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The impact of Cheddar or white brined cheese with various maturity degrees on the processed cheese consistency: A comparative study

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ABSTRACT

This study focussed on the dependence on different emulsifying salt ternary mixture composition [disodium hydrogenphosphate (DSP), tetrasodium diphosphate (TSPP), sodium salt of polyphosphate (P20; number of phosphate units in the chain ≈ 20), trisodium citrate (TSC)] of hardness and gel strength of spreadable processed cheese (PC) manufactured from Cheddar and white brined cheeses. All PC samples were stored for 60 days (6 ± 2 °C). The hardest PC and samples with the highest gel strength were those produced from DSP and TSPP in a ratio 1:1. The hardness of all examined samples increased with the extending storage period, whilst their hardness and gel strength decreased with the rising maturity degree of the raw material utilised. Furthermore, higher values of gel strength were reported for the PC samples produced with Cheddar cheese in comparison with those made from white brined cheese.

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1. Introduction

Processed cheese (PC) is a viscoelastic dairy-based gel described also as a stable oil-in-water emulsion (Chen & Liu, 2012; Hanaei, Cuvelier, & Sieffermann, 2015; Lee, Buwalda, Euston, Foegeding, & McKenna, 2003). In traditional PC production, the main raw material is natural cheese of various degrees of maturity. The types of cheese predominantly used in different world areas vary (including Cheddar, Dutch-type, Swiss-type, mozzarella and white brined cheeses). In the English-speaking countries (e.g., Britain, USA, Canada, Australia, New Zealand) the main raw material for PC production is usually Cheddar (CDC) and mozzarella cheeses (typically, e.g., for New Zealand). On the other hand, in countries around the Mediterranean area, Balkan, the Near and Middle East, white brined cheeses (WBC) represent the most consumed cheese varieties and are therefore widely used as the main raw material for the production of PC (Černíková, Nebesářová, Salek, Řiháčková, & Buňka, 2017; Moatsou & Govaris, 2011). Many dairy ingredients (e.g., anhydrous butterfat, butter, cream, milk powder, whey, buttermilk, caseinates, coprecipitates) or non-dairy components (e.g., stabilisers, preservatives, flavouring agents, hydrocolloids, acidifying agents) can be optionally added into the mixture of raw materials. Besides the ingredients in the formulation, physicochemical, technological, and microbiological factors could affect the properties of the final PC (Ferrão et al., 2016; Kapoor & Metzger, 2008).

The desired final smooth and homogeneous matrix of PC is formed by blending shredded natural cheese in the presence of emulsifying salts (ES; mainly, sodium salts of phosphates, polyphosphates, citrates or combinations of these), heated under partial vacuum and constant shear, commonly in a temperature range of 90 to 100 °C. ES are essential components in the formulation. The addition of ES results in ion exchange of calcium and sodium ions and, subsequently, casein dispersion. The dispersed proteins (sodium paracaseinates) can serve as effective surface active substances and emulsify the dispersed free fat globules. The control and stabilisation of the pH level and an influence on the formation of the final casein network over holding time at the melting temperature and/or over cooling are some additional roles of ES (Buňka et al., 2014; Chen & Liu, 2012; Dimitreli & Thomareis, 2009; Sádlíková et al., 2010 Salek, Černíková, Maděrová, Lapčík, & Buňka, 2016).

Furthermore, the consistency of PC can be affected by many factors, including, e.g.: (i) raw material composition – the type and chemical profile of the natural cheese applied (dry-matter, fat, protein, and calcium ion contents, and maturity degree), composition and concentration of ES, addition of other optional dairy and non-dairy ingredients and also the pH of the mass to be melted; and (ii) processing and storage conditions – agitation speed, target melting temperature and holding time, cooling rate and also storage temperature. Nowadays, hydrocolloids, regularly used in the production of PC, are important components affecting the consistency of PC (Dimitreli & Thomareis, 2007; Shirashoji, Jaeggi, & Lucey, 2006).

CDC is a ripened hard cheese and its body has a near white or ivory through to light yellow or orange colour. In addition, its texture can be described as firm, smooth and waxy. Furthermore, gas-holes are absent, whereas some openings and splits are acceptable. The ripening period to develop typical flavour and body characteristics is normally from 5 weeks up to 2 years (at 7–15 °C), depending on the extend of maturity required (Codex standard 263-1966; Codex Alimentarius Commission, 2013). In contrast, WBC are produced from curds that are not subjected to any elevated heating (cooking) after coagulation (such as is the case for CDC, Dutch- or Swiss-type cheeses). Their flavour is slightly acid and salty that sometimes turns to rancid and piquant. Moreover, the cheese mass has no rind, no gas-holes or other openings, except for some small mechanical openings and its texture appears to be soft but sliceable. Thus, they are consumed after several days or up to some months of ripening in brine of various NaCl concentrations (10–18 g 100 g^{-1}) (Hayaloglu, 2016; Moatsou & Govaris, 2011).

The impact of ES composition on the consistency of PC produced from different natural cheeses (the main raw material), particularly Edam (Buňka et al., 2014; Salek et al., 2015), Cheddar (Brickley, Auty, Piraino, & McSweeney, 2007), mozzarella (Chavhan, Kanawjia, Khetra, & Puri, 2015; Chen & Liu, 2012; Khetra, Chavhan, Kanawjia, & Puri, 2015; Salek et al., 2017;) and Swiss-type (Salek et al., 2016) cheeses has been previously reported. Nevertheless, research providing a direct comparison of the spread properties of PC produced under identical processing parameters and similar experimental design from two technologically very different varieties of natural cheese (CDC and WBC), and additionally with various levels of maturity, has not been performed to date. Therefore, the main aim of the present study was to compare the influence of two different varieties of natural cheese with varying levels of maturity in combination with the different composition of ES on the textural properties and the gel strength of spreadable PC during a 60-day storage period (6 ± 2 °C). Disodium hydrogenphosphate (DSP, Na_2HPO_4), tetrasodium diphosphate (TSPP, $Na_4P_2O_7$), sodium salt of polyphosphate with mean length $n \approx 20$ (P20) and trisodium citrate (TSC, $Na_3C_6H_5O_7$) were used in four types of ternary mixtures of ES. The pH of the tested samples was adjusted to the target values within the interval of 5.60–5.80, corresponding to the standard pH values of PC spreads.

2. Materials and methods

2.1. Materials

Commercially available CDC blocks [dry-matter content 62 g 100 g^{-1}; fat in dry-matter content, 50 g 100 g^{-1}; 4, 8, 12 and 16 weeks of maturity (storage at 10 ± 2 °C); 1.8 g 100 g^{-1} NaCl content], WBC blocks [Akawi-type cheese; dry-matter content 48 g 100 g^{-1}; fat in dry-matter content 38 g 100 g^{-1}; 2, 4, 8, 16 and 24 weeks of maturity (storage at 10 ± 2 °C); 7.4 g 100 g^{-1} NaCl content] and butter (dry-matter content 84 g 100 g^{-1}, fat content 82 g 100 g^{-1}) were purchased wholesale in the Czech Republic. The same batch of the individual cheese varieties was used in the whole experiment.

When Cheddar is used as raw material in Central Europe (a minority, but some producers use it), the maturity is generally approximately 8 weeks. Therefore, the half of this period and twice this period (i.e., 4–16 weeks) were chosen as an appropriate storage interval for the experiment. According to the authors' knowledge, the selected maturity interval also covers usual storage times for raw material for PC in some other countries. In the case of white brine cheese, our practical experience from the Near and Middle East shows us that the storage period could be longer than the usual 2 or 3 months. This is valid also for raw material for PC. Therefore, approximately half year was chosen as the longest storage period. DSP, TSPP and P20 were obtained from Fosfa PLC Company (Břeclav, Czech Republic); TSC, HCl, and NaOH were purchased from Sigma Aldrich Inc. (Schnelldorf, Germany). Water was also added to adjusting to the required dry matter content of the model PC.

2.2. Manufacturing procedure of the processed cheese samples

The composition of raw materials of the PC samples was calculated to achieve final products with 40 g 100 g^{-1} dry matter content and 50 g 100 g^{-1} fat in dry matter content. Moreover, four ternary mixtures of ES (TSC:TSPP:P20, DSP:TSC:P20, DSP:TSPP:P20 and DSP:TSPP:TSC) were prepared. For all four ternary mixtures the ES were blended in 12 percentage ratios (100:0:0; 50:50:0; 0:100:0; 40:40:20; 40:20:40; 20:40:40; 50:0:50; 0:50:50; 40:0:60; 20:20:60; 0:40:60; 0:0:100 – the percentages of the components were calculated on the total weight of the ES; where total weight was 100%). The total concentration of the applied ES was 3 g 100 g^{-1} of the total weight of the melt. Fig. 1 illustrates the experimental design.

A Vorwerk Thermomix TM blender cooker (2 L capacity; Vorwerk & Co Thermomix GmbH, Wuppertal, Germany) with indirect heating was employed for the production of the model PC samples in laboratory scale (the same device was used previously by Lee et al., 2004) and Nagyová et al., 2014). The manufacturing procedure was described in detail in Salek et al., 2015, 2016, 2017. The processing conditions [melting temperature 90 °C held for 1 min (total melting time: 10–12 min) at approximately 2750 rpm] were the same for all the formulations. The pH of the samples was adjusted (target values within the interval of 5.60–5.80) using acid or alkali (1 mol L^{-1} HCl or NaOH). To maintain the dry-matter content at the desired target value (40 g 100 g^{-1}), the addition of water was decreased (based on the amount of the added acid/alkali). Finally, the hot molten PC mass was poured into cylindrical plastic containers (55 mm diameter, 50 mm height) and sealed. Thereafter, the samples were left to cool and were stored under refrigeration conditions (6 ± 2 °C) until further analysis.

Analyses were performed on the 2nd, 9th, 30th and 60th day of storage; rheological analysis was undertaken on the 30th day after the production. Each PC sample tested was produced in duplicate (CDC – 4 maturity levels × 4 types of ternary mixtures × 12 percentage ratios × 2 repetitions = 384 lots; WBC – 5 maturity levels × 4 types of ternary mixtures × 12 percentage ratios × 2 repetitions = 480 lots) resulting in 864 lots in total. The raw materials applied and processing parameters were arranged to imitate industrial conditions. The samples had the same target parameters (dry matter content and pH-value) and were produced under the same conditions (e.g., the equipment, the target melting temperature, the holding time, the same packaging, the cooling time, the storage time and temperature). Therefore, the model PCs manufactured were fully comparable.

2.3. Chemical analysis of the cheese and the processed cheese samples

In the processed cheese samples, the dry matter (DM) content and the pH-values were determined. DM content was gravimetrically analysed according to ISO 5534 (ISO, 2004) by drying the samples at 102 ± 2 °C to constant mass. The pH values were determined at ambient temperature by inserting a glass tip electrode of a calibrated pH-meter (pH Spear, Eutech Instruments, Oakton, Malaysia) directly into the cheese at three randomly chosen locations.

In the cheese (CDC and WBC), the determination of free amino acid (FAA) content was undertaken in accordance with the process previously performed by Buňková et al. (2009), Hladká et al. (2014) 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 FAAs 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 natural cheese was lyophilised (Christ Alpha 1–4, Christ, Osterode, Germany) twice. Furthermore, each lyophilised sample was extracted twice and each extract was loaded on the column in triplicate (n = 12).

2.4. Hardness measurements of the processed cheese samples

The selected textural properties of the model PC samples were evaluated using a texture analyser TA.XTplus (Stable Micro Systems Ltd., Godaming, UK) equipped with a 20 mm in diameter cylindrical aluminium probe. The analysis was performed by penetration into the sample (depth 10 mm and trigger force 5 g; deformation rate was 2 mm s^{-1}) at 6 ± 2 °C (the measurement was carried out within the containers). From the force/time curves, the hardness value were obtain as the maximum force (N) observed during penetration (n = 6).

2.5. Rheological measurements of the processed cheese samples

A dynamic oscillatory shear rheometer (RheoStress 1, Haake, Bremen, Germany) equipped with a parallel plate-plate geometry having a 35 mm diameter was used for the determination of the PC viscoelastic properties. The rheological tests were carried out at 20.0 ± 0.1 °C and a gap of 1 mm was applied. Amplitude sweeps were performed to determine the linear viscoelastic regions at which the frequency sweep of the samples was obtained. During the tests, of the storage G' (elastic modulus) and G'' (viscous modulus) moduli were measured at frequencies between 0.01 and 100.00 Hz and subsequently the complex modulus (G^*) was calculated as the complex sum of G′ and G″.

The Winter and Chambon (1986) critical gel model was implemented for the changes evaluation in the samples viscoelastic properties as a function of frequency:

$$G^*(\omega) = A_F \cdot \omega^{\frac{1}{z}} \tag{1}$$

where where A_F (Pa $s^{1/z}$) represents the gel strength, ω is the frequency (Hz) and z (dimensionless) corresponds to the interaction factor. The recorded values were the mean of at least eight replicates (n = 8).

2.6. Data analysis

The experimental data obtained 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. Significance was considered as $P < 0.05$. For the estimation of A_F the method of Marquardt-Levenberg, a nonlinear regression analysis method ($A_F > 0$ and $z > 0$) was implemented. Correlation analysis was also carried out using Spearman correlation coefficient.

3. Results and discussion

3.1. Free amino acids content in Cheddar and white brined cheese

The total FAA concentrations of the CDC after 4, 8, 12 and 16 weeks were 2.75, 22.18, 41.72 and 48.66 g kg^{-1}, respectively. In comparison, in the WBC the total FAA concentrations after 2, 4, 8, 16 and 24 weeks of ripening were 8.47, 18.74, 37.96, 58.91 and 78.19 g kg^{-1}, respectively. With the prolonging of the ripening period (regardless of the natural cheese applied as the main raw material) more intensive proteolysis occurred ($P < 0.05$). Hydrolytic processing of caseins was faster in WBC in comparison with that in CDC ($P < 0.05$). A possible reason could lie in different cultures (microorganisms), which are used in the production of the above mentioned cheese. According to Fox, Guinee, Cogan, and McSweeney (2000) and Pachlová et al. (2011) it could be assumed that the amount of intact casein present in the natural cheese (main raw material) correlates with the concentration of FAA. The mean length of casein fragments after hydrolysis and so the amount of intact casein remaining could significantly influence the consistency of the PC (Diana, Rafecas, Arco, & Quílez, 2014; Petrella et al., 2015; Salek et al., 2017).

3.2. Chemical analysis of the processed cheese samples

The dry matter content (DM) of all PC samples tested (regardless of the type of cheese, the ripening period, the storage time and the composition of ES used) ranged in the interval 40.21 to 40.83 g 100 g^{-1} ($P \geq 0.05$). The composition of ES ternary mixture significantly influences the value of pH ($P < 0.05$) (Nagyová et al, 2014; Salek et al., 2015, 2016, 2017). Therefore, the pH-values were adjusted during manufacturing (see subsection 2.2). At the beginning of the storage, the pH-values of all PC without regard to the studied factors were in the interval of 5.61 to 5.84. During the 60-day storage the pH-values slightly but significantly increased by 0.1 – 0.2 ($P < 0.05$). Similar DM content and the pH-value are essential for successful comparison of consistency of the final products (Lee & Klostermeyer, 2001; Marchesseau, Gastaldi, Lagaude, & Cuq, 1997; Piska & Štětina, 2004; Sádlíková et al., 2010).

3.3. Textural and rheological properties of the processed cheese samples

For the recent study, two approaches for evaluation of PC consistency were chosen. Firstly, hardness (N) was used as the parameter describing sample behaviour under large deformation. Subsequently, the testing was enhanced by using of rheological measurements (gel strength – A_F; Pa), for studying of sample changes under small shear deformation.

The effect of three factors influencing processed cheese consistency was observed: (i) the composition of ternary mixtures of four ES; (ii) the ripening period of the main raw material – natural cheese; and (iii) the storage time up to 60 days. All these factors were studied using samples manufactured using two very different varieties of cheese – CDC and

WBC for a comparison of the effect of varying the main raw material. The results of the sample response on the large (hardness) and small (gel strength) deformations are shown in Figs. 2–7.

When ES were singly added (regardless the type of natural cheese used, the maturity level and the length of the storage period), increase of hardness and gel strength (Figs. 2–7) of PC with sodium salts of polyphosphate (P20) was observed in comparison with the samples with the other ES (DSP, TSPP and TSC; $P < 0.05$).

Sodium salt of polyphosphate probably can strongly bind calcium into complexes resulting in casein dispersion enhancement. Polyphosphates possess the strongest binding capability to bivalent ions in comparison with monophosphates, diphosphates and/or citrates (Buňka et al., 2012; Shirashoji et al., 2006). Additionally, the use of TSC resulted in PC samples with similar values of hardness to those made with TSPP ($P \geq 0.05$). Thus, TSC does not provide the ability to create new networks (Mizuno & Lucey, 2007). The results obtained are in accordance to those previously reported by El-Bakry, Duggan, O'Riordan, and O'Sullivan (2011), Nagyová et al. (2014), and Salek et al. (2015, 2016, 2017), who also used TSC.

Figs. 2, 6A and 7A illustrate the dependence of hardness and gel strength on the composition of the mixture of DSP, TSPP and P20. Regardless the other studied factors (the ripening time of raw material, the storage time and the type of cheese), there is a specific ratio of DSP and TSPP of approximately 1:1 under which the hardness and also the gel strength increased in comparison with the other mixtures of the tested ES ($P < 0.05$). This phenomenon was observed especially when the relative content of P20 was under 50%. However, this observation was not noticed when the relative ratio of P20 was over 50%. The above mentioned effect of the specific ratio of DSP:TSPP (including the dependence of the relative ratio of P20) was previously detected when Dutch-type, Swiss-type and mozzarella-type cheeses were applied (Salek et al., 2015, 2016, 2017). The explanation lies in (i) the high ability of TSPP to support forming casein gels and (ii) the small size of DSP and its capability to bind onto caseins and increase their hydration. When the relative amount of TSPP is too low, the gel is too weak due small number of interaction between caseins. On the other hand, when the relative concentration of TSPP is too high, the gel is also too weak because calcium ions are strongly bonded and are not possibly "used" during the protein network forming (Buňka et al., 2012; Kaliappan & Lucey, 2011; Mizuno & Lucey, 2007). The same effect ($P < 0.05$) was observed also when PC with the ternary mixtures of DSP:TSPP:TSC (Figs. 3, 6B and 7B). In the other samples, where DSP, TSPP and P20 were used, it was observed that with the rising relative amount of P20 in the mixture, the hardness and gel strength of the samples increased ($P < 0.05$; under the same levels of the other factors tested). The latter trend was noticed in all samples with this ternary mixture, without regard to the other tested factors (see above).

The next studied ternary mixture was the combination of DSP, TSPP and TSC. The results of consistency parameters tested are presented in Figs. 3, 6B and 7B. In some PC, the effect of TSPP on hardness and gel strength was slightly higher in comparison with the influence of TSC. In the remaining samples, the parameter tested was similar ($P \geq 0.05$) or the trend was opposite without any clear reason. The results obtained about the practical similarity of the effect of TSPP and TSC on the consistency of PC are in accordance with those previously reported by El-Bakry et al. (2011), Nagyová et al. (2014), and Salek et al. (2015, 2016, 2017). Beside that discussed above with respect to the specific 1:1 ratio of DSP and TSPP, the changes of hardness and gel strength were controlled by the relative amount of TSPP and/or TSC. When the relative amount of TSPP and/or TSC was increased in comparison with DSP, hardness and gel strength increased and vice versa ($P < 0.05$). With regard to the fact that TSC does not provide the ability of creating new networks (Mizuno &

Lucey, 2007), we could assume that the ability of ion exchange, and subsequently the intensity of caseins dispersion, are the main factors influencing hardness and gel strength in samples with this ternary mixture containing predominantly TSC. DSP possesses lower capacity of ion exchange in comparison with TSPP and/or TSC (Kapoor & Metzger, 2008; Molins, 1991). The effect of the specific ratio of DSP and TSPP 1:1 was decreasing when the relative concentration of TSC raised ($P < 0.05$). The latter mentioned trend was expected because the relative amount of the effectively and synergistically acting mixture (DSP and TSPP, 1:1) was decreasing. In most of the samples, where only TSPP and TSC were used in a ratio of 1:1, the increase of hardness and gel strength values of PC were observed ($P < 0.05$; compared with samples that also contained DSP, but excluding samples where DSP and TSPP were in ratio of approximately 1:1). The same situation was in the ternary mixture of TSC, TSPP and P20 (Figs. 5, 6D and 7D). The synergistic effect of the mixture of 50% TSPP and 50% TSC can also be expected; however, clear explanation was not found in the literature. The same phenomenon were also observed in the studies of Salek et al. (2015, 2016, 2017) where Dutch-type, Swiss-type and mozzarella type cheeses as the main raw material and the same ternary mixtures of ES were used.

Besides the effect of the specific ratios of DSP:TSPP and TSC:TSPP (described in detail above), the influence of the composition of the other ternary mixtures (DSP:TSC:P20 and TSC:TSPP:P20) on hardness (Figs. 4 and 5) and gel strength (Figs. 6C,D and 7C,D) of the samples was regulated by the ability of individual ES to ion exchange and therefore casein dispersion. The ion exchange capability of used ES was increasing in the following order: DSP > TSPP ≈ TSC > P20. The latter relationships between selected ES have been published in several articles, e.g., Dimitreli and Thomareis (2009), El-Bakry et al. (2011), Nagyová et al. (2014), Shirashoji et al. (2006), and are also in accordance with our results (Figs. 2–7).

When the relative amount of ES with better ability to exchange ions was higher, the values of hardness and gel strength increased and vice versa ($P < 0.05$).

In all four times of storage (2, 9, 30 and 60 days) and in all four types of ternary mixtures, hardness and gel strength of PC (Figs. 2–7) decreased with the rising ripening period of the CDC and also the WBC ($P < 0.05$; samples with the same time of storage and the same composition of ES were compared). The explanation of these phenomena lies in proteolysis and “shortening” of caseins in cheeses during ripening. The results of FAA analysis unambiguously showed that in CDC, and also in WBC, intensive proteolytic reactions took place (see section 3.1). When the mean length of proteins in cheese decreases, hardness and gel strength of PC is also lower and vice versa (Brickley et al., 2007; Buňka et al., 2013; Salek et al., 2015, 2016, 2017). Based on our results, we can assume that ripening period influenced the absolute values of hardness of the samples but the relations between four ES in the ternary mixtures and especially its effect on product consistency remained unchanged.

The hardness of all PC produced increased during the whole 60-day storage ($P < 0.05$) regardless of (i) the type and composition of ternary mixture; (ii) the ripening period of CDC and WBC; or (iii) the type of cheese – CDC or WBC. The absolute values of PC samples hardness (Figs. 2 and 3) increased, whereas the effect of ES was practically the same. Hardness of PC could increase, e.g., due to hydrolysis of phosphates, possible changes in the forms of binding of the salts present and thus a change in their dissociative characteristics and also due to possible changes in the crystalline modifications of milk fat (Awad & Sato, 2002; Kapoor & Metzger, 2008; Molins, 1991).

In all four types of ternary mixtures and in all days when analyses were performed, hardness and gel strength (Fig. 7) of CDC were higher ($P < 0.05$) in comparison with WBC (Figs. 2–5). This difference in the hardness and gel strength values development could be due to different chemical composition (including pH, calcium content, NaCl content, residual lactose content, etc.) and cheesemaking process of CDC and WBC (Piska & Štětina, 2004; Purna, Pollard, & Metzger, 2006). The intensity of proteolysis played also important role.

At the end of our work, correlation analysis between the values of hardness and the values of gel strength were done. The Spearman correlation coefficients for the tested ternary mixtures (calculated individually for each ternary mixture type and CDC and WBC) ranged in the interval of 0.794 to 0.922 ($P < 0.05$). This finding confirmed again that the results obtained by the equipment using large uniaxial deformation and by the equipment using small shear deformation of material were in good accordance with each other.

With respect to our previous studies (Salek et al., 2015; 2016; 2017) and our recent work, we are able to infer that the general trend of the effect of the ternary mixtures composition is the same when different natural cheeses are used as raw material. Five types of natural cheese (Dutch-type, Swiss-type, mozzarella-type, Cheddar-type and white brined-type), which are used through the whole world, were tested. In all five cheese varieties the mechanisms of function of the above mentioned ternary mixtures were practically very similar regardless of the ripening period of the cheese utilised.

4. Conclusions

The impact of the CDC and WBC maturity and different compositions of ternary mixtures of ES on the hardness and gel strength of PC during 60-days of storage was investigated. With raising storage period of the PC samples, an increase in hardness was observed. On the other hand, the hardness and gel strength of the samples decreased with prolonging of cheese ripening period for both cheeses (CDC and WBC) used as the main raw material. The hardest samples were those composed of DSP:TSPP (1:1). However, when the relative amount of DSP and TSPP (in the ratio of 1:1) were replaced by TSC or P20, the influence of the latter mentioned ratio diminished. Furthermore, higher values of hardness and gel strength were reported for the PC samples produced with CDC in comparison with those made from WBC.

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Figure legends

Fig. 1. Scheme of the experimental design with model processed cheeses manufactured using white-brined-type and Cheddar-type cheese in various time of storage and the different percentage ratios of the four types of ternary mixtures comprising DSP:TSPP:P20, DSP:TSPP:TSC, DSP:TSC:P20 and TSC:TSPP:P20 (abbreviations: DSP, Na_2HPO_4; TSPP, $Na_4P_2O_7$; P20, sodium salt of polyphosphate with mean length n ≈ 20; TSC, trisodium citrate). The model samples were tested after 2, 9, 30 and 60 days of storage.

Fig. 2. The dependence of processed cheese hardness (N) on the relative amount (%) of three emulsifying salts (disodium phosphate, tetrasodium diphosphate and sodium salt of polyphosphate) during 60-day storage at 6 ± 2 °C [results expressed as means (n = 6); processed cheese were sampled after 2 (■), 9 (■), 30 (☐) and 60 (■) days of storage]. Processed cheeses were made from white-brined-type (WBC) cheese after different time of storage (A, 2 weeks; B, 4 weeks; C, 8 weeks; D, 16 weeks; E, 24 weeks) and Cheddar-type cheese (CDC) after different time of storage (F, 4 weeks; G, 8 weeks; H, 12 weeks; I, 16 weeks). Please note the differences in y-axis values and hence the placement of panel I.

Fig. 3. The dependence of processed cheese hardness (N) on the relative amount (%) of three emulsifying salts (disodium phosphate, tetrasodium diphosphate and trisodium citrate) during 60-day storage at 6 ± 2 °C [results expressed as means (n = 6); processed cheese were sampled after 2 (■), 9 (■), 30 (☐) and 60 (■) days of storage]. Processed cheeses were made from white-brined-type (WBC) cheese after different time of storage (A, 2 weeks; B, 4 weeks; C, 8 weeks; D, 16 weeks; E, 24 weeks) and Cheddar-type cheese (CDC) after different

time of storage (F, 4 weeks; G, 8 weeks; H, 12 weeks; I, 16 weeks). Please note the differences in y-axis values and hence the placement of panel I.

Fig. 4. The dependence of processed cheese hardness (N) on the relative amount (%) of three emulsifying salts (disodium phosphate, trisodium citrate and sodium salt of polyphosphate) during 60-day storage at 6 ± 2 °C [results expressed as means (n = 6); processed cheese were sampled after 2 (■), 9 (■), 30 (☐) and 60 (■) days of storage]. Processed cheeses were made from white-brined-type (WBC) cheese after different time of storage (A, 2 weeks; B, 4 weeks; C, 8 weeks; D, 16 weeks; E, 24 weeks) and Cheddar-type cheese (CDC) after different time of storage (F, 4 weeks; G, 8 weeks; H, 12 weeks; I, 16 weeks). Please note the differences in y-axis values and hence the placement of panel I.

Fig. 5. The dependence of processed cheese hardness (N) on the relative amount (%) of three emulsifying salts (trisodium citrate, tetrasodium diphosphate and sodium salt of polyphosphate) during 60-day storage at 6 ± 2 °C [results expressed as means (n = 6); processed cheese were sampled after 2 (■), 9 (■), 30 (☐) and 60 (■) days of storage]. Processed cheeses were made from white-brined-type cheese (WBC) after different time of storage (A, 2 weeks; B, 4 weeks; C, 8 weeks; D, 16 weeks; E, 24 weeks) and Cheddar-type cheese (CDC) after different time of storage (F, 4 weeks; G, 8 weeks; H, 12 weeks; I, 16 weeks). Please note the differences in y-axis values and hence the placement of panel I.

Fig. 6. The dependence of gel strength (Pa $s^{1/z}$) of processed cheese on the relative amount (%) of three emulsifying salts (A, DSP:TSPP:P20; B, DSP:TSPP:TSC; C, DSP:TSC:P20; D, TSC:TSPP:P20; where DSP, disodium phosphate; TSPP, tetrasodium diphosphate; P20, sodium salt of polyphosphate; TSC, trisodium citrate) after 30-day storage at 6 ± 2 °C [results expressed as means (n = 6)]. Processed cheeses were made from white-brined-type (WBC) cheese after different times of storage (■, 2 weeks; ■, 4 weeks; ☐, 8 weeks; ▨, 16 weeks; ■, 24 weeks).

Fig. 7. The dependence of gel strength (Pa $s^{1/z}$) of processed cheese on the relative amount (%) of three emulsifying salts (A, DSP:TSPP:P20; B, DSP:TSPP:TSC; C, DSP:TSC:P20; D, TSC:TSPP:P20; where DSP, disodium phosphate; TSPP, tetrasodium diphosphate; P20, sodium salt of polyphosphate; TSC, trisodium citrate) after 30-day storage at 6 ± 2 °C [results expressed as means (n = 6)]. Processed cheeses were made from Cheddar-type cheese (CDC) after different time of storage (■, 4 weeks; ■, 8 weeks; ☐, 12 weeks; ■, 16 weeks).

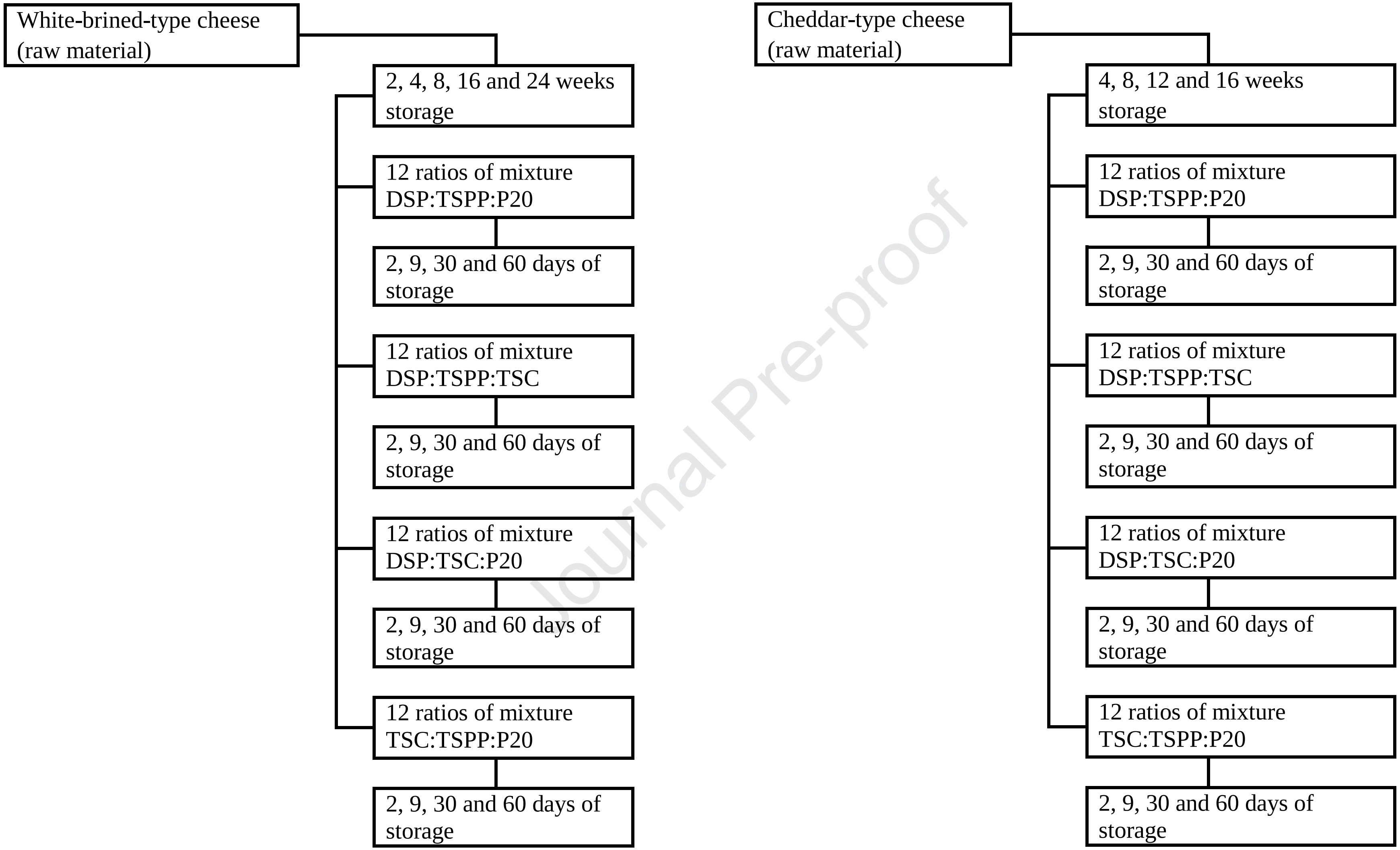
White-brined-type cheese (raw material)
2, 4, 8, 16 and 24 weeks storage
12 ratios of mixture DSP:TSPP:P20
2, 9, 30 and 60 days of storage
12 ratios of mixture DSP:TSPP:TSC
2, 9, 30 and 60 days of storage
12 ratios of mixture DSP:TSC:P20
2, 9, 30 and 60 days of storage
12 ratios of mixture TSC:TSPP:P20
2, 9, 30 and 60 days of storage
Cheddar-type cheese (raw material)
4, 8, 12 and 16 weeks storage
12 ratios of mixture DSP:TSPP:P20
2, 9, 30 and 60 days of storage
12 ratios of mixture DSP:TSPP:TSC
2, 9, 30 and 60 days of storage
12 ratios of mixture DSP:TSC:P20
2, 9, 30 and 60 days of storage
12 ratios of mixture TSC:TSPP:P20
2, 9, 30 and 60 days of storage

Figure 1

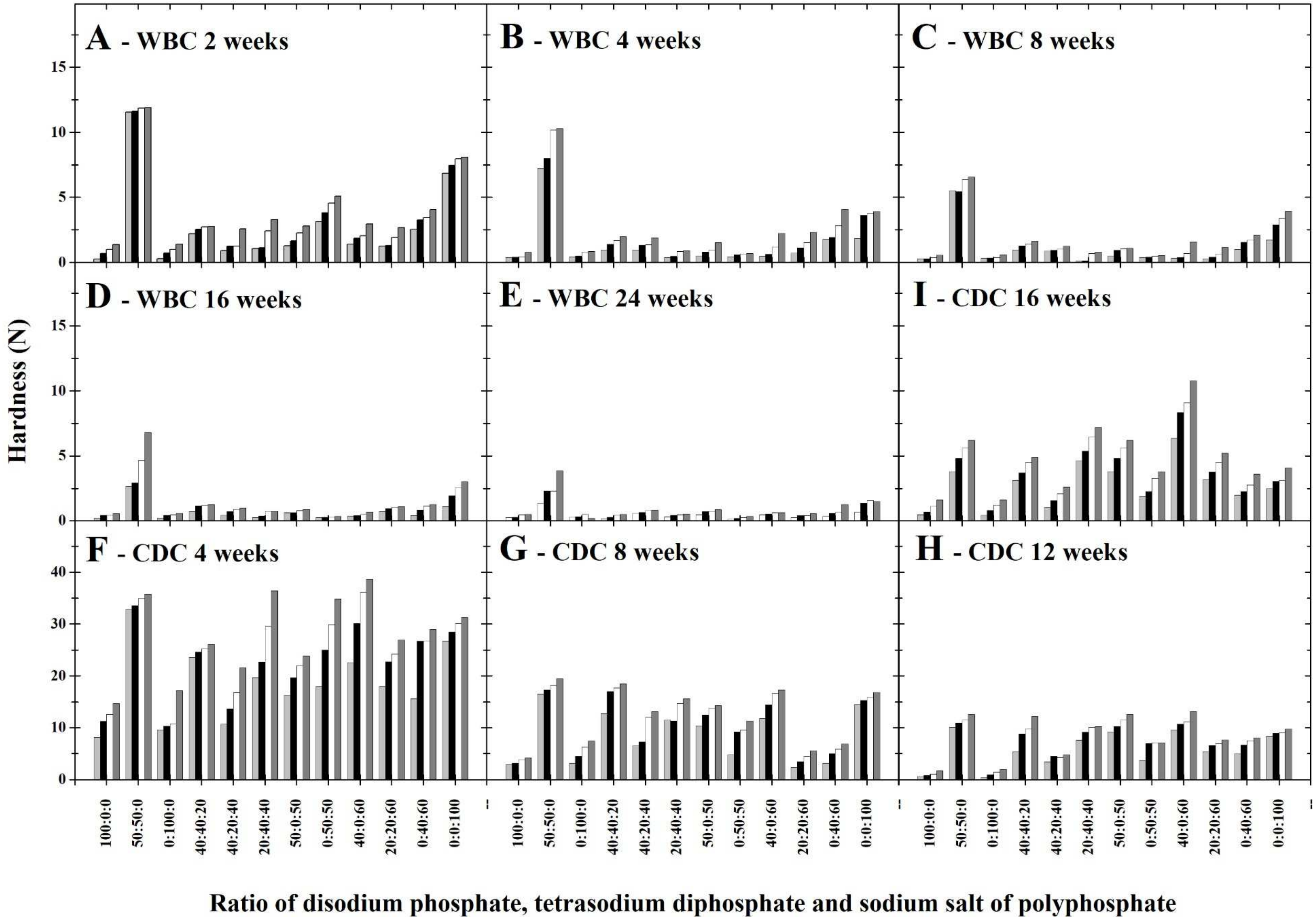
A - WBC 2 weeks
B - WBC 4 weeks
C - WBC 8 weeks
D - WBC 16 weeks
E - WBC 24 weeks
I - CDC 16 weeks
F - CDC 4 weeks
G - CDC 8 weeks
H - CDC 12 weeks
Hardness (N)
0
5
10
15
20
30
40
100:0:0
50:50:0
0:100:0
40:40:20
40:20:40
20:40:40
50:0:50
0:50:50
40:0:60
20:20:60
0:40:60
0:0:100
Ratio of disodium phosphate, tetrasodium diphosphate and sodium salt of polyphosphate

Figure 2

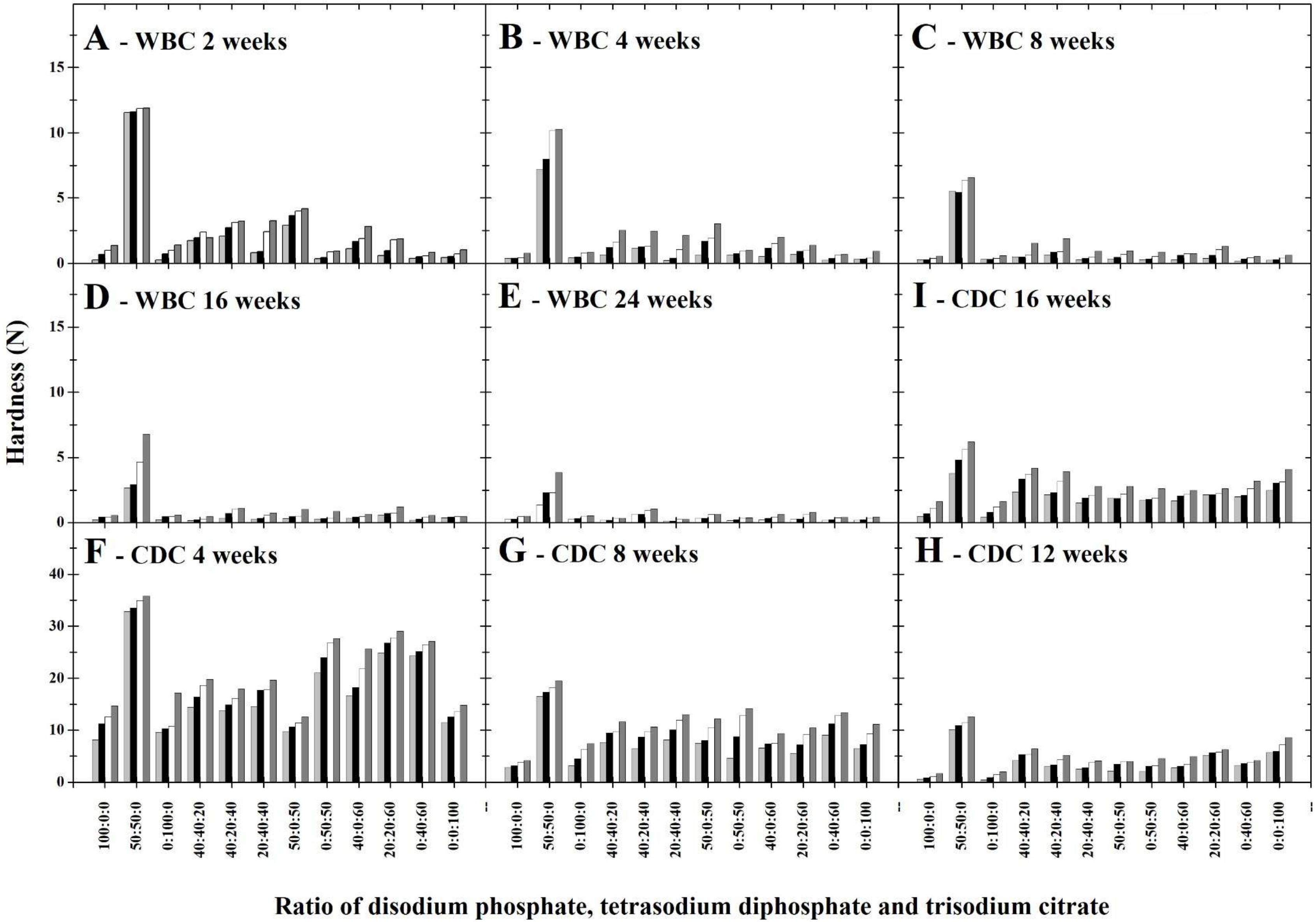
A - WBC 2 weeks
B - WBC 4 weeks
C - WBC 8 weeks
D - WBC 16 weeks
E - WBC 24 weeks
I - CDC 16 weeks
F - CDC 4 weeks
G - CDC 8 weeks
H - CDC 12 weeks
Hardness (N)
0
5
10
15
0
10
20
30
40
100:0:0
50:50:0
0:100:0
40:40:20
40:20:40
20:40:40
50:0:50
0:50:50
40:0:60
20:20:60
0:40:60
0:0:100
Ratio of disodium phosphate, tetrasodium diphosphate and trisodium citrate

Figure 3

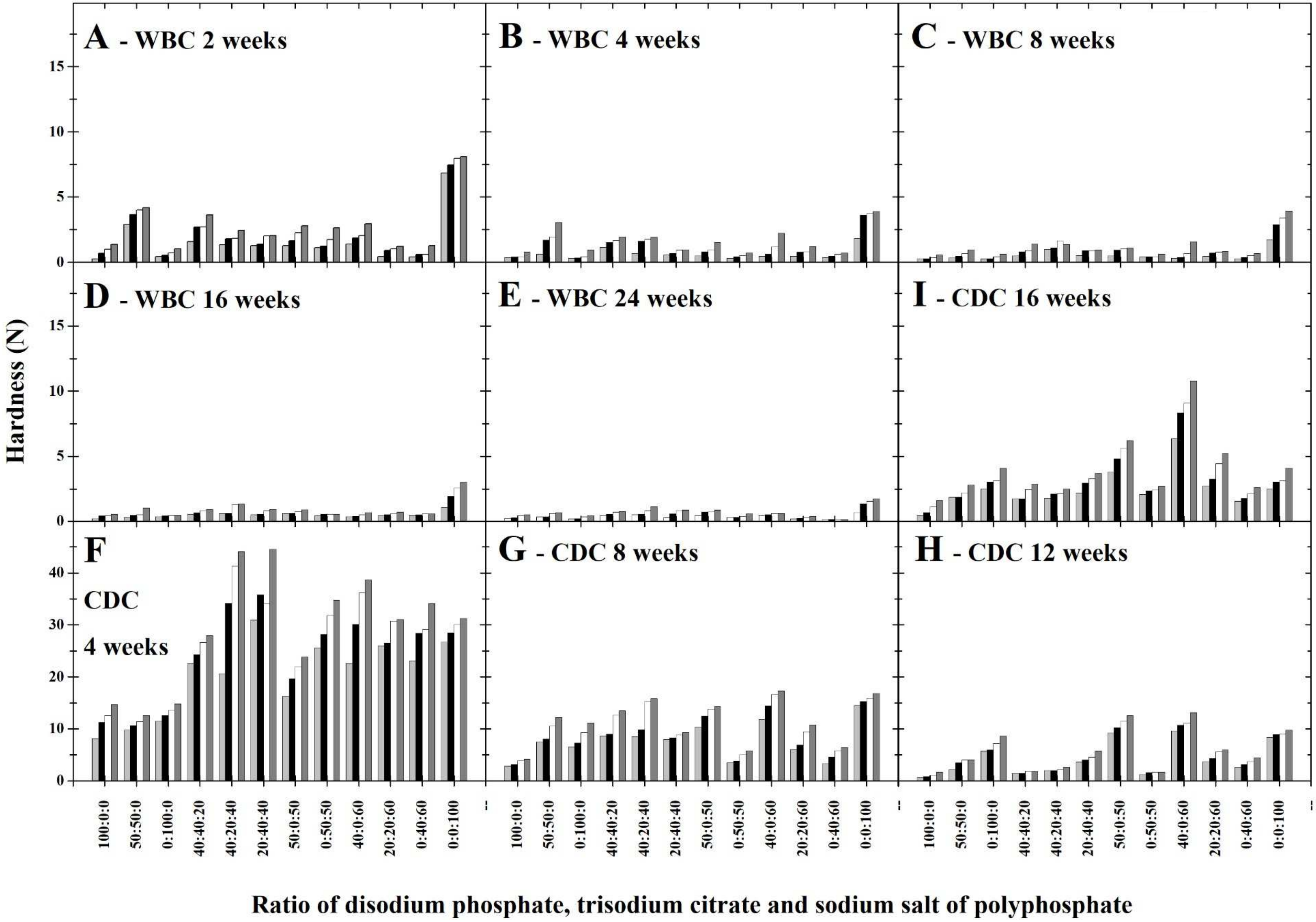
A - WBC 2 weeks
B - WBC 4 weeks
C - WBC 8 weeks
D - WBC 16 weeks
E - WBC 24 weeks
I - CDC 16 weeks
F
CDC
4 weeks
G - CDC 8 weeks
H - CDC 12 weeks
Hardness (N)
0
5
10
15
20
30
40
100:0:0
50:50:0
0:100:0
40:40:20
40:20:40
20:40:40
50:0:50
0:50:50
40:0:60
20:20:60
0:40:60
0:0:100
Ratio of disodium phosphate, trisodium citrate and sodium salt of polyphosphate

Figure 4

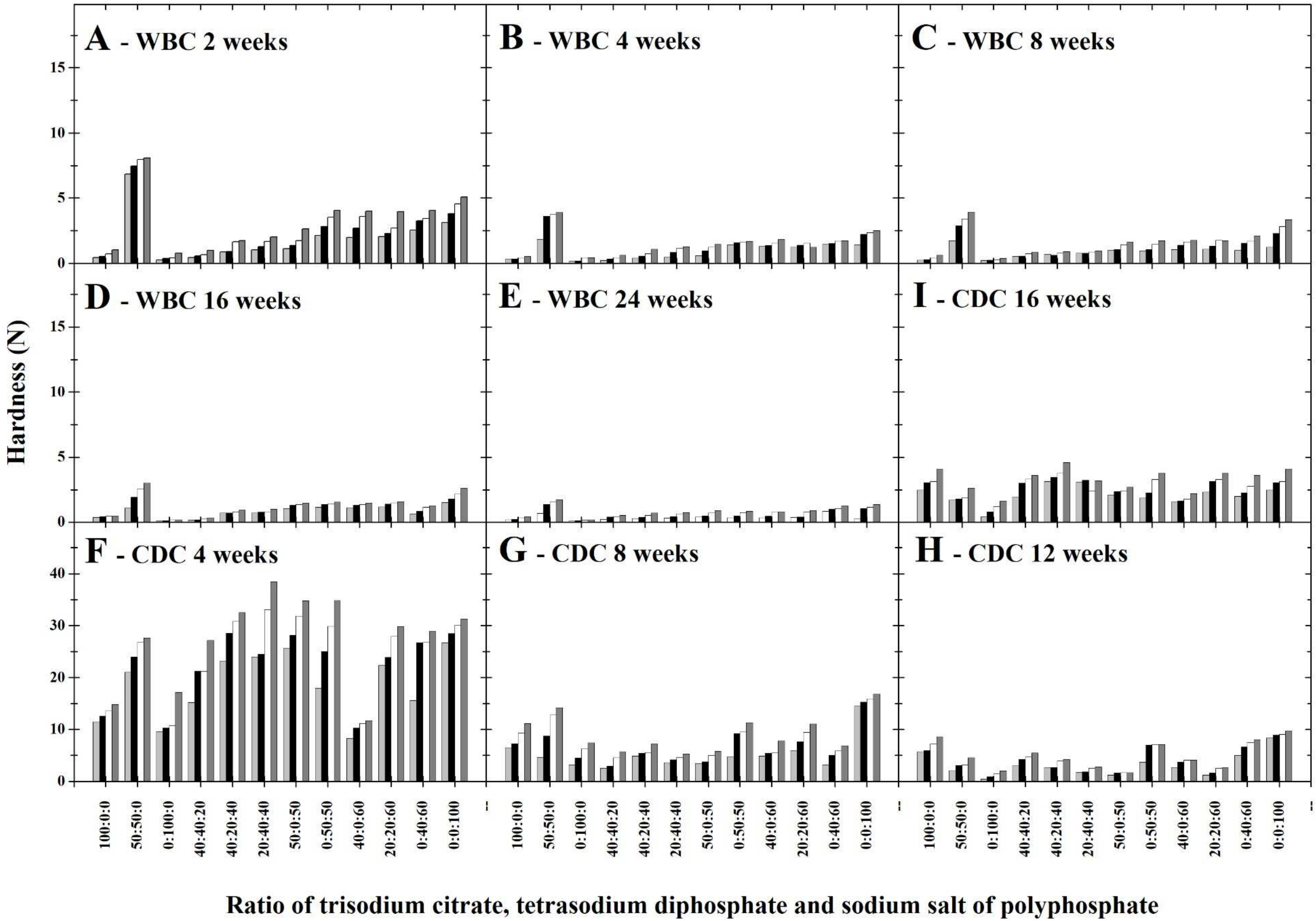
A - WBC 2 weeks
B - WBC 4 weeks
C - WBC 8 weeks
D - WBC 16 weeks
E - WBC 24 weeks
I - CDC 16 weeks
F - CDC 4 weeks
G - CDC 8 weeks
H - CDC 12 weeks
Hardness (N)
0
5
10
15
20
30
40
100:0:0
50:50:0
0:100:0
40:40:20
40:20:40
20:40:40
50:0:50
0:50:50
40:0:60
20:20:60
0:40:60
0:0:100
Ratio of trisodium citrate, tetrasodium diphosphate and sodium salt of polyphosphate

Figure 5

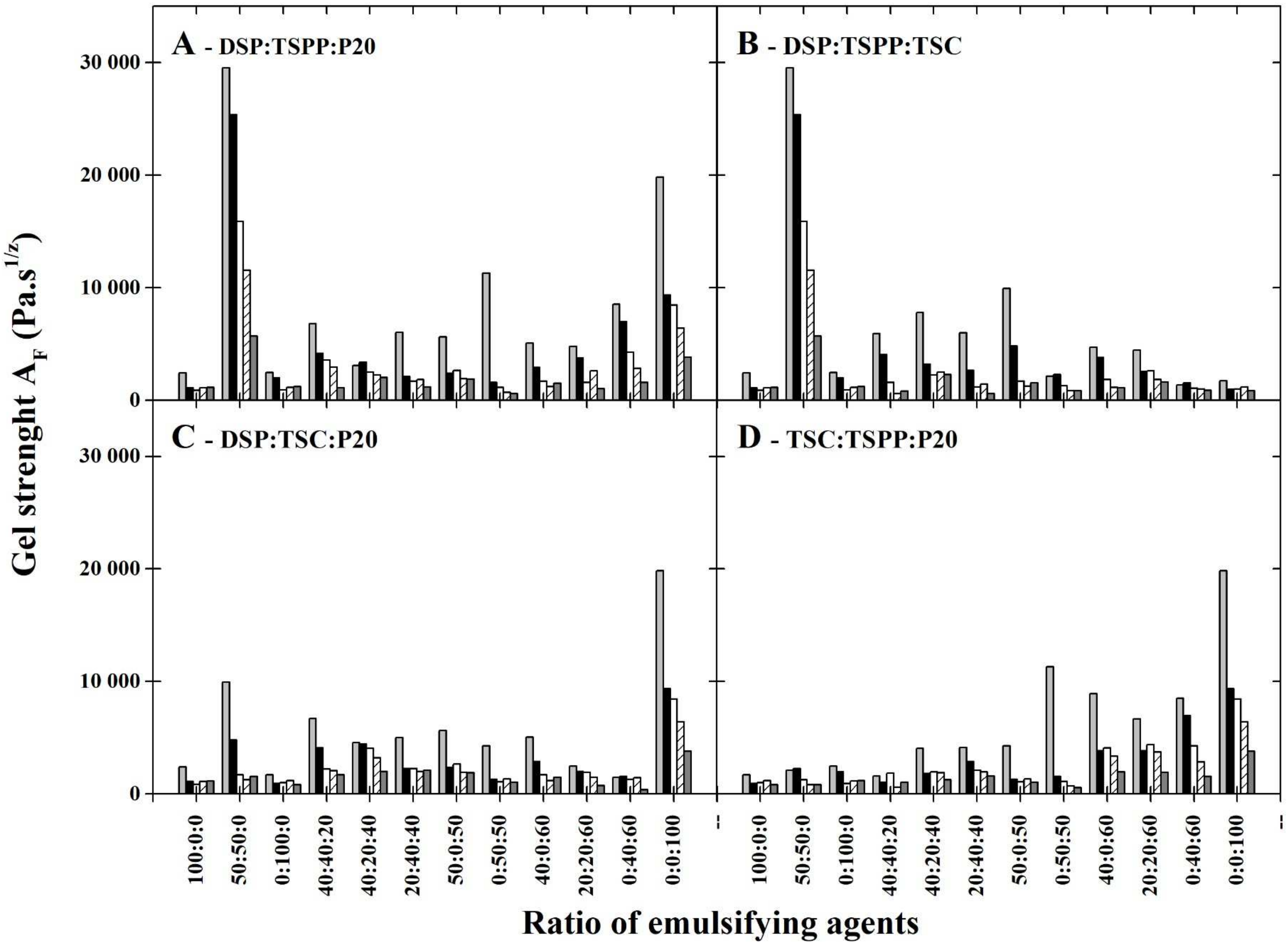
A - DSP:TSPP:P20
B - DSP:TSPP:TSC
C - DSP:TSC:P20
D - TSC:TSPP:P20
Gel strenght A_F (Pa.s$^{1/z}$)
30 000
20 000
10 000
0
100:0:0
50:50:0
0:100:0
40:40:20
40:20:40
20:40:40
50:0:50
0:50:50
40:0:60
20:20:60
0:40:60
0:0:100
Ratio of emulsifying agents

Figure 6

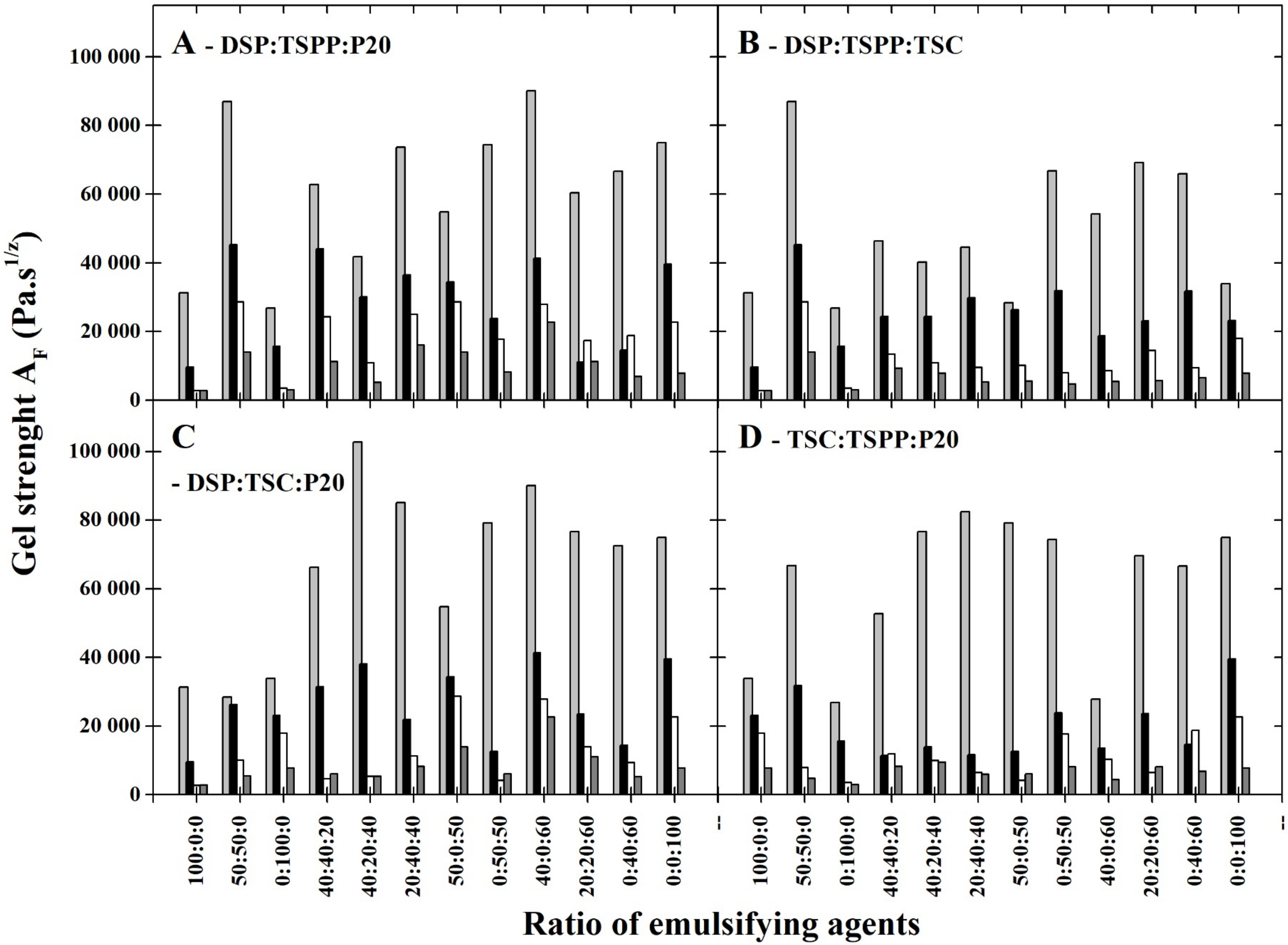
A - DSP:TSPP:P20
B - DSP:TSPP:TSC
C
- DSP:TSC:P20
D - TSC:TSPP:P20
Gel strenght A_F (Pa.s$^{1/z}$)
0
20 000
40 000
60 000
80 000
100 000
100:0:0
50:50:0
0:100:0
40:40:20
40:20:40
20:40:40
50:0:50
0:50:50
40:0:60
20:20:60
0:40:60
0:0:100
Ratio of emulsifying agents

Figure 7

Credit Author Statement

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Vendula Pachlová: Methodology; Writing - Review & Editing

Vendula Kůrová: Methodology; Writing - Review & Editing

Jana Šenkýřová: Methodology; Writing - Review & Editing

František Buňka: Conceptualization; Supervision; Writing - Review & Editing; Project administration; Visualization; Revisions of the manuscript