a freeze-thaw potato granule process, J. Food Sci., *39*, 358–364 (1974)