A technique for integrated assessment of food quality as affected by various technological processes

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Abstract. In this paper, we present a methodology for integrated assessment of food quality as affected by various processes. In particular, the method of high-frequency acoustic cavitation, which is used for making Circassian cheese, is considered. The following measurement techniques were used: sample deformation profile test, relaxation depth test by penetrating to 36 mm with a cylinder, cheese hardness when penetrated with a $\varnothing$ 2 mm cylinder, and cutting force. An integrated metric for assessing food quality is proposed, which describes its rheological properties (the depth of relaxation). In addition, a diagram of the structural and mechanical classes of food, which combines multiple organoleptic and rheological food properties, is proposed. This diagram can be used for estimating the effect of a specific treatment process on food production.

1. Introduction

Dairy products today are produced using various innovative approaches, such as novel treatment technologies, adaptive quality control with targeted supplements, as well as software-based mathematical modelling.

The existing Russian and international food quality standards are based on the physical, chemical, and organoleptic properties of food products. Thus, CODEX STAN 283-1978 ‘Codex Alimentarius. General Standard for Cheese’ and GOST R 52686-2006 ‘Cheeses. General Specifications’ contain organoleptic, physical, and chemical requirements to cheese products without any consideration for cheese rheology [1, 2].

However, the rheological properties of food products are known to be sensitive to (i) the technological properties of raw materials, (ii) applied recipes, (iii) the intensity and duration of mechanical and thermal exposure that affects the structural components in various processes.

Appropriate food quality control requires formalization of specific production processes, which should be achieved by taking into consideration the integrated properties of the product, i.e. its rheological properties [3].

Food rheology and its changes necessitate the use of instrumental control methods, which allow data to be rapidly collected for adaptive quality control.

An integrated property is a function of all the numerous baseline variables that describe the condition of semi-finished or finished products. The physical meaning of integrity is that such a property is the response of a system generated by all its components. Rheological parameters are such
integrated properties that describe the quality of semi-finished products at (nearly) any production stage [4].

Chenykh [5] proposed an integrated organoleptic metric (texture, including the rheological parameters, taste and smell as determined by the human senses) for food quality assessment.

The rheological properties (the texture-related parameters of the raw materials, the semi-finished and finished products) should be instrumentally tested for faster and more objective assessment; the rheology of semi-finished products could be subjected to formalized control routines to ultimately stabilize the quality of resulting foods [6].

An ISO 67.100.30 ‘Cheese. Including cottage cheese, whey cheese’ standard, ISO/TS 17996 [7] suggests qualifications based on cheese deformations when penetrated by a cylindrical indenter.

Khavrov proposed a comprehensive approach to rheological assessment in [8]. His approach builds upon a group of rheological properties converged by a translation factor.

Mayorov et al. proposed an interesting approach to cheese quality control [9]. The functional parametric analysis they ran showed that cheese quality had better be controlled when the curd is forming, i.e. continuous rather than discrete viscosity monitoring would be a more effective option. To that end, they proposed using automatic control systems.

In the light of the above, the goal hereof is to create a methodology for assessing the food quality as affected by various processes.

2. Material and methods
The subject of this research is the use of high-frequency acoustic cavitation in the production of Circassian cheese.

The dairy product was based on the Circassian cheese recipe per GOST R 53379-2009[10]. For comparison, we sampled Circassian cheese bought in a retail store in Moscow.

The technology behind Circassian cheese is based on heat-acid coagulation for a more complete transition of whey proteins to a dairy product. Circassian cheese was produced of milk normalized for the mass fraction of fat and pasteurized at 93ºC to 95ºC with the acidity of no more than 20ºT. To cause the milk to clot, whey was added in the amount of 8-10% of the milk volume. The exact whey amount depended on its acidity, with the recommended range being 95-150ºT). The resulting curd was kept for 5 minutes at 93-95ºC, then shaped and directed to the self-pressing unit. Cheese was thus subjected to 10 to 15 minutes of self-pressing, then flipped by shaking the mold. After self-pressing, cheese was dry-salted. Cheese in the mold stayed for 16-18 h in chambers that maintained an internal temperature of 8-10ºC. For better salting and drying, cheese was flipped twice over this time [11].

When processing Circassian cheese, the milk-to-whey ratio necessary for coagulation and curding was 90:10 in the control samples, 90:4.3 in the experimental samples where the milk had been pre-exposed to high-frequency cavitation at 45 kHz over 30 minutes using an UZO-Activator-150 unit manufactured by PKF Avangard LLC, Russia, see Figure 1.

![Figure 1. UZO-Activator-150.](image-url)
Quality assessment was based on the following tests:

- Physical and chemical tests:
  - Protein content test per GOST R 23327-98, fat content test per GOST R 5867-90, active acidity test (pH) by potentiometry using a pH-80 meter (HM Digital), titrated acidity per GOST R 3624-92, and density per GOST R 3625-84 [12-15].
  - Organoleptic tests per GOST 33630-2015 [16].
  - Rheological tests:

Samples were tested using a texture analyzer (Strukturometr ST-2, manufactured by Q-Lab LLC) [17], see Figure 2.

![Figure 2. Strukturometr ST-2, Q-Lab LLC](image)

The following measurement techniques were used: sample deformation profile test, relaxation depth test by penetrating to 36 mm with a cylinder, cheese hardness when penetrated with a Ø2 mm cylinder, and cutting force. For details about the testing unit, see the manufacturer’s website [17].

Sample deformation profile test

The method is based on finding the total \( h_{\text{tot}} \), plastic \( h_{\text{pl}} \) and elastic \( h_{\text{el}} \) deformation of a sample when compressed with a Ø36 Piston moving at 0.5 mm/s after touching the soft part of the sample with a force of 7 g until reaching a loading force of 1,500 g, then reversing the indenter movement and extracting it at the same rate until reaching 7 g again, a method proposed by Q-Lab LLC, or QL.

The ultimate value here is the arithmetic mean of three measurements.

Relaxation depth when penetrated with a 36-mm cylinder

The method is based on finding the total \( h_{\text{tot}} \) sample deformation when compressed with a Ø36 indenter moving at 0.5 mm/s after touching the soft part of the sample with a force of 7 g until reaching a loading force of 500 g. After that the indenter is immobilized at the maximum depth, at which such load is attained, and the sample structure relaxation is measured over 120 seconds.

Cheese hardness when penetrated with a Ø 2mm cylinder

The method is based on finding the kinetics of loading force changes using a Ø2 Cylinder that penetrates the sample at 0.5 mm/s to reach a depth of 7 mm after touching the sample with a force of 7 g; then finding the hardness and structural homogeneity of the sample.

Cheese cutting force
This method is based on finding the maximum cutting force applied to the sample with the Knife #2 indenter moving at 0.5 mm/s after touching the sample with a force of 5 g; the indenter should reach a depth of 15 mm.

Data was processed statistically in STATISTICA (StatSoft) [18].

3. Results and Discussion

As indicated by the physical and chemical cheese quality indicators (Table 1), high-frequency cavitation had virtually no effect either on the mass fractions of fat and protein, or on the density of the raw milk. However, cavitation did change the active acidity by 0.5 towards alkalinity and reduced the titrated acidity by 2ºT.

Note a considerable difference in the milk protein coagulation process between the control and the experimental sample as indicated by the latter needing less than half of the whey compared to its control counterpart. The authors hereof believe this could be caused by cavitating the raw milk, which activated the proteins and altered the salt composition [19], which in turn resulted in using less whey to attain the same coagulation when making Circassian cheese.

It should be noted that the experimental sample also produced 4% more Circassian cheese than the control did. This could be due to the moisture contained in the milk transitioning from unbound to bound (hydrate) state [20]. Samples were ranked as followed based on the generalized organoleptic scoring: 1 experimental sample; 2 control sample; 3 retail samples. Thus, exposing the raw milk to high-frequency acoustic cavitation did improve the product quality.

Table 1. Physical and chemical quality indicators of Circassian cheese and its ingredients

| Indicator                  | Whole milk | Caseous whey | Circassian cheese |
|---------------------------|------------|--------------|-------------------|
|                           | Control sample | Experimental sample | Control sample | Experimental sample | Retail sample |
| Mass fraction of:         |            |              |                  |
| protein,%                 | 2.80       | 2.90         | 0.80             | 18.00               | 19.00         | 17.20         |
| fat,%                     | 3.37       | 3.38         | 0.50             | 19.70               | 19.90         | 19.00         |
| Active acidity (pH)       | 6.50       | 7.00         | 4.79             | 5.90                | 6.20          | -             |
| Titrated acidity, ºT      | 18.00      | 16.00        | 80.0             | 26.0                | 25.0          | -             |
| Density, kg/m³            | 1.031      | 1.032        | 1.026            | -                   | -             | -             |
| Generalized organoleptic score, points |            |              |                  | 3.60                | 4.90          | 2.40          |

Figures 3 and 4 show the results of testing the cheese deformation profile.

**Figure 3.** Deformation profile parameters as a function of the process.

**Figure 4.** Averaged curves of the deformation profile (1 for Circassian_Control, 2 for Circassian_Experiment, 3 for Circassian_Retail)
Figures 5, 6 show the relaxation depth.

**Figure 5.** Relaxation depth as a function of the process

**Figure 6.** Averaged curves of relaxation (1 for Circassian_Control, 2 for Circassian_Experiment, 3 for Circassian_Retail)

Figures 7, 8 show the cheese hardness as measured by penetration testing with a Ø2 mm cylinder.

**Figure 7.** Maximum penetration force as a function of the process

**Figure 8.** Averaged curves of penetration (1 for Circassian_Control, 2 for Circassian_Experiment, 3 for Circassian_Retail)

Figures 9, 10 show the results of testing the cutting force (knife sharpened to 30º).

**Figure 9.** Maximum cutting force function

**Figure 10.** Averaged curves of the cutting process (10 for Circassian_Control, 1 for Circassian_Experiment, 2 for Circassian_Retail)
The measured rheological and organoleptic properties of Circassian cheese samples were then used to formulate an integrated quality score of foods affected by various processes.

Statistical processing returned a regression model of organoleptic parameters as function of the measured rheological properties shown in Figures 3 to 10; this dependence is of low significance at p<0.0035, see Table 2.

### Table 2. Regression model of organoleptic parameters as a function of the measured rheological properties (p<0.0035)

| N=9 | Regression Summary for Dependent Variable Rating (Spreadsheet 1) |
|-----|------------------------------------------------------------------|
| R=0.99484007 R?=0.98970676 Adjusted R =0.97255136 F(5.3)=57.691 p< 0.00351 |
| Std. Error of Estimate: 0.21917 |

| Beta | Std. Err. of Beta | B | Std. Err of B | t(3) | p-level |
|------|-------------------|---|---------------|------|---------|
| Intercept | -0.3749 | 0.1612 | -0.6542 | 2.0389 | 2.0839 | 0.1285 |
| General deformation | 0.0672 | 0.1339 | 0.0015 | 0.0029 | 0.5018 | 0.6503 |
| Depth of relaxation | 0.1107 | 0.1329 | 0.0096 | 0.0115 | 0.8330 | 0.4660 |
| Cheese hardness | 0.3455 | 0.1190 | 0.0013 | 0.0004 | 2.9030 | 0.0624 |
| Cutting hardness | -1.0533 | 0.1599 | -0.0280 | 0.0043 | -6.5868 | 0.0071 |

Low significance of the resulting model is due to multicollinearity factors [18]. The STATISTICA data processing algorithm cut off the skewing factors sequentially to produce a more significant regression model (p<0.00006), see Table 3. Based on this model, the authors hypothesized that the relaxation depth, a rheological property, is the optimally integrated metric.

### Table 3. Regression model of organoleptic parameters as functions of the measured rheological properties (p<0.00006)

| N=15 | Regression Summary for Dependent Variable Rating (Spreadsheet 2) |
|------|------------------------------------------------------------------|
| R+ 0.85932524 R+ 0.72305301 Adjusted R =0.70174940 F(1.13)=33.940 p< 0.0006 |
| Std. Error of Estimate: 0.70504 |

| Beta | Std. Err. of Beta | B | Std. Err of B | t(3) | p-level |
|------|-------------------|---|---------------|------|---------|
| Intercept | -6.11522 | 1.632020 | -1.61522 | 1.632020 | -3.74702 | 0.002441 |
| Depth of relaxation | 0.850325 | 0.145958 | 0.01652 | 0.002836 | 5.82584 | 0.000059 |

Statistical testing of the regression model showed its acceptability of a high significance (p<0.05). This model was better than the “naive” averages-based prediction.

We find below the results of testing the relaxation curve (Fig. 6) by the generalized Maxwell model as written below:

\[
Y(t) = K_1 \cdot \exp\left(-\frac{t}{T_1}\right) + K_2 \cdot \exp\left(-\frac{t}{T_2}\right) + \ldots + \sum_{i=1}^{n} K_i \cdot \exp\left(-\frac{t}{T_i}\right),
\]
where: \( Y(t) \) is the relaxation function, \( t \) is the current time; \( K_i \) and \( T_i \) are the constants based on the structural and mechanical properties of the material.

The generalized Maxwell model is an exponent of relaxation as a sum of multiple exponents [21]. There are a few food relaxation constants: \( K_1 \) is the share of fast relaxation of stress, \( K_2 \) is the share of prolonged relaxation, and \( K_3 \) is the share of residual relaxation.

Using an analysis app developed by Maksimov et al. [21], the researchers analysed the relaxation curve of the tested cheeses.

Following the proposed method, the found constants are presented in the form of a diagram of structural and mechanical classes, see Figure 11.

![Figure 11. Diagram of structural and mechanical classes](image)

Dot coordinates on the diagram indicate the structural and mechanical class of a sample. Samples that end up near \( K_1 \) feature high plasticity and high relaxation rate; \( K_2 \) samples have greater elastoplastic properties with long relaxation; \( K_3 \) is for slowly relaxing materials [5].

The relaxation factors of the studied samples are in the “fast relaxation, high plasticity” area of the diagram in Figure 11.

The dots follow a specific pattern. By comparing the dot coordinates, one can classify the samples by plasticity; as shown in Figure 11, Circassian_Experiment, the one exposed to high-frequency cavitation, had the greatest plasticity. Thus, it had greater residual relaxation, a sign of greater viscosity.

### 4. Conclusions

In this paper, a method for the integrated assessment of food quality as affected by various processes is proposed. An integrated quality metric is suggested, which consists in the rheological property (the relaxation depth) of food. In addition, a diagram of structural and mechanical classes is created, each class of which combines multiple organoleptic and rheological food properties. This diagram can be used for assessing the effect of a specific treatment process on food production.
Acknowledgments
The authors would like to thank V.Ya. Chernykh, Doctor of Engineering, Full Professor, Head of the Centre of Food Rheology, Bakery Research Institute.

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