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Impact of long-term storage on the quality of selected sugar-based foods stored at different temperatures

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ABSTRACT

The aim of the presented study was to evaluate the microbiological, chemical, physical and organoleptic properties of sugar-based foods (apricot-apple jam, flower meadow honey, sweetened hazelnut cocoa spread) stored at four different temperatures (−18, 5, 23 and 40 °C) for a period of 24 months. In addition, critical combinations of storage temperature and time were determined for maintaining food quality and food safety. Storage of all samples ≤23 °C appeared to be safe from a microbiology perspective, while in the case of storage at 40 °C it was not recommended to exceed a storage period of 6 or 12 months. The pH-values decreased and the dry matter, ammonia, TBARS content increased most intensively during the first 6 months of storage ($P < 0.05$). The amino acid content of sweetened hazelnut cocoa spread decreased significantly at 40 °C ($P < 0.05$). With the prolonged storage time, the organoleptic properties of the samples deteriorated. The changes were more intensive when an elevated storage temperature was used ($P < 0.05$). Moreover, under the above-mentioned conditions a marginal decrease of the total saccharide content in all samples was observed. In addition, the apparent viscosity of the honey and the firmness of the jam increased significantly at elevated temperatures of 40 °C ($P < 0.05$).

1. Introduction

Recently, the mankind is exposed to unexpected events (e.g. floods, earthquakes, fires, war, diseases) requiring new approaches for solving these incidences. Natural and anthropogenic crisis situations including wars and/or humanitarian crisis have world widely threatened our existence. Soldiers and personnel of governmental and/or non-governmental organizations are dispatched in the regions where crisis occurs. Feeding of the latter staff belongs to the most important logistic services that should be provided. The humanitarian and/or military operations have been governed in differing climatic zones (from arctic to tropic), where food should be transported. Additionally, the missions could take place also in temperate zones where the situation could be so specific and critical that freeze and/or chill chains (working under normal conditions) are not available. Moreover, the transportation (e.g. via ships) could be realised through various climatic zones and could last for several weeks. In all of the above-mentioned situations, microbiologically stable food should be used because during transportation and subsequent storage, the stock temperatures could be elevated above 25 °C, and foodstuffs might be stored at these temperatures for several months (Bubelová et al., 2017; Foltin, Brunclík, Ondryhal, & Vogal, 2018; Kadidlová, Ciprysová, Hoza, & Budinský, 2010; Tulach & Foltin, 2019).

Sugar-based foods such as jams, honey and/or some nut-based spreads world widely belong to the traditional food and consumers consider them as a part of their daily diet. The latter foodstuffs could evoke "*the feeling of home*" and contribute to the psychological balance of people. Therefore, it is very important to include those types of food into feeding of soldiers and/or members of rescue team units during missions which generally take place far from their home-countries. Additionally,

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jams, honey and nut-based spreads possess long shelf-life and without any doubt are appropriate for long-term storage. Therefore, the above-mentioned products have been included in the military combat rations and also in the state reserves of many countries (including also members the North Atlantic Treaty Organization – NATO) where are stored 24 months (or longer) at ambient temperature. The above-mentioned products represent also common articles of the food industry which are beneficial from the point of view of economic and logistic systems (Bubelová et al., 2017; Tulach & Foltin, 2019).

The temperature of 25 °C is assumed as "the ambient temperature" for the temperate climate zone at which many long shelf-life foods could be stored, and for which the producers declare insignificant changes during storage that generally could last up to 3 years (e.g. for canned food) according to (Regulation EU No 1169/2011, 2011). For long-term storage at elevated temperatures (above 25 °C), there is practically no information about possible quality and safety changes neither in literature nor from producers. Moreover, the latter changes occurring during long-term storage at elevated temperature could represent serious health risk for consumers (especially due to chemical interactions and microbiological changes – see below).

Jam is a food-matrix prepared by cooking fruit pulp with sugar, pectin, acid and other ingredients (preservatives, food colours and flavourings). The resulting consistency should be thick and firm enough to hold the fruit tissues in place (Basu, Shivhare, Singh, & Beniwal, 2011). Evaluation of the physicochemical and/or organoleptic properties of jams during storage were previously documented (Castelló, Heredia, Domínguez, Ortolá, & Tarrazó, 2011; Chauhan, Archana, Singh, Raju, & Bawa, 2013; Peinado, Rosa, Heredia, Escriche, & Andrés, 2016; Touati, Tarazona, Aguayo, & Louaileche, 2014). However, the storage period only lasted 6 months at the most.

Honey (*Apis mellifera* honey) is a natural food primarily composed of saccharides (fructose and glucose); other minor components are proteins, vitamins, free amino acids, trace minerals and other bioactive substances presenting antioxidant activity. However, its high sugar content (above 75 g/100 g) and average water activity below 0.60 make honey an unsuitable environment for the microorganism survival (with the exception of osmotic kinds of yeasts) as documented by Vorlová, Karpíšková, Chabinioková, Kalábová, and Brázdová (2018). Based on geographical origin, the chemical composition and overall acceptability of honey can vary significantly (Tomczyk, Tarapatsky, & Džugan, 2019). Temperature and humidity can both additionally affect the most important physical properties of honey, including its viscosity and crystallization. Therefore, various scientists have studied the viscosity of honey as a function of temperature at specific moisture content and/or botanical origin (Escuredo, Dobre, Fernández-González, & Seijo, 2014; Gómez-Díaz, Navara, & Quintáns-Rivero, 2009; Pan and Ji, 1998; Yanniotis, Skaltsi, & Karaburnioti, 2006). The significant effect of different heat treatments on physicochemical, colour and antioxidant activity of honey were highlighted also by Karabagias, Karabagias, and Gatzias (2018).

Sweetened hazelnut cocoa spread can be defined as a mixture of saccharides, hazelnuts, skimmed milk powder, demineralised whey powder and lecithin in a continuous phase of palm oil (Peng et al., 2015). It can be expected, due to the amount of lipids and proteins, that oxidation, hydrolysis and other phenomena may occur during storage (Gan et al., 2016; Raeisi, Sharifi-Rad, Quek, Shabanpour, & Sharifi-Rad, 2016).

On the whole, even with the best preservation method, each food has a limited shelf life from the point of view of microbiology, chemistry and/or organoleptic parameters determination. Thus, the overall deterioration of nutritional quality, increased rancidity (in a case of high fat content such as hazelnut spread) and changes in colour and texture can be expected during storage (Bubelová et al., 2017; Kristensen & Skibsted, 1999). Furthermore, Maillard reactions and Strecker degradation of amino acids in sweetened hazelnut cocoa spread can also be expected, as well as ammonia as a by-product of these reactions as documented by Kristensen, Hansen, Arndal, Trinderup, and Skibsted (2001); Zorić, Pelaić, Pedisić, Garofulić, Kovačević, & Dragović-Uzelac (2017). In addition, the currently available literature is poor in reference to long-term experiments focusing on a wider range of different foods-matrices and temperatures. In general, the limiting factor of monitoring changes in long-term storage experiments is the relative high cost. Short-term experiments (i.e., weeks up to 3 months) (Gonzales, Burin, & Buera, 1999; Touati, Tarazona-Díaz, Aguayo, & Louaileche, 2014), or "accelerated tests" (during which it is not possible to provide accurate results depicting real changes during storage at different temperatures), are thereby mostly performed.

The aim of this study was to evaluate the microbiological, chemical, rheological and organoleptic changes of selected sugar-based foods during a 2-year storage period at −18, 5, 23 and 40 °C, respectively, in order to determine whether these foods are suitable for the usage and the feeding under specific situation (crisis situations, humanitarian and/or military operations) when the chill chain is not available and the transportation and storage are carried out at elevated temperature. Jam, honey and sweetened hazelnut cocoa spread were selected because they belong to generally accepted foodstuffs for a wide range of consumers over the whole world. For this study, were selected three model samples which represent and cover the main portfolio of the sugar-based product foodstuff group. Additionally, these foodstuffs are microbiologically stable and therefore, suitable for long-term storage. On the other hand, information about chemical stability is missing and therefore, the potential health risks of the above-mentioned model foodstuffs for consumers should be pointed out. The results of this study can provide credible data about the critical combinations of the temperature and the storage time that still ensure food safety of selected sugar-based products. The conclusions of our study could be useful for the food industry and retail but also for the governments and other organizations supporting operational units during local and/or foreign missions.

2. Materials and methods

2.1. Samples and storage conditions

For this study, the following saccharide-based foods were used: (i) apricot-apple jam [**AAJ**; Hamé Ltd., Czech Republic, nutrition declaration from the packaging (per 100 g): carbohydrate 69.4 g, of which sugars 68.7 g, protein 0.2 g, fat 0.1 g; ingredients: sugars, apricots (30 g/100 g by weight), apples (20 g/100 g by weight), acidity regulator: citric acid, gelling agent: pectin, colorant: beta-carotene, aroma, antioxidant: ascorbic acid]; (ii) flower meadow honey [**FMH**; Medokomerc s. r. o., Czech Republic, nutrition declaration from the packaging (per 100 g): carbohydrate 81.7 g, of which sugars 81.7 g, protein 0.3 g, fat 0 g]; (iii) sweetened hazelnut cocoa spread [**SHCS**; Ferrero S.p.a., Italy, nutritional declaration from the packaging (per 100 g): carbohydrate 57.6 g, of which sugars 56.8 g, protein 6 g, fat 31.6 g, of which saturates 11.0 g; ingredients: sugars, palm oil, hazelnuts (13 g/100 g), low fat cocoa powder (7.4 g/100 g), skimmed milk powder (6.6 g/100 g), whey powder (milk), emulsifier: soy lecithin, vanillin]. One hundred and ninety pieces originated from the same batch were obtained as single-serving plastic packages sealed with aluminium (20 g for AAJ and FMH; 15 g for SHCS). The three independent batches of AAJ, FMH and SHCS were purchased in the retail in the Czech Republic. For each analysis, minimal three packages were sampled. The minimal durability declared by manufacturers was 18 months and 12 months for AAJ and FMH (recommended temperature up to 25 °C), respectively. In the case of SHCS, the use by date was at the level of 12 months. In all samples tested, the possibility of shelf-life extension was also studied.

The storage experiment was conceived to represent 3 different climatic zones (arctic, temperate, tropic). The samples were then stored in a freezer (−18 ± 2 °C; simulating storage conditions in the arctic zone), a refrigerator (5 ± 2 °C; a reference temperature – chill chain), a controlled temperature chamber (23 ± 2 °C; simulating storage conditions in the temperate zone) and a thermostat (40 ± 2 °C; simulating storage conditions in the (sub)tropical zone). During the experiment, the tested samples were subjected to microbiological, basic chemical, sensory, chromatographic (amino acids and saccharide content) and rheological analyses; see details below in Sections 2.2-2.7. All analyses were performed at the beginning of the storage experiment ("day zero"), and 3-month intervals were chosen for the temperatures of 5 and 23 °C. More significant changes were expected during storage at 40 °C and, therefore, sampling was also realised after 1 month of storage; 3-month intervals remained unchanged. No significant changes were expected for the storage temperature of −18 °C and, therefore, the analyses were only performed after 3, 12 and 24 months of storage. Another exception for analyses were applied due to expected changes of some properties: (i) amino acid content, fat and crude protein contents were only considered at the beginning of the experiment and after the 12th and 24th month, and (ii) microbiological analyses were conducted at the beginning and after 1, 3, 12 and 24 months of storage. The overall expected design of the experiment is presented in Fig. S1 – S3 in the Supplementary material (for AAJ, FMH and SHCS, respectively). The storage and evaluation of the tested samples was terminated when the organoleptic properties were assessed as unacceptable (e.g. after 12-month storage at 40 °C in all three sugar-based products). The cancelled storage times were depicted in Fig. S1 – S3 (in the Supplementary material) using the grey highlighting. Furthermore, protein, fat, ammonia, TBARS and amino acid contents were analysed only in SHCS due to composition of samples (scarcely any fat and protein contents were expected in AAJ and FMH).

2.2. Microbiological analysis

Microbiological quality was controlled by assessment of the total number of microorganisms (CFU) according to ISO Standard No. 4833:2013 (ISO, 2013), spore-forming microorganisms according to Harrigan (1998), the colony forming units of yeasts and/or moulds according to ISO Standard No. 21257–2:2008 (ISO, 2008). All analyses were at least performed in triplicate in each sampled package.

2.3. Basic chemical analyses

The pH-values were determined by a spear pH-meter (Eutech Instruments, Malaysia). Dry matter, fat and protein contents were determined according to ISO 1442:1997 (ISO, 1997), ISO 1871:2009 (ISO, 2009) and ISO 17189:2003 (ISO, 2003), respectively. The ammonia content was determined by the microdiffusion Conway method (Buňka, Hrabě, & Kráčmar, 2004). Lipid oxidation was evaluated by the 2-thiobarbituric acid method as described by Kristensen and Skibsted (1999), and the results were expressed as absorbance units at the used wavelength ($A_{538}\cdot mg^{-1}$) per sample mg. All analyses were at least performed in triplicate in each sampled package.

2.4. Sensory analysis

The sensory analysis was performed by a panel of 24 selected assessors or experts, trained according to ISO Standard No. 8586:2012 (ISO, 2012). The samples were served in random order at a controlled temperature of 20 ± 2 °C in a sensory laboratory equipped with sensory booths (under normal light condition) in accordance with ISO 8589:2007 (ISO, 2007). Water was provided for mouth rinsing between sample evaluations to avoid any carry-over effects. The samples were evaluated using a seven-point hedonic scale for the following criteria: appearance, consistency, flavour (1-excellent, 4-good, 7-unacceptable), and off flavour was evaluated by a seven-point intensity scale (1-negligible, 4-medium, 7-excessive). Each point of the hedonic scale was described in detail using intensity terms. Therefore, the scales were presented as hedonic scales, however, were applied as intensity scales (due to description of each point). Data were expressed using medians (standard deviations were not calculated which is common when non-parametric methods are implemented).

2.5. Determination of amino acids

Fifteen amino acids (aspartic acid, threonine, serine, glutamic acid, proline, glycine, alanine, valine, isoleucine, leucine, phenylalanine, tyrosine, histidine, lysine, arginine, methionine and cysteine) were determined by using ion-exchange chromatography as described by Buňka et al. (2004); Buňka, Kříž, Veličková, Buňková, and Kráčmar (2009). During the acid hydrolysis, asparagine and glutamine were converted into aspartic and glutamic acid, respectively. All analyses were at least performed in triplicate in each sampled package.

The Essential Amino Acid Index (EAAI) was calculated according to equation (1).

$$EAAI = \sqrt[n]{\frac{100\times A_1}{B_1}\times\ldots\times\frac{100\times A_n}{B_n}} \tag{1}$$

A … Amount of a specific amino acid in the test protein in g/100 g of pure protein.

B … Amount of the same amino acid in the reference protein in g/100 g of pure protein.

2.6. Determination of saccharide content by high performance liquid chromatography

Saccharide content was determined by high-performance liquid chromatography (HPLC) with refractometric detection (Shimadzu prominence LC system, Shimadzu, Japan) and ZORBAX NH_2 column (250 × 4.6 mm, 5 μm, Agilent Technologies, USA) maintained at 23 ± 1 °C. A mixture of HPLC grade Acetonitrile and water was used as mobile phase in the ratio 80:20 (v/v) at a flow rate of 1.4 $ml\cdot min^{-1}$. The content of tested saccharide (fructose, glucose, galactose, sucrose, maltose and lactose) was calculated based on the external standard curve. Prior to analysis, proteins were removed using Carrez I [30 g/100 g (w/v) $ZnSO_4$] and Carrez II [15 g/100 g (w/v) $K_4Fe(CN)_6$] solutions in a homogenised mixture of 5 g of sample with 25 ml of distilled water, which was heated on a magnetic stirrer for 15 min at 50 °C (Yanniotis et al., 2006). All analyses were at least performed in triplicate in each sampled package.

2.7. Determination of selected rheological properties

The rheological analysis of the samples was performed using a dynamic oscillatory shear rheometer (RheoStress 1, HAAKE, Bremen, Germany). A parallel plate-plate geometry having a 35 mm diameter was used for the determination of the AAJ and SHCS viscoelastic properties (at 20.0 ± 0.1 °C with a gap of 1 mm). Silicone oil was used to prevent sample edge dehydration during the test. The G' (elastic modulus) and G'' (viscous modulus) moduli were determined at a frequency range of 0.01–100.00 Hz and, subsequently, the complex modulus (G^*) was calculated as the complex sum of G' and G'' (equation (2)) (Basu et al., 2011).

$$G^* = \sqrt{(G')^2 + (G'')^2} \tag{2}$$

The rheological behaviour of the FMH was studied using Z10 bob in cup geometry (volume 1.00 ml, gap 2.1 mm). The shear stress (τ) as a function of the shear rate (φ) was recorded. For viscosity measurements, 1 ml of FMH was sheared at 40 s^{-1} during 1 min at 20.0 ± 0.1 °C (Yanniotis et al., 2006). All rheological analyses were at least performed in triplicate in each sampled package and the results were expressed at a reference frequency value of 1 Hz.

2.8. Statistical analysis

Normal distribution (which is prerequisite for parametric test use) was not observed in all obtained data groups. Therefore, non-parametrical tests were employed, the Kruskal-Wallis and Wilcoxon tests, respectively. The influence of (i) sample storage time; and (ii) storage temperature were evaluated separately. Additionally, the two-way analysis of variants (ANOVA) was also applied for evaluation of the interaction effect of the independent variables (temperature and time of storage) on the observed quality parameters. The statistical software Unistat® 6.5 (Unistat Ltd., London, UK) and the significance level of 0.05 were applied.

3. Results

3.1. Microbiological analysis

At the beginning of storage, the total number of aerobic and/or facultative anaerobic mesophilic microorganisms (TC) were in the range of $1.3 \cdot 10^{2}$ CFU/g (colony forming units per gram of tested sample) in FMH. During 24 months of storage, the level of TC was in the same logarithmic order in comparison with the amounts at the beginning at all temperatures used ($P \geq 0.05$). The number of aerobic and anaerobic spore-forming microorganisms was $2.5 \cdot 10^{2}$ CFU/g and $5.0 \cdot 10^{1}$ CFU/g, respectively. Elevated storage temperatures (5, 23, 40 °C) resulted in an approximate increase in the number of aerobic and anaerobic spore-forming microorganisms by two logarithmic orders ($P < 0.05$) after 3 months of storage. Yeasts and/or moulds were only detected in FMH at the 24th month at all temperatures used ($P < 0.05$). The number of TC, aerobic and anaerobic spore-forming microorganisms in AAJ were in the range of $1.0 \cdot 10^{1}$ CFU/g, $2.1 \cdot 10^{1}$ CFU/g and $5.0 \cdot 10^{1}$ CFU/g, respectively. No changes in the level of TC were observed at −18 and 5 °C, while an increase by one logarithmic order (TC) and two logarithmic orders (spore-forming bacteria) was observed at 23 and 40 °C ($P < 0.05$) during the first 3 months. Similarly, yeasts were only detected at the 24th month at all temperatures used ($P < 0.05$). Finally, no microorganisms were detected in the SHCS.

3.2. Basic chemical analyses

The results of pH-values and dry matter content for AAJ, FMH and SHCS stored for 24 months at four temperatures (from −18 to 40 °C) are shown in Table 1. The ammonia, fat, crude protein contents and TBARS-value of SHCS are shown in Table 2.

During the 24-month storage period of AAJ, FMH and SHCS, a significant decrease in pH-values was observed (Table 1; $P < 0.05$) when temperatures above 5 °C were used. Whereas, pH-values in frozen samples did not change significantly ($P \geq 0.05$) from the initial pH-value of 3.20, 3.80 and 6.12 for AAJ, FMH and SHCS, respectively. Moreover, an intensive growth of the dry matter content when higher storage temperatures (above 23 °C) were used was observed (Table 1; $P < 0.05$) for AAJ and FMH. In the case of SHCS, the dry matter content did not change significantly ($P \geq 0.05$) as in the case of the AAJ and FMH samples stored below 5 °C. The values of protein and fat content also correspond to the nutritional values stated by the manufacturer on the packaging for SHCS ($P \geq 0.05$). The interactions between the temperature and time of storage were also significant ($P < 0.05$).

The initial ammonia level of 12.2 mg/kg (see Table 2) changed during 24 months of storage at −18, 5 and 23 °C. At −18 °C, only a slight increase ($P \geq 0.05$) in the ammonia content was observed, thus proving that the freezing temperatures did not stop the process of deamination. At 5 and 23 °C, a more noticeable increase in ammonia was observed. At

Table 1
Results of pH (−) and dry matter content (g/100 g w/w) of the apricot-apple jam, flower meadow honey, sweetened hazelnut cocoa spread stored during 24-month period at four different temperatures (−18 °C, 5 °C, 23 °C and 40 °C). The results are expressed as means ± standard deviation (n = 27). [a].

		apricot-apple jam		flower meadow honey		sweetened hazelnut cocoa spread	
storage time (months)	storage temp. (°C)	pH (−)	dry matter content (g/100 g w/w)	pH (−)	dry matter content (g/100 g w/w)	pH (−)	dry matter content (g/100 g w/w)
0	23	3.20 ± 0.01 A	70.27 ± 0.10 A	3.80 ± 0.03 A	84.65 ± 0.07 A	6.12 ± 0.02 A	99.50 ± 0.06 A
1	40	3.07 ± 0.02 B	71.33 ± 0.03 B	3.62 ± 0.01 B	85.66 ± 0.08 B	5.98 ± 0.02 B	99.63 ± 0.08 A
3	−18	3.25 ± 0.01^{a}B	70.79 ± 0.07^{a}B	3.82 ± 0.01^{a}A	84.47 ± 0.05^{a}B	6.08 ± 0.02^{a}A	99.52 ± 0.09^{a}A
	5	3.21 ± 0.01^{b}A	70.56 ± 0.11^{b}B	3.79 ± 0.02^{b}A	83.89 ± 0.04^{b}B	6.07 ± 0.01^{a}B	99.68 ± 0.05^{b}B
	23	3.19 ± 0.01^{c}A	70.98 ± 0.06^{c}B	3.75 ± 0.02^{c}B	84.73 ± 0.08^{c}A	6.02 ± 0.03^{b}B	99.77 ± 0.04^{c}B
	40	3.08 ± 0.02^{d}B	74.13 ± 0.05^{d}C	3.64 ± 0.03^{d}B	86.96 ± 0.10^{d}C	5.99 ± 0.02^{b}B	99.64 ± 0.08^{d}A
6	5	3.15 ± 0.02^{a}B	70.59 ± 0.02^{a}B	3.70 ± 0.01^{a}B	84.03 ± 0.09^{a}C	6.01 ± 0.03^{a}C	99.45 ± 0.10^{a}B
	23	3.11 ± 0.01^{b}B	72.16 ± 0.05^{b}C	3.63 ± 0.01^{b}C	84.93 ± 0.09^{b}B	5.92 ± 0.03^{b}C	99.39 ± 0.12^{a}C
	40	3.02 ± 0.01^{c}C	77.49 ± 0.08^{c}D	3.57 ± 0.03^{c}C	89.32 ± 0.06^{c}D	5.87 ± 0.03^{b}C	99.49 ± 0.11^{a}A
9	5	3.07 ± 0.01^{a}C	71.25 ± 0.12^{a}C	3.61 ± 0.02^{a}C	84.09 ± 0.06^{a}C	5.95 ± 0.02^{a}D	99.61 ± 0.06^{a}B
	23	3.01 ± 0.01^{b}C	74.39 ± 0.05^{b}D	3.49 ± 0.01^{b}D	85.11 ± 0.05^{b}C	5.96 ± 0.02^{a}C	99.36 ± 0.08^{b}C
	40	2.91 ± 0.02^{c}D	80.17 ± 0.06^{c}E	3.50 ± 0.01^{b}D	90.08 ± 0.04^{c}E	–	–
12	−18	3.22 ± 0.02^{a}A	71.32 ± 0.07^{a}C	3.72 ± 0.03^{a}B	84.31 ± 0.06^{a}C	6.00 ± 0.02^{a}B	99.38 ± 0.07^{a}A
	5	3.00 ± 0.02^{b}D	71.90 ± 0.07^{b}D	3.54 ± 0.03^{b}D	84.44 ± 0.02^{b}D	5.88 ± 0.02^{b}E	99.56 ± 0.05^{b}A
	23	2.94 ± 0.01^{c}D	73.91 ± 0.05^{c}E	3.38 ± 0.01^{c}E	85.66 ± 0.09^{c}D	–	–
	40	2.81 ± 0.02^{d}E	83.03 ± 0.06^{d}F	3.40 ± 0.02^{c}E	90.78 ± 0.09^{d}F	–	–
15	5	2.97 ± 0.02^{a}D	71.87 ± 0.06^{a}D	3.51 ± 0.01^{a}D	84.37 ± 0.04^{a}D	–	–
	23	2.90 ± 0.01^{b}E	75.87 ± 0.04^{b}F	3.32 ± 0.01^{b}F	86.12 ± 0.04^{b}E	–	–
	40	–	–	–	–	–	–
18	5	2.94 ± 0.02^{a}E	71.81 ± 0.04^{a}D	3.47 ± 0.02^{a}E	84.38 ± 0.04^{a}D	–	–
	23	2.84 ± 0.01^{b}F	78.42 ± 0.05^{b}G	3.28 ± 0.01^{b}G	86.75 ± 0.11^{b}F	–	–
	40	–	–	–	–	–	–
21	5	2.90 ± 0.01^{a}F	72.38 ± 0.02^{a}E	3.44 ± 0.02^{a}E	84.74 ± 0.06^{a}E	–	–
	23	2.79 ± 0.02^{b}G	78.60 ± 0.06^{b}H	3.25 ± 0.02^{b}G	87.94 ± 0.08^{b}G	–	–
	40	–	–	–	–	–	–
24	−18	3.19 ± 0.01^{a}A	71.72 ± 0.06^{a}D	3.84 ± 0.02^{a}A	83.90 ± 0.03^{a}D	6.02 ± 0.02 B	99.22 ± 0.06 B
	5	2.87 ± 0.02^{b}G	72.66 ± 0.06^{b}F	3.39 ± 0.01^{b}F	84.79 ± 0.06^{b}E	–	–
	23	2.75 ± 0.02^{c}G	78.92 ± 0.03^{c}I	3.19 ± 0.02^{c}H	87.71 ± 0.09^{c}H	–	–
	40	–	–	–	–	–	–

[a] The means within a column (the difference between the storage temperature) followed by different superscript letters differ ($P < 0.05$). The means within a column (the difference between the storage period) followed by different capital letters differ ($P < 0.05$). The dash (−) symbol indicates an analysis that has not been performed due to an unsatisfactory sensory analysis as defined in chapter 2.1 in material and method section.

Table 2
Result of ammonia (mg/kg), TBARS (A_{538}/mg), protein (g/100 g w/w) and fat (g/100 g w/w) content of the sweetened hazelnut cocoa spread stored during 24-month period at four different temperatures (−18 °C, 5 °C, 23 °C and 40 °C). The results are expressed as means ± standard deviation (n = 27). [a].

Storage time (months)	Storage temperature (°C)	Ammonia (mg/kg)	TBARS (A_{538}/mg)	Protein[b] (g/100 g w/w)	Fat[b] (g/100 g w/w)
0	23	12.2 ± 0.2 A	27.4 ± 0.5 A	5.94 ± 0.05 A	30.06 ± 0.36 A
1	40	20.3 ± 0.5 B	50.5 ± 1.4 B	–	–
3	−18	14.4 ± 0.3^{a}B	60.7 ± 1.4^{a}B	–	–
	5	13.6 ± 0.2^{b}B	69.3 ± 1.5^{b}B	–	–
	23	14.8 ± 0.3^{b}B	74.2 ± 1.6^{c}B	–	–
	40	23.1 ± 0.5^{c}C	87.1 ± 1.7^{d}C	–	–
6	5	15.0 ± 0.2^{a}C	89.6 ± 1.8^{a}C	–	–
	23	16.3 ± 0.3^{b}C	96.2 ± 2.0^{b}C	–	–
	40	29.4 ± 0.4^{c}D	154.1 ± 3.3^{c}D	6.48 ± 0.06 B	31.70 ± 0.39 B
9	5	15.9 ± 0.3^{a}D	128.0 ± 3.0^{a}D	–	–
	23	16.6 ± 0.3^{b}C	136.3 ± 3.2^{b}D	6.13 ± 0.05 B	31.28 ± 0.29 B
	40	–	–	–	–
12	−18	16.4 ± 0.4^{a}C	141.1 ± 3.2^{a}C	5.94 ± 0.05^{a}A	30.35 ± 0.30^{a}A
	5	17.7 ± 0.3^{b}E	179.3 ± 3.5^{b}E	5.57 ± 0.03^{b}B	31.47 ± 0.32^{b}A
	23	–	–	–	–
	40	–	–	–	–
15	5	–	–	–	–
	23	–	–	–	–
	40	–	–	–	–
18	5	–	–	–	–
	23	–	–	–	–
	40	–	–	–	–
21	5	–	–	–	–
	23	–	–	–	–
	40	–	–	–	–
24	−18	20.3 ± 0.3 D	124.1 ± 2,7 D	5.82 ± 0.04 B	29.95 ± 0.45 A
	5	–	–	–	–
	23	–	–	–	–
	40	–	–	–	–

[a] The means within a column (the difference between the storage temperature) followed by different superscript letters differ (P < 0.05). The means within a column (the difference between the storage period) followed by different capital letters differ (P < 0.05). The dash (–) symbol indicates an analysis that has not been performed due to an unsatisfactory sensory analysis as defined in chapter 2.1 in material and method section.

[b] Instead of 12th month, data from the 6th and 9th month of storage at a given temperature are displayed due to an unsatisfactory sensory analysis, for further details see chapter 2.1 in material and method section.

a storage temperature of 40 °C, the ammonia levels tripled by the end of 6th months (P < 0.05). At day zero, the TBARS value was measured as 27.4 $A_{538}\cdot mg^{-1}$ (see Table 2). The TBARS values increased fivefold (−18 °C; P < 0.05), approximately sevenfold (5 and 23 °C; P < 0.05), and more than tenfold (40 °C; P < 0.05). Both of the independent variables (the temperature and the storage period) influenced (the interactions were significant; P < 0.05) the ammonia levels and also TBARS-values of tested samples.

3.3. Sensory analysis

The results of sensory analysis are displayed in the **Supplementary material**. The initial results for AAJ were excellent for appearance, consistency, flavour; off flavour was negligible. With increasing temperature and time, significant changes in consistency (spreadability), as well as in appearance were observed (see Table S1 and Fig. S4 in **Supplementary material**). Moreover, samples stored at 40 °C were scored as unacceptable and did not show a typical apricot flavour over time, yet the sweetness of the product was maintained. In addition, no undesirable odour was detected in the samples at all temperatures, except 40 °C at the 12th month. No worse than unsatisfactory for appearance, consistency and less good flavour was scored at the 24th month.

At the beginning, the FMH was scored as excellent for appearance, consistency, flavour, whilst off flavour was negligible (see Table S2 in **Supplementary material**). The process of crystallization was observed after 18 months (5 °C) and 24 months (−18 °C), respectively (see Fig. S5 in **Supplementary material**). Up to the 12th month, the samples (except for 40 °C) were scored no worse than good for appearance, consistency and flavour, with the off flavour to be negligible. In the case of samples stored at 40 °C, a bitter taste at the 12th month was detected; appearance and consistency deteriorated to less good.

Finally, the initial score for SHCS were excellent for appearance, consistency, flavour, with negligible off flavour. During the first three months, good and less good evaluation in the case of 40 °C was scored. Rancid taste was present (except for −18 °C), therefore SHCS was considered as unacceptable (flavour and off flavour) after a 6-month storage period at 40 °C and a 9-month storage period at 5 °C and 23 °C. However, the SHCS stored at −18 °C was considered good for appearance and consistency, flavour less excellent with negligible off flavour after 24 months (see Table S3 in **Supplementary material**).

The sensory evaluation of all three tested sugar-based products was significantly influenced by the simultaneous effects of the temperature and storage time (P < 0.05).

Overall, during the 24-month storage period, the organoleptic quality of AAJ, FMH, SHCS expressed as appearance, consistency, flavour and off flavour deteriorated (P < 0.05). Therefore, the storage of unacceptable samples was terminated (see Fig. S1 – S3 in the Supplementary material). Generally, the AAJ and FMH storage at 40 °C was terminated after 12 months. The SHCS storage was terminated after 6 months at 40 °C, 9 months at 23 °C and 12 months at 5 °C.

3.4. Amino acids content

Glutamic acid, aspartic acid, leucine, arginine, valine, proline and histidine were detected as the most abundant amino acids (AA), whilst least represented AA were methionine and cysteine. A decrease of AA content in SHCS was observed during the sample's storage (**Table 3**; P < 0.05). Prolonged time and storage temperature resulted in an AA content decline ranging from 1.69 g/100 g–6.14 g/100 g (Table 3; P < 0.05). An essential amino acids index (EAAI) was calculated and determined to be 109.09 at the beginning of the storage. A decline in EAAI by 9.93 (40 °C, 6 months; P < 0.05), 6.58 (23 °C, 9 months; P < 0.05), 3.40 and 5.04 (−18 and 5 °C, 12 months; P < 0.05) and 9.61 at (−18 °C, 24 months; P < 0.05) was observed. The results show that the EAAI decreased both due to temperature and length of storage (P < 0.05). The latter mentioned parameter was also influenced by the interactions of the both observed independent variables (the temperature and the storage period; P < 0.05).

3.5. Saccharide content

Saccharides determined at day zero in AAJ were sucrose, fructose, glucose and maltose (Table 4). The initial total saccharide content of AAJ decreased by 0.28, 0.38, 0.51 g/100 g (24th month; −18, 5, 23 °C, respectively) and 0.57 g/100 g (12th month, 40 °C). In FMH, the analysed saccharides were fructose and glucose (Table 5). During storage, the initial total saccharide content decreased by 0.55, 1.75, 2.00 g/100 g (−18, 5, 23 °C, respectively; 24th month) and by 1.54 g/100 g (40 °C, 12th month). Finally, SHCS was found to contain sucrose and lactose

Table 3
The amino acid content (g/100 g) of sweetened hazelnut cocoa spread stored during 24-month period at four different temperatures (−18 °C, 5 °C, 23 °C and 40 °C). The results are expressed as means ± standard deviation (n = 27). [a].

Amino acid	0 months 23 ± 2 °C	12 months −18 ± 2 °C	12 months 5 ± 2 °C	9 months[b] 23 ± 2 °C	6 months[b] 40 ± 2 °C	24 months - 18 ± 2 °C
Threonine	4.13 ± 0.07 A	4.06 ± 0.03^{a}A	4.01 ± 0.05^{a}B	4.05 ± 0.04^{a}A	3.99 ± 0.04^{b}B	4.00 ± 0.01 B
Valine	6.35 ± 0.12 A	6.20 ± 0.08^{a}A	6.00 ± 0.08^{b}B	6.11 ± 0.07^{a}B	5.90 ± 0.07^{b}B	6.13 ± 0.04 B
Isoleucine	4.93 ± 0.12 A	4.84 ± 0.04^{a}A	4.69 ± 0.07^{b}B	4.59 ± 0.06^{b}B	4.64 ± 0.05^{b}B	4.77 ± 0.03 C
Leucine	9.21 ± 0.15 A	8.98 ± 0.09^{a}B	9.01 ± 0.13^{a}A	8.99 ± 0.11^{a}A	8.85 ± 0.10^{a}B	8.91 ± 0.09 B
Phenylalanine	5.35 ± 0.10 A	5.32 ± 0.01^{a}A	5.28 ± 0.06^{a}A	5.15 ± 0.05^{b}B	5.17 ± 0.05^{b}B	5.17 ± 0.08 B
Lysine	2.39 ± 0.06 A	2.33 ± 0.04^{a}A	2.30 ± 0.04^{a}A	2.22 ± 0.04^{b}B	2.17 ± 0.03^{b}B	2.32 ± 0.04 A
Methionine	1.38 ± 0.08 A	1.29 ± 0.05^{a}A	1.28 ± 0.03^{a}A	1.23 ± 0.08^{a}A	1.20 ± 0.06^{a}B	1.03 ± 0.02 B
Sum of essential amino acids	33.74	33.01	32.56	32.34	31.93	32.33
Asparagic acid	10.6 ± 0.15 A	10.5 ± 0.11^{a}A	10.6 ± 0.14 ^{a}A	10.4 ± 0.11 ^{a}A	10.5 ± 0.12 ^{a}A	10.3 ± 0.12 B
Serine	5.29 ± 0.05 A	5.16 ± 0.03^{a}B	5.25 ± 0.07^{a}A	5.16 ± 0.05^{a}B	5.10 ± 0.05 ^{b}B	5.13 ± 0.02 B
Glutamic acid	19.3 ± 0.31 A	19.2 ± 0.26^{a}A	18.8 ± 0.29^{a}A	18.4 ± 0.24^{b}B	18.1 ± 0.29^{b}B	19.1 ± 0.20 A
Proline	6.42 ± 0.12 A	6.30 ± 0.11^{a}A	6.18 ± 0.09^{a}B	5.97 ± 0.07^{b}B	5.56 ± 0.09^{c}B	6.22 ± 2.09 A
Glycine	3.82 ± 0.05 A	3.73 ± 0.04^{a}B	3.66 ± 0.05^{a}B	3.56 ± 0.04^{b}B	3.41 ± 0.04^{c}B	3.69 ± 0.20 A
Alanine	4.63 ± 0.07 A	4.59 ± 0.04^{a}A	4.43 ± 0.06^{b}B	4.31 ± 0.05^{c}B	4.25 ± 0.05^{c}B	4.47 ± 0.01 C
Tyrosine	2.61 ± 0.04 A	2.55 ± 0.06^{a}A	2.51 ± 0.03^{a}B	2.43 ± 0.03^{b}B	2.27 ± 0.03^{c}B	2.52 ± 0.06 A
Histidine	5.97 ± 0.09 A	5.82 ± 0.04^{a}B	5.79 ± 0.03^{a}B	5.85 ± 0.09^{a}A	5.63 ± 0.03^{c}B	5.76 ± 0.02 B
Arginine	7.02 ± 0.06 A	6.84 ± 0.07^{a}A	6.84 ± 0.09^{a}B	6.78 ± 0.08^{a}B	6.70 ± 0.07^{b}B	6.79 ± 0.03 B
Cysteine	1.32 ± 0.07 A	1.22 ± 0.06^{a}A	1.22 ± 0.09^{a}A	1.19 ± 0.04^{a}B	1.08 ± 0.02^{b}B	0.99 ± 0.06 B
Total sum	100.72	99.02	97.75	96.29	94.54	97.28

[a] The means within a line (the difference between the storage temperature) followed by different superscript letters differ (P < 0.05). The means within a line (the difference between the storage period) followed by different capital letters differ (P < 0.05).

[b] Instead of 12th month, data from the 6th and 9th month of storage at a given temperature are displayed due to an unsatisfactory sensory analysis, for further details see chapter 2.1 in material and method section.

(Table 6). Similarly, the decrease of initial total saccharide content were 1.19 g/100 g at −18 °C (24th month) and 0.18, 0.52, 1.05 g/100 g for 5, 23 and 40 °C, respectively (12th month).

3.6. Rheology analysis

The initial values of apparent viscosity in FMH (11.52 Pa s) did not change significantly during the first 12 months at −18, 5 and 23 °C (P ≥ 0.05). In contrast, samples stored at 40 °C showed a significant increase in viscosity due to the increase of dry matter content and crystallization formation (P < 0.05) (see Fig. 1A and Fig. S3 in Supplementary material). This fact manifested itself significantly at the 9th and 12th month, when the resulting consistency of the sample did not allow the analysis to be performed, and therefore the data is not shown. After the 12th month a slight continuous increase in viscosity was observed at 23 °C (P < 0.05), whilst samples stored at −18 and 5 °C did not show significant changes (P ≥ 0.05). The firmness of AAJ only varied significantly (P < 0.05) at 23 and 40 °C. The initial complex modulus value of 1.28 kPa increased twice, three and seven times after 3, 6 and 12 months at 40 °C, respectively. At 23 °C, a maximum increase of three times the day zero value was observed at the end of the experiment. In contrast, the changes for SHCS in complex modulus values showed the opposite trend, a decrease of half from the original value of 2.33 kPa was recorded for temperatures of −18, 5 and 40 °C (P < 0.05). On the other hand, changes in the complex modulus values were not significant for the SHCS stored at 23 °C (P ≥ 0.05), see Fig. 1B and C, respectively. The interactions between the storage time and temperature possessed a significant effect on the viscosity of the FMH and also the complex modulus of the AAJ and SHCS (P < 0.05).

4. Discussion

In general, the higher storage temperature used resulted in increased numbers of TC and spore-forming microorganisms (P < 0.05) in AAJ and FMH. By contrast, there were no significant changes at −18 °C (P ≥ 0.05). Therefore, it can be concluded that storage of all samples at ≤ 23 °C appeared to be safe from a microbiology perspective, while it was not recommended to exceed a storage period of 12 months under storage at 40 °C.

The pH-values decreased and the dry matter increased during storage of AAJ, FMH and SHCS; this trend was more noticeable when the higher storage temperature was used. The decrease could be explained by the ongoing antimicrobial activity and/or biochemical changes. Acidity in FMH is attributed to the content of gluconic acid, which is the result of an enzymatic reaction during nectar maturation (Vorlová et al., 2018). Another explanation can be found in the occurrence of postharvest fermentation, which is related with a decrease of pH and increase of free acidity in stored honeys as reported by Da Silva et al. (2020) and Seraglio et al. (2021). Smetanska, Alharthi, and Selim (2021) attributed the high acidity of honey to the fermentation of sugar into organic acids and to the presence of inorganic ions such as phosphate and chloride ions, which are responsible for the stability of honey against microbial spoilage. The pH-values measured for FMH were comparable (P > 0.05) with few sample findings of Da Silva et al. (2020). The author also reported much higher pH-values in some cases of stored honeys, similarly as Seraglio et al. (2021). The pH-values in AAJ were lower than those found by Touati et al. (2014) who reported pH-values of 3.40 and Smetanska et al. (2021) who observed pH-values in the range of 3.26–4.91. These variations could be attributed to the plant floral types. Chauhan et al. (2013) reported similar pH-values of 3.08–3.26 in coconut jams; in addition, the trend of decreasing pH-values coincides with the data in this work.

The present dry matter content study results were comparable to other authors findings (Tomczyk, Tarapatskyy, & Dżugan, 2019; Vorlová et al., 2018; Yanniotis et al., 2006). The increase of AAJ and FMH dry matter contents due to both elevated storage temperature and prolonged storage time was probably due to evaporation of moisture, which developed as water droppings on the lid.

During 24 months of storage, the organoleptic quality in AAJ, FMH and SHCS deteriorated, and quality worsening was more intensive when an elevated storage temperature was used (P < 0.05). The AAJ and FMH developed colour changes during storage, which may be due to nonenzymatic browning (Bubelová et al., 2017; Castelló et al., 2011; Wibowo, Grauwet, Gedefa, Hendrickx, & Van Loey, 2015; Zorić et al., 2017). The significant effect of temperature conditions on colour parameters of honey was observed also by Karabagias et al. (2018). The magnitude of this rate was found to be higher in the FMH and AAJ samples stored at 40 °C when compared to those stored at ≤ 23 °C. An increase in

Table 4
Results of determination of saccharide content (g/100 g) of the apricot-apple jam stored during 24-month period at four different temperatures (−18 °C, 5 °C, 23 °C and 40 °C). The results are expressed as means ± standard deviation (n = 27). [a].

storage time (months)	storage temp. (°C)	Sucrose	Fructose	Glucose	Maltose	Sum
0	23	32,67 ± 0,15 A	19,27 ± 0,12 A	11,25 ± 0,20 A	5,06 ± 0,19 A	68,24 ± 0,17 A
1	40	33,69 ± 0,25 B	19,15 ± 0,16 A	10,47 ± 0,05 B	5,21 ± 0,25 A	68,52 ± 0,18 A
3	−18	29,39 ± 0,19^{a}B	19,59 ± 0,13^{a}A	13,29 ± 0,13^{a}B	5,80 ± 0,18^{a}B	68,07 ± 0,16^{a}A
	5	30,41 ± 0,20^{b}B	22,18 ± 0,16^{b}B	11,15 ± 0,19^{b}A	5,33 ± 0,14^{b}A	69,07 ± 0,17^{b}B
	23	32,73 ± 0,18^{c}A	18,19 ± 0,13^{c}B	11,87 ± 0,25^{c}B	5,60 ± 0,15^{c}B	68,39 ± 0,18^{a}A
	40	29,63 ± 0,22^{d}C	20,09 ± 0,20^{d}B	12,42 ± 0,05^{d}C	5,90 ± 0,21^{c}B	68,05 ± 0,17^{a}A
6	5	33,67 ± 0,24^{a}C	17,64 ± 0,08^{a}C	12,37 ± 0,14^{a}A	5,69 ± 0,03^{a}B	69,37 ± 0,12^{a}B
	23	32,46 ± 0,21^{b}A	19,79 ± 0,04^{b}C	11,36 ± 0,27^{b}A	5,32 ± 0,01^{b}C	68,93 ± 0,13^{b}B
	40	33,79 ± 0,27^{a}B	17,39 ± 0,15^{c}C	11,66 ± 0,07^{b}D	6,56 ± 0,24^{c}A	69,39 ± 0,18^{a}B
9	5	31,50 ± 0,26^{a}D	18,37 ± 0,09^{a}D	11,78 ± 0,03^{a}B	6,72 ± 0,03^{a}C	68,38 ± 0,10^{a}A
	23	32,41 ± 0,20^{b}A	19,43 ± 0,12^{b}A	11,25 ± 0,19^{b}A	5,10 ± 0,04^{b}A	68,18 ± 0,14^{a}A
	40	31,49 ± 0,20^{a}C	18,90 ± 0,18^{a}B	11,59 ± 0,23^{a}A	6,19 ± 0,21^{a}C	68,16 ± 0,21^{a}A
12	−18	32,91 ± 0,26^{b}A	19,28 ± 0,02^{b}A	11,37 ± 0,15^{a}A	4,92 ± 0,01^{b}A	68,47 ± 0,11^{a}A
	5	32,54 ± 0,14^{b}A	19,98 ± 0,08^{c}C	11,19 ± 0,27^{b}A	4,98 ± 0,06^{b}A	68,68 ± 0,14^{b}B
	23	33,71 ± 0,23^{c}B	19,44 ± 0,07^{d}D	11,25 ± 0,15^{b}A	5,17 ± 0,09^{c}A	69,57 ± 0,14^{c}B
	40	32,65 ± 0,25^{a}A	19,35 ± 0,19^{a}A	11,89 ± 0,20^{a}B	4,81 ± 0,21^{a}D	68,70 ± 0,21^{a}C
15	5	32,68 ± 0,02^{a}A	19,27 ± 0,11^{a}A	11,06 ± 0,04^{b}A	5,06 ± 0,20^{a}A	68,06 ± 0,09^{b}A
	23	34,43 ± 0,16^{a}E	19,51 ± 0,18^{a}A	10,83 ± 0,03^{a}C	4,59 ± 0,14^{a}D	69,36 ± 0,13^{a}B
	40	–	–	–	–	–
18	5	33,84 ± 0,11^{b}B	19,50 ± 0,21^{a}A	11,08 ± 0,19^{b}A	4,76 ± 0,16^{a}D	69,19 ± 0,17^{a}C
	23	36,12 ± 0,13^{a}F	16,89 ± 0,25^{a}E	10,39 ± 0,09^{a}D	5,15 ± 0,13^{a}A	68,55 ± 0,15^{a}C
	40	–	–	–	–	–
21	5	34,85 ± 0,02^{b}B	18,09 ± 0,22^{b}B	10,38 ± 0,21^{a}B	5,44 ± 0,17^{a}C	68,77 ± 0,16^{a}B
	23	34,69 ± 0,12^{a}D	20,12 ± 0,23^{a}C	10,08 ± 0,01^{a}C	5,10 ± 0,18^{a}A	69,99 ± 0,14^{a}B
	40	–	–	–	–	–
24	−18	33,95 ± 0,11^{b}C	18,31 ± 0,16^{b}D	11,94 ± 0,13^{b}B	4,99 ± 0,19^{a}A	69,19 ± 0,15^{b}B
	5	33,53 ± 0,14^{c}C	18,03 ± 0,17^{b}B	10,99 ± 0,16^{b}A	5,68 ± 0,13^{b}B	68,23 ± 0,15^{c}A
	23	32,67 ± 0,15 A	19,27 ± 0,12 A	11,25 ± 0,20 A	5,06 ± 0,19 A	68,24 ± 0,17 A
	40	–	–	–	–	–

[a] The means within a column (the difference between the storage temperature) followed by different superscript letters differ ($P < 0.05$). The means within a column (the difference between the storage period) followed by different capital letters differ ($P < 0.05$). The dash (–) symbol indicates an analysis that has not been performed due to an unsatisfactory sensory analysis as defined in chapter 2.1 in material and method section.

ammonia content was observed, which is generally considered a marker of Maillard reactions and Strecker degradation (Kristensen et al., 2001). The previously mentioned changes in ammonia content were reflected in the results of sensory analysis. Bubelová et al. (2017) and Kadidlová et al. (2010) reported a significant increase of the ammonia content during storage at 6–40 °C. Moreover, the trend of both authors corresponds to our observations. The course of the above-mentioned reactions is also shown by the decreasing content of AA, the trend of which "copies" our documented increase in the content of ammonia. Statistical analysis confirms that ammonia production corresponds with the storage temperature used ($P < 0.05$). Similarly to our results, the reductions in AA content were higher with longer storage times and higher temperatures as reported by Touati et al. (2014). To our knowledge, no work has been done to study changes in AA content in similar types of product to SHCS. An increase of the TBARS value ($P < 0.05$) was noticed during storage and, as suggested by Raeisi et al. (2016), it can be considered as a good chemical indicator for quality assurance during storage. The gradual lipid oxidation of the high SHCS fat content was reflected in the results of sensory analysis as a rancid taste was documented. TBARS values increased more progressively under higher temperature use than with extended storage time. Maillard reactions and the lipid oxidation could contribute to the development of sensory active substances such as aldehydes, ketones, alcohols, acids etc. And therefore, their influence on the flavour of the products is evident (Sharma et al., 2015; Wibowo et al., 2015). Additionally, appearance and consistency of jams and honey could be deteriorated also due to crystallization of the present sugars as was previously reported by Dettori, Tappi, Piana, Rosa, and Rocculi (2018), Escuredo et al. (2014), Kabbani, Sepulcre, and Wedekind (2011) and Wibowo et al. (2015). In particular, visible crystals were observed also in this study in the samples of AAJ and FMH especially during longer storage times.

The saccharide composition of AAJ and FMH was similar to those reported by Chauhan et al. (2013) and Touati et al. (2014) for jams, and by Tomczyk et al. (2019), Vorlová et al. (2018) and Yanniotis et al. (2006) for honeys ($P > 0.05$). Moreover, Tomczyk et al. (2019) reported a sucrose content ranging from 3.53 to 6.29 g/100 g. Our documented marginal decrease of the total saccharide content in all samples corresponds with the authors mentioned above, except for Touati et al. (2014), who reported a decrease of 5.52, 9.02 and 7.46 g/100 g after 60 days at 5, 25 and 37 °C, respectively. The saccharide level decrease was concomitant with AA content indicating their implication in the non-enzymatic browning process.

Juszczak and Fortuna (2006) reported higher viscosity values ($P < 0.05$) in comparison with work by Pan and Ji, 1998, who reported viscosity between 0.70 and 19.55 Pa s at 10 °C. This difference can be attributed to the higher water content of Chinese honeys in contrast with

Table 5
Results of determination of saccharide content (g/100 g) of the flower meadow honey stored during 24-month period at four different temperatures (−18 °C, 5 °C, 23 °C and 40 °C). The results are expressed as means ± standard deviation (n = 27). [a].

storage time (months)	storage temp. (°C)	Fructose	Glucose	Sum
0	23	47,02 ± 0,19 A	36,36 ± 0,16 A	83,38 ± 0,18 A
1	40	45,96 ± 0,16 B	33,66 ± 0,19 B	79,62 ± 0,19 B
3	−18	45,31 ± 0,17^{a}B	37,93 ± 0,17^{a}B	83,24 ± 0,16^{a}A
	5	44,95 ± 0,13^{b}B	34,62 ± 0,20^{b}B	79,57 ± 0,17^{b}B
	23	44,77 ± 0,14^{b}B	36,39 ± 0,22^{c}A	81,16 ± 0,18^{c}B
	40	46,10 ± 0,18^{c}C	36,60 ± 0,24^{c}A	82,70 ± 0,21^{d}C
6	5	46,85 ± 0,13^{a}C	33,65 ± 0,21^{a}C	80,54 ± 0,17^{a}C
	23	46,06 ± 0,14^{b}C	34,02 ± 0,22^{b}B	80,08 ± 0,18^{b}C
	40	47,30 ± 0,18^{c}A	32,91 ± 0,19^{c}C	80,21 ± 0,19^{b}D
9	5	48,93 ± 0,14^{a}D	33,44 ± 0,25^{a}C	82,37 ± 0,20^{a}D
	23	46,62 ± 0,19^{b}D	33,24 ± 0,22^{a}C	79,86 ± 0,21^{b}C
	40	47,48 ± 0,08^{a}C	35,59 ± 0,18^{a}C	83,07 ± 0,13^{a}B
12	−18	47,08 ± 0,19^{b}A	34,46 ± 0,21^{b}B	81,54 ± 0,20^{b}E
	5	48,54 ± 0,22^{c}E	32,47 ± 0,17^{c}D	81,01 ± 0,20^{c}B
	23	45,78 ± 0,21^{d}B	37,53 ± 0,08^{d}D	83,31 ± 0,15^{d}A
	40	44,79 ± 0,17^{a}B	37,23 ± 0,15^{a}D	82,02 ± 0,16^{a}D
15	5	45,11 ± 0,13^{b}F	36,51 ± 0,22^{b}A	81,62 ± 0,18^{b}D
	23	44,65 ± 0,15^{a}B	35,39 ± 0,16^{a}E	80,04 ± 0,16^{a}F
	40	–	–	–
18	5	43,01 ± 0,17^{b}G	37,70 ± 0,22^{b}E	80,71 ± 0,20^{b}E
	23	47,25 ± 0,17^{a}A	35,71 ± 0,20^{a}E	82,95 ± 0,19^{a}G
	40	–	–	–
21	5	48,44 ± 0,23^{b}E	34,81 ± 0,15^{b}F	83,25 ± 0,19^{b}A
	23	44,94 ± 0,22^{a}D	36,66 ± 0,19^{a}A	81,63 ± 0,21^{a}C
	40	–	–	–
24	−18	47,35 ± 0,22^{b}A	34,95 ± 0,23^{b}D	82,30 ± 0,23^{b}D
	5	47,54 ± 0,15^{b}H	33,78 ± 0,17^{c}B	81,32 ± 0,16^{c}B
	23	47,02 ± 0,19 A	36,36 ± 0,16 A	83,38 ± 0,18 A
	40	–	–	–

[a] The means within a column (the difference between the storage temperature) followed by different superscript letters differ (P < 0.05). The means within a column (the difference between the storage period) followed by different capital letters differ (P < 0.05). The dash (–) symbol indicates an analysis that has not been performed due to an unsatisfactory sensory analysis as defined in chapter 2.1 in material and method section.

Table 6
Results of determination of saccharide content (g/100 g) of the sweetened hazelnut cocoa spread stored during 24-month period at four different temperatures (−18 °C, 5 °C, 23 °C and 40 °C). The results are expressed as means ± standard deviation (n = 27). [a].

storage time (months)	storage temp. (°C)	Sucrose	Lactose	Sum
0	23	48,90 ± 0,13 A	9,28 ± 0,02 A	58,18 ± 0,08 A
1	40	47,22 ± 0,06 B	8,24 ± 0,13 B	55,46 ± 0,10 B
3	−18	48,18 ± 0,06^{a}B	8,37 ± 0,14^{a}B	56,56 ± 0,10^{a}B
	5	48,95 ± 0,15^{b}A	8,49 ± 0,02^{a}B	57,44 ± 0,09^{b}B
	23	47,19 ± 0,20^{c}B	8,06 ± 0,02^{b}B	55,25 ± 0,11^{c}B
	40	48,97 ± 0,16^{b}A	7,84 ± 0,05^{c}C	56,80 ± 0,11^{d}C
6	5	50,96 ± 0,28^{a}B	7,99 ± 0,04^{a}C	58,95 ± 0,16^{a}C
	23	49,97 ± 0,19^{b}C	7,85 ± 0,06^{b}C	57,82 ± 0,13^{b}C
	40	49,16 ± 0,23^{c}C	7,71 ± 0,04^{c}C	56,87 ± 0,14^{c}C
9	5	45,75 ± 0,06^{a}C	9,10 ± 0,07^{a}A	54,85 ± 0,07^{a}D
	23	47,81 ± 0,07^{b}D	7,52 ± 0,05^{b}CD	55,32 ± 0,06^{b}B
	40	–	–	–
12	−18	50,60 ± 0,11^{a}C	8,34 ± 0,04^{a}B	58,93 ± 0,08^{a}C
	5	50,37 ± 0,09^{b}D	8,51 ± 0,08^{b}B	58,88 ± 0,09^{a}C
	23	–	–	–
	40	–	–	–
15	5	–	–	–
	23	–	–	–
	40	–	–	–
18	5	–	–	–
	23	–	–	–
	40	–	–	–
21	5	–	–	–
	23	–	–	–
	40	–	–	–
24	−18	50,15 ± 0,19 D	8,19 ± 0,13 B	58,34 ± 0,16 A
	5	–	–	–
	23	–	–	–
	40	–	–	–

[a] The means within a column (the difference between the storage temperature) followed by different superscript letters differ (P < 0.05). The means within a column (the difference between the storage period) followed by different capital letters differ (P < 0.05). The dash (–) symbol indicates an analysis that has not been performed due to an unsatisfactory sensory analysis as defined in chapter 2.1 in material and method section.

Czech honeys as described by Vorlová et al. (2018) and similarly for Polish and Slovak honeys (Tomczyk et al., 2019). Based on the obtained values from rheology, AAJ falls into the category of weak gels as stated by Clark and Ross-Murphy (2005) and Gunasekaran and Ak (2000).

5. Conclusion

This study evaluated the effect of four different storage temperatures (−18, 5, 23 and 40 °C) on the quality of saccharide-based foods (apricot-apple jam, flower meadow honey, sweetened hazelnut cocoa spread) over a period of 24 months. Samples stored at −18 °C (simulating storage conditions in the arctic zone) had the least impact on physico-chemical changes and, at the same time, their sensory quality was well preserved. Storage at 5 °C (a reference temperature – chill chain) and 23 °C (simulating storage conditions in the temperate zone) generally caused slight changes on the physicochemical changes of AAJ, FMH and SHCS. A storage temperature of 40 °C (simulating storage conditions in the (sub)tropical zone) caused the huge deterioration of tested foodstuffs. Storage of all samples at ≤ 23 °C appeared to be safe from a microbiology perspective, while storage at 40 °C was not recommended when exceeding a storage period of 12 months. Therefore, AAJ and FMH should only be considered for storage at 40 °C for a period of 12 months. On the contrary, with a temperature under 23 °C the storage time can exceed a period of 2 years. The same conclusion can be stated for SHCS, but only when stored at −18 °C. A storage period of 9 months should not

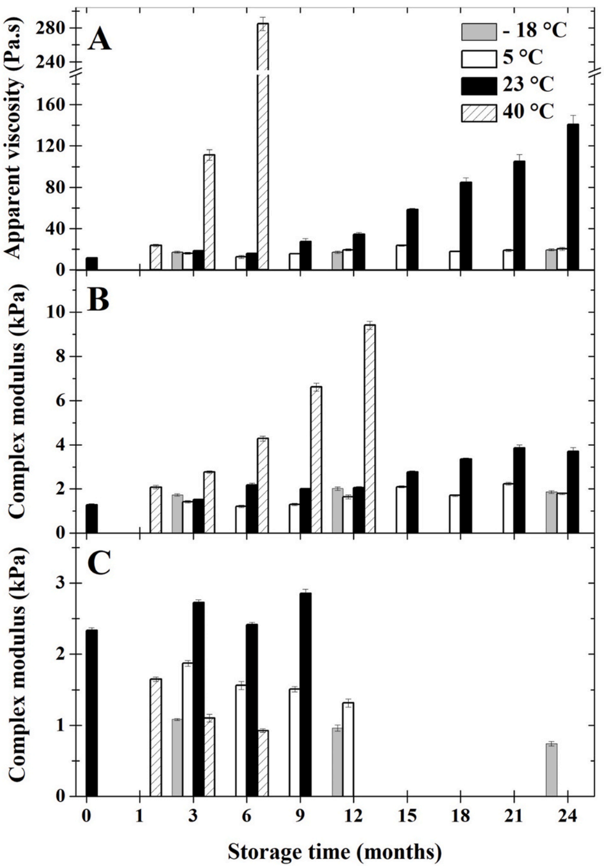

Fig. 1. The dependence of apparent viscosity (Pa·s) of the flower meadow honey sample (part A), the complex modulus G* (kPa) of the apricot apple jam sample (part B) and the complex modulus G* (kPa) of the sweetened hazelnut cocoa spread sample (part C) on various temperature regimes (– 18 °C light grey columns; 5 °C white columns; 23 °C black columns; and 40 °C dense section line columns) and storage time (months). The results are presented as means ± standard deviations (n = 27).

be exceeded within the range of 5–23 °C; at 40 °C it should not even exceed 6 months. These conclusions were primarily determined due to increased ammonia and TBARS values (rancid taste), and decreased saccharide and amino acid contents. Based on these findings, the tested AAJ and FMH meet the requirements for the minimum durability of the individual combat ration components and are also appropriate for usage of the state material reserves.

Declarations of interest

None.

CRediT authorship contribution statement

Tomáš Šopík: Methodology, Investigation, Formal analysis, Writing – original draft, Revision. **Zuzana Lazárková:** Methodology, Investigation, Writing – original draft, Revision. **Leona Buňková:** Methodology, Investigation, Writing – review & editing, Revision. **Khatantuul Purevdorj:** Methodology, Investigation, Writing – review & editing. **Richardos Nikolaos Salek:** Methodology, Investigation, Writing – review & editing, Revision. **Jaroslav Talár:** Methodology, Writing – review & editing. **Martin Novotný:** Methodology, Writing – review & editing. **Pavel Foltin:** Methodology, Writing – review & editing. **Vendula Pachlová:** Methodology, Investigation, Writing – review & editing. **František Buňka:** Conceptualization, Data curation, Visualization, Supervision, Project administration, Writing – original draft, Revision, Impact of long-term storage on the quality of selected sugar-based foods stored at different temperatures.

Declaration of competing interest

We would like to submit the enclosed manuscript entitled "Impact of long-term storage on the quality of selected sugar-based foods stored at different temperatures", which we wish to be considered for publication in LWT. Moreover, no conflict of interest exits in the submission of this manuscript, and the manuscript is approved by all authors for publication. I would like to declare on behalf of my coauthors that the work described was original research that has not been published previously, and not being under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2022.113095.

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