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Quality evaluation of white brined cheese stored in cans as affected by the storage temperature and time

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ABSTRACT

The microbiological, chemical, physical and organoleptic changes of white brined cheese stored under four different temperatures (−18; +6; +22 and + 40 °C) for a period of 6 months were evaluated. The samples were stable from microbiological point of view when stored up to +22 °C. The growth of microorganisms was significant after 1-month storage at +40 °C ($P < 0.05$). The dry matter, fat and protein contents increased and the pH-values decreased during 6-months storage ($P < 0.05$) and the rate was affected by the temperature used ($P < 0.05$). The ammonia content, TBARS-value (a marker of oxidation stability) and free amino acid content of white brined cheese significantly increased due to the prolonging of the storage time ($P < 0.05$) and elevating temperature ($P < 0.05$). The corrected stress and elongational viscosity increased ($P < 0.05$) with the extended storage time and higher temperature.

1. Introduction

Milk and dairy products are recognised as important sources of energy and contain essential nutrients including proteins, lipids, minerals and vitamins and in some cases also important sources of lactose. Milk proteins and their fractions are the main source of bioactive peptides, which are considered as potential ingredients for health-promoting functional foods (Vargas-Bello-Pérez, Márquez-Hernández, & Hernández-Castellano, 2019). Thorning et al. (2016) stated that the intake of dairy products might improve body composition and it was associated with reduced risk of type 2 diabetes, a reduced risk of cardiovascular disease (e.g., stroke) and a reduce risk of colorectal cancer, bladder cancer, gastric cancer and breast cancer. In addition, there is a beneficial effect of milk and dairy products intake on bone mineral density. According to Barać, Pešić, Vučić, Vasić, and Smiljanić (2017) and Gantner, Mijić, Baban, Škrtić, and Turalija (2015), white brined cheese are also a good source of bioactive peptides and proteins. Moreover, milk and dairy products are also good sources of energy especially due to dairy fat.

On the other hand, milk and the most of dairy products due to their high nutritional value together with practically neutral pH-value and high water activity could serve as an excellent growth medium for different microorganisms, whose multiplication depends mainly on temperature and on the presence of competing microorganisms and their metabolic products (Claeys et al., 2013). Therefore, when there is a need of use in dairy products with prolonged shelf-life, various approaches shall be applied for preservation and for food safety maintaining of the latter mentioned foodstuffs, e.g., heat treatment (ultra-high temperature for long-life milk, condensed milk and creams or sterilisation in containers and/or doses for sterilised processed cheese), reduction of pH (yoghurts and generally, fermented dairy products), reduction of water activity due to evaporation and drying (dairy powders) and addition of saccharose in condensed milk or salting of cheese and/or of course chill chain (Buňka, Štětina, & Hrabě, 2008; Bylund, 1995;

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Lazárková et al., 2011). The special case of a cheese, so called white brined cheese (WBC), the most of which is transported and stored in brine (NaCl solution). White cheese is a brined cheese variety with a semi-soft or semi-hard texture and a salty, acid taste. Furthermore, salt acts as a preservative that permits the cheese to be held in the warm prevailing climate. Salt plays a multi-faceted role in cheese ripening and influences the physical, chemical and biological properties of cheese including proteolysis and flavour development (Hayaloglu, Guven, & Fox, 2002). In addition, the higher the NaCl concentration (in the brine), the higher are the salt, fat and protein contents and lower is the moisture content (Madadlou, Khororowshahi-asl, Mousavi, & Farmani, 2007).

Recently, several humanitarian and/or military missions are in motion worldwide and the food safety feeding shall be guaranteed for the personnel of those missions (Tulach & Foltin, 2019). According to AMedP-4.6 (2019), local food source could also be used, but local suppliers shall be approved by medical authorities using audit principles and risk assessment evaluation (AMedP-4.5, 2019). Therefore, some groups of foodstuffs are possible to be purchased from local producers (such as local fresh fruits and vegetables, bread and baked products, milk and dairy products, and some special items that are not frequently required). On the other hand, this possibility could be limited and is strongly dependent on the actual offer in a local market (Foltin, Brunclík, Ondryhal, & Vogal, 2018). For example, the offer of milk and dairy products from local producers is deficient in some of regions, where missions are recently carried out, and these countries are usually not self-sufficient in these commodities (Kumar, Joshi, Kumar, & Parappurathu, 2014; Yigrem et al., 2015). Actually, most of the food is imported from the home bases (countries).

Nowadays, missions occur at various climate zones (especially in subtropical and tropical), the distances from the home bases are long and the shipping could span for weeks. Therefore, foodstuffs with prolonged shelf-life are essential for transport and also storage in places where an operation is realised. Moreover, during transportation and subsequently storage in areas of humanitarian and/or military missions, the temperature in stocks could be elevated above +25 °C. The latter mentioned temperatures could lead to protein and fat changes and reactions such as complex of the Maillard reaction, the Strecker degradation and/or lipid oxidation could also occur. When foodstuffs are not sterilised, microbiological quality would be changed and food safety should be evaluated. Last but not least, texture properties would be influenced due to the above mentioned reasons (Bubelová et al., 2015; Friedman, 1996; Kadidlová, Cyprisová, Hoza, & Budinský, 2010; Kristensen & Skibsted, 1999; Pizzoferrato et al., 1998). On the other hand, the logistic chains could also lead through arctic areas with temperature below −10 °C (Tulach & Foltin, 2019).

As it was described above, dairy products are very important for maintaining of a good health, physical performance and cognitive function. Short shelf-life of the most of the dairy products (especially under "non-chilled" and elevated temperatures) and limited local offer (recently, missions often are in motion in areas with a lack of offer and/or low level of dairy industry and especially local hand-made traditional production predominates) result in insufficient presence of this goods in personnel feeding. A similar situation is also in cases, when only foodstuffs as humanitarian support (without permanent presence of mission personnel) are delivered because many affected areas are in subtropical and tropical zones. For this purpose, WBC would be appropriate because its shelf-life is prolonged due to the presence of brine. This type of cheese is widely used in the Balkan area and also the Near and Middle East with warm climate conditions and chill chain is not always maintained (Hayaloglu, Ozer, & Fox, 2008). On the other hand, there is practically no information about possible quality changes of WBC during long storage under different temperatures covering different climatic zones neither in the literature nor from producers.

Therefore, the aim of the current study was to evaluate the microbiological, chemical, physical and organoleptic changes of WBC stored at four different temperatures (−18; +6; +22 and + 40 °C) for a period of 6 months. The temperatures of +22 °C and +40 °C represented transportation through subtropic and tropic areas without any possibility of cooling chain (including storage conditions). The temperature of −18 °C simulated shipping under arctic conditions and +6 °C was used as "reference". Secondary, based on the results, food safety assessment was carried out and combination of critical levels of the storage temperature and time were estimated.

2. Material and methods

2.1. White brined cheese sample manufacture and sampling

Model white brined cheeses ("Balkan cheese") in tinned can were manufactured using industrial plants in a factory regularly producing the above mentioned type of cheese in the Czech Republic (Dairy Plant Polná, Ltd., Polná). The manufacturer exports these products in many countries of the Southern Europe region and also the Near and Middle East. For cheese samples manufacture, a slightly modified protocol previously published in the work of Pachlová et al. (2016) was used. Briefly, raw milk from cow (acidity ranged from 0.13 to 0.15%, w/w; expressed as lactic acid content) was clarified (using filters) and standardised with respect to the casein:fat ratio, pasteurised at +78 °C for 20 s, cooled to +31 ± 1 °C and transferred to a cheese vat (5000 L). Then starter culture (commercial concentrated lyophilised mesophilic starter contained: *Lactococcus lactis* subsp. *lactis*, *L. lactis* subsp. *cremoris* and *Leuconostoc* spp.; Chr. Hansen, Hørsholm, Denmark) and 0.08% (w/w) $CaCl_2$ were added for the improvement of the clotting properties of the heat-treated milk to increase yield. The inoculated milk was held for 30 min at +31 ± 1 °C and liquid rennet (Chy-Max M 1000, 950 IMCU mL^{-1}; Chr. Hansen) was added at a level of 215 mL that is sufficient to coagulate the milk in 31–33 min. The coagulum was cut into cubes and stirred for reaching the final size of approximately 1 cm (40 min). The curd was then transferred into stainless steel moulds and covered with cheese cloth, followed by a plate. Pressure was applied at a temperature of +21 ± 2 °C (ambient temperature) for 25 min (15 min at 0.015 MPa and then 10 min at 0.030 MPa). The plate and also the cheese cloth were removed and the curd was divided into blocks of about 6 × 6 × 2 cm. The blocks were placed in brine (18–20%, w/w) for 16 h at +16 ± 1 °C. One kilogram of brined and drained blocks was then arranged on the bottom of a tinned can, 500 g of brine (17–19%, w/w) were added, and thereupon the can was closed and stored for 2 days at +6 ± 2 °C for stabilisation of the environment in the cheese. Then, cans were divided into four groups and stored at four different temperatures (−18; +6; +22 and + 40 °C) for a period of 6 months. The same protocol was repeated five times (5 independent lots).

All below described analyses were applied after 2 days of storage at +6 ± 2 °C (signed as "time 0") and then after 3 and 6 months (calculated from "time 0") under all four temperatures applied (−18; +6; +22 and + 40 °C). In the case of temperature of +40 °C, the samples were analysed also after 1 month of storage because more intensive changes were expected. Three cans were always sampled for all analyses applied (5 lots × 3 cans = 15 tested cans for all times and temperatures).

Each analysis (excluding sensory analysis) were carried out in duplicate for each can (15 cans sampled × 2 repetitions = 30

analyses; n = 30). Sensory analysis was performed using 12 assessors trained according to ISO 8586:2012 (ISO, 2012; see subsection 2.5) and all lots were evaluated (5 lots × 12 assessors = 60 assessments; n = 60). All samples for each analysis was tempered to +20 ± 1 °C using climatic chamber (24 h before analysis).

2.2. Microbiological analysis

The total number of aerobic and/or facultative anaerobic mesophilic microorganisms was determined according to ISO 4833−1:2013 (ISO, 2013), the lactic acid bacteria according to ISO 15214:1998 (ISO, 1998), coliforms number according to ISO 4832:2006 (ISO, 2006a), number of aerobic and anaerobic spore-forming microorganisms according to Harrigan (1998) and number of yeasts and/or moulds according to ISO 6611:2004 (ISO, 2004a).

2.3. Chemical analysis

The dry matter, fat and protein contents were determined according to ISO 5534:2004 (ISO, 2004b), ISO 1735:2004 (ISO, 2004c) and ISO 8968−1:2014 (ISO, 2014), respectively. The pH was measured using a pH-meter equipped with a glass tip electrode (pH Spear, Eutech Instruments, Oakton, Malaysia) into the samples.

The ammonia content was determined by the microdiffusion method of Conway, as described by Buňka, Hrabě, and Kráčmar (2004). Lipid oxidation was evaluated by the 2-thiobarbituric acid method described by Kristensen and Skibsted (1999) as "TBARS value". Results were expressed as absorbance units per mg of sample (λ = 532 nm for red pigment and λ = 450 nm for yellow pigment).

The determination of free amino acid (FAA) content was realised in accordance with the process previously performed by Buňková et al. (2009) and Pachlová et al. (2011) using the AAA 400 amino acid analyser (Ingos, Prague, Czech Republic). The FAA content was calculated as a sum of 22 individual FAA and the content of similar substances (γ-aminobutyric acid, alanine, aspartic acid, asparagine, arginine, citrulline, cysteine, glutamic acid, glutamine, glycine, histidine, isoleucine, leucine, tyrosine, lysine, methionine, ornithine, phenylalanine, proline, serine, threonine, valine; results were expressed in g kg^{-1}). Additionally, prior to the particular determination each WBC was lyophilised (Christ Alpha 1−4, Christ, Osterode, Germany).

2.4. Texture analysis

The cylindrical WBC samples (diameter 35 mm, height 10 mm) were compressed to failure using the TA.XTplus texture analyser (Stable Micro Systems Ltd., Godaming, UK) equipped with a 100 mm in diameter plate aluminium probe. A special software Exponent Lite (version 4.0.13.0; Stable Micro Systems Ltd.) enabled data collection and expressing them into digitised force−time curves. The following parameters were set up: 50% strain; trigger force 5 g; deformation rate 2 mm s^{-1}; temperature +20 ± 1 °C. From the force−time curve, the hardness values were obtained as the maximum force (N) observed during the compression. The force versus time data were converted to a corrected stress, Hencky strain, Hencky strain rate and elongational viscosity using the following equations:

$$\sigma_C = \frac{F(t)H(t)}{A_0 H_0} \quad (1)$$

$$\varepsilon_H = \ln\left(\frac{H_0}{H_{(t)}}\right) \quad (2)$$

$$\dot{\varepsilon_H} = \frac{v}{2H_{(t)}} \quad (3)$$

$$\eta_E = \frac{2F(t)H(t)}{\pi r^2 v} \quad (4)$$

where σ_C is the corrected momentary stress (Pa), ε_H the dimensionless momentary Hencky strain, $\dot{\varepsilon_H}$ Hencky strain rate (biaxial extensional strain rate; s^{-1}), η_E elongational viscosity (Pa·s), $F(t)$ the momentary force at time t (s), H_0 the initial cylindrical sample height (m), $H(t)$ the height (m) of the deformed sample at the time t, A_0 the cross-sectional area of the original sample (m^2), v the velocity (deformation rate; m s^{-1}) and r is the radius of the sample (m) (Chatziantoniou, Thomareis, & Kontominas, 2019; ISO, 2006b; Kampf & Nussinovitch, 1997; Wium & Qvist, 1997).

2.5. Sensory analysis

Sensory evaluation was carried out at each sampling time by a panel consisting of 12 selected assessors and experts trained according to the ISO 8586:2012 (ISO, 2012). A seven-point hedonic scale (1-excellent, 4-good, 7-unacceptable) for appearance, consistency and flavour; a seven-point intensity scale (1-soft, 4-medium, 7-extra hard) for hardness; and a seven-point intensity scale (1-negligible, 4-medium, 7-excessive) for off-flavour were used for the assessment of WBC. The samples were served in random order and at controlled temperature of +20 ± 2 °C in a sensory laboratory equipped with sensory booths (under normal light condition) in accordance to ISO 8589 (ISO, 2007). Water was provided for mouth rinsing between the tested WBC samples evaluation to avoid carry-over effects.

2.6. Statistical analysis

The obtained experimental data were analysed using the Unistat® 6.5 (Unistat, London, UK) statistical software. Kruskal−Wallis and Wilcoxon tests were applied for the evaluation of the results. Correlation analysis was also carried out using Spearman correlation coefficient. Significance was considered as $P < 0.05$.

3. Results and discussion

3.1. Results of microbiological analysis

At the beginning of the storage ("time 0" − see above), the total number of aerobic and/or facultative anaerobic mesophilic microorganisms (TC) were in the interval of 3.71−3.99 log cfu g^{-1} (colony forming units per gram of the tested sample). The number of aerobic and anaerobic spore-forming microorganisms ranged between 1.40 and 1.81 log cfu g^{-1} and 1.28 to 1.54 log cfu g^{-1}, respectively. From the lactic acid bacteria (mainly starter cultures) development point of view, the amount was in the range of 8.51−8.82 log cfu g^{-1}. During storage at −18 °C, the level of TC and spore-forming microorganisms remained stable and after 6 months, the numbers were in the same logarithmic order in comparison with the amounts at the beginning ($P \geq 0.05$). When storage temperatures were elevated to +6 and + 22 °C, the numbers of TC and spore-forming microorganisms increased by approximately one logarithmic order ($P < 0.05$) after 3-month storage. The final amount

(after 6 months) of TC, aerobic and anaerobic spore-forming microorganisms also increased ($P < 0.05$) to 5.42–5.67 log cfu g^{-1}, 2.86–2.99 log cfu g^{-1} and 3.63–3.98 log cfu g^{-1}, respectively. During 1-month storage at +40 °C, significant increase ($P < 0.05$) by two logarithmic orders (TC) and one logarithmic order (spore-forming bacteria) were already observed. After 3 months at +40 °C, the raising of the concentrations of TC, aerobic and anaerobic spore-forming microorganisms were also observed ($P < 0.05$): 7.28–7.79 log cfu g^{-1}, 4.59–4.88 log cfu g^{-1} and 4.79–4.99 log cfu g^{-1}, respectively. Follow-up storing at +40 °C led to subsequently count increase of TC, aerobic and anaerobic spore-forming bacteria ($P < 0.05$) and after 6 month the numbers reached eight, five and six logarithmic orders, respectively. In general, it could be reported that the higher the storage temperature was used, increased numbers of TC and spore-forming microorganisms were observed ($P < 0.05$). At the end of the experiment, regardless of the storage temperatures, the number of lactic acid bacteria was in the interval of 6.43–6.72 log cfu g^{-1}. No coliforms, yeasts and/or moulds were detected in any samples tested during the 6-month storage period.

The higher amounts of lactic acid bacteria in comparison with TC (at the beginning of the storage) could be explained that the agar for TC is not rich enough for the cultivation of lactic acid bacteria; therefore, many lactic acid bacteria did not grow in the agar. The growth of bacteria counts was noticed also by Cagri-Mehmetoglu (2018) during ripening/storage of the WBC samples. Cankurt (2019) obtained higher numbers of TC after 30 days of ripening/storage of WBC at +4 °C and the counts ranged in 8–9 logarithmic orders. It could be concluded that the hygienic standards in our used industrial factory were very good, because especially at the beginning of the storage ("time 0"), the TC numbers were relatively low and probably starter cultures were in common amounts (Bylund, 1995). The latter mentioned findings are very important for food safety maintenance and is necessary to have a product (in "time 0") that will possess the microorganism counts as low as possible.

From the above mentioned results, it could be concluded that the storing of WBC up to 6 months at temperatures $\leq$ +22 °C seemed to be safe from microbiology analysis and food safety management point of view. On the other hand, in the case of samples stored at +40 °C, it is not recommended to maintain them under the latter mentioned temperature more than 1 month.

3.2. Results of chemical analysis

The results of dry matter, fat, crude protein, ammonia contents, pH-values, TBARS-value and hardness of WBC stored during 6 months at four temperatures (from −18 to +40 °C) are shown in Table 1. The dry matter, fat and crude protein contents at the beginning of the storage corresponded with common results of WBC standardly produced in the industrial factory ($P \geq 0.05$). The pH-values at the "time 0" were 5.00 ± 0.02 (Table 1), which correspond with the results in the works of Cankurt (2019) and Cinbas and Kilic (2006).

During the 6-month storage period, a significant increase of the dry matter content of the WBC was observed (Table 1; $P < 0.05$). The latter mentioned growth was more intensive when higher storage temperature were used and also with the prolonging of the storage time. Moreover, a similar rate of the dry matter content rise was noticed also by Hayaloglu et al. (2008), who stored Turkey Mihalic Cheese for 90 days at +4 to + 5 °C. According to Floury, Jeanson, Aly, and Lortal (2010), the reason of the above-mentioned phenomena could lie in a net movement of Na^+ and Cl^- ions (after placing the samples in the brine), from the brine into the cheese, resulting from the osmotic pressure difference between the cheese moisture and the brine. Consequently, moisture diffuses occur throughout the cheese matrix to restore osmotic pressure equilibrium. The transport of salt and moisture could be exactly described using the "effective diffusion coefficient" (m^2 s^{-1}). The effective diffusion coefficient for both salt and moisture increase with the raising of the storage temperature. Turhan (1996) and Turhan and Kaletunc (1992) observed that the temperature elevation from +4 to +20 °C led to an increase of the effective diffusion coefficient for salt and water from 2.1 × 10^{-10} m^2 s^{-1} to 4.0 × 10^{-10} m^2 s^{-1} and 1.7 × 10^{-10} m^2 s^{-1} to 3.6 × 10^{-10} m^2 s^{-1}, respectively. In addition, in the above-mentioned works a similar WBC was used as in our study, especially from the points of view of the dry matter and fat contents.

The crude protein and fat contents also raised ($P < 0.05$) during the 6-months storage (Table 1) and the increase positively correlated ($P < 0.05$) with the temperature used. From the point of view of the growth rates in the individual storage temperatures, it could be concluded that the increase was caught by the moisture decrease. Hayaloglu et al. (2008) also observed a similar rate of the crude protein and fat rise and supported the above-mentioned reasoning. In Table 1, the development of the pH-values of WBC depending on the storage temperature and time is presented. The pH-values of WBC decreased with increasing of the storage temperature ($P < 0.05$) and also with the prolonging of the storage time ($P < 0.05$). The rate of the reduction of the WBC pH-values in time at +4 to +5 °C was similar to the rate published by Cankurt (2019).

Table 1
The dry matter, crude protein, fat, total free amino acids (FAA) and ammonia content, TBARS-value, pH and hardness of white brine cheese stored in cans during a 6-month period at four different temperatures (−18 °C, +6 °C, +22 °C and +40 °C).[a]

Storage time (months)	Storage Temperature (°C)	Dry matter content (%, w/w)	Crude protein content (%, w/w)	Fat content (%, w/w)	Ammonia content (mg 100 g^{-1})	TBARS Value (AU mg^{-1})	pH-value (−)	Total FAA content (%, w/w)	Hardness (N)
0	–	41.87 ± 0.11^{A}	14.85 ± 0.52^{A}	20.4 ± 0.7^{A}	15.2 ± 0.3^{A}	7.2 ± 0.1^{A}	5.00 ± 0.02^{A}	0.05 ± 0.00^{A}	39.4 ± 1.5^{A}
1	40	55.11 ± 0.07^{B}	19.70 ± 0.65^{B}	27.4 ± 0.9^{B}	43.2 ± 0.9^{B}	18.5 ± 0.4^{B}	4.80 ± 0.01^{B}	0.97 ± 0.04^{B}	161.6 ± 2.5^{B}
3	−18	46.83 ± 0.04 ^{aB}	16.43 ± 0.30 ^{aB}	22.1 ± 0.7 ^{aB}	15.5 ± 0.3 ^{aA}	23.1 ± 0.5 ^{aB}	4.69 ± 0.01 ^{aB}	0.18 ± 0.01 ^{aB}	48.0 ± 1.0 ^{aB}
	6	48.21 ± 0.07 ^{bB}	16.97 ± 0.37 ^{bB}	23.1 ± 0.6 ^{bB}	20.3 ± 0.4 ^{bB}	24.5 ± 0.5 ^{bB}	4.48 ± 0.01 ^{bB}	0.49 ± 0.02 ^{bB}	57.9 ± 1.1 ^{bB}
	22	55.62 ± 0.11 ^{cB}	20.04 ± 0.46 ^{cB}	26.9 ± 0.8 ^{cB}	38.1 ± 0.7 ^{cB}	28.1 ± 0.6 ^{cB}	4.37 ± 0.02 ^{cB}	1.03 ± 0.08 ^{cB}	120.2 ± 2.1 ^{cB}
	40	60.66 ± 0.05 ^{dC}	21.49 ± 0.41 ^{dC}	30.2 ± 1.1 ^{dC}	53.3 ± 1.1 ^{dC}	35.9 ± 0.6 ^{dC}	4.30 ± 0.01 ^{dC}	2.16 ± 0.15 ^{dC}	183.4 ± 2.7 ^{dC}
6	−18	49.12 ± 0.08 ^{aC}	17.66 ± 0.53 ^{aC}	23.0 ± 0.6 ^{aC}	19.1 ± 0.6 ^{aB}	20.6 ± 0.5 ^{aC}	4.51 ± 0.02 ^{aC}	0.29 ± 0.01 ^{aC}	54.6 ± 1.9 ^{aC}
	6	50.36 ± 0.10 ^{bC}	17.84 ± 0.55 ^{bC}	25.1 ± 0.7 ^{bC}	25.4 ± 0.5 ^{bC}	29.5 ± 0.5 ^{bC}	4.34 ± 0.01 ^{bC}	0.98 ± 0.09 ^{bC}	83.5 ± 1.8 ^{bC}
	22	57.80 ± 0.07 ^{cC}	20.87 ± 0.72 ^{cC}	28.6 ± 0.7 ^{cC}	41.0 ± 1.0 ^{cC}	34.4 ± 0.5 ^{cC}	4.17 ± 0.01 ^{cC}	1.55 ± 0.10 ^{cC}	159.3 ± 3.0 ^{cC}
	40	61.74 ± 0.06 ^{dD}	21.89 ± 0.67 ^{dD}	31.9 ± 0.9 ^{dD}	59.7 ± 1.5 ^{dD}	55.3 ± 0.8 ^{dD}	3.94 ± 0.01 ^{dD}	3.29 ± 0.16 ^{dD}	308.3 ± 5.6 ^{dD}

[a] Abbreviation: AU, absorbance units. The results are expressed as mean ± standard deviation (n = 30); means within a column (the difference between the storage temperature) followed by different superscript lowercase letters differ ($P < 0.05$); the samples stored at different times were evaluated independently (for 3 and 6 months); means within a column (the difference between the storage period) followed by different superscript uppercase letters differ ($P < 0.05$); the samples stored at different temperatures were evaluated independently; all stored samples (from the first month of storage) were also compared with the sample at the beginning ("time 0"; in the first line).

The ammonia content, TBARS-value and FAA content of WBC significantly increased due to the prolonging of the storage time ($P < 0.05$) and also elevating temperature ($P < 0.05$) as it was depicted in Table 1. Moreover, it is obvious that the dry matter content rise is not the only one reason for the clarification of the observed phenomena. The increase of ammonia content showed that interaction of proteins and peptides could occur, especially the complex of Maillard reactions and Strecker degradation, during which ammonia is formed and liberated (Friedman, 1996; Pizzoferrato et al., 1998). Similar trends were noticed also by Bubelová et al. (2015), Kadidlová, Ciprysová, Hoza, and Budinský (2010) and Lazárková et al. (2011), where significant rise of the ammonia content was observed during the prolonging of the storage at (+6 to +40 °C).

Additionally, a significant increase of TBARS-value (Table 1; $P < 0.05$) during the 6-months storage at temperatures from −18 to +40 °C was noticed, pointing out to changes of lipids. TBARS-value is the marker of the concentration of secondary products of lipid oxidation and describe those processes very well (Kristensen & Skibsted, 1999). Therefore, it can be concluded that lipid oxidation was in progress during the 6-month storage of WBC and the rate of those processes positively correlated with the storage temperature ($P < 0.05$).

An increase of FAA content of WBC was observed during the samples storage (Table 1; $P < 0.05$) which could be caused by proteolytic reactions due to running of microbiological and biochemical processes (Cinbas & Kilic, 2006; Hayaloglu et al., 2002). The results unambiguously showed that the intensity of proteolytic interactions strongly depended on the storage temperature ($P < 0.05$), which corresponds also with the results of the microbiological analysis described above. Glutamic acid and glutamine, lysine, leucine, proline, serine and tyrosine were detected as the most abundant FAA observed in our WBC. Our levels of FAA correspond for storage under +6 °C with the papers of Cinbas and Kilic (2006), Hayaloglu et al. (2002), Öner and Saridag (2018) and Salek et al. (2020) for local WBCs and are also comparable with results of Alichanidis, Anifantakis, and Polychroniadou (1984) and Azarnia, Ehsani, and Mirhadi (1997) for world-spread Greek Feta Cheese and Iranian Brine Cheese, respectively.

3.3. Results of textural analysis

The results of deformation curves (texture analysis) were expressed using the plots corrected stress versus Hencky strain (Fig. 1) and also elongational viscosity versus Hencky strain rate (Fig. 2) up to 50% deformation. Moreover, a similar approach was used also by Chatziantoniou et al. (2019), Kampf and Nussinovitch (1997) or Wium and Qvist (1997). Figs. 1 and 2 unambiguously showed that the corrected stress and elongational viscosity increased ($P < 0.05$) with the prolonged storage time and also elevated temperature. Those results could be supported by the values of the hardness presented in Table 1. In all curves in Fig. 2, an initial sharp increase in elongational viscosity is evident, which corresponds to the transient flow regimes, followed by an approximately linear part, corresponding to the squeezing flow regime. The linear parts of the curves for samples, remained almost horizontal, with elongational viscosity becoming practically independent of Hencky strain rate. The point of the change of transient flow regime to squeezing flow regime were moved into lower levels of Hencky strain rates ($P < 0.05$) when storage temperature was increased and storage time was raised (see also in subsection 3.2 about the effective diffusion coefficient). This interpretation is in accordance with the results of Chatziantoniou et al. (2019), Kampf and Nussinovitch (1997) or Wium and Qvist (1997). When the curves for the samples stored at −18 °C for 3 and 6 months were compared with other curves, it is obvious that the dependence of the corrected stress on Hencky strain or the dependence of the elongational viscosity on Hencky strain rate had different course.

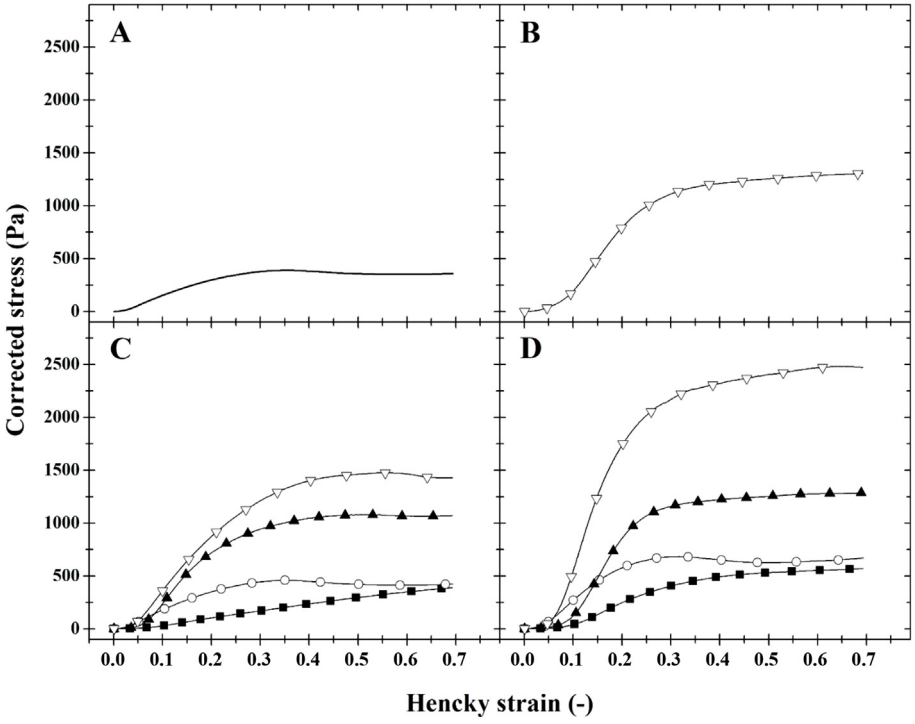

Fig. 1. The dependence of corrected stress (Pa) on Hencky strain (dimensionless) of white brine cheese stored in cans at −18 °C (■), +6 °C (○), +22 °C (▲) and +40 °C (▽) for 6 months: A, beginning of the storage, "time 0"; B, 1-month storage; C, 3-month storage; D, 6-month storage.

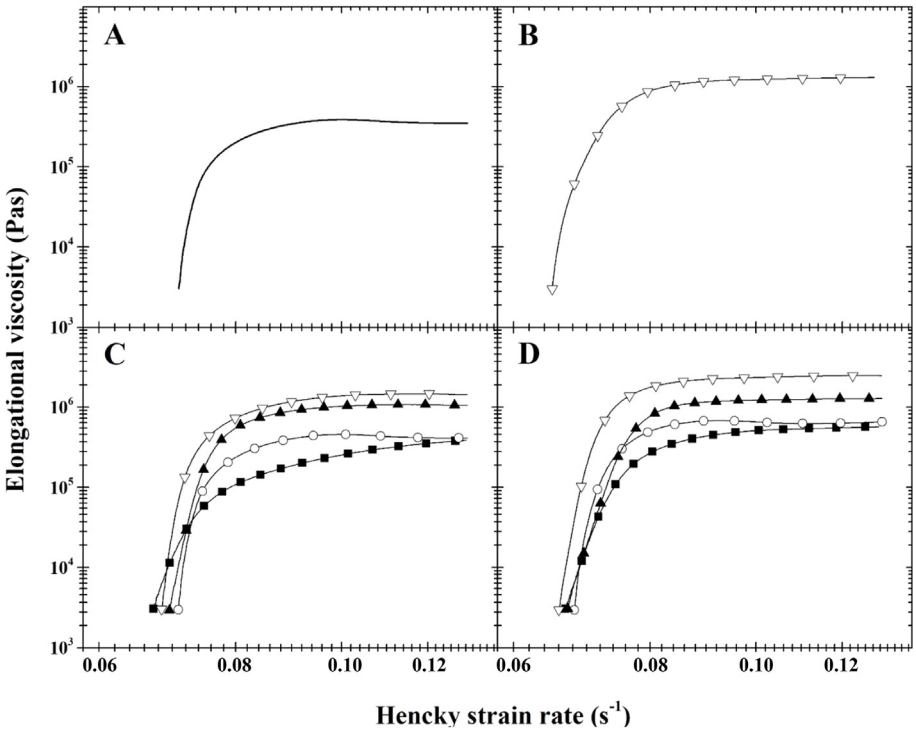

Fig. 2. The dependence of elongational viscosity (Pa s) on Hencky strain rate (s^{-1}) of white brine cheese stored in cans at −18 °C (■), +6 °C (○), +22 °C (▲) and +40 °C (▽) for 6 months: A, beginning of the storage, "time 0"; B, 1-month storage; C, 3-month storage; D, 6-month storage.

The latter mentioned phenomena could point to different structure changes of WBC stored at −18 °C in comparison with samples stored at higher temperatures. There was a possible hypothesis, that the reason could lie in different course of fat crystallisation, which was probably influenced by the storage temperature. Temperature below freezing point of water could lead to the change in polymorphisms of milk fat and therefore, to the rate of change of the relationship of α-, β′- and β-form of triacylglycerols in comparison with higher temperature, when the latter mentioned rate could be lower (Sato & Ueno, 2011).

3.4. Results of sensory analysis

The results of sensory analysis are displayed in Table 2. At the beginning ("time 0"), WBC possesses excellent appearance, consistency and flavour, medium (standard) hardness and no off-flavours. During 6-months storage, the organoleptic quality expressed as appearance, consistency and flavour was deteriorated ($P < 0.05$). The worsening was more intensive when elevated storage temperature was used ($P < 0.05$). The deteriorated organoleptic quality of WBC during storage was noticed also by Cankurt (2019). Appearance of WBC stored 3 months at −18, +6 and + 22 °C were fine and after 6 months still very good (−18 and + 6 °C) or good (+22 °C). On the other hand, the temperature 40 °C possessed a significantly deterioration effect. After 1 month, the evaluation was less good and after 3 months unacceptable. The reason could lie especially in slight browning caught by products of the Maillard reaction, which was described above (ammonia content of WBC positively correlated with evaluation of appearance; $P < 0.05$).

Table 2
Sensory analysis (appearance, consistency, hardness, flavour and off-flavour) of the white brine cheese stored in cans during a 6-month period at four different temperatures (−18 °C, +6 °C, +22 °C and +40 °C).[a]

Storage time (months)	Storage temperature (°C)	Appearance	Consistency	Hardness	Flavour	Off-flavour
0	–	1^{A}	1^{A}	4^{A}	1^{A}	1^{A}
1	40	5^{B}	5^{B}	6^{B}	5^{B}	5^{B}
3	−18	2^{aB}	2^{aB}	4^{aA}	2^{aB}	1^{aA}
	6	2^{aB}	2^{aB}	4^{aA}	2^{aB}	1^{aA}
	22	2^{aB}	3^{bB}	5^{bB}	2^{aB}	1^{aA}
	40	7^{bC}	6^{cC}	6^{cC}	7^{bC}	6^{bC}
6	−18	3^{aC}	3^{aC}	5^{aB}	3^{aC}	2^{aB}
	6	3^{aC}	3^{aC}	5^{aB}	4^{bC}	3^{bB}
	22	4^{bC}	5^{bC}	6^{bC}	5^{cC}	5^{cB}
	40	7^{cD}	7^{cD}	7^{cD}	7^{dC}	7^{dD}

[a] The results are expressed as median ± standard deviation (n = 60). The means within a column (the difference between the storage temperature) followed by different superscript lowercase letters differ ($P < 0.05$); the samples stored at different times were evaluated independently (for 3 and 6 months). The means within a column (the difference between the storage period) followed by different superscript uppercase letters differ ($P < 0.05$); the samples stored at different temperatures were evaluated independently; all stored samples (from the first month of storage) were also compared with the sample at the beginning ("time 0"; in the first line). Seven-point hedonic scales were used: appearance, consistency and flavour, (1-excellent, 4-good, 7-unacceptable); hardness, 1-soft, 4-medium, 7-extra hard; off-flavour, 1-negligible, 4-medium, 7-excessive.

Consistency of WBC after 6-months storage was evaluated as very good (−18 and + 6 °C) or good (+22 °C). The reason for worsening of consistency evaluation could be found in increase of the hardness assessed using sensory analysis and also texture analysis (see above). There was a significantly positive correlation between hardness and evaluation of consistency and also the hardness ($P < 0.05$). When storage temperature of +40 °C was used, the effect on deterioration processes of consistency was very intensive. After 1 month, the consistency was less good and the hardness was higher than standard. After 3- and 6-months storage, the consistency was not good or unacceptable, respectively, and the hardness was evaluated in the same manner (Table 2; $P < 0.05$). Strongly positive correlation between the consistency and the hardness was also observed ($P < 0.05$). The development of WBC flavour evaluation was very similar to appearance and consistency. The worsening of flavour was especially caught by products of the Maillard reactions, Strecker's degradation and/or oxidative properties. The latter mentioned findings could be supported by the evaluation of off-flavours (Table 2) and also the development of ammonia content and TBARS-value (Table 1) of WBC tested during storing. There were noticed also positive correlation between flavour evaluation and ammonia content and also TBARS-value ($P < 0.05$).

4. Conclusion

The microbiological, chemical, physical and organoleptic changes of WBC stored at four different temperatures (−18; +6; +22 and + 40 °C) for a period of 6 months were evaluated. The samples were stable from microbiological point of view when stored up to +22 °C. The growth of microorganisms was significant after 1-month storage under +40 °C. The dry matter, fat and protein contents, the ammonia content, TBARS-value and free amino acid content significantly increased and the pH-values decreased due to the prolonging of the storage time and also elevating temperature. The hardness of WBC also raised with the extended storage time and also higher temperature. The temperature +40 °C possessed a significant deterioration effect on the sensory quality and after 3 months it was evaluated as unacceptable.

When all the presented results and also principles of food safety management were taken into account, it could be concluded that WBC is practically stable when the temperature was ≤ +22 °C and the storage time up to 3 months. In the case of temperature ≤ +6 °C, the time for transport and storage could be minimally 6 months. On the other hand, responsible personnel should confirm and check that the transport temperature at +40 °C will be reached only in case of emergency and that the storage time under these conditions will be below 1 month for food safety maintenance and guarantee of good organoleptic quality.

Credit author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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