Design of a quality index for the objective evaluation the quality of breads.
Application to wheat breads using selected bake off technology for bread making.

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Abstract

Bread quality index was established using the instrumental analysis of bread parameters that influence the consumers’ acceptability. The instrumental methods that describe bread appearance, structure and texture have been chosen in order to enable the identification and quantification of main discrepancies of wheat bread produced by different processes such as fully baked frozen bread (FBF), partially baked frozen (PBF) and bread from unfermented frozen dough (UFD) in comparison to bread baked conventionally (CON). The quality index was calculated as a sum of grouped linearly normalized variables multiplied by group factor of significance and relatively to the CON bread. The significant linear correlation was established between instrumental and descriptive sensory analysis of bread appearance ($r=0.966$), crumb structure ($r=0.731$), crust appearance ($r=0.691$) and texture ($r=0.664$). The presented quality index could be very useful for bread producers when innovative production processes are applied.

Keywords: Bread; Quality index; Texture; Freezing process; Bake off technology

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1. Introduction

There are different approaches to the product quality assessment: transcendent, product-based, user-based, manufacturing-based and values based (Garvin, 1988; Pickel, 1989). Some are based on the standpoint of the product attributes “what the product is” and the others on the consumers standpoint – "what a consumer gets", how the product is perceived by the individual. That is similar to the criteria based on intrinsic and extrinsic factors developed by Bech, Juhl, Hansen, Martens & Anderson (2000) who modelled the relationship between the subjective quality as perceived by consumer and the objective quality as a help in product development. The objective quality is constituted of the total measurable or documentary attributes of a product (Grunert, Jeepesen, Risom, Sonne, Hansen & Trondsen, 2002). Food quality besides product attributes concerns also the production system, how much energy is used, or how the raw materials are produced, but to the consumers it is proven that sensory quality of bread is more important (Kihlberg, Johansson, Kohler & Risvik, 2004).

Bakery products have a short shelf-life, and the loss of freshness has a negative influence on product quality and consumer acceptance. The staling process involves decrease in the mobility of water due to reassociation of polymers, and crystallization of amylopectin (Baik & Chinachoti, 2000; Gray & BeMiller, 2003). One of the approaches to increase bread shelf-life up to twelve months is freezing that can be applied before proofing, to the partially baked bread or at fully baked bread (Rosell & Gomez, 2007). Bake off technology that consists in producing bread from industrial refrigerated or frozen or non frozen bakery goods and retailing them to the bakery shops and supermarkets for the final baking, has many advantages and among them the
standardization of product quality is very important. Frozen partially baked bakery
products are among the leading products in terms of innovation in the bread industry. If
the process is optimized, obtained bread has sensory and textural properties close to the
bread obtained by a conventional method (Bárcenas, Benedito, & Rosell, 2004;
Barcenas & Rosell, 2005).

One of the major problems of the part-baked and frozen bakery product is crust flaking
(Le Bail, Monteau, Margerie, Lucas, Chargelegue & Reverdy, 2005). Crust flaking can
be related to mechanical damages due to the intense thermomechanical shock during
chilling–freezing and final baking. Furthermore, many studies have reported that frozen
part-baked bread has a smaller loaf volume, a rougher crust and a more compact crumb
due to the processing conditions, especially freezing conditions (Carr, Rodas, Della
Torre & Tadini, 2006; Bárcenas, Benedito, & Rosell, 2004; Bárcenas & Rosell, 2007).

The quality of bread made from frozen dough is influenced by dough formulation, as
well as process parameters such as dough mixing time (Rouille, Le Bail, & Coucoux,
2000), freezing rate, storage duration, and thawing rate (Inoue & Bushuk, 1991; Le Bail,
Havet, & Pasco, 1998; Lu & Grant, 1999; Neyreneuf & Delpuech, 1993). Several
problems in the production of bread from frozen dough have been described, mainly
reduced yeast activity, prolonged fermentation time, and loaf volume lowering (Inoue &
Boshuh, 1992; Rosell & Gomez, 2007) mostly due to the physical damage of the protein
network (Varriano-Marston, Hsu, & Mahdi, 1980) and the yeast deterioration.

The bread freshness can be assessed through texture analysis (Armero & Collar, 1998).
The textural profile can be identified instrumentally by universal textural instrument or
sensory measuring attributes from consumers approach. Brady & Mayer (1985) obtained low correlation coefficients between sensory and instrumental analysis of textural attributes of rye and French bread. Nevertheless, it is was established by Gambaro, Varela & Gimenez (2002) that instrumental cohesiveness positively correlated to the soft center, softness, stickiness, and sensory chewiness, visual dryness, oral hardness and manual hardness. According to Collar & Bollaín (2005), a good accordance between sensory and instrumental patterns of bread crumb texture during aging of enzyme supplemented breads was observed. In research of Wang, Zhou, & Isabelle (2007) good correlation between the sensory evaluation and instrumental analysis of bread supplemented with green tea extract was set in colour intensity determination but not in porosity determination while the correlation coefficients for the hardness were relatively low for the trained panelists and high for the untrained panelists.

The aim of this study was to establish a methodology allowing the global assessment of the quality of bread. For this purpose, a quality index has been designed and is evaluated by comparing breads made in different conditions. The white wheat breads with extended keepability produced by bake off technology were used as test samples. The physicochemical characteristics and the freshness of bread were determined instrumentally and sensory in order to find the relation of quantitative expression of the product quality relatively to the conventionally produced bread. Physical parameters such as specific volume, shape, crumb to crust ratio, crust flaking, crust hardness, crumb cell distribution and crumb firming were determined instrumentally. Descriptive sensory analysis encompassing appearance, structure, texture and flavour parameters in order to link technological and sensory quality was performed.
2. Materials and methods

2.1. Laboratory baking

For bread preparation wheat flour (chemical composition and rheological properties determined by ICC Methods) obtained from Moulins Soufflet Pantin, France; improver consisting of emulsifier, enzymes and ascorbic acid gained from Puratos, Belgium; fresh compressed yeast (*Saccharomyces cerevisiae*) from Kvasac, Croatia (Lesaffre Group, France); salt from Solana Pag, Croatia and tap water were used.

Dough was mixed in Diosna SP40F spiral mixer 2 minutes at 90 rpm and 7 minutes at 180 rpm, divided automatically by Werner Pfleiderer (WP, Germany) divider, proofed in WP proofing cabinet and baked in WP Rototherm oven.

The baking formulation for conventional (CON) bread was (weight bases): flour 100 %, water 58 %, salt 2 %, compressed yeast 5 %, and improver 1 %. After mixing, the dough rested for 10 minutes, it was divided into pieces 70 g and rounded. Dough pieces were placed in proofing cabinet at 35 °C, 95 % RH for 60 minutes and baked at 230 °C for 17 minutes with 0.5 l steam at start.

A portion of fully baked breads was frozen (“Fully baked and frozen”, FBF) in a freezer at –22 °C and stored at –18 °C in plastic bags for 30 days. FBF breads were unfrozen at room temperature 60 minutes before analysis.

Partially baked and frozen (PBF) breads were prepared according to the following formulation: flour 100 %, water 52 %, salt 2 %, compressed yeast 2 %, and improver 1 %. Dough was divided at 70 g pieces, rounded, and placed in proofing cabinet at 34 °C,
95 % RH for 105 minutes. Breads were partially baked at 190 °C for 3 minutes with 0.2 l steam at start and at 165 °C for 14 minutes. Breads were cooled at room temperature 30 min, frozen at -22 °C, and kept at – 18 °C for 30 days. Part-baked breads were unfrozen at room temperature for 10 min and finally baked at 230 °C for 10 minutes without steam.

The formulation for unfermented frozen dough (UFD) was as following: flour 100 %, water 56 %, salt 2 %, compressed yeast 5 %, and improver 3 %. After mixing and dividing, dough was frozen at -22 °C, and kept at – 18 °C for 30 days. After 60 minutes of thawing at room temperature, dough was proofed and baked in the same manner as CON bread.

2.2. Instrumental analysis

After 1 h of cooling at room temperature, bread was subjected to the following analysis: specific volume, shape, crumb to crust ratio, crust flaking, crumb cell analysis, and texture analysis. Moisture content was determined according to ICC Standard Method 110/1.

Bread volume was determined by a rapeseed displacement method (AACC Standard 10-05) and the specific volume (volume to mass ratio) was calculated. Bread height and diameter was measured by a calliper and the shape (height to diameter ratio) was calculated. For crumb to crust ratio determination, crust was separated from the crumb using the razor blade. The differentiation between crust and crumb is very subjective and may vary from one person to the other one. In our case, the crust was considered as
the dried and significantly coloured material located at the outer zone of the bread.

Crumb to crust ratio is expressed as weight ratio on dry basis.

Crust flaking test was carried out in specific crushing system developed by Le Bail et al (2005). Bread was crushed on its flanks and on its base by 30 % of its diameter and height in crushing system. Pieces of the crust were collected and weighted. A digital picture of crust pieces was taken. Using an UTHSCSA Image Tool 3.0 Software, area of crust pieces was measured. The result is expressed as a weight ratio (weight of crust lost / weight of bread, g /100 g) and as the classes of crust pieces size.

Crumb cells were analyzed by scanning longitudinal section of bread sample, 12.5 mm thick, on flatbed scanner (CanoScan 4400F). Images were analyzed by Image J software according to Gonzales-Barron & Butler (2006). Number of cells in cm² and ratio of cell area and total area was calculated.

Crust penetration test was carried out on 10 mm thick and 25 mm wide crust pieces from bread top using the 6 mm stainless steel probe and Texture Analyser TA.HDplus (Stable Micro Systems, UK) with 30 kg load cell (Crowley et al, 2002). Compression test mode was used with test speed 1.7 mm/s. The crust hardness is expressed as force (in N) needed to penetrate the sample.

Bread firmness is a force necessary to attain a given deformation and sensory as a force required to compress a substance between incisor teeth (Carr & Tadini, 2003). Crumb firmness was determined according to the AACC Method 74-09 on TA.HDplus Texture
Analyzer (Stable Micro Systems, UK) with a probe 36 mm diameter using a 30 kg load cell. Two slices from the middle 12.5 mm thick were stacked together for each test. Crust was removed just before testing. Sample was compressed by 40 % at speed rate 1.7 mm/s. The firmness is reported as the force (in g) required compressing the sample by 25 % of its original width.

2.3. Sensory analysis

Product sensory profile was described by appearance, structure, texture and flavour. The same quality parameters determined instrumentally were evaluated by descriptive sensory analysis (Table 1) with additional evaluation of bread flavour. The most important words for description of bread sensory profile were selected by 6 trained panellists according to ISO 11035:1994(2) and Carr & Tadini (2003). Unstructured 10 cm long scale anchored with “weak” (0) and “strong” (10) was used to attribute intensity. The assessors placed a mark on the line to indicate degree of intensity. Numerical values are attributed by measuring the distance in millimetres between the mark made by assessor and the left hand end of the line and multiplied by factor of significance: 2 for shape and appearance, 3 for crust appearance, 3 from crumb structure, 3 for texture and 9 for flavour that were taken from DLG-Prüfschema (BIB-Ulmer Spatz, 2006) and adjusted for the products made by bake off technology. Sensory score was calculated relatively to the reference bread that was CON bread. Sum of mean intensity values multiplied by the factor of significance was divided by the sum of mean intensity values multiplied by significance factors for reference bread.

2.4. Quality index expression
The results obtained by instrumental analysis were normalized by linear transformation according to Molnar (1988) and Schulz & Köpke (1997). The maximum measured value is ascribed to 1, and the minimum value to 0 in the case of desirable attribute, and vice versa for undesirable attribute. The variables are normalized following the equations (Molnar, 1988):

\[
z_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \quad \text{if } x_{\max} = x_{\text{opt}}
\]

\[
z_i = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}} \quad \text{if } x_{\min} = x_{\text{opt}}
\]

Where "x" designs parameters such as specific volume (cm³/g); shape (height/diameter) (mm/mm); crumb to crust ratio (g/100g db); moisture content (%); crust flaking (g/100g); crumb cell area/total measured area; cell number in cm²; crumb firmness (N) or crust hardness (N).

The quality index was calculated as a sum of grouped normalized variable multiplied by factor of significance for group of attributes (2 for shape and appearance, 3 for crust appearance, 3 for crumb structure, and 3 for texture), relatively to the CON bread:

\[
QI = \left( \frac{2\sum z_{sa} + 3\sum z_{ct} + 3\sum z_{cb} + 3\sum z_{cx}}{2\sum z_{sa} + 3\sum z_{ct} + 3\sum z_{cb} + 3\sum z_{cx}} \right)_{\text{sample}}
\]

\[
QI = \left( \frac{2\sum z_{sa} + 3\sum z_{ct} + 3\sum z_{cb} + 3\sum z_{cx}}{2\sum z_{sa} + 3\sum z_{ct} + 3\sum z_{cb} + 3\sum z_{cx}} \right)_{\text{CON}} \quad (3)
\]

where

z_{sa} is for shape and specific volume (cm³/g),
$z_{ct}$ for crust flaking (g/100g) and crumb to crust ratio (g/100g db),

$z_{cb}$ for crumb cell number in cm$^2$ and cells area / total area,

$z_{tx}$ for crumb firmness (N) and crust hardness (N).

2.4. Statistical analysis

All measurements were done at least in duplicate. The results are expressed as average values. The software Statistica 7.1 (StatSoft Inc, USA) was used for the statistical analysis of the data.

3. Results and discussion

Wheat flour used in experimental baking had rather low protein content but good Alveograph properties for bread-making (Table 2). Farinogram showed good water absorption, short dough development time and good stability. Amylolitic activity of the flour was low; therefore, the improver with amylolytic enzymes was added. Furthermore, ascorbic acid in improver helped enhancing plastic-elastic features of dough.

3.1. Instrumentally determined bread appearance, structure and texture

Analysis of variance (ANOVA) revealed that samples produced by different process (CON, FBF, PBF and UFD) showed significant differences in terms of following instrumentally determined physicochemical attributes: moisture ($p = 0.0022$), specific volume ($p = 0.0009$), crumb to crust ratio ($p = 0.0117$), crust flaking ($p = 0.0052$), crust hardness ($p = 0.0001$), and crumb firmness ($p < 0.0001$) (Table 3). There was no statistical significant difference in the shape ($p = 0.4404$) and crumb cell distribution.
(cell area/total area; \( p = 0.4097 \), and number of cells per \( \text{cm}^2 \); \( p = 0.0605 \)) between groups of bread samples.

Partially baked frozen bread revealed by instrumental analysis significantly lower specific volume (\( p = 0.05 \)) than the conventional bread. That is mostly in agreement with Carr et al (2006), who revealed that frozen part-baked French bread had a lower specific volume and weight than fresh bread; but that frozen storage did not influence water content and crumb porosity. Frozen dough bread did not show significant difference in specific volume in comparison to CON but the bread height to diameter ratio was lower. It was found that the bread height and specific volume are strongly influenced by the amount of the liquid that is released from the frozen dough during thawing (Seguchi, Nikaidoo, & Morimoto, 2003).

Crust flaking and crumb to crust ratio were analyzed as important quality factors in bake-off technology. The results are shown in Table 3. Crust was thick about 2 mm and it formed 35-40 % of weight (dry basis) of the baked bread samples. In the case of frozen dough crumb to crust ratio was the lowest. It was found that the crust flaking increased with bread freezing since of FBF and PBF breads it was significantly higher than for CON bread. The flakes classification by size revealed that in FBF bread 18 % of flakes were sizing 10 – 100 \( \text{mm}^2 \) and 80 % were smaller than 10 \( \text{mm}^2 \); 10 % of PBF bread flakes were sizing 10 – 100 \( \text{mm}^2 \) and 89 % were smaller than 10 \( \text{mm}^2 \) in comparison to CON and UFD bread where 98 % of flakes were smaller than 10 \( \text{mm}^2 \). This indicates that intensive thermo-mechanical treatment of the bread during freezing, thawing and re-baking caused crust drying and searing, which resulted in the increased crust flaking.
Image analysis of the crumb revealed that the ratio of total cell area and total measured area of the FBF was similar to CON, but in the UFD and PBF it was lower (Table 3). However, number of crumb cells per cm² was higher in PBF and UFD than in CON but the cells were smaller. This indicates that freezing influenced the cell distribution in the way that cells were higher in number but smaller in size. This is probably the result of proofing conditions and decreased yeast activity as it was found by Baardseth, Kvaal, Lea, Ellekjaer & Faerestad (2000). This could be also explained by finding of Barcenas & Rosell (2006a,b) that changes occurred due to ice crystals growth during storage time can damage crumb structure resulting in more compact crumb.

Crust penetration test revealed that the CON bread had the highest crust hardness (9.09 N), UFD following, than FBF and PBF the lowest (4.3 N) (Table 3). Process of freezing and thawing influenced negatively the crust hardness.

Frozen bread and part-baked frozen bread especially had significantly higher crumb firmness than conventional bread while bread baked from frozen dough had the lowest firmness (Table 3). That is in agreement with the results obtained by Ribotta, Perez, Leon & Anon (2004) indicating that the dough freezing and storage at 18 °C causes reduced dough firmness and elasticity.

3.3 Results of sensory analysis

The most favoured bread by the panellists was the CON bread (Fig 2). The mean scores for bread samples obtained by descriptive sensory analysis of the panel for CON bread was reported 1.00; FBF 0.83; PBF 0.84 and UFD 0.96 (Table 4). By analysis of variance the significant difference in overall sensory quality between breads produced by
different processes was proven at level $p = 0.01$ and $p = 0.001$ and no significant
difference between panellists was found. The results of mean scores for selected
attributes with standard deviation are graphically presented in Fig. 2. FBF bread was the
only sample with changed intensity of flavour. Freezing of FBF bread resulted in
decreased sensation of saltiness and increased sweet savour. Further more, freezing
influenced the crumb colour appearing brighter and bread juiciness was less
pronounced. The crust was broken and the flaking was high. PBF bread had
significantly lower volume, the crust was more dry and detached from the crumb, and
crust colour was uneven. The crust flakiness was also high as shown by mechanical
crushing test. UFD bread was very similar to the conventional and it had very soft
crumb. In all bread samples saltiness was too pronounced and therefore salt content
should be reduced.

3.4. Quality index of bread samples

The quality index of breads was established in the following order: CON > UFD > FBF
> PBF (Table 4). The quality of conventionally produced bread was evaluated as the
best while UFD and FBF were following very closely. The softness of the UFD bread
crumb as well as low crust flaking contributed the most to its high rating which was
confirmed by descriptive sensory analysis. PBF bread was evaluated with the lowest
quality index due to low specific volume and porosity, high flaking and high initial
crumb firmness. This discrepancy from conventional bread was strongly distinguished
by instrumental analysis. The correlation between instrumentally determined QI and
sensory score (DSA) was low ($r = 0.536$) which is due to the omission of flavour
analysis by instrumental methods but ranking of breads is the same by both methods (Table 4).

4. Conclusion

The quality variation of bread produced by different processes can be described relatively to the reference sample with a quality index. Presented quality index is based on the instrumental analysis of selected parameters that are strongly linked to the consumers’ acceptance. In the case when innovative bread making process such as bake off technology is applied, the instrumental analysis could give to producer valuable information considering the bread appearance, structure and texture since the deviations in product quality are easily quantified. Instrumental methods are suitable for routing testing as well. Good linear correlation between the instrumental analysis and the results of descriptive sensory analysis was proven for bread appearance ($r = 0.966$), and lower for crust appearance ($r = 0.694$), crumb structure ($r = 0.731$) and texture ($r = 0.664$). When the change in production process or formulation strongly influences product flavour it is necessary to make sensory analysis but when physical characteristics are changed instrumental determination gives more reliable quantitative information on product quality.

The presented model of the quality index could be tailored according to the users need. The next step in quality index expression established on the instrumental determinations would be a method development for aroma and taste identification and quantification since bread flavour effects the consumers’ acceptability the most.
Although there are many papers published for description of overall quality (Molnar, 1988; Molnar, 1995; Schulz & Köpke, 1997), pea quality (Bech et al, 2000), Australian tea (Caffin, D’arcy, Yao & Rintoul, 2004), water (Jin, Wang & Wei, 2004), this is the first work on quality index of bakery products and it could be applied for different types of bakery products.

Acknowledgement

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References


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<table>
<thead>
<tr>
<th>Process</th>
<th>Mean</th>
<th>Mean±SD</th>
<th>Min-Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance, sensory</td>
<td>7.6</td>
<td>7.8</td>
<td>8.0</td>
</tr>
<tr>
<td>Shape, H/D</td>
<td>4.8</td>
<td>5.0</td>
<td>5.2</td>
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**Diagrams:**
- **Appearance, sensory**
- **Shape, H/D**
- **Vspec, cm³g⁻¹**
Fig. 1. Whisker plot of bread sensory analysis (score multiplied by factor of significance) for conventional bread (CON), fully baked frozen bread (FBF), partially baked frozen (PBF) and frozen dough bread (UFD), mean value and standard deviation.

Fig. 2. Correlation between sensory determined bread appearance (a), and instrumentally determined specific volume (b) and shape (c) for conventional bread (CON), fully baked frozen bread (FBF), partially baked frozen (PBF) and frozen dough bread (UFD), mean value and standard deviation.
### Table 1

Selection of bread attributes for sensory and instrumental analysis, and linkage between sensory and technology quality parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>f</th>
<th>Descriptive sensory analysis</th>
<th>Instrumental analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appearance</strong></td>
<td>2</td>
<td>Volume at the first sight - attractive</td>
<td>Specific volume - Rapeseed displacement method &amp; weighing</td>
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<tr>
<td></td>
<td></td>
<td>Shape - regularity, roundness, flatness</td>
<td>Shape (diameter/height) - Measurement of bread height and diameter by caliper</td>
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<tr>
<td><strong>Crust appearance</strong></td>
<td>3</td>
<td>Crust flaking by touch and cutting</td>
<td>Crust flaking (according to Le Bail et al, 2005)</td>
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<td></td>
<td></td>
<td>Crust thickness visually</td>
<td>Crumb to crust ratio (weight or volume ratio)</td>
</tr>
<tr>
<td><strong>Crumb appearance and structure</strong></td>
<td>3</td>
<td>Crumb cells – number, size, distribution, wall thickness</td>
<td>Crumb cells number per cm²; cell area / total area</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>3</td>
<td>Texture in mouth or by finger</td>
<td>Crumb texture: Bread firmness following the AACC Method 74-09</td>
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<td></td>
<td></td>
<td>Juiceness – degree of perceived moistness</td>
<td>Moisture content by drying - ICC Standard 110/1</td>
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<tr>
<td></td>
<td></td>
<td>Crust hardness by finger</td>
<td>Crust hardness by texture instrument</td>
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<tr>
<td><strong>Flavour</strong></td>
<td>9</td>
<td>Malty – aromatic sensation that produces a taste or smell reminiscent of toasted grains</td>
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<tr>
<td>(Taste + Aroma)</td>
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<td>Alcoholic – characteristic odour of item containing alcohol (ethanol)</td>
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<td></td>
<td></td>
<td>Buttery – rich smell of melted butter</td>
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<td></td>
<td></td>
<td>Green-earthy – characteristic odour of fresh earth, wet soil or humus</td>
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<td></td>
<td></td>
<td>Wheat - flavour typical of wheat kernel treated with boiled water</td>
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<td></td>
<td></td>
<td>Salty - perception of salinity</td>
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<td>Standard solution: sodium chloride 5 g/l</td>
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<td>Sweet - having or denoting the characteristic taste of sugar</td>
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<td>Standard solution: sucrose 16 g/l</td>
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<td>Sour - sharp biting taste like the taste of vinegar or lemons</td>
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<td></td>
<td>Standard solution: tartaric acid or citric acid 1 g/l</td>
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<td>Bitter - perceived by the back of the tongue and characterized by solutions of quinine,</td>
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<td>caffeine, and other alkaloids; usually caused by over-roasting.</td>
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<td>Standard solution: caffeine 0,5 g/l</td>
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<td></td>
<td>Yeast - aroma of fresh baked bread</td>
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<td></td>
<td></td>
<td>Bland - lack of taste, flat and neutral</td>
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<td></td>
<td></td>
<td>Nutty - taste typical of freshly ground hazelnuts</td>
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<td></td>
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<td>Milk - taste typical of fresh milk</td>
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\(f\) - factor of significance
Table 2

Physicochemical characteristics of the used wheat flour (Moulins SOUFFLET, Pornic, France, harvest year 2006, stored at −20°C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
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<tbody>
<tr>
<td>Water content (%)</td>
<td>14.4</td>
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<tr>
<td>Ash (%)</td>
<td>0.52</td>
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<tr>
<td>Protein (g/100g dm)</td>
<td>9.54</td>
</tr>
<tr>
<td>Falling number (s)</td>
<td>450</td>
</tr>
<tr>
<td>Sedimentation value (cm³)</td>
<td>33</td>
</tr>
<tr>
<td>Wet gluten (%)</td>
<td>24.9</td>
</tr>
<tr>
<td>Gluten index (%)</td>
<td>94.4</td>
</tr>
<tr>
<td><strong>Farinogram</strong></td>
<td></td>
</tr>
<tr>
<td>water absorption (%)</td>
<td>54.0</td>
</tr>
<tr>
<td>dough development time (min)</td>
<td>2.0</td>
</tr>
<tr>
<td>dough stability (min)</td>
<td>7.3</td>
</tr>
<tr>
<td>dough strength (BU)</td>
<td>58</td>
</tr>
<tr>
<td>degree of softening (BU)</td>
<td>60</td>
</tr>
<tr>
<td><strong>Alveogram</strong></td>
<td></td>
</tr>
<tr>
<td>tenacity, P (mm)</td>
<td>58</td>
</tr>
<tr>
<td>extensibility, L (mm)</td>
<td>113</td>
</tr>
<tr>
<td>deformation energy, W (10⁻⁴ J)</td>
<td>211</td>
</tr>
<tr>
<td>curve configuration ratio, P/L</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Amylogram</strong></td>
<td></td>
</tr>
<tr>
<td>start of gelatinization (°C)</td>
<td>50.8</td>
</tr>
<tr>
<td>max viscosity (AU)</td>
<td>1,560.0</td>
</tr>
<tr>
<td>temperature at max viscosity (°C)</td>
<td>81.4</td>
</tr>
</tbody>
</table>
Table 3

Physicochemical characteristics of bread samples (CON conventionally baked bread; FBF fully baked frozen; PBF partially baked frozen and UFD unfermented frozen dough) – mean values.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture (%)</th>
<th>Specific volume (cm³/g)</th>
<th>Shape (h/d)</th>
<th>Crumb/crust (g/100g)</th>
<th>Crust flakiness (g/100g)</th>
<th>Crust hardness (N)</th>
<th>Crumb firmness (N)</th>
<th>Cells Area/Total Area</th>
<th>No Cells/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>(0.028)</td>
<td>(0.255)</td>
<td>(0.009)</td>
<td>(0.035)</td>
<td>(0.324)</td>
<td>(0.676)</td>
<td>(9.808)</td>
<td>(0.017)</td>
<td>(0.045)</td>
</tr>
<tr>
<td></td>
<td>31.04</td>
<td>6.059</td>
<td>0.686</td>
<td>1.923</td>
<td>0.380</td>
<td>9.092</td>
<td>1.617</td>
<td>0.216</td>
<td>9.80</td>
</tr>
<tr>
<td>FBF</td>
<td>(0.283)</td>
<td>(0.090)</td>
<td>(0.003)</td>
<td>(0.042)</td>
<td>(0.144)</td>
<td>(0.140)</td>
<td>(8.481)</td>
<td>(0.023)</td>
<td>(0.273)</td>
</tr>
<tr>
<td></td>
<td>30.60</td>
<td>6.184</td>
<td>0.689</td>
<td>1.927</td>
<td>2.024</td>
<td>6.133</td>
<td>2.557</td>
<td>0.220</td>
<td>8.80</td>
</tr>
<tr>
<td>PBF</td>
<td>(0.311)</td>
<td>(0.146)</td>
<td>(0.087)</td>
<td>(0.057)</td>
<td>(0.751)</td>
<td>(1.221)</td>
<td>(8.569)</td>
<td>(0.033)</td>
<td>(0.407)</td>
</tr>
<tr>
<td></td>
<td>29.44</td>
<td>5.234</td>
<td>0.672</td>
<td>1.870</td>
<td>3.355</td>
<td>7.213</td>
<td>3.424</td>
<td>0.172</td>
<td>12.76</td>
</tr>
<tr>
<td>UFD</td>
<td>(0.099)</td>
<td>(0.298)</td>
<td>(0.007)</td>
<td>(0.084)</td>
<td>(0.040)</td>
<td>(0.837)</td>
<td>(4.746)</td>
<td>(0.033)</td>
<td>(0.831)</td>
</tr>
<tr>
<td></td>
<td>31.67</td>
<td>6.362</td>
<td>0.625</td>
<td>1.612</td>
<td>0.346</td>
<td>7.383</td>
<td>0.604</td>
<td>0.207</td>
<td>11.36</td>
</tr>
</tbody>
</table>
The correlation between quality index (QI) determined instrumentally and score obtained by descriptive sensory analysis (DSA) for conventional bread, fully baked frozen bread (FBF), partially baked frozen bread (PBF) and bread from frozen dough (UFD), $r = 0.536$.

<table>
<thead>
<tr>
<th>Sample</th>
<th>QI</th>
<th>DSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FBF</td>
<td>0.977</td>
<td>0.828</td>
</tr>
<tr>
<td>PBF</td>
<td>0.523</td>
<td>0.845</td>
</tr>
<tr>
<td>UFD</td>
<td>0.999</td>
<td>0.960</td>
</tr>
</tbody>
</table>