Analecta Technica Szegedinensia

Vol. 15, No. 1 ISSN 2064-7964 2021

INFLUENCE OF ADDITIVES ON RHEOLOGICAL AND TEXTURAL PROPERTIES OF CELLULOSE BASED FAT MIMETIC

Ivana Nikolić, Ljubica Dokić, Zita Šereš, Dragana Šoronja-Simović, Nikola Maravić, Jana Zahorec*

University of Novi Sad, Faculty of Technology Novi Sad, Bulevar cara Lazara 1, 21000 Novi Sad, Serbia,
*e-mail: ivananikolic@tf.uns.ac.rs; ivananikolic.tf@gmail.com

Received: February 11, 2021 • Accepted: May 7, 2021

ABSTRACT

Cellulose based fat mimetics play important role in substitution of fat in reduced fat food products. Production of food often includes application of additives. This work examines the influence of additives on the obtaining stable fat mimetic based on fibers of microcrystalline cellulose. Applied additives affect to the durability of food products and increase their shelf life. The influence of added additives was observed trough the rheological and textural properties of MCG fat mimetic, thus its further functional characteristics. Increasing concentration of fibers positively influenced to crosslinking during hydration and increased strength and consistency of obtained gel. But, application of small hydrophilic molecules of additives disturbed rheological and textural properties of fat mimetics. Obtained gels were still with the thixotropic behavior, but with significantly reduced viscoelastic properties, consistency, firmness and cohesiveness. Based on results, in the aim to ensure obtaining of stable, cross–linked gel of fat mimetic with adequate rheological, textural and functional properties, the mixture of additives is added after the hydration of fat mimetic gels, because of competition for polar water molecules between small additives molecules and available hydroxyl groups of cellulose chains.

Keywords: microcrystalline cellulose fat mimetic, additives, gel structure, rheology, texture

1. INTRODUCTION

Reducing the fat content and energy value of a food product implies the application of an adequate fat substitute. Ideal fat substitute should have all the functional characteristics of lipids, but also lower energy value, preferably 0 kcal/g. The functional properties that a fat substitute should have are sensory properties (odor and taste) and rheological properties (viscosity, consistency, texture). Also, fat substitutes should have emulsifying properties, to be thermostable, to allow dissolution of liposoluble aromas, vitamins, etc. [1, 2, 3]. The chemical structure of fat substitutes can be similar to lipids, proteins or carbohydrates and they are divided into two groups, group of fat substitutes and group of fat mimetics.

Fat substitutes are macromolecules that resemble to triglycerides (fats and oils) in both physical and chemical characteristics and that can theoretically replace fats in food on a one–to–one basis (gram–for–gram basis). They are obtained by chemical synthesis or enzymatic modification of fats and oils and labeled as "lipid–based fat substitutes".

Fat mimetics imitate the sensory and physical properties of fat, but they cannot replace the fat on a one–to–one basis. They are commonly labeled as "protein or carbohydrate–based" fat substitutes, where common food ingredients (starch or cellulose) have been previously chemically or physically modified to mimic the role of the fat. Their main characteristic is the great water absorption capacity. The energy value of the fat mimetics varies from 0 to 4 kcal/g [3].

Microcrystalline cellulose (MCC) is one of the most commonly used fat mimetics in food products, thanks to its ability to simulate the functional properties of fats, such as the appropriate mouthfeel, consistency, firmness and structure. Its application is significant in confectionery and bakery products, frozen desserts, salad dressings, fillings, cheeses and spreads [4]. There are two types of microcrystalline cellulose, powdered MCC and colloidal MCC [5]. Powdered MCC is very good fat mimetic in products that have a reduced moisture content, for example, emulsion systems in confectionery products, such as biscuit fillings. It is most often used in combination with sugar syrups and in the amount of up to 15 % [6].

DOI: https://doi.org/10.14232/analecta.2021.1.53-63

Commercial colloidal microcrystalline cellulose is usually a mixture of MCC powder (cellulose gel) and Na–CMC (cellulose gum in amount of 8.5–15 %). Adequately dispersed cellulose crystals in a colloidal cellulose gel form a three–dimensional crosslinked structure, which is stable over a wide range of pH and temperature and which provides optimal functional properties of colloidal MCC. The viscosity of a colloidal microcrystalline cellulose suspension depends on various factors and generally it forms thixotropic gel. Various food products may contain colloidal MCC, such as low–fat products, dough, canned products, beverages, dairy and confectionery products, salad dressings, sauces [7].

The definition of appropriate components and their quantity is required for the formulation of a new food product. Besides that, the order of addition of raw materials is also very important in the aim to achieve desired product quality. Certain raw materials achieve their functional properties only in the adequate stage of production, or some components may reduce the functional properties of other components when they are added in inadequate phase of production.

Food products often contain additives, depending on their composition, in the aim to improve certain product properties. Additives are added to food products in the technological process of production, during preparation, processing, shaping or packaging [8]. According to technological criteria such as method and purpose of application during production, the additives can be classified into several groups: additives added during processing, canning additives, direct additives, indirect additives, mineral additives, nutritional additives, food coloring and other additives [9]. Preservatives ideally prevent microbiological spoilage of food. The preservative provides prolonged protection of food from subsequent spoilage after opening the package or when the package is not hermetically sealed. There are three basic types of preservatives used in food, antimicrobial preservatives, antioxidants and anti–browning agents.

Antimicrobial preservatives are used to control and prevent the growth of microorganisms in food products. According to the INS (International Numbering System for Food Additives) and E system of numerical labeling of additives, they were assigned by INS and E numbers from 200–290. Antioxidants are used to prevent the oxidation of lipids and/or vitamins in food products. The main role is to prevent self–oxidation, which is reflected in the development of rancidity and unpleasant odor and taste of food. In the system of numerical designation of additives, they are assigned by INS and E numbers from E 300–E 324. Antioxidants, can be natural substances, such as vitamin C (E 300) or vitamin E (E 306), or synthetically produced chemical substances, such as butyl–hydroxyanisole (BHA, E 320) and butyl–hydroxytoluene (BHT). Anti–browning agents are chemical substances that are used to prevent enzymatic and non–enzymatic browning of food products. The most commonly used are vitamin C (E 300), citric acid (E 330) and sodium sulfite (E 221) [10].

This work examines the influence of additives on the process of obtaining stable cellulose based fat mimetics. Applied additives affect to the durability of food products and increase their shelf life. Cellulose based fat mimetics play important role in substitution of fat in low energy food product, thus the influence of added additives on functional rheological and textural properties of the fat mimetic is examined in this work. By obtained results, the order of adding the raw materials during the production of low energy, or low fat, or reduced fat food products, which includes the application of cellulose based fat mimetics will be defined.

2. MATERIALS AND METHODS

2.1. Materials

During the experimental work was used cellulose based fat mimetic Vivapur MCG 611F manufactured by John Rettenmaier & Sönhe GMBH + CO, Rosenberg, Germany. The chemical composition of MCG 611F includes microcrystalline cellulose (MCC=81.2–88.7 %) and sodium carboxymethyl cellulose (NaCMC=11.3–18.8 %). The distilled water was used for the hydration of fat mimetic fibers. Also, the mixture of additives was applied and included sodium ascorbate E 301, trisodium citrate E 331 and sodium acetate E 262.

2.2. Methods

2.2.1. Preparation of fat mimetics

The powder of the observed fat mimetic was dispersed in distilled water in concentrations of 5 and 10 %, as commonly used concentration for formation of cellulose gel systems. Separately were prepared the fat mimetics with same fiber concentrations, but with addition of additives. The mixture of additives was used and included 0.150 g of sodium ascorbate E301, 0.150 g of trisodium citrate E331 and 0.200 g of sodium acetate E262 per 100 g of cellulose gel. The dispersed systems were prepared by a homogenizer (Ultra Turrax T–25, IKA Werke GmbH & Co, Germany), with S25 N–18G accessories using the rotation speed of 6500 rpm for 4 min. After preparation, the dispersions were kept at 4°C for 24 h to form a gel.

2.2.2. Rheological determination

Rheological properties of obtained fat mimetic gel systems were determined by rotational viscometer HAAKE RheoStress RS600 (Thermo Electron Corporation, Karlsruhe, Germany) with plate–plate sensor PP60 Ti (plate diameter was 60 mm and gap 1 mm). The measurements were done at 25±0.1°C. Flow properties were defined by hysteresis loop method and observing the shear stress (τ) over shear rate ($\dot{\boldsymbol{\gamma}}$). The samples were exposed for 3 min to shear rate ramped up from 0–100 s^{-1}. The following 3 min the shear rate was constant at 100 s^{-1} and finally ramped down to 0 s^{-1} for 3 min.

Storage modulus (G') and loss modulus (G") were defined by dynamic oscillatory measurements in the range of linear viscoelastic regime (LVE). The moduli were observed during increased frequency from 1 to 10 Hz and at constant shear stress of 1 Pa. The results were expressed as value Tan δ=G"/G' [11].

Viscoelastic response of the samples at constant stress, as well as their behaviour after removing the stress, were determined by creep & recovery analysis. The analysis was performed in the LVE regime in which the deformation amplitude was proportional to applied stress amplitude. The creep time with constant stress (σ=1 Pa) was 150 s and the recovery period after removing the stress was 450 s. Creep data, collected under constant stress (σ) over time (t), can be described by a creep compliance (J) function, in terms of shear deformation (γ), using equation (1).

$$J(t) = \gamma(t)/\sigma \tag{1}$$

The linear development of compliance as a function of time is imitated by mechanical model with several springs (elastic contribution) and dashpots (viscous contribution) [12]. Mathematically, the relationship between elastic and viscous properties can be simulated by Burger's model that is combination of Kelvin model (consisting of a spring and dashpot connected in parallel to each other) and Maxwell model (consisting of a spring and dashpot connected in series to each other) placed in series.

The creep data were analysed by Burger's model presented by equation (2):

$$J(t) = J_0 + J_1 \cdot (1 - \exp(-t/\lambda)) + t/\eta_0 \tag{2}$$

For the recovery phase the equation of the Burger's model is equation (3):

$$J(t) = J_{max} - J_0 - J_1 \cdot (1 - \exp(-t/\lambda)) \tag{3}$$

The value J_0 is the instantaneous compliance, J_1 is retarded (viscoelastic) compliance, J_{max} is maximum compliance, λ is mean retardation time and η_0 is Newtonian viscosity [13, 14]. The part of the curve that describes the recovery of the system can be described by the proportions of elastic (J_e) and viscous (J_v) deformations in the maximum compliance of the system. There is a relative elastic part J_e/J_{max} [%] (part of the structure that recovered after removing the stress) and relative viscosity part J_v/J_{max} [%] (part of the structure that did not recover after removing the stress, lost amount of deformation) [15].

2.2.3. Determination of textural characteristics

Textural characteristics were determined using a Texture Analyzer TA.HD Plus, Stable Micro Systems. A specific method *Comparison of the consistencies by back extrusion* was used and performed by Back extrusion cell (A/BE) kit, which contains a base for positioning the sample, a plexiglass sample vessel with an inner diameter of 50 mm and a compression disk with a diameter of 35 mm. A 5 kg measuring cell was used. During the measurement, the sensor disk penetrates 30 mm through the sample, after which it returns to the starting position. The parameters of the method are: moving speed before analysis 1 mm/s, during analysis 1 mm/s, returning speed 10 mm/s, distance 30 mm and contact force 10 g. The firmness of the gel system is described by maximum realized force during the penetration of the disk at a distance of 30 mm. The consistency of the gel system is defined by the size of the surface that the obtained curve builds with the abscissa. The negative part of the graph was obtained during the return of the measuring disk through the sample and describes the flow resistance that the sample exhibits. The cohesiveness of the sample is defined by the negative maximum on the graph, and the area that the curve of the negative part of the graph builds with the abscissa represents the viscosity index (Fig. 1) [16].

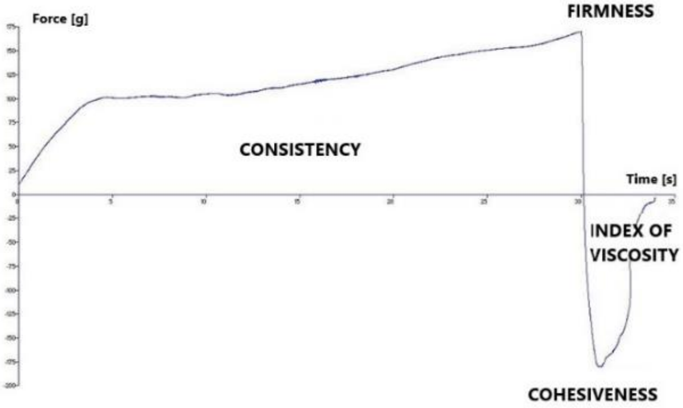

Figure 1. Typical curve of textural properties for gel

3. RESULTS AND DISCUSSION

3.1. Rheological characteristics of fat mimetics

3.1.1. Flow curves of MCG fat mimetics without and with added additives

The rheological behavior of observed MCG 611F fat mimetics and the obtained flow curves are shown at Fig. 2. The influence of increased fibers concentration in the fat mimetics gel, from 5 to 10 %, as well as the influence of addition of additives mixture on flow curves were observed.

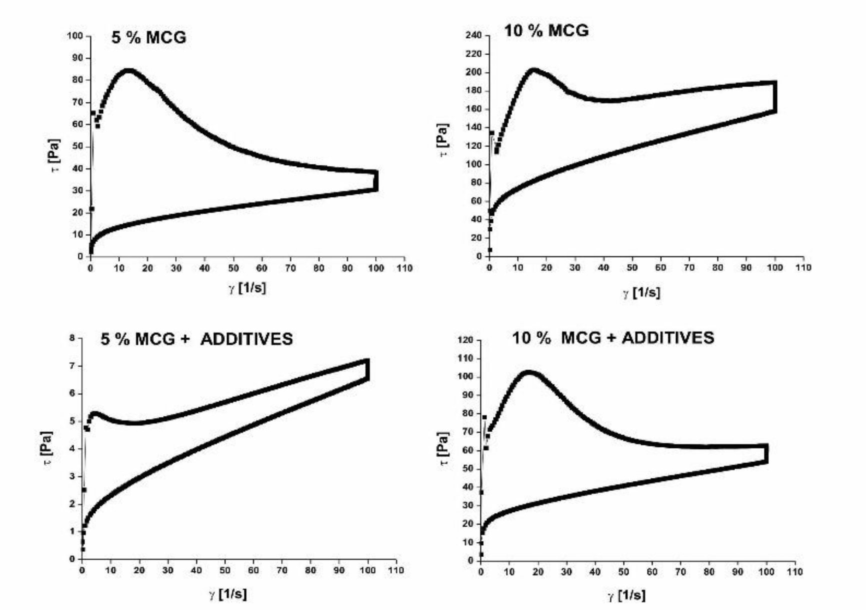

Figure 2. Flow curves of MCG 611F fat mimetics with different fibers concentrations and with addition of additives mixture

A common characteristic of all shown flow curves for MCG 611F fat mimetics is thixotropic type of flow, that pointed to the viscoelastic structure of the system. The obtained curves formed a specific hysteresis loop during the increasing and decreasing shear rate phases. The strength of the structure of the rheological system can be assumed based on the appearance and surface of the hysteresis loop. When the shear rate increases, the internal structure is destroyed, and when the shear rate decreases, the rheological system is structured and recovered. In the presence of weak secondary linkages, the structure is easily destroyed, and this is manifested by a small area of the hysteresis loop. Therefore, the larger surface area indicates the complex structure of the rheological system, as well as the possibility of significant changes in the structure during the shear stress action [17].

Such rheological behavior of MCG fat mimetics is a consequence of the nature of MCG fibers that consist this fat mimetic. Microcrystalline cellulose fibers are very easily interconnected, due to their pronounced ability to hydrate and to increase in volume in the aqueous medium. That generally leads to crosslinking and the formation of a three–dimensional gel structure [18]. As the concentration of MCG fibers increases, the degree of crosslinking also increases, which caused the strengthening of the gel structure and reflected in a significant increase in the value of the hysteresis loop area. Rheological parameters that describe presented flow curves are the value of the hysteresis loop area A_0, yield stress τ_0, critical shear rate $\dot{\gamma}_c$ and critical shear stress τ_c (Tab. 1).

Table 1. Rheological parameters of flow curves for MCG 611F fat mimetics with different fibers concentrations, without and with the addition of additives

MCG gel composition	Rheological parameters of flow curves			
	$\tau_0 \pm$ SD [Pa]	$\tau_c \pm$ SD [Pa]	$\dot{\gamma}_c \pm$ SD [1/s]	$A_0 \pm$ SD [Pa/s]
5 % MCG	2.19 ± 0.01	79.43 ± 7.02	13.16 ± 0.24	2909.00 ± 62.45
5% MCG+ADDITIVES	0.37 ± 0.02	5.30 ± 0.25	4.63 ± 0.06	149.31 ± 6.99
10 % MCG	7.20 ± 0.50	208.37 ± 26.44	19.16 ± 1.99	6717.33 ± 567.71
10% MCG+ADDITIVES	3.64 ± 0.09	102.64 ± 9.22	16.99 ± 0.15	3369.00 ± 26.31

Yield stress τ_0 is the minimum value of shear stress needed for the system to begin to flow [19]. The ascending curves of MCG gels at critical shear rates ($\dot{\gamma}_c$) and at critical shear stresses (τ_c) had a peak, which indicated to the destruction of their structure after which the system flows freely. The values of the critical shear rate and critical shear stress increased with increasing concentration of MCG fibers in the system. Also, there is an increase in the value of the yield stress, which pointed to the initial resistance of system to flow, as well as an increase in the area of the hysteresis loop with increasing fibers concentration.

A significant decrease in all observed rheological parameters can be observed for the flow curves of MCG gels in which formation the additives were included. The most noticeable decrease in the value of hysteresis loop area was for 5 % gel with added additives, compared to 5 % MCG gel without the additives. Also, the value of hysteresis loop area was reduced for 10 % MCG gel under the influence of additives addition, but in a lesser extent (Fig. 2). This observation was confirmed by the parameters of flow curves presented at Tab. 1. The area of the hysteresis loop of 5 % MCG gel which contained additives decreased for 94.87 % compared to the area of the hysteresis loop of 5 % MCG gel without additives. For 10 % MCG gel this reduction in the hysteresis loop area was for 49.85 % compared to 10 % MCG gel without additives. The values of all other observed rheological parameters were also significantly reduced with the addition of additives into the gel structure (Tab. 1). Reduction of critical shear rates and critical shear stresses with addition of additives indicated to the presence of much weaker bonds in the gel system with additives and obtained systems are very susceptible to stress and easily break down compared to gels without additives.

The inclusion of selected additives in the structure of MCG gel resulted in significant decrease in the strength and stability of the system and a sudden decrease in the consistency of the gel. An important feature of all observed gel systems is that regardless of the addition of additives, these gels retained the thixotropic flow properties and an ability to form a hysteresis loop. Additionally, gels with 10 % of MCG fibers and additives had stronger and more stable structure than gels with 5 % of these fibers and additives.

3.1.2. Viscoelastic properties of fat mimetics without and with the addition of additives

The viscoelastic behavior of the observed fat mimetics was defined by dynamic oscillatory measurements and creep & recovery test. Both types of measurements were performed in a linear viscoelastic regime at stress values that do not have a destructive effect on the system structure. Fig. 3 shows the results of dynamic oscillatory measurements in the region of linear viscoelastic regime.

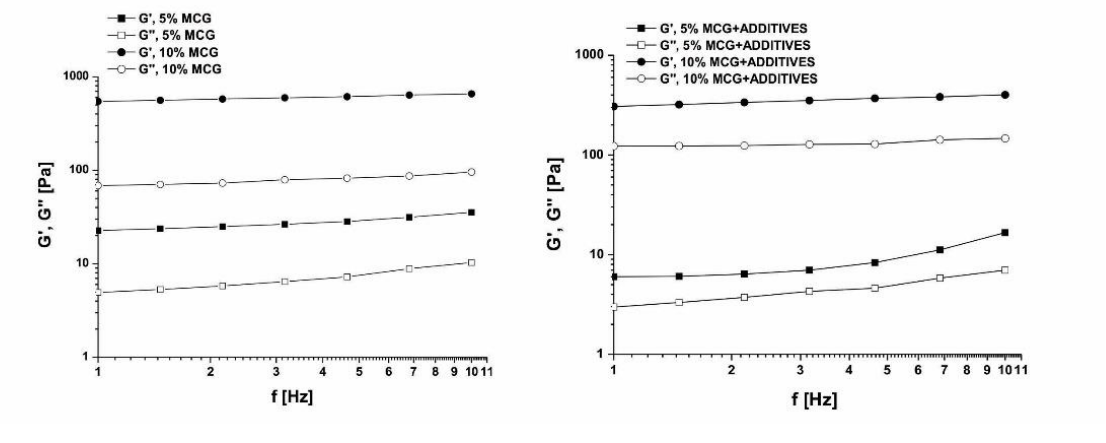

Figure 3. Changes of storage G'and loss G" modulus with increasing frequency for MCG gels without and with additives

For all observed systems it was characteristic that storage and loss modulus increased with increasing frequency. Also, the storage modulus G' was always higher than loss modulus G", in the range of applied frequencies. Such viscoelastic behavior is typical for concentrated systems in which the cross–linked gel structure is formed [19].

An additional parameter that describes the viscoelastic nature of the system is Tan δ. This rheological parameter is defined as the ratio G"/G' and represents a measure of the relative magnitude of the viscous and elastic parts of the system. The lower the values of Tan δ, the nature of the system is more elastic [20].

Since the observed MCG gels had the higher storage modulus G' than the loss modulus G", thus it was normal for their ratio or value of Tan δ to be less than one. The values of this viscoelastic parameter for all observed gel systems were ranged from 0.133 to 0.533, as shown in Fig. 4. Also, the values of the Tan δ parameter for fat mimetics without and with the addition of additives are shown in Fig. 4.

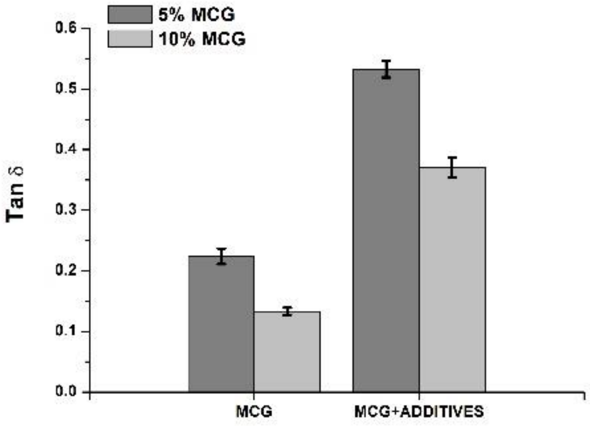

Figure 4. Tan δ for MCG fat mimetics depending on fibers concentration and presence of additives

As it was already mentioned, lower values of the parameter Tan δ indicate a firmer and stronger gel structure. That means larger amount of bonds with elastic nature, which contribute to a firmer consistency of the system and confirm a stronger structure. It can be seen from Fig. 4 that the values of Tan δ for gels with additives, regardless of the gel concentration, are always higher than Tan δ for gels without additives. Based on this, it can be concluded that the presence of additives significantly reduces the number of possible bonds with elastic nature and to some extent reduces the degree of crosslinking in the system. This is certainly due to the size of the additive molecules, which are very small compared to the macromolecules of fibers fat mimetics, and which are fitted in the macromolecules interspace. Also, the polarity of these small additives molecules certainly prevents the interaction between the fibers and the polar water molecules. This leads to a decrease in the degree of hydration of fiber macromolecules, to a decrease in their activity and degree of crosslinking.

According to the decreasing values of Tan δ, it is noticeable that gels with higher fibers concentration, regardless of the presence of additives, are always with more elastic nature and stronger structure than gels with 5 % of fibers. Amount of 10 % of MCG fibers in the system instead of 5 % reduced the value of Tan δ for 40.62 %. While the application of additives during formation of MCG gel increased the values of Tan δ for 137,95 % and for 178,95 % compared to gels without additives in the structure. It means that additives have the greatest influence on obtaining a weak elastic structure of gels.

The viscoelastic properties of gel systems during the action of constant stress are additionally defined by creep & recovery curves. The intermolecular bonds of the sample are stretched during the influence of constant stress. The initial compliance of the system (J_0) is related to the initial elastic deformations, and the subsequent compliance of the system (J_1) to the viscoelastic deformations. This phase is described by the first part of creep & recovery curve and it is called the creep phase. The creep phase is followed by a recovery phase, in which there is no influence of stress and the balance between the intermolecular bonds is established, thus the system is partially recovered from the influence of stress. The resistance of viscoelastic materials to the influence of constant stress is usually nonlinear and the permanent deformation of these systems is usually less than the total deformation applied to the system, due to their ability to attain recover of significant part of the structure with stored energy [12, 14]. Creep & recovery curves of fat mimetics without and with the addition of additives are shown in Fig. 5.

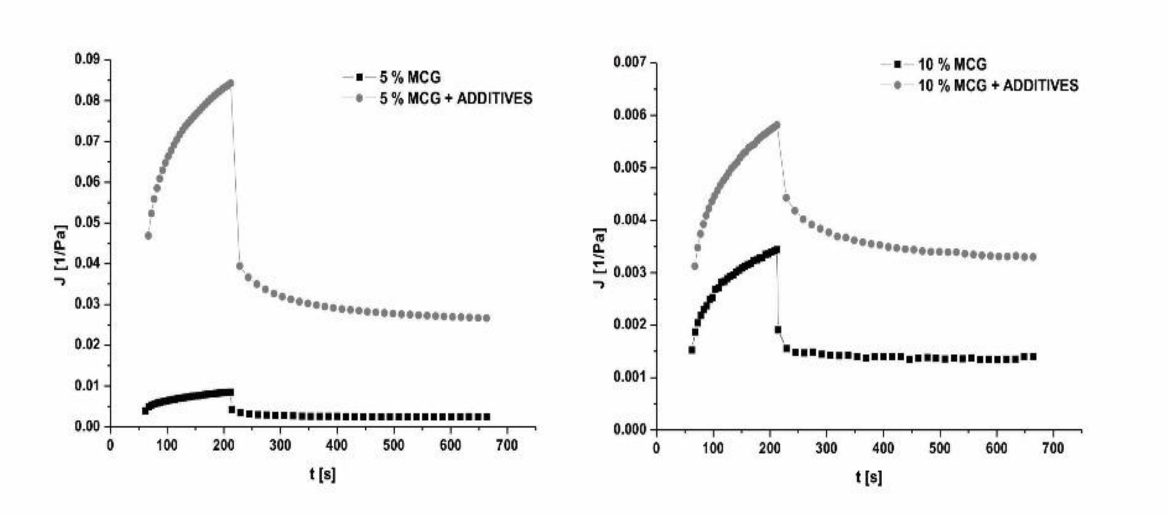

Figure 5. Creep & recovery curves of MCG gels with and without additives

Increasing concentration of fibers in the fat mimetic decreased the compliance of the system (J) during the constant stress, which means that the gel system with 10 % of MCG fibers provided greater resistance to deformation. This is contributed by more intensive crosslinking at high fibers concentration, which strengthening gel consistency and increases the stability of the gel structure. Addition of additives during the formation of gels caused pronounced increase in compliance of all fat mimetics, compared to fat mimetics without additives.

Thus, the application of additives during gel formation significantly reduced the ability of system to resist the influence of stress and the system is more susceptible to deformation due to weak connection of the structure and poor consistency. All obtained creep & recovery curves were well fitted to the equations of the Burger's model, which is confirmed by high coefficient of determination, r >0.99. Characteristic parameters of the creep & recovery curves influenced by increase in the fibers concentration in the gel and the application of additives are shown in Tab. 2.

Table 2. Parameters of the Burger's model for creep & recovery curves of MCG gels with and without additives

MCG gel composition	Creep phase					
	J_0 ± SD·10^3 [1/Pa]	J_1 ± SD·10^3 [1/Pa]	η_0 ± SD·10^3 [Pas]	λ_1 ± SD [s]	J_{max} ± SD [1/Pa]	
5% MCG	4.38 ± 0.49	2.99 ± 0.21	23.53 ± 1.58	92.33 ± 0.01	9.05 ± 0.62	
5% MCG + ADDITIVES	46.91 ± 0.21	27.81 ± 0.08	2.52 ± 11.30	92.20 ± 0.04	84.27 ± 1.55	
10% MCG	1.45 ± 0.07	1.14 ± 0.008	61.35 ± 0.41	92.45 ± 0.04	3.30 ± 0.06	
10% MCG + ADDITIVES	3.13 ± 0.09	1.92 ± 0.06	36.53 ± 1.48	92.37 ± 0.02	5.82 ± 0.03	
	Recovery phase					
	J_0 ± SD·10^3 [1/Pa]	J_1 ± SD·10^3 [1/Pa]	η_0 ± SD·10^3 [Pas]	λ_1 ± SD [s]	J_e/J_{max} ± SD [%]	J_v/J_{max} ± SD [%]
5% MCG	4.77 ± 0.65	1.07 ± 0.06	24.03 ± 1.31	288.50 ± 0.10	64.77 ± 0.64	35.25 ± 0.62
5% MCG + ADDITIVES	39.49 ± 2.46	8.80 ± 0.05	15.85 ± 0.41	288.33 ± 0.05	68.33 ± 0.62	31.67 ± 0.60
10% MCG	2.05 ± 0.12	0.61 ± 0.15	41.05 ± 5.99	288.57 ± 0.06	61.87 ± 0.81	38.13 ± 0.81
10% MCG + ADDITIVES	2.43 ± 0.02	0.83 ± 0.01	12.22 ± 1.11	288.50 ± 0.01	77.71 ± 0.20	22.29 ± 0.23

The observed fat mimetics during the influence of constant stress provide certain resistance and exhibit creep properties. During the recovery phase, the observed systems showed significant ability to recover their structure. Observing the viscosity of fat mimetics, an increase in the viscosity with the increase of the fibers concentration was noticed. That was expected, due to more intensive crosslinking and stronger gel structure of fat mimetics with 10 % of fibers. However, in the presence of additives this degree of crosslinking is significantly lower and the viscosity of all gel systems with additives is significantly lower than in gel systems without additives. During creep phase the viscosity decreased with the addition of additives for 40.46 and for 89.29 %, while during the recovery phase the viscosity decreased for 34,04 and for 70,23 %. Consequently, the values of the compliance parameters (J_0, J_1 and J_{max}) increased, indicating to a decreased system resistance to the applied stress, due to the weakening of its structure. The changes of all these creep & recovery parameters showed in Tab. 2 confirmed the results of the previous rheological determination of the observed gel systems. Also, in all obtained gels the amount of elastic bonds, value J_e/J_{max}, is always higher than the amount of viscous bonds, value J_v/J_{max}, during the recovery phase of the system. That means that all observed gels are still with dominantly elastic semi–solid structure, which is more or less weakened depending on their composition and the presence of additives. The amount of these bonds is in accordance with the viscoelastic parameter Tan δ for all observed gels.

3.2. Textural properties of fat mimetics without and with additives

Viscoelastic properties of gel food systems are analyzed at small deformations and under conditions which do not disturbed the gel structure. But, industrial processes, as well as the application of gels, often require high stresses. Therefore, large deformation tests, such as textural determinations are very useful for characterizing of gel systems. Textural methods are based on the deformation of the sample to the point of permanent structural change [21]. The firmness and consistency of gel are closely related textural parameters, which are determined by the penetration of the sensor element through the gel. The parameters that describe the cohesiveness and viscosity are determined during the return of the sensor element through the gel sample and are related to the resistance that the system provides. Increasing the concentration of fibers in observed gels of fat mimetic led to an increase in the firmness and gel consistency. The absolute values of the gel viscosity and cohesiveness index also increased with increasing fibers concentration in the gel (Tab. 3).

Table 3. Textural parameters of MCG fat mimetics without and with additives

MCG gel composition	Firmness $F_1 \pm$ SD [g]	Consistency $A_1 \pm$ SD [gs]	Cohesiveness $F_2 \pm$ SD [g]	Index of viscosity $A_2 \pm$ SD [gs]
5 % MCG	110.11 ± 8.62	2383.77 ± 663.32	-90.93 ± 4.10	-190.48 ± 5.91
5 % MCG+ADDITIVES	20.57 ± 0.09	412.75 ± 1.96	-15.59 ± 0.07	-1.14 ± 0.01
10 % MCG	343.68 ± 51.54	7766.73 ± 990.12	-361.16 ± 25.52	-818.10 ± 21.94
10 % MCG+ADDITIVES	134.39 ± 13.09	2939.99 ± 485.83	-115.31 ± 15.83	-251.39 ± 28.00

Increasing the fibers concentration in observed gels of MCG fat mimetic certainly contributed to increase in the texture parameters, which indicated to stronger consistency, greater strength, system viscosity and connectivity of components. Those results of textural determination confirmed previously determined rheological parameters of the gels without additives (Tab. 3). But, the textural properties of fat mimetic gels were significantly changed with the application of additives during formation of the gels, and all textural parameters were reduced. The firmness of MCG gel decreased for 81.32 % and for 60.90 % with addition of additives compared to MCG gels without additives. All other observed textural parameters also decreased with application of additives. The presence of small polar molecules of additives, such as applied ascorbates, citrates and acetates, certainly has a negative effect on the process of fibers hydration and the crosslinking process, and thus on the formation of a stable crosslinked gel structure [22].

4. CONCLUSIONS

Cellulose fibers of observed fat mimetic have a pronounced hydration and molecular interaction ability, which provide intensive crosslinking and formation of three–dimensional gel structure. With the increase of the fibers concentration in the system, the degree of crosslinking is larger, and thus the strength of the gel structure and its consistency. Small molecules of additives, which have also hydrophilic nature, interfere with hydration and physically prevent crosslinking. Because of that structural interactions in the hydrated mixture of cellulose fibers of MCG fat mimetic and additives, the rheological and functional properties of obtained gel are reduced, pointing to lower degree of crosslinking and the decreased stability of obtained gel structures. The obtained results indicate that the application of additives in a mixture with MCG fat mimetic fibers during hydration is undesirable. Additives cannot be used before or during the hydration of fat mimetic gels, because of their negative influence on gel formation. In order to ensure obtaining of stable, cross–linked gel of fat mimetic with adequate rheological, textural and functional properties, the mixture of additives is added in subsequent stages of low–fat food products production.

ACKNOWLEDGMENT

This research was done within the project financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Project No. 451–03–68/2020–14/200134. The Authors especially thank to company J. Rettenmmaier & Söhne, GMBH + CO KG for donation of raw materials.

REFERENCES

[1] Akoh, C.C.: Fat replacer, Food Technology, 52 (3), 47–52, (1998).
[2] Cho, S. S., Prosky, L.: Application of complex carbohydrates to food products fat mimetics, In Complex Carbohydrates in Food (S.S. Cho, L. Prosky i M.L. Dreher, eds.), pp. 411–429, Marcel Dekker, Inc, New York, (1999).
[3] Ognen, C. F., Darie, N., Ognean, M.: Fat Replacers, Journal of Agroalimentary Process and Technologies, 12 (2), 433–442, (2006).

[4] BeMiller, J. N.: Carbohydrate Chemistry for Food Scientists, pp. 222–243, AACC International, (2007).
[5] Humphreys, W. M.: Fiber–Based Fat Mimetics: Microcrystalline Cellulose, In Handbook of Fat Replacers (S. Roller i S. Jones, eds.), Chapter 7A, CRC Press, Boca Raton, New York, (1996).
[6] Gómez, M., Moraleta, A., Oliete B.: Effect of fibre size on the quality of fibre–enriched layer cakes, LWT–Food Science and Technology, 43, 33–38, (2010).
[7] Dreher, M.: Food Sources and Uses of Dietary Fiber, In Complex Carbohydrates in Foods (S.S. Cho, L. Prosky i M.L. Dreher., eds.), pp. 327-371, Marcel Dekker, Inc., New York, (1999).
[8] https://sh.wikipedia.org/wiki/Prehrambeni_aditivi
[9] https://www.tehnologijahrane.com/enciklopedija/aditivi-podjela-vrste
[10] „Sl. glasnik RS”, br. 63/2013; www.tehnologijahrane.com
[11] Mezger, T.: The Rheology Handbook: For users of rotational and oscillation rheometers, Vincentz Verlag, Hannover, (2002).
[12] Evageliou, V., Alevisopoulos, S., Kasapis, S.: Application of stress-controlled analysis to the development of low fat spreads, Journal of Texture Studies, 28, 319–335, (1997).
[13] Vithanage, C. R., Grimson, M. J., Smith, B. G., & Wills, P. R. : Creep test observation of viscoelastic failure of edible fats. Journal of Physics: Conference Series, 286, 012008, (2011). doi:10.1088/1742-6596/286/1/012008
[14] Steffe, F. J. : Rheological methods in food process engineering, 2nd ed. Still Valley, Freeman Press, (1996).
[15] Lazaridou, A., Biliaderis, C. : Gluten–free doughs: rheological properties, testing procedures–methods and potential problems, In E. Gallagher (Ed.), Gluten–Free Food Science and Technology, pp. 52–83. United Kingdom. Blackwell Publishing Ltd, (2009).
[16] TA.HD.: Texture Analyser Product Specification, Stable Micro Systems Ltd., Godalming Surrey, Vienna, (2004).
[17] Segura, J. A., Herrera, M. L., Añón, M.C.: Margarines: a rheological study, Journal of the American Oil Chemists' Society, 72, 375–378, (1995).
[18] Hoefler, C. A.: Hydrocolloids, Eagan Press Handbook Series, Eagan Press, Minnesota, USA. (2004).
[19] Ghannam, M. T., Esmail, M. N.: Rheological properties of carboxymethyl cellulose, Journal of Applied Polymer Science, 64 (2), 289–301, (1997).
[20] Tadros, T.: Application of rheology for assessment and prediction of the long–termphysical stability of emulsions, Advances in Colloid and Interface Science, 108–109, 227–258, (2004).
[21] Angioloni, A., Collar, C.: Small and large deformation viscoelastic behaviour of selected fibre blends with gelling properties, Food Hydrocolloids, 23, 742–748, (2009).
[22] Sánchez-González, I., Rodríguez–Casado, A., Careche, M., Carmona, P.: Raman analysis of surimi gelation by addition of wheat dietary fibre, Food Chemistry, 112, 162–168, (2009).