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Influence of Fiber Addition on White Sauces Made with Corn Starch: Effect on Their Freezing/Thawing Stability

Beatriz Herranz, Adrián Martínez, and María Dolores Alvarez

Abstract: Fiber-enriched white sauces with apple (AF401), potato (KF200), and microcrystalline cellulose (MCC) were selected among six white sauces, all of them elaborated by replacing corn starch and milk with 3% of different dietary fibers. It was investigated the freezing/thawing (F/T) stability of these three enriched white sauces studying their physico-chemical (color, syneresis percentage, total soluble solids content), rheological (viscoelastic and steady measurements), and sensorial properties before and after a freezing/thawing treatment. White sauce with MCC resulted in being the most like the control (without fiber) showing a higher elasticity and a heat stability. Moreover, the sauce elaborated with MCC has a sensorial profile as a traditional corn starch sauce with high "creaminess" and lower "heterogeneity" after the F/T treatment. Therefore, the properties provided by MCC make this product interesting in food design, and MCC sauce could be used as an industrial frozen fiber-enriched white sauce.

Keywords: béchamel, freezing stability, microcrystalline cellulose, rheology, sensory properties

Practical Application: These days, there is an increase in the demand of precooked frozen dishes due to current lifestyles and because the use of fiber exhibits many proven health benefits. A béchamel sauce made from corn starch and enriched with different fibers was elaborated, frozen and thawed in microwave. Both fresh and frozen/thawed microcrystalline cellulose (MCC) sauces exhibited very similar rheological and sensorial properties to an industrial and traditional frozen white sauce without fiber. Therefore, MCC-enriched white sauce resulted to be a feasible strategy to produce a white sauce suitable for frozen dishes with good functional properties and sensorial quality.

Introduction

Nowadays, the lack of time for cooking and the demand for comfort and speed of food production have generated an increase in the requirement of precooked frozen dishes, in which sauces play an important role (Arocas, Sanz, & Fiszman, 2009a; Román, Reguilón, & Gómez, 2018). The most common phenomena involved in the destabilization of sauces entails creaming, flocculation, and coalescence during their preparation and/or storage (Mandala, Savvas, & Kostaropoulos, 2004). These phenomena are of great significance in white or béchamel sauces as they are commercialized in a frozen state and therefore, their long-term frozen storage stability is a crucial purchasing factor for the consumer, who demands high quality products. The white sauce is considered an oil-in-water emulsion with a dispersed phase, formed by oil droplets, and, with a continuous phase formed by the rest of the ingredients, especially the milk proteins and the starch. Both type and content of starch play a fundamental role in the rheological properties and, hence, the final texture of the white sauce (Román et al., 2018; Sanz, Tárrega, & Salvador, 2016) because phenomena of gelatinization and retrogradation could be responsible for a "runny" or "gummy" texture (Arocas, Sanz, & Fiszman, 2009).

In this sense, previous studies have been carried out, obtaining some advances, in order to diminish the negative effects of these destabilization phenomena and improve the textural and sensorial properties of white sauces by using different types of native and modified starches (Arocas et al., 2009; Arocas, Sanz, & Fiszman, 2009c; Arocas, Sanz, Hernández-Carrión, Hernando, & Fiszman, 2010b; Arocas, Sanz, Salvador, Varela, & Fiszman, 2010a), changing processing conditions (Arocas et al., 2009, 2010b), adding hydrocolloids (Arocas et al., 2009c; Heyman, Depypere, Delbaere, & Dewettinck, 2010) or proteins (Guardeño, Hernando, Llorca, Hernández-Carrión, & Quiles, 2012), and thermally inhibited native starches (Sanz et al., 2016). Arocas et al. (2009) found better results with the use of modified starches as they reduced the negative structural changes caused by freezing (decrease in the viscoelastic modulus and higher syneresis). However, today there is a tendency to promote the use of "natural" components like native starches, which present less technological quality, but they have the advantage of not having the status of additives, and of being cheaper.

However, with an increase of scientific evidence, the enrichment of foods with different dietary fibers is also an actual tendency (Augusto, Falguera, Cristianini, & Ibarz, 2011; Elleuch et al., 2011; Zhang & Li, 2018). The addition of the dietary fibers to these type of emulsion-based foods will produce changes in the sauce structure and rheology behavior, so it is important to study how these changes can affect the stability and sensorial properties of these products. In addition, these effects are dependent fiber type.

This work aims to study the effect of dietary fibers on the freezing/thawing stability of a béchamel sauce elaborated from corn starch, to produce a fiber-enriched white sauce while exhibiting similar rheological and sensorial properties to those of an

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Table 1–Composition of control and enriched-fiber white sauces.

Ingredients (%)	Control sauce	Enriched-fiber sauce
Water	83.22	83.22
Powdered skimmed milk	9.30	7.80
Starch corn ("Maizena")	4.70	3.20
Sunflower oil	2.55	2.55
Salt	0.23	0.23
Fiber	0.00	3.00*

industrial frozen white sauce without fiber intended to be thawed in a microwave.

Materials and Methods

Materials

Native corn starch (Maizena; Unilever, Barcelona, Spain) and six different fibers (apple [AF150], pea [EF150], oat [HF401], hydroxypropyl methyl cellulose [K4M], potato [KF200], and microcrystalline cellulose gel-811F [MCC]) donated by "Rettenmaier bérica, S.L." (Barcelona) were initially used in the production of the white sauces. The main technological characteristics of each fiber supplied by the manufacturer are shown in Table S1. The rest of ingredients are powdered skimmed milk (Central Lechera Asturiana, Asturias, Spain), sunflower oil (Koipesol, Madrid, Spain), and salt (sodium chloride).

Preparation of white sauce samples

Six fiber-enriched white sauces and one control (without the addition of fiber) were produced following the formula used by Arocas et al. (2009, 2009c, 2010a, 2010b) with slight modifications, replacing partial amounts of the total of corn starch (4.70%) and milk (9.30%) with 3.00% of each fiber (Table 1). Hence, all white sauces samples were a "source of fiber." According to Regulation (EC) No 1924/2006, a food is a "source of fiber" when "it can only be made where the product contains at least 3 g of fiber per 100 g, or at least 1.5 g of fiber per 100 kcal" (EC, 2006).

Using a Thermomix TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain), all ingredients were heated up to 90 °C at 1,100 rpm and preserved at 90 °C with the same agitation speed for 6 min. Following preparation, each sauce was at once cooled down to 37 °C in a Hetofrig CB60VS water-bath (Heto LabEquipment A/S, BirkerØd, Denmark). Freshly prepared white sauces were then analyzed.

Freezing, thawing, and heating procedures

Freezing experiments were based on previous work by Alvarez et al. (2011, 2013); white sauce samples were placed on flat-freezing and microwave-thawing trays and then frozen by forced air convection in a Frigoscandia tunnel (Frigoscandia, S.A., Paris, France) at a freezing rate of 0.91 cm/hr until their thermal centers reached −24 °C. After freezing, the samples were immediately packed in polyethylene plastic bags, sealed under light vacuum (−0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at −24 °C, where they stayed for at least one month before thawing.

Based on previous research Alvarez, Herranz, Campos, and Canet (2017), frozen samples were unpacked and thawed in a Panasonic M1712N (Samsung Electronics S.A., Madrid, Spain) microwave oven. To heat the samples, they were placed in the centered position and irradiated with an output power rating of 700 W. First, each sample was irradiated for 5 min, removed from the microwave, and stirred gently (shear rate ≈ 10 s^{-1}) with a spoon to distribute the heat in the sample. Heating of the samples was continued back in the microwave where irradiation was carried out under the same conditions until the thermal center reached 50 °C. After heating, all the frozen/thawed (F/T) products were cooled to 37 °C by placing them in the same Hetofrig CB60VS water-bath mentioned above. Samples were tested at 37 °C, which was considered an adequate temperature for the consumption of these white sauces.

All the white sauces with each fiber type and for each treatment (fresh and F/T samples) were tested in duplicate.

Rheological properties

Measurements of steady and oscillatory rheological data were performed using a Kinexus pro-rotational rheometer (Malvern Instruments Ltd., Worcestershire, UK), equipped with a cone and plate geometry (4° cone angle, 40 mm diameter). Loaded samples were rested for 5 min before analysis, to ensure both thermal and mechanical equilibrium at the time of measurement. The samples were covered with a very thin film of Vaseline oil (PRS-Codex) to avoid dehydration of them. The temperature was maintained to within 0.1 °C by a Peltier element in the lower plate keeping the temperature at 37 °C, except when nonisothermal heating processes were carried out.

Steady shear rheological measurements

Before measurement, a pre-shear was performed at a shear rate of 100 s^{-1} over 1 min for temperature equilibration, standardization of the shear rate of each sample, as well as avoiding particle trapping near the tip of the cone (Shelat et al., 2015). Following equilibration, flow curves were obtained for shear rates ranging from 0.1 to 100 s^{-1} at 37 °C and 5 points per decade (16 total points). Similar shear rates are commonly reached during chewing and swallowing processes of foods (Shama & Sherman, 1973; Yoshida, Igarashi, Iwasaki, Fuse, & Togashi, 2015). The Ostwald de Waele or the power-law model (Eq. (1)) was used to determine the shear rate effect on the apparent viscosity values of the white sauces:

$$\eta_a = K\dot{\gamma}^{n-1} \quad (1)$$

being η_a the apparent viscosity (mPa·s), K the consistency coefficient (mPa·s^n), $\dot{\gamma}$ the shear rate (s^{-1}), and n the flow behavior index. The apparent viscosity at 50 s^{-1} (η_{50}) was also obtained from apparent viscosity versus shear rate curves, which is used to imitate oral conditions (Espinal-Ruiz, Restrepo-Sánchez, Narvaez-Cuenca, & McClements, 2016; Pal, 2011).

Small-amplitude oscillatory shear measurements

Stress sweep tests. To determine the linear viscoelastic (LVE) region, stress sweeps tests were run at 1 Hz at 37 °C with the shear stress (σ) of the input signal varying from 0.1 to 100 Pa (Herranz, Canet, & Alvarez, 2017). Changes in complex modulus (G^*) and loss tangent (tan δ) were recorded. The critical (maximum) values of shear strain (γ_{max}), and shear stress (σ_{max}) on the limit of LVE range were derived by the method previously described in Campo-Deaño, Tovar, and Borderías (2010).

Frequency sweep tests. Samples underwent stress testing that varied harmonically with time at variable frequencies ranging from 10 to 0.1 Hz. The strain amplitude was set at 0.5% within the LVE range.

Food Chemistry

Temperature sweep tests. Temperature sweep tests were performed for dynamic thermomechanical analysis (DTMA) from 20 to 80 °C at a linear heating rate (5 °C/min). Frequency (1 Hz) and strain $\gamma = 0.5\%$ (within the LVE range) were fixed.

All rheological measurements were carried out at least in quintuplicate.

Measurement of syneresis, total soluble solids content, and color

Syneresis percentage was determined by centrifugal force (Alvarez, Fernández, & Canet, 2009). Five grams of each white sauce (fresh and frozen/thawed) were put in the centrifuge tubes and subsequently centrifuged (Sorvall RC-728311; GMI, Inc., Ramsey, MN, USA) at 6,000 rpm (corresponding to 15,000 × *g*) for 30 min. Syneresis is expressed as the percentage of liquid separated per total weight of the sample in the centrifuge tube (Alvarez et al., 2011, 2013). TSS was determined using a hand-held refractometer Atago dbx-30 (Itabashi-ku, Tokyo, Japan) and the results were expressed in °Brix.

Based on previous research (Alvarez, Fernández, & Canet, 2011, 2017), the color of the samples was measured with a Hunter-Lab model D25 (Reston, VA) color difference meter fitted with a 5 cm diameter aperture. Results were expressed following the CIELAB system (D65 illuminant and 10° viewing angle). Lightness (L^*), redness (a^*), and yellowness (b^*) were determined. The total color difference (ΔE^*) between each F/T sample and its fresh counterpart was calculated following the method of Francis and Clydesdale (Francis & Clydesdale, 1975). All the instrumental measurements were performed at least four times.

Sensory analysis

Testing was carried out by a panel of 10 semi-trained panelists. They were chosen among the members of the Characterization, Quality, and Safety Department of the ICTAN with a wide experience in descriptive evaluation of semisolid products and they were regular white sauce consumers. The descriptive evaluation used by Arocas et al. (2010a), which is specific for white sauces, was used. Sensory evaluations were carried out in individual booths (ISO 8589:2007). Seven textural attributes (three nonoral and four oral attributes), defined previously by Arocas et al. (2010a) were evaluated. Each panelist received and scored all four freshly prepared and F/T white sauces in separate sessions and by duplicate. Therefore, a total of four separate 60 min sessions were performed. White sauces were presented, one by one in a sequential monadic way, in a randomized order, and each panelist evaluated the group of four sauces heated in a microwave at 37 °C. The panelists used 8 cm unstructured scales, anchored at the ends with “low” and “high,” to rate the selected seven attributes in the different sauces.

Statistical analysis

Application of one-way analysis of variance elicited the effect of replacing corn starch and milk components with each type of fiber at both processing levels (fresh and F/T samples; Herranz et al., 2017). Also, for each sauce type, all instrumental parameters and sensory attributes were studied for the effect on stability due to freezing/thawing and reheating of the sample. Minimum significant differences were calculated using Fisher’s least significant difference (LSD) tests with a 95% confidence interval for comparison of instrumental parameters and sensory attributes (Alvarez et al., 2011; Herranz et al., 2017). Pearson correlations were established to examine the relationship between the instrumental parameters and sensory attributes.

Data analysis was carried out with SPSS Statistics 19.0 (SPSS Inc., Chicago, IL, USA) and XLSTAT add-in for Microsoft Excel software version 2012 (Addinsoft, Paris, France).

Results and Discussion

Selection of fibers

Initially, the flow curves of fresh white sauces, produced with six different fiber types, were obtained to make a fiber-enriched béchamel to replicate, as close as possible, commercial white sauce (made with only corn starch), with optimal textural and sensory properties. All samples showed shear thinning behavior ($n < 1$), due to the apparent viscosity decreasing as the shear rate increased (Figure 1). This thinning behavior is typical of starch-based sauces (Arocas et al., 2009; Mandala et al., 2004; Román et al., 2018; Sanz et al., 2016). The viscosity curves of most samples showed great similarity to the control, sauces produced with K4M and HF401 were an exception to this. Fitting the flow curves to the power law model, the consistency index (K), flow index (n), and the apparent viscosity at 50 s^{-1} (η_{a50}) were obtained (Table 2). This latter parameter has been related to the perception of thickness in the mouth (Morell, Hernando, Lorca, & Fiszman, 2015). As can be seen in Table 2, sauces with K4M and HF401 had the highest and the lowest, significant ($P < 0.05$), K and η_{a50} values, respectively, in comparison with the control sauce without fiber. For this reason, both fibers were not considered for further study. Also, the sauce with pea (EF150) fiber showed a higher consistency than the control, although differences were not significant. However, it was also discarded from the study as it was shown to be an unstable sauce, as their rheological properties changed very quickly as seen by the higher standard deviation of their K and mainly n mean values (17.1 ± 2.54 and 0.243 ± 0.232, respectively).

Rheological Characterization of Fiber-Enriched White Sauces

Stress sweep tests

Study of the addition of different fibers, and of one cycle of F/T (freezing, storage, and thawing) plus heating, on the LVE range of white sauces, were explored. For that propose shear stress (σ_{max}) and shear strain (γ_{max}) amplitudes, which can be taken as measurements of rheological stability (Mezger, 2006), complex modulus (G^*), and loss factor ($\tan\delta = G''/G'$) within the LVE range were evaluated (Table 3). Regarding the fresh sauces, the control presented a very stable network with the highest values of both shear stress (σ_{max}) and shear strain (γ_{max}) amplitudes, followed by MCC-enriched sauce. Thus, the addition of fibers altered the conformational stability to different degrees. Presence of fibers decreased the resistance (σ_{max}) and deformability (γ_{max}), significantly ($P < 0.05$), of the fresh sauces, but especially those with added AF401 and KF200 which were much more unstable. The rigidity (G^*) of fiber-enriched sauces were like that of the control, except for the KF200-enriched sample. Moreover, for all fresh samples the values of tan δ, which shows the ratio of the amount of energy lost to the amount of energy stored, were lower than one, reflecting a solid-like character. The fiber-enriched sauce whose structural stability appears less affected, with respect to the control, was the MCC-enriched sample. In fact, Zhang (2001) reported that MCC could act as a viscosity-increasing agent, a moisture binder, an emulsion stabilizer, and could help improve the texture of many food products. It seems that when CMC is added to an oil-in-water emulsion at higher concentrations can increase emulsion stability (Cao, Dickinson, & Wedlock, 1990).

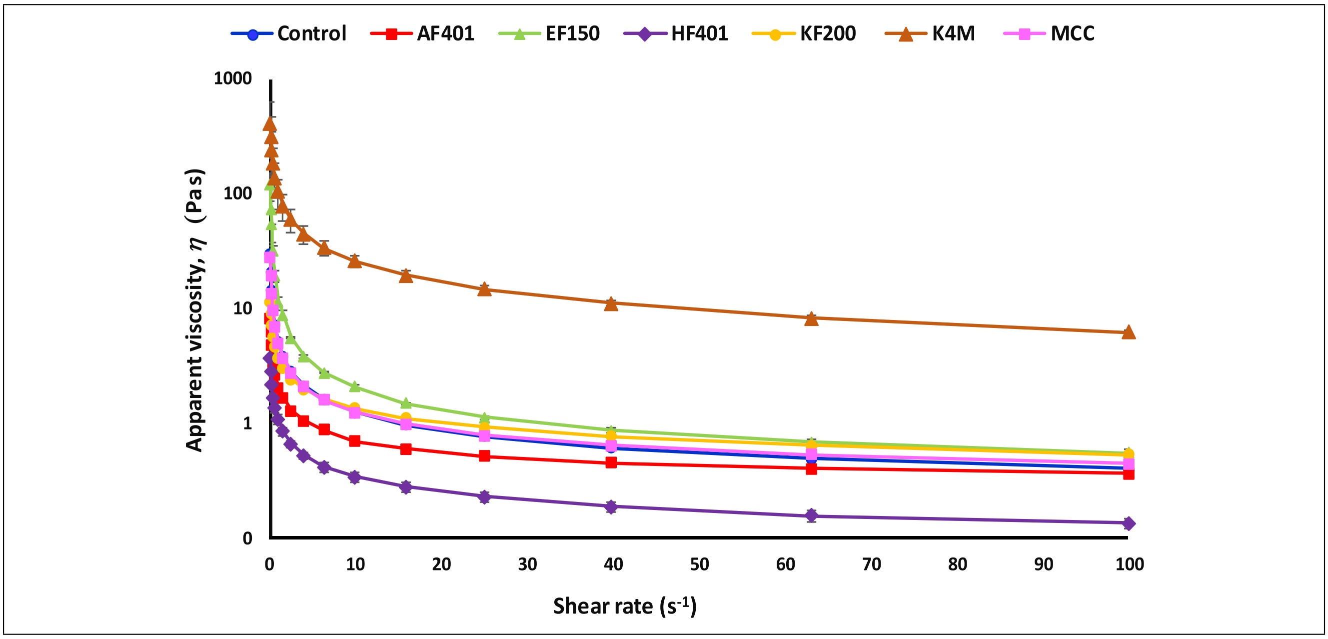

Figure 1–Apparent viscosity changes versus shear rate of the freshly prepared white sauces enriched with different fibers in comparison with the control one.

Table 2–Effect of the type of fiber on the power law parameters derived from flow curves and the apparent viscosity at shear rate of 50 s^{-1} (η_{a50}) of freshly prepared white sauces.

Fiber type	K (Pa·s^n)	n	R^2	η_{a50} (Pa·s)
Control	6.34 ± 0.202B	0.325 ± 0.002B	0.992 ± 0.000	0.595 ± 0.017B,C
AF401	2.43 ± 0.081B	0.510 ± 0.050A	0.982 ± 0.003	0.482 ± 0.038C,D
EF150	17.1 ± 2.54B	0.243 ± 0.232B	0.985 ± 0.003	0.825 ± 0.060B
HF401	1.16 ± 0.064C	0.481 ± 0.035A	0.994 ± 0.002	0.189 ± 0.018D
K4M	101 ± 31.7A	0.414 ± 0.076A,B	0.999 ± 0.001	9.96 ± 0.484A
KF200	4.92 ± 1.44B	0.460 ± 0.118A,B	0.996 ± 0.000	0.832 ± 0.090B
MCC	5.55 ± 0.186B	0.398 ± 0.010A,B	0.990 ± 0.001	0.639 ± 0.047B,C

Different capital letters (A–D) in the same column indicate significant differences ($P < 0.05$) among white sauces elaborated with different type of fiber in comparison with the control one.

Table 3–Effect of the type of fiber and processing on the limit values of linear viscoelastic (LVE) range of fiber-enriched white sauces.

Fiber type	Processing level	σ_{max} (Pa)	γ_{max} (%)	G^* (Pa)	tan δ
Control	Fresh	2.25 ± 0.022Ab	11.3 ± 1.17Aa	20.1 ± 1.82Bb	0.390 ± 0.039Ba
AF401	Fresh	0.176 ± 0.003Db	0.794 ± 0.136Ca	22.8 ± 3.56Bb	0.482 ± 0.028A,Ba
KF200	Fresh	0.328 ± 0.002Cb	0.485 ± 0.119Ca	70.8 ± 19.5Ab	0.393 ± 0.070Ba
MCC	Fresh	2.15 ± 0.031Bb	7.25 ± 1.93Ba	30.8 ± 6.80Bb	0.548 ± 0.105Aa
Control	F/T	2.59 ± 0.006Ba	3.22 ± 0.227Bb	80.7 ± 5.30Ca	0.222 ± 0.028Bb
AF401	F/T	0.530 ± 0.006Da	1.19 ± 0.265Ca	45.9 ± 10.3Da	0.319 ± 0.045Ab
KF200	F/T	0.807 ± 0.001Ca	0.453 ± 0.053Da	180 ± 19.8Aa	0.292 ± 0.023Aa
MCC	F/T	6.44 ± 0.014Aa	4.85 ± 0.618Aa	134 ± 17.4Ba	0.304 ± 0.027Ab

Effect of fiber type. For the same processing level, different capital letters (A–D) indicate significant differences ($P < 0.05$) among white sauces elaborated with different type of fiber. Effect of one freeze/thaw cycle. For the same sauce type, different small letters (a, b) indicate significant differences ($P < 0.05$) among fresh white sauces and F/T counterparts. F/T, white sauces subjected to a freeze/thaw cycle and microwave heating.

In addition, CMC is physiologically inert and has beneficial effects on lowering glycemic and cholesterol levels (Ou, Kwok, Li, & Fu, 2001; Uskoković, 2008), and therefore its use in formulated products is very attractive (Arancibia, Bayarri, & Costell, 2013).

In turn, the cycle of freezing/thawing and subsequent heating by the microwave produced a hardening and a structural improvement, as shown by the significant increases ($P < 0.05$) of both shear amplitudes and G^*, and decrease of tan δ, respectively, with both F/T control and MCC-enriched sauces containing the more stable networks.

These results are in accordance with previous data reported by Arocas et al. (2009) who found that white sauce networks produced with native corn starch were notably affected by a freeze/thaw cycle. In particular, the F/T systems were stiffer (higher σ_{max}) and less deformable (lower γ_{max}) to the applied

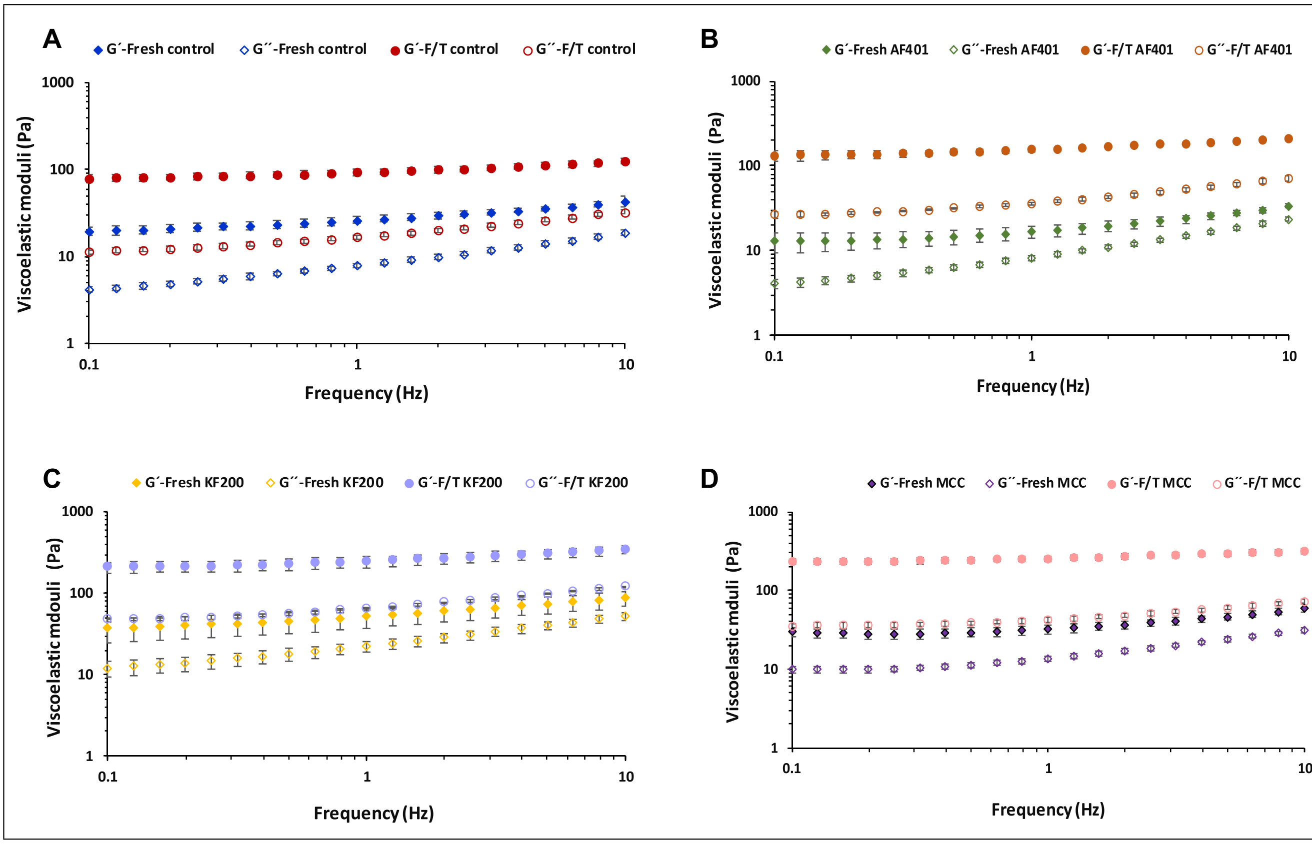

Figure 2–Mechanical spectra of the fresh and frozen/thawed (F/T) white sauces: controls without added fiber (A), AF401-enriched sauce (B), KF200-enriched sauce (C), and MCC-enriched sauce (D). Temperature (37 °C) mean values of six measurements ± standard deviation.

stress, which was attributed by the authors just cited to starch retrogradation phenomenon occurring during the freezing process, changing the network structure of the white sauce. Specifically, the use of xanthan and locust bean gums and the subsequent reheating after freezing reduced these structural changes (Arocas et al., 2009c). Therefore, it seems that both the type of fiber and the freezing/thawing affected the conformational stability of the network, formed by corn starch together with proteins and lipids, in different ways. In general, with the addition of the different fibers to the white sauces, they became more rigid but brittle to different degrees. The presence of fibers could hinder the interactions between the starch polymer chains that take place during starch retrogradation (Arocas et al., 2009c).

Frequency sweep tests

The mechanical spectra of all the samples at 37 °C are shown in Figure 2. In general, for fresh samples, storage modulus (G') was less than one order of magnitude greater than the viscous modulus (G''), indicating solid-like character. Moreover, although G' increased slightly with increasing frequency, G'' showed a considerable dependence on frequency, increasing particularly in the high frequency range (3–10 Hz), reflecting weak gel behavior. These spectra were remarkably similar to those obtained for white sauces prepared with different native starches by Sanz et al. (2016), who associated the weaker gel behavior of the samples made with native corn starch, with the reduced thickening ability of this native starch. Oscillatory spectra of all the studied sauces were also like those obtained for other white model sauces produced with wheat and rice flours (Mandala et al., 2004; Román et al., 2018; Sanz et al., 2016).

To quantify the frequency dependence of G' and G'', they can be fitted to the power law equations (Eq. (2) and (3)):

$$G'(f) = G'_0 . f^{n'} \tag{2}$$

$$G''(f) = G''_0 . f^{n''} \tag{3}$$

where G'_0 and G''_0 are elastic and viscous moduli at a frequency (*f*) of 1 Hz, and n' and n'' denote the rate of change of G' and G'' respectively with increasing frequency, so both exponents provide conformational network stability (Herranz et al., 2017).

Table 4 shows the higher values of n'' exponent regarding n' values in all the fresh samples corroborate the stronger G'' frequency dependence mentioned above, reflecting their weak gel behavior (Lopes da Silva, & Rao, 2007). However, between the fresh samples, the sauces prepared with AF401 and KF200 showed higher n' and n'' values than the control sample, whereas the opposite was true for the MCC-enriched sauce. This result would indicate that MCC-enriched sauce is more stable. Arancibia et al. (2013) found differences in microstructure and particle size distribution between carboxymethyl cellulose (CMC) and tapioca modified starch emulsions and these differences were clearly related to their rheological behavior. MCC is a synergistic, coprocessed composite consisting of microcrystalline cellulose and carboxymethyl cellulose. CMC-based emulsion exhibited a negative charge of ζ-potential values, especially in emulsions with 5% oil, due to the presence of the anionic groups in the polymer chain of CMC and its surface properties. It is considered that the larger

Table 4–Effect of the type of fiber and processing on the rheological parameters derived from dynamic power law fits of fiber-enriched white sauces.

Fiber type	Processing level	G'_0 (Pa·s$^{n'}$)	n'	R^2	G''_0 (Pa·s$^{n''}$)	n''	R^2
Control	Fresh	27.1 ± 2.04Cb	0.167 ± 0.033Aa	0.977 ± 0.027	8.15 ± 0.564Cb	0.328 ± 0.004Ba	0.994 ± 0.001
AF401	Fresh	17.8 ± 2.88Db	0.212 ± 0.043Aa	0.937 ± 0.040	8.69 ± 0.630Cb	0.389 ± 0.014Aa	0.989 ± 0.006
KF200	Fresh	44.6 ± 0.526Ab	0.206 ± 0.004Aa	0.986 ± 0.001	21.0 ± 0.480Ab	0.343 ± 0.005Ba	0.995 ± 0.000
MCC	Fresh	35.2 ± 4.03Bb	0.156 ± 0.027Aa	0.862 ± 0.035	14.9 ± 1.10Bb	0.267 ± 0.011Ca	0.946 ± 0.008
Control	F/T	95.2 ± 7.42Ca	0.096 ± 0.007A,Bb	0.972 ± 0.004	17.6 ± 1.00Da	0.232 ± 0.006Ab	0.979 ± 0.002
AF401	F/T	159 ± 9.51Ba	0.105 ± 0.032Ab	0.946 ± 0.066	38.6 ± 1.02Ca	0.217 ± 0.022Ab	0.954 ± 0.026
KF200	F/T	253 ± 36.6Aa	0.113 ± 0.003Ab	0.960 ± 0.026	68.3 ± 2.63Aa	0.212 ± 0.007Ab	0.969 ± 0.003
MCC	F/T	261 ± 19.4Aa	0.069 ± 2.75Bb	0.965 ± 0.008	45.6 ± 3.02Ba	0.160 ± 0.006Bb	0.933 ± 0.006

Effect of fiber type. For the same processing level, different capital letters (A–D) indicate significant differences ($P < 0.05$) among white sauces elaborated with different type of fiber. Effect of one freeze/thaw cycle. For the same sauce type, different small letters (a, b) indicate significant differences ($P < 0.05$) among fresh white sauces and their F/T counterparts. F/T, white sauces subjected to a freezing/thawing cycle and microwave heating.

ζ -potential values indicate a higher electrostatic repulsion between the droplets that can increase emulsion stability. Moreover, the addition of CMC to emulsions made with 5% oil produced that the fat droplets were closely associated with one another and clumped together in certain regions giving more structured system.

The freeze/thaw cycle and subsequent heating produced a structural reinforcement of all the sauces networks, where the G' modulus was one order of magnitude greater than G'' (Figure 2) and, at the same time an improvement in conformational network stability as shown by the significant decrease of the n' and n'' values with respect to the corresponding fresh sauces. This structural improvement was also observed by Arocas et al. (2009c) when they added xanthan and locust bean gum in white sauces made with native corn starch. As it was observed in the previous section (stress sweep tests), the F/T MCC-enriched sample resulted as the most stable sauce (lowest value of n'') and more similar to the F/T control, although more rigid.

Temperature sweep tests

To study the network stability of these white sauces during heating (cooking process), temperature sweep tests were carried out. Figure 3 shows the thermal profiles (obtained in the 20–80 °C) of all the sauces within the LVE range are reported in terms of complex viscosity (η^*), whereas Figure 4 shows the loss tangent (tan δ) of the sauces. The thermal profiles of G^* and G' showed the same behavior as the thermal profiles of η^* with the profiles of G'' being like those of tan δ (data not shown).

As shown in Figure 3 and 4, and Table 5, three stages can be observed in the thermal profiles of all the fresh white sauces.

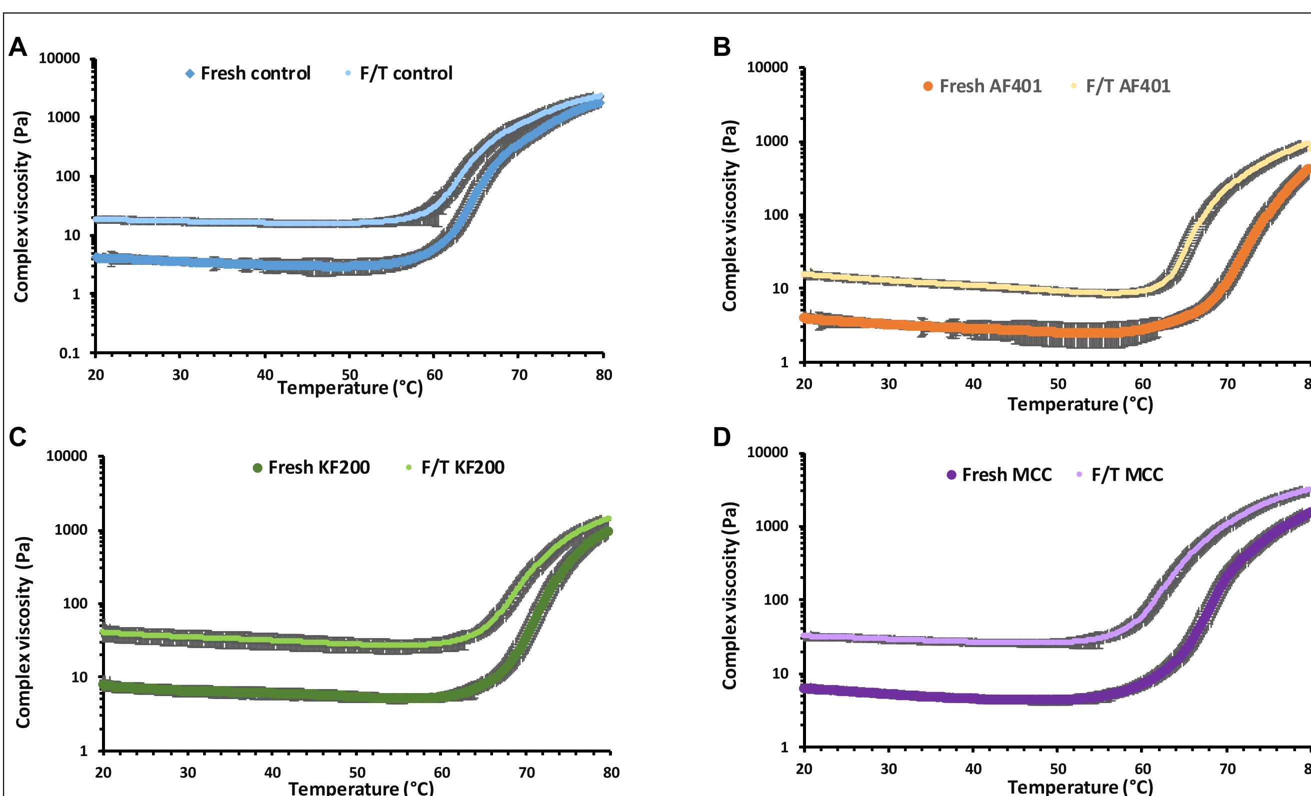

Figure 3–Complex viscosity as a function of increasing temperature (from 20 to 80 °C) of fresh and frozen/thawed white sauces enriched with AF401 (B), KF200 (C), and MCC (D), and control sample (A).

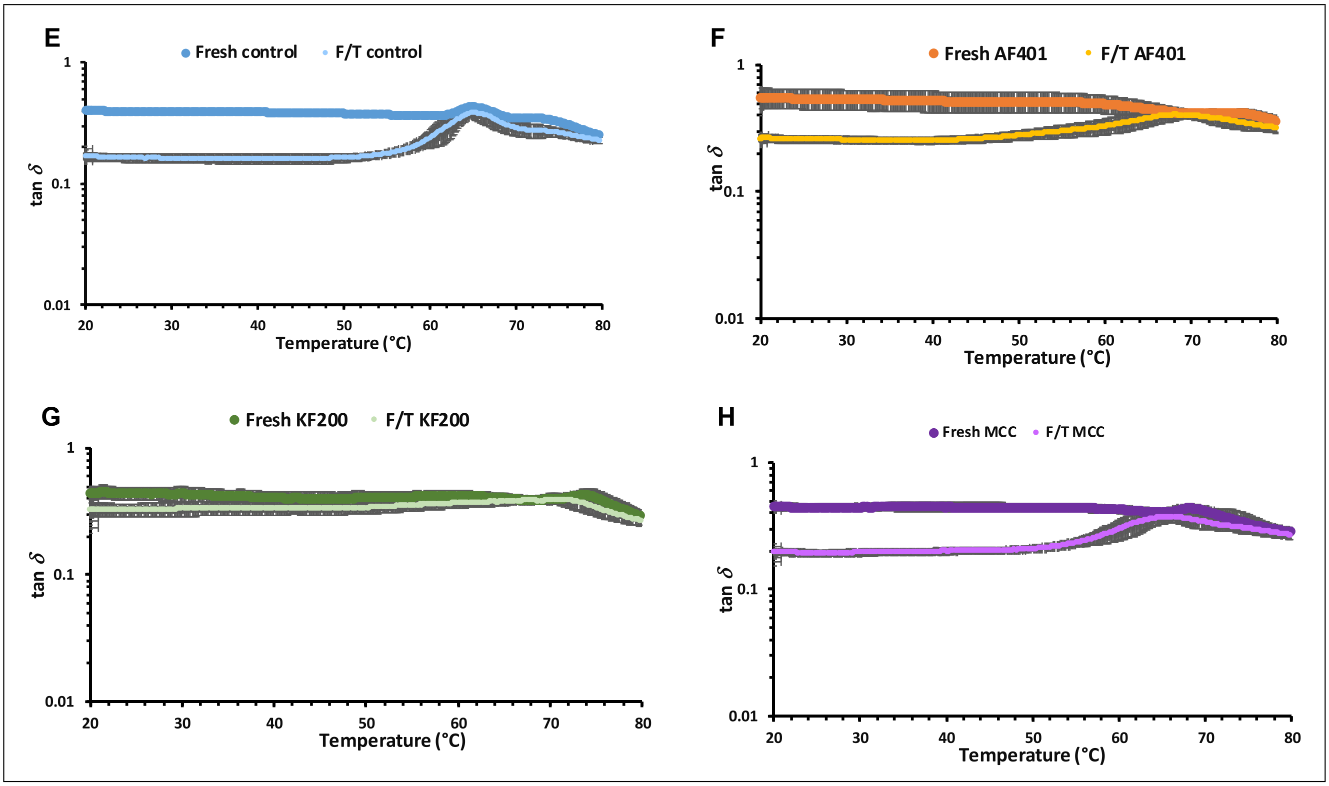

Figure 4–Tan δ as a function of increasing temperature (from 20° to 80 °C) of fresh and frozen/thawed white sauces enriched with AF401 (F), KF200 (G), MCC (H), and control sample (E).

Before heating (T_0 = 20 °C), all samples showed similar tan δ values although KF200 was the most viscous sample. At early heating temperatures, the complex viscosity values decreased to reach a minimum value at $T_{\mathrm{inflexion1}}$, showing all the sauces similar tan δ values. This decrease in viscosity may be due to an initial modification of the network because of the rupture of weak interactions, such as hydrogen bonds, producing a softening of the structure. This decrease was clearer and longer lasting for fresh sauces with added AF401 and KF200 than for the control sauce (Figure 3). There was a small initial increase in the η^* values, ranging between $T_{\mathrm{inflexion1}}$ and $T_{\mathrm{inflexion2}}$, and with a lesser gradient. Nevertheless, this viscosity increase is especially notable and exponential at higher temperatures ($> T_{\mathrm{inflexion2}}$), producing at the same time a considerable decrease in tan δ (Figure 3). Therefore, a continuous structural reinforcement and stability of the network is produced, as shown by the viscoelastic parameters' values. This stronger reinforcement of the network could correspond to a sol-to-gel transition as Debet and Gidley (2006) reported previously, so that a 3-dimensional gel network is constructed from the rest of the amylose molecules, reinforced by strong interactions among the swollen starch particles (Debet & Gidley, 2006; Hsu, Lu, & Huang, 2000; Ring, 1985), due to the remains of some ungelatinized starch granules starting to swell, or even amylose molecules dissolving from the swollen starch granules, forming new interactions and increasing the strength of the network (Hsu et al., 2000). In turn, Rayment, Ross-Murphy, and Eills (1995) stated that the starch particles could act as a rigid filler in the matrix, forming strong interactions with the existing matrix. In any case, it must be considered that in these sauces, there was an earlier network formed during the preparation process, so other ingredients can influence the stability of the network. Moreover, at the end of the heating (~70 to 80 °C), this increase in G^* could be also partially associated to sample drying because of these high temperatures.

This exponential strengthening seems to continue at temperatures higher than 80 °C ($> T_F$). This indicates that as temperature increases, stronger interactions are formed in the network and, at the same time, the sample is partially drying. Processed-samples showed, in general, higher values of viscosity and lower values of tan δ (higher viscoelasticity) than their fresh counterparts, along the whole heating process, except for the case of the η^* of the F/T AF401-enriched sauce at $T_{\mathrm{inflexion2}}$, which was lower than that of its fresh counterpart (Table 5).

Regarding the fiber type effect, both fresh KF200 and MCC samples had higher complex viscosity values than the control at both T_0 and $T_{\mathrm{inflexion1}}$ (Figure 3C and 3D). However, at $T_{\mathrm{inflexion2}}$, the AF401-enriched sauce had a significantly higher η^* value (Table 5), whereas at T_F, the apple-enriched sample resulted being the weakest. Moreover, AF401-enriched sauce also showed the highest value of tan δ at T_F (decreased viscoelasticity), meaning that the presence of apple fiber decreased either η^* or the viscoelasticity of the sauce system, being less stable during the heating process and not reaching an adequate texture at elevated temperatures. On the contrary, the MCC-enriched sauces seem to be the most heat-stable, as its behavior was similar to the control during the whole heating process, reaching similar viscosities and tan δ values at similar temperatures (Figure 4). In fact, there were no significant differences between the $T_{\mathrm{inflexion1}}$ and $T_{\mathrm{inflexion2}}$ values corresponding to both the fresh control and MCC-enriched sauces, with both temperatures being significantly lower ($P < 0.05$) than those obtained in the fresh AF401- and KF200-enriched sauces (Table 5). In this regard,

Table 5–Effect of the type of fiber and processing on the rheological properties in the LVE range from thermo-mechanical analyses of fiber-enriched white sauces.

Fiber type	Processing level	η^*_{T0} (Pa·s)	tan δ_{T0}	$T_{inflexion1}$	$\eta^*_{Tinflexion1}$ (Pa·s)	tan $\delta_{Tinflexion1}$	$T_{inflexion2}$	$\eta^*_{Tinflexion2}$ (Pa·s)	tan $\delta_{Tinflexion2}$	η^*_{TF} (Pa·s)	tan δ_{TF}
Control	Fresh	4.36 ± 0.596Bb	0.400 ± 0.010Aa	48.2 ± 1.34Ca	3.00 ± 0.339B,Cb	0.380 ± 0.010Aa	63.3 ± 3.15Ba	10.4 ± 0.050Cb	0.360 ± 0.0001Ba	1830 ± 520Aa	0.257 ± 0.030Ba
AF401	Fresh	4.47 ± 1.39Bb	0.513 ± 0.107Aa	53.9 ± 0.949A,Ba	2.46 ± 0.907Cb	0.527 ± 0.102Aa	70.5 ± 2.08Aa	40.9 ± 0.040Aa	0.403 ± 0.010Aa	448 ± 173Ba	0.363 ± 0.020Aa
KF200	Fresh	9.05 ± 1.35Ab	0.363 ± 0.040Aa	56.9 ± 3.03Aa	5.07 ± 0.610Ab	0.417 ± 0.040Aa	69.1 ± 1.91Aa	15.9 ± 1.01Bb	0.380 ± 0.020A,Ba	1001 ± 387A,Ba	0.293 ± 0.030Ba
MCC	Fresh	6.65 ± 0.424A,Bb	0.420 ± 0.03Aa	48.7 ± 2.02B,Ca	4.32 ± 0.546A,Bb	0.447 ± 0.040Aa	64.3 ± 1.65Ba	14.6 ± 1.19Bb	0.403 ± 0.010Aa	1519 ± 125Ab	0.280 ± 0.010Ba
Control	F/T	18.7 ± 0.962Ba	0.153 ± 0.010Bb	47.9 ± 3.55Ba	15.7 ± 1.27Ba	0.163 ± 0.02Bb	60.2 ± 1.69Aa	25.8 ± 2.62Ba	0.223 ± 0.010Bb	2313 ± 88.5Aa	0.230 ± 0.020Ba
AF401	F/T	17.2 ± 6.30Ba	0.223 ± 0.010Ab	58.5 ± 3.81Aa	8.35 ± 3.13Ba	0.313 ± 0.03Ab	66.4 ± 3.98Aa	25.0 ± 7.76Bb	0.410 ± 0.020Aa	949 ± 405Ba	0.320 ± 0.030Aa
KF200	F/T	47.5 ± 12.0Aa	0.230 ± 0.020Ab	55.9 ± 2.25A,Ba	26.5 ± 5.54Aa	0.347 ± 0.04Aa	66.8 ± 2.29Aa	54.8 ± 13.3Aa	0.367 ± 0.020Aa	1338 ± 569Ba	0.267 ± 0.020A,Ba
MCC	F/T	33.1 ± 1.48A,Ba	0.167 ± 0.020Ab	50.1 ± 3.05A,Ba	25.5 ± 3.12Aa	0.207 ± 0.01Ab	59.1 ± 3.78Aa	37.5 ± 2.12Aa	0.267 ± 0.020Bb	3152 ± 569Ba	0.267 ± 0.020A,Ba

Effect of fiber type. For the same processing level, different capital letters (A–C) indicate significant differences ($P < 0.05$) among white sauces elaborated with different type of fiber.
Effect of one freeze/thaw cycle. For the same sauce type, different small letters (a, b) indicate significant differences ($P < 0.05$) among white sauces with different processing level (fresh and F/T samples). F/T, white sauces subjected to a freezing/thawing cycle and microwave heating.
T_0, initial temperature (20 °C); T_F, final temperature (80 °C); $T_{inflexion1}$ and $T_{inflexion2}$, points of inflexion along the heating process (20–80 °C).

MCC fiber was more successful at mimicking the effect of corn starch.

Steady rheometer measurements: flow behavior

The flow curves of fresh and frozen/thawed white sauces enriched with selected fibers are shown in Figure S1. All the F/T white sauces exhibited a shear-thinning flow behavior ($n < 1$), as was also observed in their fresh counterparts (Figure 1), although viscosity profiles were higher in F/T sauces. As seen in Table 6, the type of fiber had a significant effect on the K and η_{a50} values in both fresh and processed (F/T) samples. In fresh samples, MCC showed similar K and η_{a50} values to the control sample, while KF200-sauces showed a K value similar to that of the MCC-sample but with a significantly higher η_{a50} value than the other fresh sauces, which could also be associated to its higher G^* value derived from the stress sweeps (Table 3). After the freeze/thaw cycle, all sauces exhibited a significant increase of their consistencies (K) and η_{a50} values, although the processing only affected the flow behavior for the MCC sample, which was significantly lower ($P < 0.05$) in the processed sample than in the fresh. This higher degree of shear thinning behavior could be related to the formation of a greater number of entanglements in the emulsion (Ma & Boye, 2013) also to a lower particle size (Román et al., 2018). However, Sanz et al. (2016) reported a remarkable decrease in both K and n values after the freeze/thaw cycle in white sauces produced with native starches, therefore, it seems that the heating with a microwave just after the thawing influenced the conformation structural of all samples. It is important to note that after the freeze/thaw cycle, the MCC-enriched sauce showed either significantly higher values of K and η_{a50} or significantly lower n values than those corresponding to the F/T control sample. Arancibia et al. (2013) reported that the addition of CMC to oil in water emulsions significantly increased K values and decreased n values. However, the K and η_{a50} values in the F/T control samples were also significantly higher than in the KF200 and AF401-enriched sauces. These observations corroborate the results of the dynamic measurements (Table 3 to 5), as both fresh and F/T, MCC-enriched sauces had viscoelastic parameters more like the control samples (reflecting similar stability to shearing), whereas KF200-enriched sauces produced molecular networks stronger to shear, shown by their higher values of G^*, G'', and η^*.

Other quality physical parameters

Table 7 shows the syneresis, the total soluble solids content expressed in °Brix, and the color parameters of white sauces, which are also other important quality parameters to study the influence of the fiber addition in the fresh and processed sauces.

Syneresis, the release of water, is a common negative phenomenon observed after the freezing of the starch contained in the sauces and is mainly related to amylose retrogradation (White, Abbas, & Johnson, 1989). In fresh sauces, AF401 shows the highest percentage of syneresis, meaning that the AF401 fiber is less capable of retaining liquid components. The syneresis percentages of the remaining fresh samples were significantly lower (<10%), and there was no significant difference between the syneresis values of the control and the MCC-enriched sauces, so both MCC and KF200 fibers keep or improve the retention of liquid in the fresh matrices sauces as when compared to corn starch. After freezing/thawing treatment, both F/T control and MCC-enriched sauces had significantly lower syneresis percentages than the processed AF401 and KF200 sauces. However, the freezing/thawing damage significantly ($P < 0.05$) affected the

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Table 6–Effect of type of fiber and processing on the power law parameters derived from the flow curves and the apparent viscosity at shear rate of 50 s^{-1} (η_{a50}) of fiber-enriched white sauces.

Fiber type	Processing level	K (Pa·s^n)	n	R^2	$\eta_{a,50}$ (Pa·s)
Control	Fresh	6.34 ± 0.202Ab	0.325 ± 0.002Ba	0.992 ± 0.000	0.595 ± 0.017Bb
AF401	Fresh	2.43 ± 0.081Cb	0.510 ± 0.050Aa	0.982 ± 0.003	0.482 ± 0.038Cb
KF200	Fresh	4.92 ± 1.44Bb	0.460 ± 0.118Aa	0.996 ± 0.000	0.832 ± 0.090Ab
MCC	Fresh	5.55 ± 0.186A,Bb	0.398 ± 0.010A,Ba	0.990 ± 0.001	0.639 ± 0.047Bb
Control	F/T	15.8 ± 0.223Ba	0.352 ± 0.024Ca	0.991 ± 0.009	1.45 ± 0.078Ba
AF401	F/T	6.77 ± 0.255Da	0.500 ± 0.004Aa	0.989 ± 0.002	1.17 ± 0.045Ca
KF200	F/T	9.65 ± 0.700Ca	0.472 ± 0.004Ba	0.998 ± 0.000	1.38 ± 0.077Ba
MCC	F/T	32.2 ± 0.150Aa	0.286 ± 0.005Db	0.998 ± 0.000	2.03 ± 0.052Aa

Effect of fiber type. For the same processing level, different capital letters (A–D) indicate significant differences ($P < 0.05$) among white sauces elaborated with different type of fiber. Effect of one freeze/thaw cycle. For the same sauce type, different small letters (a, b) indicate significant differences ($P < 0.05$) among fresh white sauces and their F/T counterparts. F/T, white sauces subjected to a freezing/thawing cycle and microwave heating.

Table 7–Effect of type of fiber and processing on the syneresis, soluble solids content and color of fiber-enriched white sauces.

Fiber type	Processing level	Syneresis (%)	°Brix	L^*	a^*	b^*	ΔE^*
Control	Fresh	6.88 ± 0.259Ba	17.4 ± 1.02Aa	80.3 ± 0.039Aa	−3.36 ± 0.030Ca	4.39 ± 0.159Ca	–
AF401	Fresh	24.9 ± 0.908Aa	12.3 ± 1.29Ca	59.9 ± 0.211Da	4.34 ± 0.176Ab	13.0 ± 0.452Ab	–
KF200	Fresh	5.72 ± 0.171Cb	15.2 ± 0.651Ba	78.2 ± 0.063Ba	−3.32 ± 0.093Cb	3.98 ± 0.153Db	–
MCC	Fresh	6.68 ± 0.259Ba	17.4 ± 0.208Ab	70.3 ± 0.182Cb	−1.03 ± 0.066Ba	8.03 ± 0.096Ba	–
Control	F/T	5.01 ± 0.348Db	18.0 ± 0.971Aa	78.9 ± 0.840Ab	−3.95 ± 0.108Db	2.35 ± 0.666Db	2.62 ± 0.920C
AF401	F/T	22.5 ± 0.561Bb	10.8 ± 0.321Ca	58.9 ± 0.169Cb	5.25 ± 0.007Aa	14.9 ± 0.172Aa	2.36 ± 0.210C
KF200	F/T	23.5 ± 0.687Aa	13.4 ± 0.451Bb	72.8 ± 0.407Bb	−0.92 ± 0.100Ba	8.42 ± 0.310Ba	9.15 ± 0.110B
MCC	F/T	6.67 ± 0.013Ca	18.8 ± 0.624Aa	79.3 ± 0.241Aa	−2.99 ± 0.017Cb	3.28 ± 0.305Cb	10.3 ± 0.070A

Effect of fiber type. For the same processing level, different capital letters (A–D) indicate significant differences ($P < 0.05$) among white sauces elaborated with different type of fiber. Effect of one freeze/thaw cycle. For the same sauce type, different small letters (a, b) indicate significant differences ($P < 0.05$) among fresh white sauces and their F/T counterparts. F/T, white sauces subjected to a freezing/thawing cycle and microwave heating.
L^*, lightness (whiteness); a^*, grade of green/red; b^*, grade of blue/yellow; ΔE^*, total color difference between each frozen/thawed white sauce and its fresh counterpart.

KF200 structure as shown by the highest syneresis value for the F/T KF200-enriched sample, whereas there were no significant differences in syneresis percentages, for the remaining samples of the F/T sauces, and freshly made counterparts. Plus, F/T MCC and control sauces were the samples with the lower syneresis percentages, again reflecting a greater degree of F/T stability. This stability may be due to a higher number of entanglements between the polymer chains of this fiber and the amylose chains, reducing the amylose-amylose interactions. It should be noted that applying microwave heating just after the freeze/thaw cycle, likely decreased the syneresis percentage of all these sauces so that it allowed the breakdown of the interactions between amylose molecules facilitating the re-association between them and fibers through water molecules (Arocas et al., 2009). At the same time, in both fresh and F/T sauces, there were no significant differences between water soluble compounds of the MCC-enriched sauces and those of the control sauces, which were significantly higher than in the other two enriched sauces.

Regarding the color dataset (Table 7), the color of the fibers used influences the color of the sauce. AF401 fiber is a brown powder, and both fresh and F/T AF401-enriched sauces were darker brown in color, with significantly greater redness and yellowness values and the lowest lightness. On the contrary, both KF200 and MCC fibers were white powders and produced colored sauces more like the controls. However, both fiber type and processing affected the color parameters of the sauces in separate ways. In the fresh samples, the lightening caused in the sauce by MCC incorporation was significantly lower than that attributed by KF200 addition, although both sauces had significantly lower L^* values than the control without added fiber. However, after processing the MCC-sauce was a brighter sample without significant differences to the control white sauce. Processing decreased the lightness of control, AF401 and KF200 sauces, but favored higher L^* values in the sauce with added MCC, which could be partially due to its higher water-holding capacity. However, L^* parameter decreases in F/T control sample respect to fresh sample in spite of it has a high water holding capacity unlike what happens for MCC sample. This phenomenon could be due to that the control sample was more affected by the cycle of freezing/thawing. Nevertheless, in the case of MCC sample, MCC could form bonds with water molecules increasing lightness (L^*).

However, although there are significant differences between both the a^* and b^* values of the different white sauces, as expected, both fresh and F/T samples with added either MCC or KF200 had quite similar negative and positive a^* and b^* values to those of the control sauces. In addition, the processing of the MCC-enriched sauce also reduced the differences in the yellowness of this sample and that of the control one. The total color differences (ΔE^*), calculated with respect to the fresh counterparts were significantly higher for both F/T sauces made with MCC and KF200 when compared to the control sauce, but in the case of the MCC-enriched sauce the decreased differences between the lightness and the yellowness is due to the freeze/thaw cycle when compared to the control sauce.

Sensory textural attributes

Table S2 and Figure 5 show the sensory scores given by the panelists for the nonoral and oral textural properties of both fresh and processed sauces produced with the different fibers. The freeze/thaw cycle produced different sensorial profiles for the white sauces depending on the type of fiber incorporated. With regards to the nonoral sensory attributes of texture in the fresh sauces (Figure 5), and in the case of the consistency the

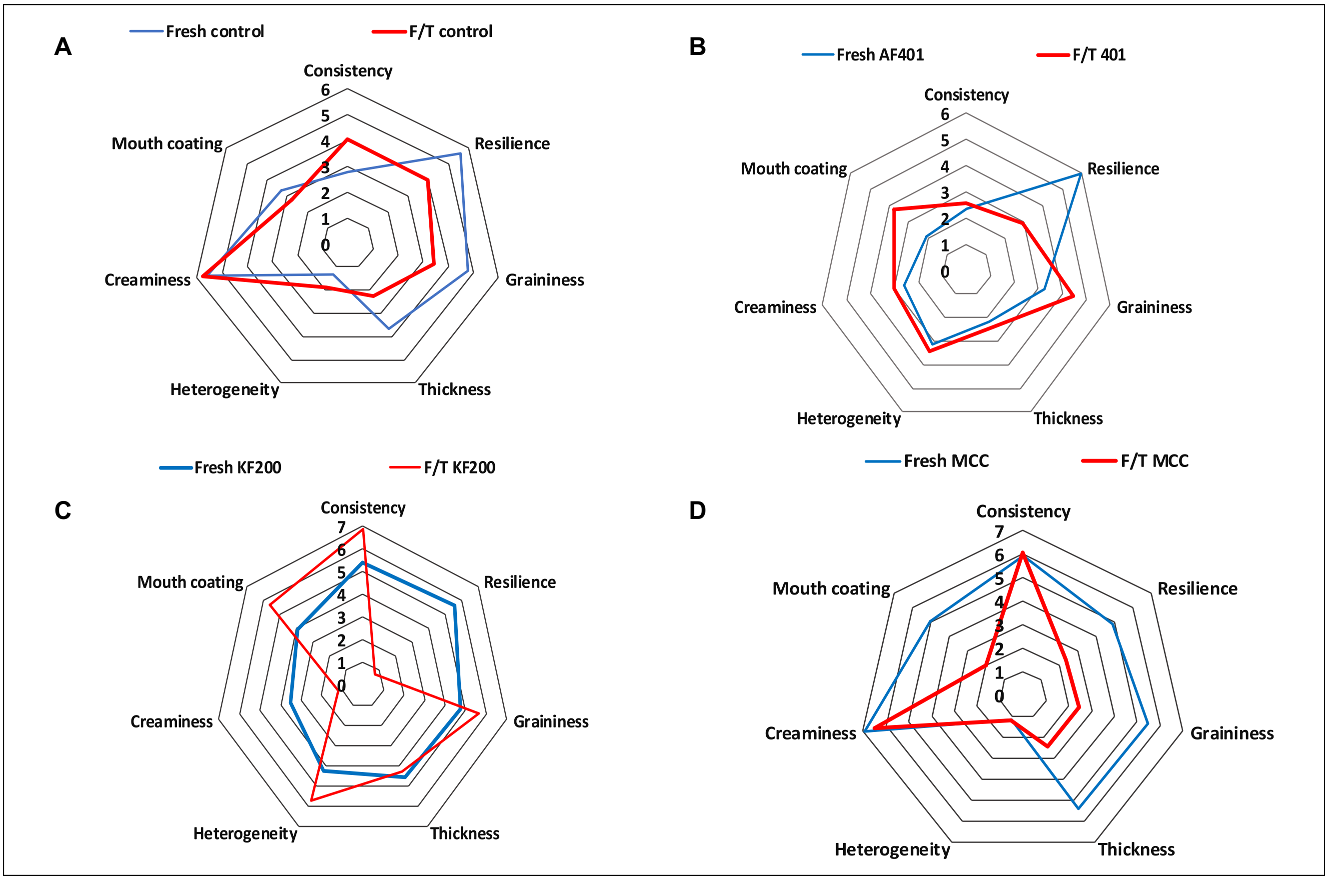

Figure 5–Descriptive sensory parameters of fresh and frozen/thawed sauces enriched with different fibers: (A) control, (B) AF401, (C) KF200, and (D) MCC.

panelists distinguished significantly between MCC and KF200 sauces, with higher scores than the other two samples. Untrained panelists did not distinguish the fresh sauces by their resilience. In the case of graininess, the panelists distinguished significantly between AF401 and MCC sauces, which scored lower and higher, respectively. In the case of oral thickness, the panelists distinguished significantly between AF401, with the lowest score, and the other two fiber-enriched samples. The AF401-enriched sauce also scored lower for mouth coating, although differences between the fresh control, AF401 and KF200 samples were not significant for this oral attribute. The MCC-enriched sauce had the highest score for creaminess and presented the lowest heterogeneity, without significant differences between scores for this sample and the control sauce, for both attributes. Therefore, the addition of MCC increased the creaminess of the samples. Creaminess is a pleasant sensation when eating, associated with indicators of richness and high quality, mainly in foods containing fat (Akhtar, Murray, & Dickinson, 2006). Therefore, in fresh sauces, the control and MCC sauces (Figure 5A and 5D, respectively) had the most similar sensorial profiles, with only significant differences in their consistencies.

In addition, after the freeze/thaw cycle, both the control and MCC sauces maintained the highest scores for creaminess and the lowest for heterogeneity, with both samples also scoring lower for resiliency, graininess, thickness, and mouth coating than their fresh counterparts. On the contrary, the F/T KF200 sauce scored the highest for mouth coating, heterogeneity, thickness, and graininess, and the lowest for creaminess and resilience, being the sauce most negatively affected by the freeze/thaw cycle as evidenced by its difference in sensory profile (Figure 5C). The KF200 fiber does not seem to interact between amylose molecules, and therefore the freezing increased starch retrogradation in this matrix decreasing its sensory quality.

These observations are in accordance with the results obtained from the previous instrumental analyses, reflecting that both fiber type and the freeze/thaw cycle had a significant effect on the sensory textural quality of the white sauces, and that in both fresh and F/T samples the sauce produced with MCC was the most similar to the control sample. In fact, both control and MCC samples, fresh and processed, were more stable sauces with higher creaminess, and in this study, creaminess was positively correlated with σ_{max} ($r = 0.710$) and γ_{max} ($r = 0.733$), while being negatively correlated with syneresis ($r = -0.827$), also, γ_{max} was also negatively correlated with heterogeneity ($r = -0.770$). Characterization of processed AF401- and KF200-enriched sauces was by their higher graininess, heterogeneity, and mouth coating, with mouth coating positively correlated with graininess ($r = 0.928$) and thickness ($r = 0.700$). Finally, resilience was positively correlated with both n' and n'', $r = 0$ .793 and $r = 0.852$, respectively, and negatively with G^* ($r = -0.862$), G'_0 ($r = -0.953$), G''_0 ($r = -0.958$), and η_{a50} ($r = -0.772$). Therefore, there is a good relationship between instrumental measurements and sensorial properties in white sauces depending on the fiber type.

Conclusions

The freeze/thaw cycle and subsequent heating produced a structural reinforcement of the networks of all samples (control and enriched with fibers) and, at the same time, an improvement in their conformational stability except in AF401 sample. Both fresh and processed MCC-enriched white sauces showed a greater elasticity and more stable networks than those enriched with AF401 and KF200 fibers. Moreover, processed MCC-enriched samples showed higher values of lightness and lower percentage of syneresis like the control one. However, MCC samples presented a more similar sensory textural profile both before and after the freezing/thawing treatment with higher creaminess and lower heterogeneity than samples enriched with AF401 and KF200. Therefore, the use of MCC in white sauces is a feasible strategy to produce a white sauce enriched with fiber suitable for use in frozen dishes, as evidenced by an adequate freezing/thawing stability and sensorial properties similar to the ones corresponding to the control corn starch based sauce.

Authors' Contributions

Beatriz Herranz and María Dolores Álvarez designed the study and wrote the manuscript. Beatriz Herranz and Adrián Martínez performed rheological analysis. María Dolores Álvarez and Adrián Martínez carried out textural and sensorial analysis. Adrián Martínez performed syneresis, total soluble solids (TSS) content, and color measurements. All authors interpreted the results, revised, and approved the manuscript.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Apparent viscosity changes versus shear rate of the fresh and frozen/thawed (F/T) white sauces enriched with different fibres in comparison with the control one.

Table S1. Technological properties of the different fibers used in the elaboration of white sauces.

Table S2. Effect of the addition of fiber and processing on the textural attributes (nonoral and oral) of fiber-enriched white sauces.