Analysis of apple beverages treated with high power ultrasound – a quality function deployment approach

Running title: Quality function deployment of high power ultrasound treated apple beverages

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Abstract:

BACKGROUND: The objective of this paper was to demonstrate application of quality function deployment in analysing effects of high power ultrasound on quality properties of apple juices and nectars. In order to develop a quality function deployment model, joint with instrumental analysis of treated samples, a field survey was performed to identify consumer preferences towards quality characteristics of juices/nectar.

RESULTS: Based on field research, three most important characteristics were 'taste' and 'aroma' with 28.5% of relative absolute weight importance, followed by 'odour' (16.9%). Quality function deployment model showed that the top three 'Quality Scores' for apple juice were treatments with amplitude 90µm, 9min treatment time and the sample temperature of 40°C; 60µm/9min/60°C and 90µm/6min/40°C. For nectars, top three were treatments 120µm/9min/20°C; 60µm/9min/60°C and A2.16 60µm/9min/20°C.

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CONCLUSION: This type of quality models enables a more complex measure of large scale of different quality parameters. Its simplicity should be understood as its practical advantage and as such, this tool can be a part of design quality when using novel preservation technologies.

Keywords: apple juice; apple nectar; ultrasound treatment; quality function deployment; quality characteristics

INTRODUCTION

High power ultrasound processing of juices and nectars has an increasing potential in terms of reduced processing time, higher throughput and lower energy consumption. [1, 2] Main quality characteristics of juices and nectars treated with ultrasound are sensory properties, [3] rheological properties, [4] °Brix, pH and acidity, [5] and colour. [3, 4] The complexity of comparing juices / nectars in relation to various ultrasound treatments and quality parameters becomes a challenge for researchers to develop (mathematical) models and analyse data in terms of a single quality score.

Quality function deployment (QFD) as an innovative quality tool was introduced in Japan in the mid-60s. [6] Akao [7] defined it as a ‘‘method for developing a design quality aimed at satisfying the customer and then translating the customer’s demands into design targets and major quality assurance points to be used throughout the production phase’’. Its customer centricity to product / process innovation emphasizes its benefit. [8] First step in applying QFD is to develop a house of quality (HOQ) and translate customer requirements to quality characteristics. [9] Collection of the consumer wishes and evaluation of their importance presents the first step in product development. [10] Four key elements of each HOQ are: (i) WHAT (customer needs or requirements recognized as demanded quality), (ii) HOW (technical / technological / quality characteristics), (iii) relationship (between WHAT and HOW), and (iv) HOW MUCH (target value). [9]

Various food products have been analysed using QFD, such as chocolate, [11] extra virgin olive oil, [12] Bulgogi bovine meat, [9] suwar suwir, [13] as well as organic products. [14] Although some food products have been in the focus of QFD, the literature review revealed that juices/nectars have not been in focus. Also, new – innovative technologies such as high power ultrasound have not been analysed and this was identified as a research gap by the authors of this paper. The objective of this paper was to demonstrate application of QFD in analysing effects of high power ultrasound on quality properties of apple juices and nectars.

EXPERIMENTAL

To apply QFD, two researches have been performed. On one side, survey designed for consumers has been conducted in order to identify consumer preferences towards quality characteristics of juices/nectars. In parallel, apple juices and nectars have been treated with high power ultrasound and quality characteristics – sensory attributes and physical characteristics have been analysed.

From the demanded level of quality extracted from the answers of consumers, a House of Quality has been constructed.

Field research

The survey on consumers' perception of juices and nectars has been conducted during the end of 2016. A total of 195 respondents from Zagreb and Belgrade as the biggest and most developed food markets in Croatia and Serbia were interviewed. The sample was predetermined in terms of age (mainly young population), number of respondents (at least 75 per country) and locality of residence (urban). Sample in terms of gender and education was not stratified. In spite of its relatively limited size per country, the sample used here was found useful for defining inputs in the House of Quality.

The questionnaire consisted of two sections. First section included general demographic information about the respondents. The second section gave the respondents the opportunity to rank seven basic sensory / quality characteristics of juices and nectars (colour, odour, overall taste, sweetness, sourness, fruity taste, viscosity) from 7 'the most important' to 1 'the least important'. Direct ranking has been processed by the use of rank sums as an indicator of attribute importance since this method is capable of showing not only the rank order, but also the distance between attribute ranks.

Apple juice and nectar preparation

Based on the national regulation, [15] for production of fruit juices and complementary products, two different apple juices were made. Pure (100 %) apple juice and 50% apple nectar were made with minimum of 11.2°Bx. Concentrated apple - 70 ± 0,5°Bx (Dona trgovina d.o.o., G. Stubica, Croatia).

Compositions of 100% apple juice (per 1L) were concentrated fruit juice 168g, sugar 0g, citric acid 0g, water 881g; and for 50% apple nectar were: concentrated fruit juice 84g, sugar 59g, citric acid 3g, water 927g. Untreated samples were denoted A1.0 (1-juice) and A2.0 (2-nectar). Ultrasound treated was denoted A1.1-A1.16 and A2.1-A2.16 (Table 1).

Experimental methodology

The experiment was designed in STATGRAPHICS Centurion (StatPoint Technologies, Inc, Warrenton, VA, USA) software. The experiment consisted of 16 experimental trials (Table 1). The independent variables were amplitude: X1 (μm), temperature: X2 (°C) and treatment time: X3 (min). The operating variables were considered at three levels, namely low (-1), central (0) and high (1). Experiments were organized in a factorial design (including factorial points, axial points and centre point) and the remaining part involving the replication of the central point to get good estimate of the experimental error. Repetition experiments were carried out after the other experiments followed by order of runs designed by program. The designs were based on the central composite design, face cantered design characteristic with two centre points. The total number of experiments of the designs (N) can be calculated as follows:

$$N = N_i + N_o + N_j \qquad /1/$$

where $Ni=2^n$ is the number of experiments ($2^3=8$), No is the number of centre points and $Nj=2 \times n$ ($2 \times 3=6$), is the number of star points. [2] Design matrix for the experiment and the regression model proposed for the response is given below: [16]

$$Y = \beta_o + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i<j}^{n} \beta_{ij} X_i X_j \qquad /2/$$

where β_0 is the value of the fixed response at the central point of the experiment which is the point (0, 0, 0); βi, βii and βij are the linear, quadratic and cross-product coefficients, respectively. The model was fitted by multiple linear regressions. Calculations were done at 95 % of confidence level. Analysis of variance (ANOVA) was carried out to determine any significant differences in profiles of juices and nectars ($p<0.05$) among the applied treatments.

Ultrasound treatment

Juice or nectar samples (100 mL) were placed in a round-bottom glass beaker 200 mL, which served as the treatment chamber. An ultrasonic processor (S-4000, Misonix Sonicators, Newtown, CT, USA), set at 600W, 20 kHz, 12-260 µm with a 12.7 mm diameter probe, was introduced into the vessel. Ultrasonication was carried out at 60, 90 and 120 µm amplitude. Juice and nectar samples at 20, 40 and 60°C were treated by ultrasounds for 3, 6 and 9 min. For this study, 16 samples of juices and 16 samples of nectars were ultrasonically treated (Table 1).

Rheological analysis and pH

Determination of rheological properties of model systems

Torque measurements were carried out on the model systems using a Rheometric Viscometer (Model RM 180, Rheometric Scientific, Inc., Piscataway, USA) with the spindle (no. 3; Ø=14 mm; *l*=21 cm). Shear stress against the increasing shear rates from the lowest value of 0 s^{-1} to 1290 s^{-1}, as well as downwards, was applied. The volume of the beaker was 36 mL. The samples were kept in a thermostatically controlled water bath for about 15 minutes before measurements, in order to attain the desirable temperature of 25˚C. Measurements were done in triplicates for each sample. The shear rate versus shear stress was interpreted using the Rheometric computer program. The values for *n* and *k* were obtained from plots of log shear stress versus log shear rate, according to the power law equation:

$$log\tau = logk + nlog\gamma \quad /3/$$

where τ is the shear stress (Pa); γ is the shear rate (s^{-1}); *n* is the flow behaviour index, and *k* is the consistency coefficient (Pa s^n).

Apparent viscosity (η_{app}) was calculated at 1290 s^{-1} using Newtonian law, in addition to linear least square method for regression analysis.

$$\tau = \eta_{app}\gamma \quad /4/$$

pH determination

pH level of samples was obtained using a pH-meter (HI-2030-edge, Hanna Instruments). Results presented in Table 2 were extracted from Šimunek et al.[17]

Colour changes

Visual colour of juices was measured using Konica Minolta CM 3500-d colorimeter. Data were expressed in CIELAB coordinates (L*, a* and b*). Total colour difference (ΔE) was determined by using the Equation (5):

$$\Delta E = \sqrt{(a^* - a_o^*)^2 + (b - b_o^*)^2 + (L^* - L_o^*)^2} \quad /5/$$

Values for a_o, b_o, L_o were values obtained from the untreated juices and nectars. Degree of difference of hue as the quantitative attribute of colourfulness chroma (C^*_{ab}) was calculated: [18]

$$C^* = \sqrt{a^2 + b^2} \quad /6/$$

The difference in Chroma and lightness value was calculated using equation (7)

$$\Delta C = C^* - C_o^* \quad /7a/$$

$$\Delta L = L^* - L_o^* \quad /7b/$$

Hue difference ΔH was calculated using equation 8: [19]

$$\Delta H = \sqrt{\Delta E^2 - \Delta L^2 + \Delta C^2} \quad /8/$$

Sensory analysis

A trained 10-member panel consisting of researchers from the University of Zagreb participated in the research was used to evaluate the quality of juices. They evaluated the samples for the following sensory characteristics: taste, odour, aroma and colour, Table 4. [1, 2, 16] For taste and aroma 1 was the lowest and 6 was the highest score, while for odour and colour 1 was the lowest and 4 was the highest score. Data obtained from the panellists were processed using one-way analysis of variance (ANOVA). Tukey's HSD post hoc test to distinguish statistical differences between the treatments ($p < 0.05$).

Quality function deployment

HOQ used in this paper is presented in Figure 1 and consists of four key elements: A: demanded quality (WHATs); B: quality characteristics (HOWs); C: relationship matrix (WHAT vs. HOW) and; D: target values obtained during the observed period for different treatments (HOW MUCH). This HOQ was modified in line with research from several authors. [9, 20, 21]

Ranking of predetermined sensory attributes (colour, odour, taste, sweetness, sourness, fruity taste, viscosity) from the field research was used as inputs for defining weight importance of these quality characteristics. W_i is the weight importance of the 'i' demanded quality characteristics identified by the consumers. Relative weight is the percentage of the weight importance divided by the sum of all weight importance, equation 9.

$$RW_i = \frac{W_i}{\sum_i^n W_i} * 100\ [\%] \qquad /9/$$

Ten quality characteristics (HOWs) used in the matrix were the characteristics identified as rheological parameters (viscosity, consistency coefficient, flow index), colour changes (ΔE, ΔH) sensory properties (taste, flavour, odour, colour) and pH. Relationships between the WHATs and HOWs in order to identify important product properties were performed using the scale consisting of '0', '1', '3' and '9', where '9' indicates a very strong relationship, '3' strong, '1' weak, and '0' none. [9, 14] Absolute weight importance was calculated using equation 10:

$$AW_j = \sum_{i=1}^n RW_i * RS_{ij} \qquad /10/$$

Where:

RW_i is the relative weight (WHATs) of 'i' demanded quality characteristic (n – number of demanded quality characteristics).

RS_{ij} is the relationship score (WHATs vs. HOWs) between demanded quality characteristic 'i' and product quality characteristics 'j' (m – number of product quality characteristics).

Based on the absolute importance, the relative absolute weight importance (RAW) was calculated. [9] Target values were defined either as max/min theoretical values and/or from results obtained by measuring the juices/nectars with no treatment.

After defining the HOQ and calculating weight importance (W), absolute weight importance (AW) as well as their relative absolute weights (RAW), the final step was to evaluate each of the treatments. Results for each product quality characteristic were ranked by comparing the results between the samples and treatments. Depending on the results ranks were from 16 'the best result' to 1 'the worst result'. These ranks were multiplied by RAW. The final 'Quality Score' was calculated as presented in equation 11:

$$QS_k = \sum_{j=1}^{m} RAW_j * RA_{jk} \qquad /11/$$

Where:

RAW_j is the relative absolute weight importance of product quality characteristics 'j'

RA_{jk} is the rank of product quality characteristics 'j' of the treatment type 'k'

QS_k is the final 'Quality Score' of treatment type 'k'. Semantic differential chart were used to visualize the competitive evaluation of the ultrasound treatments for two types of fruit beverages. This method enables comparison of ultrasound treatments taking into account all quality characteristics.

RESULTS AND DISCUSSION

Field research

The sample comprises 66.7% women and 33.3% men. With regard to age, highest per cent of the respondents (70.8%) were below 24 years old. The predominant interviewees were students (56.4%) and higher educated population (31.8%).

Figure 2 presents the distance between attribute ranks showing that overall flavour and fruit taste obtained the highest rank sums and are overall considered as the most important sensory / quality characteristic. This information was included within demanded quality characteristics (WHATs) in QFD.

Quality function deployment

Upon completion of the field research and laboratory testing of apple juices and nectars treated with ultrasound, the next step was to complete the HOQ and establish absolute and relative importance of each quality characteristic. Figure 3 presents the relative and absolute importance of the quality characteristics for juices / nectars. The three most important characteristics are 'taste' and 'aroma' with 28.5% of RAW, followed by 'odour' (16.9%).

From the results in Tables 2, 3, and 4, one can observe non-significant differences in rheological properties of ultrasound treated samples compared to untreated. The sugar composition and ultrasound processing procedures for juices and nectars are likely factors that can explain the small differences in rheological properties. [17] On the other hand there are significant differences in colour of ultrasound treated apple juice A1.11 (amplitude 120µm, 9min treatment time and the sample temperature of 20°C) with highest differences in total colour difference (ΔE) and A1.2 (amplitude 60µm, 9min treatment time and the sample temperature of 60°C) with highest hue difference (ΔH). For apple nectar having highest differences in total colour difference (ΔE) A2.15 (amplitude 90µm, 9min treatment time and the sample temperature of 40°C) and A2.12 with highest hue difference (ΔH) (amplitude 60µm, 3min treatment time and the sample temperature of 20°C).

For sensory values, statistically significant differences for sensory properties are for A1.11 (amplitude 120µm, 9min treatment time and the sample temperature of 20°C) for taste difference and A1.15 (amplitude 90µm, 9min treatment time and the sample temperature of 40°C) for aroma values. Deterioration effect (sensorial) is most often higher if ultrasound amplitude is higher and treatment time is longer. [2, 16] Odour values are better for A1.5 (amplitude 120µm, 6min treatment time and the sample temperature of 40°C) than for untreated one. Sample A1.10 (amplitude 60µm, 6min treatment time and the sample temperature of 40°C) was found to be with least difference. Ultrasound processing of juices is reported to have a minimal effect on the degradation of key quality parameters such as colour and anthocyanin content in strawberry and blackberry juices. [22, 23] Sonication is also reported to enhance cloud stability of juice. [24]

For nectar, highest values compared to untreated sample and for taste were A2.11 (amplitude 120µm, 9min treatment time and the sample temperature of 20°C) and for aroma A2.1 (amplitude 90µm, 6min treatment time and the sample temperature of 60°C). For values of colour and odour for ultrasound treatments compared to untreated, there was no significant difference. Sample A2.6 (amplitude 120µm, 3min treatment time and the sample temperature of 20°C) was found to be with least "changes".

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Final step was to rank the data for selected quality characteristics multiplying them by RAW and defining the final 'Quality Score' of juices and nectars. Figure 4 presents semantic differential chart with the following rule applied: the higher the values the better the final 'Quality Score'.

Top three apple juice treatments were A1.15 (amplitude 90µm, 9min treatment time and the sample temperature of 40°C), A1.2 (amplitude 60µm, 9min treatment time and the sample temperature of 60°C) and A1.4 (amplitude 90µm, 6min treatment time and the sample temperature of 40°C). Worst score was obtained with treatment A1.10 (amplitude 60µm, 6min treatment time and the sample temperature of 60°C). During ultrasound treatment cavities formed by sonication may be filled with water vapour and gases dissolved in the juice, such as O_2 and N_2, which may be responsible for oxidative degradation of juice (that influence quality of juice). [25-27] Several chemical reactions occur, like pyrolysis of water, oxidative species, reactive oxidative species and reactive nitrogen species reactions. [28, 29] Degradation/changes of chemical molecules during ultrasonic processing could be related to oxidation reactions, promoted by the interaction of free radicals such as hydroxyl (·OH) formed during sonication following the reaction ($H_2O \rightarrow \cdot OH + H\cdot$). [30-32] An example is degradation of anthocyanins, [22] chemical decomposition by opening of rings and formation of chalcone. Sonication results in a modification of macromolecular structures and a decrease of molecular weight. 33 Also, it is known that phenol degradation is favoured at high frequencies. 34 However, some researches indicate lower level of degradation of polyphenols when ultrasound is used for extraction. 35

The effect of ultrasound on fruit juices is mainly been attributed to physical (cavitation, mechanical effects or micromechanical shocks) and/or chemical changes due to formation of free radicals (H* and OH* due to sonochemical reaction) formed by the decomposition of water inside the oscillating bubbles. 36 There have been demonstrated detrimental effects on the quality or nutritional parameters including ascorbic acid content in fruit juices, anthocyanin content in strawberry and blackberry juices. This positive effect of ultrasound is assumed to be due to the effective removal of occluded oxygen from the juice. Several studies show that high ultrasonic power causes major alterations in materials by inducing greater shear forces (depending on the nature and properties of the medium). An increase of temperature results in a decrease of both viscosity and surface tension, and induces an increase of vapour pressure. A rise in vapour pressure causes more solvent vapours to enter the bubble cavity and numerous cavitation bubbles, which will collapse less violently and reduce sonication effects.

For nectars, top three were treatments A2.11 (amplitude 120µm, 9min treatment time and the sample temperature of 20°C), A2.2 (amplitude 60µm, 9min treatment time and the sample temperature of 60°C) and A2.16 (amplitude 60µm, 9min treatment time and the sample temperature of 20°C), while worst treatment was A2.15 (amplitude 90µm, 9min treatment time and the sample temperature of 40°C). The major reaction path for the degradation of polar compounds is pyrolysis within cavitation bubbles in the liquid or gas pockets trapped in the crevices of the solid boundaries in the liquid medium. [26] Some authors have suggested that the efficacy of ultrasonic treatment and cavitational effects could be minimised with an increase in temperature. [37, 38] An increased thermal effect results as a masque effect of sonication, and/or a decrease of the violence of implosion due to the increased vapour pressure at higher temperatures. 39-41

The potential of high power ultrasound is also its “green and innovative” dimension since it involves less time, water and energy. 42 There is an increasing interest in novel technologies not only in terms of improved quality, but also to reduce the environmental footprint of food and production costs. 43

CONCLUSION

This study suggests that QFD has a potential in analysing high power ultrasound treated fruit beverages. It enables merging consumer research of the seven most important sensory attributes, and possibility to transfer these demanded quality characteristics to ten measurable product characteristics.

High power ultrasound processing can be optimised in order to assure preservation effect of apple beverages, but also to retain their sensory and quality properties. Consumers have pointed that the most important characteristics are 'overall flavour and 'fruit taste', followed by 'odour'.

From the analysis of ultrasound treated apple juices and nectars, non-significant differences in rheological properties of ultrasound treated samples compared to untreated were found. On the other hand there are significant differences in colour of ultrasound treated apple juice A1.11 (amplitude 120µm, 9min treatment time and the sample temperature of 20°C) with highest differences in total colour difference (ΔE). For apple nectar, highest differences in total colour difference (ΔE) were observed for A2.15 (90µm, 9min, 40°C). Statistically significant differences for sensory properties were found for A1.11 (120µm/9min/20°C). For nectars, the highest values compared to untreated sample for taste are for sample A2.11 (120µm/9min/20°C). 'Quality Score' of juices and nectars scaled top three apple juice treatments as A1.15 (90µm/9min 40°C), A1.2 (60µm/9min/60°C) and A1.4 (90µm/6min/40°C). Worst score was obtained with treatment A1.10 (60µm/6min/60°C). For nectars, 'Quality Score' defined top three treatments A2.11 (120µm/ 9min/20°C), A2.2 (60µm/9min/60°C) and A2.16 (60µm/9min/20°C), while worst treatment was A2.15 (90µm/9min/40°C).

This type of quality models enables a more complex measure of large scale of different quality parameters. Its simplicity should be understood as its practical advantage and as such, this tool can be a part of design quality when using novel preservation technologies. Development of specific QFD models for beverages and novel technologies could be a research challenge in the future.

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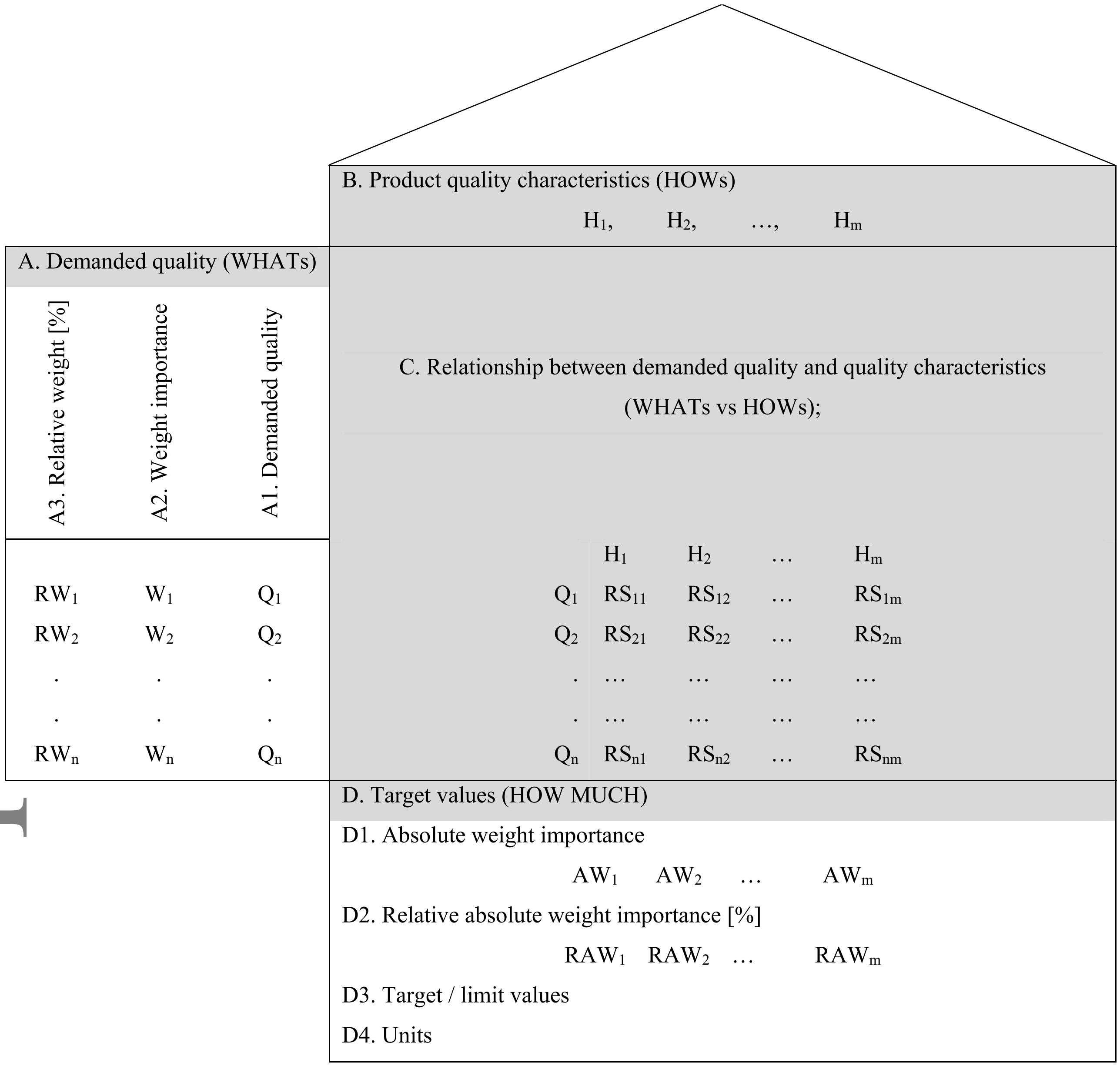

Figure 1. House of quality (HOQ), modified from [9,20,21]
Legend: W1 – Viscosity; W2 – Overall flavor; W3 – Sourness; W4 – Sweetness; W5 - Odor; W6 – Fruit taste ; W7 – Color. H1 – Total color difference (ΔE); H2 – Hue difference (ΔH); H3 – Taste; H4 – Color; H5 – Taste ; H6 – Odor; H7 – Viscosity; H8 – Consistency; H9 – Flow index; H10 – pH.

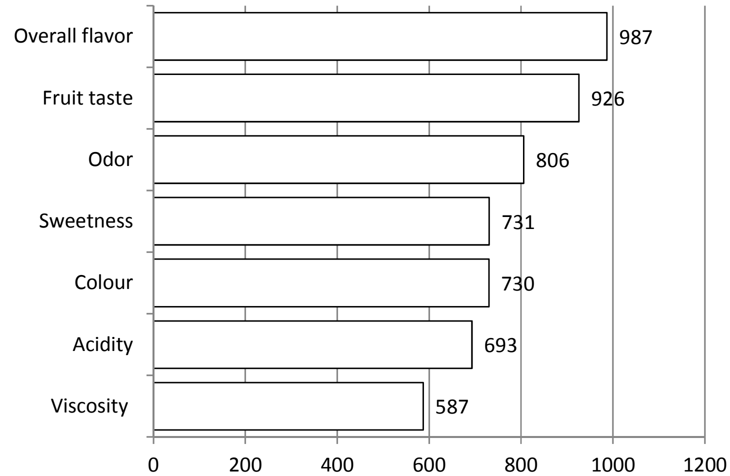

Figure 2. Rank sums of sensory attributes.
Legend: Respondents ranked seven basic sensory/quality characteristics (color, odor, overall flavor, sweetness, sourness, fruit taste, viscosity) from 7 ‘the most important’ to 1 ‘the least important’. Ranks sums shows rank order and distance between attribute ranks (N = 195).

Weight			Color		Sensory attributes				Other quality parameters			
Relative weight - RW [%]	Weight importance - W	Quality characteristics (HOWs) / Demanded quality (WHATs)	Total color difference (ΔE)	Hue difference (ΔH)	Taste	Color	Aroma	Odor	Viscosity	Consistency	Flow index	pH value
3.57%	1	Viscosity							●	⊙	●	
25.00%	7	Overall flavor			●		●	⊙		⊙		
7.14%	2	Acidity			⊙		⊙	○				●
14.29%	4	Sweetness			⊙		⊙	○				
17.86%	5	Odor			⊙		⊙	●				
21.43%	6	Fruit taste			●		●	⊙				
10.71%	3	Color	●	●		●						
Absolute weight importance			0.96	0.96	5.36	0.96	5.36	3.21	0.32	0.86	0.32	0.64
Relative absolute weight importance [%]			5.1%	5.1%	28.2%	5.1%	28.2%	16.9%	1.7%	4.5%	1.7%	3.4%
Target / Limit values			≤ 2	≤ 2	6	4	6	4	6	2.692	1.754	3.57
Unit			Lab scale		Hedonic scale				μ (mPas)	k(Pas^n) x10^{-5}	n	

Figure 3. House of quality for apple juice and nectar
Legend: ● ‘strong relationship’ = 9, ⊙ ‘moderate’ = 3, ○ ‘weak relationship’ = 1 and blank = ‘non-existent’ or ‘zero’

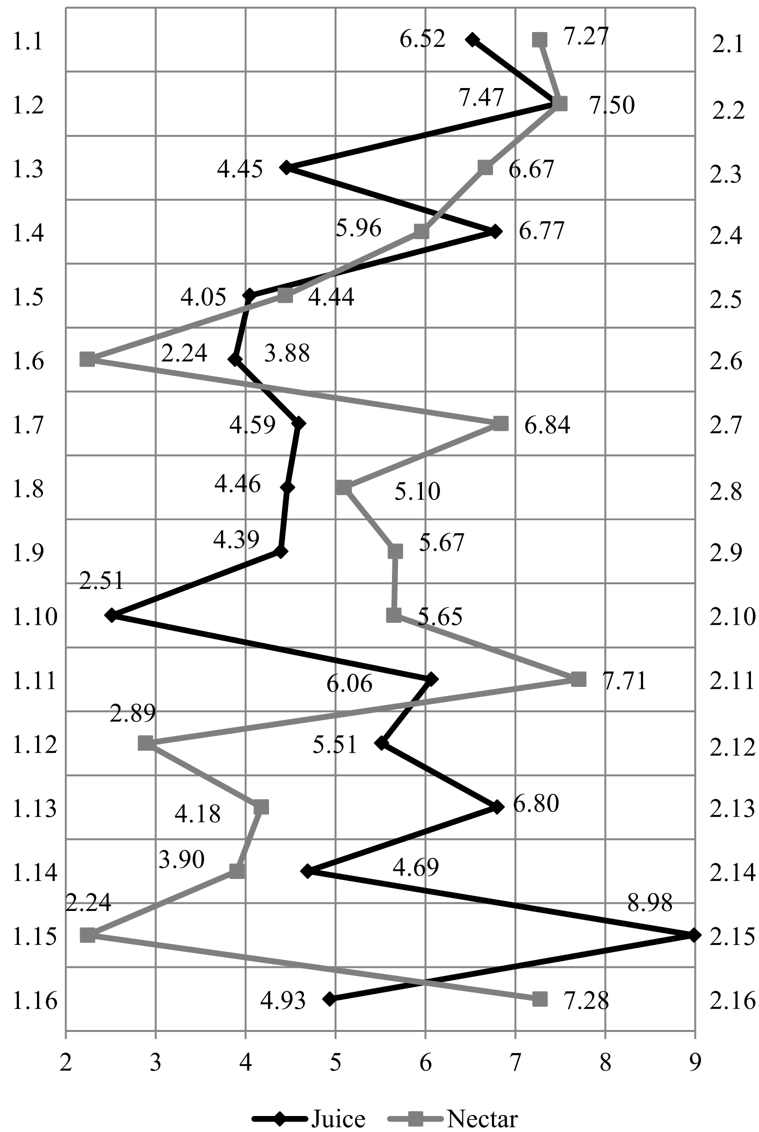

Figure 4. Semantic differential chart of final 'Quality Score' of apple juice and nectar.

Legend: „1“ (juice) and „2“ (nectar) ; „1.1 – 1.16“ and „2.1 – 2.16“ – ultrasound treated samples.
Rule of the thumb: the higher the values the better the final 'Quality Score'

Table 1. Ultrasound treatment of juices and nectars

Samples		Treatment	Amplitude (µm)	Temperature (°C)	Treatment time (min)
Juices	Nectars				
A1.0	A2.0	Untreated	-------	-------	-------
A1.1	A2.1	ultrasound treatment	90	60	6
A1.2	A2.2	ultrasound treatment	60	60	9
A1.3	A2.3	ultrasound treatment	90	40	3
A1.4	A2.4	ultrasound treatment	90	40	6
A1.5	A2.5	ultrasound treatment	120	40	6
A1.6	A2.6	ultrasound treatment	120	20	3
A1.7	A2.7	ultrasound treatment	120	60	3
A1.8	A2.8	ultrasound treatment	90	40	6
A1.9	A2.9	ultrasound treatment	60	60	3
A1.10	A2.10	ultrasound treatment	60	40	6
A1.11	A2.11	ultrasound treatment	120	20	9
A1.12	A2.12	ultrasound treatment	60	20	3
A1.13	A2.13	ultrasound treatment	90	20	6
A1.14	A2.14	ultrasound treatment	120	60	9
A1.15	A2.15	ultrasound treatment	90	40	9
A1.16	A2.16	ultrasound treatment	60	20	9

Legend: „1.0“ (juice) and „2.0“ (nectar) – untreated samples; „1.1 – 1.16“ and „2.1 – 2.16“ – ultrasound treated samples, A – apple

Table 2. The effects of ultrasound treatment on rheological properties and pH of juices and nectars

	Viscosity Apparent viscosity μ **(mPa s)****	**Consistency coefficient** k **(Pa s^n) x10^{-5}**	**Flow index** n	**pH**		**Viscosity Apparent viscosity** μ **(mPa s)****	**Consistency coefficient** k **(Pa s^n) x10^{-5}**	**Flow index** n	**pH**
A1.0	6.00±0.09 ^{a}	2.31±0.02 ^{a}	1.80±0.03 ^{a}	3.56	A2.0	6.00±0.01 ^{a}	1.60±0.03 ^{a}	1.81±0.03 ^{a}	3.13
A1.1	5.00±0.08 ^{a}	2.27±0.03 ^{a}	1.77±0.02 ^{a}	3.55	A2.1	5.00±0.02 ^{a}	1.59±0.02 ^{a}	1.82±0.02 ^{a}	3.13
A1.2	5.00±0.05 ^{a}	1.67±0.04 ^{b}	1.81±0.02 ^{a}	3.57	A2.2	6.00±0.01 ^{a}	1.69±0.01 ^{a}	1.81±0.01 ^{a}	3.13
A1.3	5.00±0.04 ^{a}	1.33±0.05 ^{b}	1.84±0.01 ^{a}	3.55	A2.3	5.00±0.03 ^{a}	1.31±0.02 ^{a}	1.84±0.01 ^{a}	3.13
A1.4	6.00±0.03 ^{a}	1.63±0.06 ^{b}	1.81±0.02 ^{a}	3.55	A2.4	5.00±0.04 ^{a}	1.39±0.01 ^{a}	1.83±0.01 ^{a}	3.14
A1.5	6.00±0.04 ^{a}	3.06±0.04 ^{b}	1.73±0.05 ^{a}	3.55	A2.5	6.00±0.04 ^{a}	1.88±0.04 ^{a}	1.80±0.01 ^{a}	3.13
A1.6	6.00±0.02 ^{a}	3.35±0.05 ^{b}	1.72±0.04 ^{a}	3.55	A2.6	5.00±0.04 ^{a}	3.14±0.01 ^{b}	1.72±0.02 ^{a}	3.13
A1.7	5.00±0.04 ^{a}	1.25±0.04 ^{b}	1.85±0.02 ^{a}	3.56	A2.7	6.00±0.02 ^{a}	1.11±0.04 ^{a}	1.87±0.02 ^{a}	3.13
A1.8	6.00±0.04 ^{a}	1.96±0.05 ^{b}	1.79±0.01 ^{a}	3.55	A2.8	6.00±0.02 ^{a}	1.25±0.04 ^{a}	1.86±0.02 ^{a}	3.15
A1.9	5.00±0.07 ^{a}	1.03±0.01 ^{b}	1.88±0.03 ^{a}	3.55	A2.9	5.00±0.02 ^{a}	2.82±0.04 ^{b}	1.73±0.03 ^{a}	3.13
A1.10	5.00±0.06 ^{a}	1.75±0.06 ^{b}	1.81±0.03 ^{a}	3.55	A2.10	6.00±0.03 ^{a}	2.33±0.03 ^{b}	1.76±0.04 ^{a}	3.13
A1.11	6.00±0.02 ^{a}	1.61±0.04 ^{b}	1.82±0.02 ^{a}	3.55	A2.11	6.00±0.04 ^{a}	1.18±0.02 ^{a}	1.86±0.02 ^{a}	3.14
A1.12	6.00±0.03 ^{a}	3.85±0.03 ^{b}	1.70±0.04 ^{a}	3.55	A2.12	5.00±0.04 ^{a}	1.78±0.02 ^{a}	1.80±0.02 ^{a}	3.13
A1.13	6.00±0.01 ^{a}	2.81±0.05 ^{b}	1.75±0.02 ^{a}	3.55	A2.13	6.00±0.02 ^{a}	1.03±0.02 ^{a}	1.88±0.03 ^{a}	3.14
A1.14	6.00±0.01 ^{a}	2.16±0.04 ^{b}	1.78±0.02 ^{a}	3.55	A2.14	5.00±0.02 ^{a}	1.55±0.01 ^{a}	1.82±0.04 ^{a}	3.13
A1.15	6.00±0.01 ^{a}	2.32±0.04 ^{a}	1.77±0.02 ^{a}	3.55	A2.15	6.00±0.01 ^{a}	1.93±0.01 ^{a}	1.79±0.02 ^{a}	3.13
A1.16	6.00±0.02 ^{a}	2.86±0.04 ^{b}	1.74±0.02 ^{a}	3.55	A2.16	5.00±0.01 ^{a}	1.29±0.01 ^{a}	1.85±0.02 ^{a}	3.15

Legend: „1.0“ (juice) and „2.0“ (nectar) – untreated samples; „1.1 – 1.16“ and „2.1 – 2.16“ – ultrasound treated samples, A – apple.
Means of three replications ± standard deviation. Means in the same column with different small letters are significantly different ($p<0.05$)

Table 3. The effects of ultrasound treatment on the color properties of juices and nectars

	ΔE	ΔH		ΔE	ΔH
A1.0			A2.0		
A1.1	4.32±0.03 [a]	5.95±0.01 [a]	A2.1	0.49±0.04 [a]	0.64±0.02 [a]
A1.2	4.48±0.02 [a]	6.11±0.01 [a]	A2.2	2.93±0.04 [b]	4.02±0.02 [b]
A1.3	3.54±0.01 [b]	4.94±0.01 [b]	A2.3	0.47±0.03 [a]	0.62±0.02 [a]
A1.4	3.71±0.02 [b]	5.01±0.03 [b]	A2.4	0.21±0.04 [a]	0.17±0.03 [a]
A1.5	0.98±0.02 [b]	1.35±0.03 [b]	A2.5	2.92±0.05 [b]	4.01±0.03 [b]
A1.6	3.83±0.03 [a]	5.33±0.03 [a]	A2.6	2.97±0.06 [b]	4.10±0.03 [b]
A1.7	0.80±0.03 [b]	1.05±0.06 [b]	A2.7	2.18±0.06 [b]	3.01±0.04 [b]
A1.8	1.16±0.04 [b]	1.49±0.03 [b]	A2.8	2.74±0.06 [b]	3.77±0.04 [b]
A1.9	1.04±0.04 [b]	1.46±0.06 [b]	A2.9	0.20±0.07 [a]	0.20±0.04 [a]
A1.10	2.48±0.04 [b]	2.78±0.03 [b]	A2.10	2.94±0.06 [b]	4.04±0.03 [b]
A1.11	0.27±0.03 [b]	0.25±0.06 [b]	A2.11	2.84±0.05 [b]	3.77±0.03 [b]
A1.12	0.89±0.03 [b]	1.21±0.03 [b]	A2.12	3.32±0.06 [b]	4.52±0.04 [b]
A1.13	2.28±0.02 [b]	3.17±0.04 [b]	A2.13	3.10±0.03 [b]	4.26±0.05 [b]
A1.14	4.19±0.02 [a]	5.50±0.03 [a]	A2.14	3.04±0.02 [b]	4.17±0.03 [b]
A1.15	1.13±0.02 [b]	1.45±0.05 [b]	A2.15	3.36±0.02 [b]	4.37±0.04 [b]
A1.16	3.37±0.03 [b]	4.66±0.03 [b]	A2.16	2.95±0.02 [b]	4.03±0.05 [b]

Legend: „1.0“ (juice) and „2.0“ (nectar) – untreated samples; „1.1 – 1.16“ and „2.1 – 2.16“ – ultrasound treated samples, A – apple.
Means of three replications ± standard deviation. Means in the same column with different small letters are significantly different ($p<0.05$)

Table 4 – The effects of ultrasound treatment on the sensory properties of juices and nectars

	Taste	Color	Aroma	Odor		Taste	Color	Aroma	Odor
A1.0	5.10±0.03 [a]	3.60±0.02 [a]	5.20±0.05 [a]	3.45±0.05 [a]	A2.0	4.90±0.02 [a]	3.50±0.05 [a]	4.70±0.06 [a]	3.50±0.05 [a]
A1.1	3.90±0.02 [b]	3.80±0.03 [a]	4.20±0.04 [b]	3.25±0.04 [a]	A2.1	4.55±0.05 [a]	3.50±0.04 [a]	3.95±0.05 [b]	3.40±0.04 [a]
A1.2	3.90±0.03 [b]	3.60±0.03 [a]	3.90±0.04 [b]	3.15±0.03 [b]	A2.2	4.25±0.04 [a]	3.30±0.04 [a]	4.15±0.04 [b]	3.20±0.05 [a]
A1.3	4.60±0.04 [a]	3.40±0.02 [a]	4.50±0.02 [a]	3.25±0.06 [a]	A2.3	4.55±0.05 [a]	3.50±0.03 [a]	4.05±0.02 [b]	3.65±0.06 [a]
A1.4	4.10±0.03 [b]	3.70±0.03 [a]	3.80±0.03 [b]	3.40±0.05 [a]	A2.4	4.45±0.03 [a]	3.40±0.02 [a]	4.35±0.03 [a]	3.65±0.06 [a]
A1.5	4.40±0.02 [b]	3.80±0.03 [a]	4.50±0.04 [a]	3.90±0.06 [b]	A2.5	4.70±0.06 [a]	3.40±0.04 [a]	4.40±0.04 [a]	3.35±0.05 [a]
A1.6	4.60±0.03 [a]	3.60±0.05 [a]	4.30±0.04 [a]	3.40±0.07 [a]	A2.6	4.85±0.07 [a]	3.30±0.03 [a]	4.95±0.05 [a]	3.45±0.04 [a]
A1.7	4.60±0.03 [a]	3.80±0.06 [a]	4.60±0.03 [a]	3.35±0.02 [a]	A2.7	4.55±0.07 [a]	3.50±0.04 [a]	4.25±0.06 [a]	3.30±0.03 [a]
A1.8	4.50±0.03 [a]	3.60±0.01 [a]	4.60±0.02 [a]	3.30±0.03 [a]	A2.8	4.65±0.06 [a]	3.60±0.04 [a]	4.35±0.07 [a]	3.40±0.04 [a]
A1.9	4.60±0.03 [a]	3.40±0.04 [a]	4.50±0.01 [a]	3.50±0.04 [a]	A2.9	4.65±0.07 [a]	3.60±0.05 [a]	4.35±0.07 [a]	3.30±0.05 [a]
A1.10	4.70±0.01 [a]	3.90±0.04 [a]	4.70±0.02 [a]	3.65±0.03 [a]	A2.10	4.65±0.04 [a]	3.30±0.03 [a]	4.25±0.07 [a]	3.25±0.06 [a]
A1.11	4.40±0.01 [b]	3.80±0.02 [a]	4.60±0.02 [a]	3.10±0.04 [b]	A2.11	4.15±0.06 [b]	3.50±0.05 [a]	4.15±0.05 [b]	3.30±0.07 [a]
A1.12	4.40±0.02 [b]	3.60±0.03 [a]	4.40±0.01 [a]	3.30±0.04 [a]	A2.12	4.75±0.07 [a]	3.60±0.04 [a]	4.45±0.03 [a]	3.40±0.07 [a]
A1.13	4.20±0.01 [b]	3.60±0.04 [a]	4.10±0.03 [b]	3.20±0.02 [a]	A2.13	4.75±0.07 [a]	3.60±0.05 [a]	4.35±0.06 [a]	3.30±0.07 [a]
A1.14	4.30±0.02 [b]	3.70±0.01 [a]	4.20±0.05 [b]	3.55±0.03 [a]	A2.14	4.75±0.05 [a]	3.60±0.06 [a]	4.45±0.02 [a]	3.20±0.08 [a]
A1.15	4.00±0.01 [b]	3.70±0.01 [a]	3.00±0.06 [b]	2.90±0.03 [b]	A2.15	4.75±0.04 [a]	3.50±0.07 [a]	4.55±0.04 [a]	3.55±0.09 [a]
A1.16	4.30±0.02 [b]	3.80±0.02 [a]	4.50±0.05 [b]	3.25±0.02 [a]	A2.16	4.60±0.03 [a]	3.50±0.07 [a]	4.30±0.03 [a]	3.10±0.08 [a]

Legend: „1.0“ (juice) and „2.0“ (nectar) – untreated samples; „1.1 – 1.16“ and „2.1 – 2.16“ – ultrasound treated samples, A – apple.