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Rheological, textural, and sensory properties of non-fat yogurt containing cress (*Lepidium sativum*) seed gum and various starches

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Abstract

This study evaluated the effects of cress (*Lepidium sativum*) seed gum (CG) and various starches on the viscosity, viscoelasticity, texture, syneresis, and sensory quality of non-fat yogurt after up to 7 days in cold storage. Yogurt was prepared with CG alone or in combination with one of four different starches: sweet potato (*Ipomoea batatas*; SPS), chickpea (*Cicer arietinum*; CPS), corn (*Zea mays*; CS), or Turkish bean (*Phaseolus vulgaris*; TBS). All the yogurt samples had pseudoplastic propertie ($n < 1$) irrespective of the storage time, while samples containing CG with SPS or CPS had the highest consistency coefficients (k) at 0 and 7 days, respectively. The sample containing CG with CPS also had the highest elastic modulus (G'), irrespective of the storage time, suggesting the formation of a solid-like gel. The addition of CG alone or in combination with any of the starches conferred significant firmness to the yogurt samples, while the addition of CG together with starch significantly reduced wheying-off and improved the sensory acceptability compared with the control.

Keywords: cress seed gum; yogurt; starch; texture; sensory properties.

Practical Application: The yoghurt containing starches and cress seed gum is good choice for the producers where better stability of structure is required during transportation to avoid wheying-off. The resultant product is also good in textural, functional, sensory and nutritional attributes.

1 Introduction

Yogurts are widely consumed across the globe and are produced by fermenting different types of milks with bacteria such as *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, and *Lactobacillus acidophilus*. Some yogurts are also enriched with other probiotic strains, such as Bifidobacterium spp., to confer additional health benefits (Coskun & Karabulut Dirican, 2019; Costa et al., 2020; Pei et al., 2017; Shah, 2007; Tamime & Robinson, 1999). Yogurts are considered to have cardioprotective properties, to reduce the risk of type 2 diabetes, and to have positive effects on body composition and weight (Barros et al., 2020; Chen et al., 2014; Dalmeijer et al., 2013; Panahi et al., 2018; Wang et al., 2013), but the consumption of full-fat yogurt, which contains at least 3.25% fat according to the Food and Drug Administration (FDA) (Food and Drug Administration, 1996a, b), can lead to the development of obesity and other worldwide health problems, including cardiovascular diseases and metabolic disorders (Munsters & Saris, 2014). Consequently, consumers are moving toward low-fat (containing no less than 0.5% fat (Food and Drug Administration, 1996a, b) or non-fat (containing no more than 0.5% fat (Food and Drug Administration, 1996a, b) dairy products (Brennan & Tudorica, 2008). However, milk fat is the main factor that determines the quality of yogurt, so simple fat reduction can have severe impacts on its structure and texture (Cayot et al., 2008; Haque & Ji, 2003), with low-fat yogurts having a poor texture, weak structure, and whey separation unless stabilizers are added (Lee & Lucey, 2010; Mistry & Hassan, 1992).

Among the various approaches that can be used to reduce the fat content and stabilize the texture of yogurt without compromising its quality, the application of hydrocolloids has attracted the attention of producers, resulting in several types of hydrocolloids already being used as additives globally (Gallardo-Escamilla et al., 2007; Lee & Chang, 2016; Nguyen et al., 2017; Ramirez-Figueroa et al., 2002; Rascón-Díaz et al., 2012; Seth et al., 2018; Yousefi & Jafari, 2019). Hydrocolloids are a diverse group of biopolymers that are used as gelling, thickening, emulsifying, water-binding, or coating agents in industrial food products (Li & Nie, 2016; Nikoofar et al., 2013) and can also help to improve the textural properties, sensory properties, and microbial stability of food products (Hadjimbei et al., 2020; Ramirez-Figueroa et al., 2002; Zhao et al., 2009). In particular, starch is used in a number of food products as a stabilizing, gelling, and water-retaining agent and can be used to control product uniformity, stabilize the texture, and increase the appeal and surface properties of yogurts (Altemimi, 2018; Sameen et al., 2017).

Cress (Lepidium sativum) seeds are produced in many parts of the world and contain large amounts of gum, which is exuded

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as a clear gel around the surfaces of the seeds when soaked in water, allowing it to be easily extracted (Karazhiyan et al., 2011) . Cress seed gum (CG) includes D-xylose, D-galactose, L-arabinose, L-rhamnose, D-galacturonic acid, and 4-O-methyl-D-glucuronic acid and has a molecular weight of approximately 540 KDa. It is considered to be as rigid as xanthan gum and to have similar rheological properties, allowing it to be used as a substitute, which can bring extra benefits due to its plant-based origin and medicinal properties (Behrouzian et al., 2014; Karazhiyan et al., 2011; Naji et al., 2012).

The present study was designed to investigate the effects of CG in combination with sweet potato (Ipomoea batatas) starch (SPS), chickpea (Cicer arietinum) starch (CPS), corn (Zea mays) starch (CS), or Turkish bean (Phaseolus vulgaris) starch (TBS) on the textural, sensory, and steady and dynamic rheological properties of non-fat set yogurt during processing and after up to 7 days of storage.

2 Materials and Methods

2.1 Materials

Fresh sweet potatoes, chickpeas, Turkish beans, and garden cress seeds were obtained from a local produce market in Riyadh, Saudi Arabia. Non-fat milk powder (55% lactose, 34.5% protein, 3.5% moisture, and 7.2% ash) was purchased from a local store (Nestle, NIDO, Switzerland). Corn starch was donated by ARASCO (Riyadh, Saudi Arabia).

2.2 CG Extraction

Clean cress seeds (100 g) were soaked in 900 mL of distilled water with stirring for 5 h at 60 °C according to the method of (Qian et al., 2012). The extracted mucilage slurry was filtered through a 40-mesh screen and precipitated with two volumes of 95% ethanol. The precipitated cress seed mucilage was then separated by centrifugation at 2000 × g for 10 min, and the mucilaginous precipitate was freeze dried, ground, and stored in airtight jars until further use.

2.3 Starch Extraction

2.3.1 Isolation of SPS

SPS was extracted according to the method adopted by Sit et al. (2013). The tubers were thoroughly washed, peeled, and diced before being slurried with an equal amount of distilled water using a blender (B. Braun Melsungen AG, Hessen, Germany) for approximately 3 min and filtered through a cheese cloth. The retained portion of the sample was then re-slurried and re-filtered through a 200-mesh sieve, following which the whitish filtrate containing starch was allowed to sediment for 1 h prior to decanting the supernatant. The sedimented starch was washed by centrifugation at 2000 × g for 15 min and the top layer containing the pigmented material was removed. The white layer at the bottom was then re-washed through centrifugation as above. The starch was isolated, air dried, and ground by a coffee grinder before being stored at 4 °C in an airtight glass container for further use.

2.3.2 Isolation of CPS and TBS

Dirt-free dry chickpeas and Turkish beans were each ground in a coffee grinder at low speed for approximately 3 min. The ground material was then blended with an equal proportion of distilled water (1:1; w/w) for 5 min using a heavy-duty blender (B. Braun Melsungen AG). The resulting slurry was sieved through a 200-mesh sieve and the whitish filtrate was centrifuged at 2000 × g for 15 min (Singh et al., 2004). The whitish sediment was then washed five times by re-suspending in distilled water to obtain pure white starch. The collected starch was dried at room temperature, ground to powder with a coffee grinder, and stored in an airtight glass jar at 4 °C until further use.

2.4 Amylose content

The amylose contents of the starches extracted from the beans and tubers were estimated by mixing 100 mg of sample with 1 mL of ethanol (absolute) and 9 mL of sodium hydroxide (1 M). The mixture was then boiled for 10 min in a water bath and cooled to ambient temperature. A 5-mL aliquot of the mixture was added to 1 mL of acetic acid (1 N) and 2 mL of iodine solution that was prepared by dissolving 0.2 g of iodine and 2 g of potassium iodide in distilled water to give a total volume of 100 mL. The absorbance (A) of the reaction mixture was measured at 620 nm by a spectrophotometer, and the amylose content was estimated using the equation $3.06 \times A \times 20$.

2.5 Yogurt preparation

Non-fat yogurt comprising skim milk, CG, and starch was prepared. Part of the skim milk was replaced with 1 g of CG and 10 g of starch while maintaining a total solid weight of 140 g/L. To ensure complete solubility, the CG was first dissolved in distilled water and the powdered starch was blended with the skim milk powder. The CG solution was then added to the dry blend of starch and skim milk to give a final volume of 1 L (14%). The temperature of the suspension was increased to 60 °C and maintained at that temperature for 30 min before being decreased to 42 °C for the addition of starter culture at 3% of the dry ingredients. The starter comprised two bacterial strains: Streptococcus thermophiles and Lactobacillus bulgaricus. The liquid suspension was divided into 10 plastic cups (50 mL each) for incubation at the optimum temperature of 42 °C until coagulation occurred or the pH reached 4.6 (Barrantes et al., 1994). An incubation temperature of 42 °C was selected based on experimental trials that compared the apparent texture and pH at temperatures of 36 °C, 42 °C, and 45 °C. The prepared yogurt samples were kept at ~5 °C for 7 days, and the physicochemical properties of the samples were evaluated at ambient temperature at days 0 and 7.

2.6 Determination of yogurt composition

2.6.1 Total Solid Content

The total solid content of each yogurt sample was estimated according to the standard methods of Association of Official Analytical Chemists (2007) (#940.09). Briefly, 10 g of each sample was dried at 105 °C ± 5 °C for 1 h in a forced air oven and the dry weight was expressed as the percentage total solids.

2.6.2 Total Ash Content

The total ash content of each yogurt sample was determined using the standard methods of Association of Official Analytical Chemists (2007) (#942.05). In this procedure, 5 g of each sample was charred at 550°C ± 5°C for 5 h and the residual weight was expressed as the percentage ash content.

2.6.3 Crude Protein Content

The crude protein content of each yogurt sample was estimated using the Kjeldahl method according to Association of Official Analytical Chemists (2007) (#992.15). Briefly, 2 g of each sample was acid digested under heat flux using concentrated sulfuric acid. The total titratable nitrogen content of the sample was then multiplied by a factor of 5.7 to convert it to the crude protein content.

2.6.4 Crude Fat Content

The crude fat content of each yogurt sample was estimated by the Gerber method (Badertscher et al., 2007), using a calibrated butyrometer to take a direct reading.

2.6.5 Total Carbohydrate Content

The total carbohydrate content of each yogurt sample was estimated using the following Equation 1:

$$Total\ carbohydrates\ (\%) = 100 - (protein\% + fat\% + moisture\% + ash\%) \quad (1)$$

2.7 Apparent viscosity

The apparent viscosity of each yogurt sample was determined using a rotational viscometer (RV–DVII; Brookfield) at ambient temperature with a disk probe no. 63. This probe was selected because it allowed the viscosity readings for the samples to fall within the sensitivity spectrum of the viscometer. According to the recommendations of the manufacturer, a sample should be equilibrated at ambient temperature for 10 min before estimating its viscosity. Therefore, to establish thermal equilibrium and avoid time-dependent phenomena, the viscosity reading was taken 2 min after immersion of the spindle and duplicate data were recorded after 40 s. The obtained data were plotted as the shear stress vs. shear rate and the following power law model was fitted:

$$\sigma = k\gamma^{n} \quad (2)$$

where σ represents the shear stress (Pa.s), *k* represents the consistency index (Pa.s), γ denotes the shear rate (s–1), and n indicates the flow behavior index, which was estimated from the slope obtained when log shear stress was plotted against log shear rate.

2.8 Dynamic rheology and steady flow behavior

The dynamic viscoelastic properties of each yogurt sample were estimated at ambient temperature using a calibrated rotational rheometer (DHR-1; TA Instruments, New Castle, PA) fitted with parallel plate geometry (40 mm diameter) at a 50-µm gap. A frequency sweep was conducted at constant strain (0.5%) from 0.1 to 100 rad/s and the obtained data were interpreted in terms of the elastic or storage modulus (G′) and the viscous or loss modulus (G″). A strain sweep was also performed to ensure the shear strain independence of the measured data and to determine the linear viscoelastic range (LVR) of the yogurt gels. To measure LVR, a strain sweep experiment was conducted between 0.1 and 50 Pa.s at a constant frequency of 0.1 Hz or 0.628 rad/s. As a result, data were collected for a frequency sweep of 0.1 to 10 rad/s at a constant strain of 1.0 Pa.s. Measurements were made in triplicate and the respective errors were found to be up to ±10%. The obtained data were processed using the software provided by the manufacturer (Rheology Advantage Data Analysis 5.7.0; TA Instruments). The selected range of frequencies is generally used to ensure that G' and G" lie within the LVR. To test the possible slippage behavior of each sample during dynamic viscoelastic measurement, graphs of the viscosity vs. shear rate were also plotted in duplicate. However, no slippage was noticed for the samples.

2.9 Yogurt texture profile analysis

The firmness of each yogurt sample was determined according to the method of (Steffe, 1996). Each sample was subjected to a compression test on a texture analyzer (TA-XT2 Texture Analyzer; Texture Technologies Crop, Scarsdale, NY). This device is equipped with a cylindrical probe that moves to a depth of 20 mm in the sample placed on a platform at a test speed of 70 mm/min in two compression cycles.

2.10 Whey Separation

Whey separation from the surface of each yogurt sample (wheying-off) was measured using the siphon drainage method (Amatayakul et al., 2006). A sample cup of yogurt was taken from storage (4 °C), weighed, and placed at a 45° angle. Whey was then collected from the side of the cup and the cup was re-weighed. The amount of wheying-off was calculated by dividing the weight loss by the initial weight of the yogurt sample and expressed as g/100 g of yogurt.

2.11 Sensory Evaluation

Sensory evaluation was performed by 10 trained panelists recruited from faculty and postgraduate students of the Department of Food Science and Nutrition at King Saud University, Riyadh, Saudi Arabia. Each yogurt sample was evaluated for the following characteristics: viscosity, creaminess, flavor, color, and overall acceptability. Each evaluation was made using a 9-point hedonic scale, where 9 indicated "extremely liked," 5 indicated "neither liked nor disliked," and 1 indicated "extremely disliked." Plain crackers and cold mineral water were used as palate cleansers during the evaluation of different samples, following Saint-Eve et al. (2004).

2.12 Statistical Analysis

All measurements were made in triplicate and the data were subjected to analysis of variance. A full factorial design was applied to test the effects of CG, starch type, storage time, and replicate on each response variable Duncan's multiple range test was then conducted to compare means at p ≤ 0.05 using the PASW® Statistics 18 software (SPSS Inc., Hong Kong, China P.R.).

3 Results and discussion

3.1 Shear viscosity

There were no significant differences in the total solid or ash contents between the yogurt samples that had been enriched with CG either alone or in combination with one of the starches and the control sample. However, the control sample (with no additives) had a higher crude protein content and lower total carbohydrate content than the test samples. Similarly, Saleh et al. (2020a) reported that the addition of okra (*Abelmoschus esculentus*) gum and various starches to yogurt did not result in any significant changes in its proximate composition. In terms of the amylose contents of the starches, CPS had the highest content (32.2%), followed by SPS (22.9%) and CS (20.4%), while TBS had the lowest content (17.5%). This variation in amylose content could be related to the fact that the starches originated from tubers (sweet potato), beans (chickpea, Turkish bean), and cereals (corn), which vary greatly in their physicochemical properties.

To maintain the quality and organoleptic properties of non-fat yogurt, various additives are included as stabilizers, such as starch, pectin, gelatin, gums, and mucilages (Saleh et al., 2020a; Saleh et al., 2020b; Yu et al., 2016). The shear viscosity profiles of the yogurt samples plotted as the shear rate vs. shear stress are presented in Figure 1. These profiles indicate that all of the yogurt samples exhibited time-dependent thixotropic behavior, whereby the shear rate increased as the viscosity decreased. The downward-sloping curves of the viscosity profiles suggest that the yogurt samples had a non-Newtonian shear thinning nature and exhibited yield stress. Shear thinning in yogurt originates from the alignment of polymeric molecules along the applied shear, which results in weakening of the physical interactions at the polymer–polymer interface (Yu et al., 2016), while yield stress is generally related to the presence of crosslinked or interactive structures (Paoletti, Nardo et al., 1995) and is also correlated with the firmness of non-fat yogurt (Yu et al., 2016).

In the fresh yogurt samples (0 days of storage), the highest yield stress and thus the firmest yogurt was observed when both CG and SPS were added, while the lowest yield stress and thus softest yogurt was observed when only CG was added, with the overall pattern of yield stress across the different samples being ordered as follows: SPS > CS > CPS > control > TBS > CG (Figure 1). There was only a small physical gap between the CS, CPS, and control samples, such that all three samples showed superimpositions among each other even at the start of shear testing, indicating the similar nature of the interactions of these yogurt gels under shear. The line for the yogurt sample containing CG alone remained very close to the horizontal axis even at higher shear rates. The higher stability of the yogurt sample containing both CG and SPS suggests that the presence of these additives favored the three-dimensional casein network in the yogurt gel. A strong interaction between casein micelles and added jujube (Ziziphus jujuba) mucilage has previously been reported in the structure of yogurt (Yekta & Ansari, 2019). Thus, it can be inferred that the functionality of CG was manipulated by the starches in the yogurt gel structure. This variation in the level of firmness among the yogurt samples as indicated by variation in the yield stress may be correlated with the extent and type of interactions between the milk proteins and the added polysaccharides.

After 7 days of storage, changes in the yield stress were observed such that CS > CPS ≈ control > SPS > CG > TBS. This outperformance of the CS-containing sample indicates the greater stability of this yogurt gel under the studied storage conditions. The control yogurt also became firmer with an increase in storage time. These data suggest that CG synergistically interacted with the casein network and improved the stability of the resultant yogurt gels under storage. Starch-based variations in the yogurt gels may have been due to differences in the starch granules and their respective amylose contents (e.g., TBS contained the least amylose). These findings contrast with those of Saleh et al. (2020b), who reported a reduced firmness of yogurt gel with the addition of starches with higher amylose contents. However, the present study examined the effects of adding different starches mixed with CG, which is a polyelectrolyte (Karazhiyan et al., 2009), for the possible improvement of the yield stress and overall stability. The apparent physical gap between the control and the sample containing CG alone decreased after storage, whereas that between the control and the sample containing CG with TBS increased. Thus, it appears that SPS is suitable for

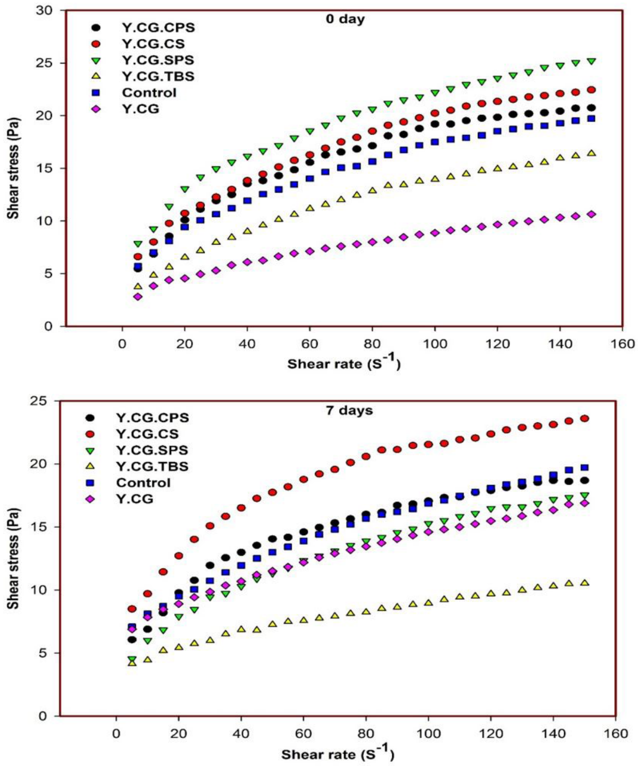

Figure 1. Plots of the shear rate vs. shear stress for different yogurt samples after 0 and 7 days of storage. Control = plain yogurt), Y.CG.SPS = yogurt with cress seed gum and sweet potato starch, Y.CG.CS = yogurt with cress seed gum and corn starch, Y.CG.CPS = yogurt with cress seed gum and chickpea starch, Y.CG.TBS = yogurt with cress seed gum and Turkish bean starch.

stabilizing fresh yogurt while CS is more effective for maintaining the firmness of yogurt during storage at chilled temperatures.

The power law model was found to be suitable for expressing the rheological behavior of all of the yogurt samples, as the coefficient (R2) values were greater than 0.97 in all instances (Table 1). In the shear stress vs. shear rate plot, the vertical intercept denotes the consistency index (k) and the slope represents the flow behavior index (n). Thus, a steeper slope of the plotted data suggests an increased endurance against the applied shear. The rheological behaviors of the yogurt samples in terms of k and n are shown in Table 1. All of the yogurt samples exhibited time-dependent non-Newtonian thixotropic behavior irrespective of the type of starch and storage period, as the value of n was less than 1 (n = 1 for Newtonian behavior). A higher total solid content generally results in such deviated behavior, as this phenomenon of shear thinning indicates the polymeric alignment in the field of the applied shear and the physical weakening of polymer–polymer interactions (Yu et al., 2016). In the fresh yogurt samples (0 days of storage), the lowest amount of pseudoplasticity (n = 0.45) and thinnest yogurt gel was observed when both CG and TBS were added, which could be related to the fact that TBS contains the least amylose among the starches examined. It has been hypothesized that the starch fractions act as fillers in the casein network, enhancing the integrity and stability of the yogurt gel (Morell et al., 2015), so a lower amount of amylose leaching during processing may result in a relatively lower amount of amylose being available as a filler, resulting in a weaker gel structure. Similarly, Ramirez-Santiago et al. (2010) reported that the *n* value of yogurt decreased in the presence of soluble fibers originating from Mexican yam bean (Pachyrhizus erosus).

There was a clear difference in *k* between the yogurt samples made with different starches. In the fresh yogurt samples (0 days of storage), all of the *k* values were between 0.23 and 0.65 Pa, but the sample containing CG together with SPS had the highest consistency while the sample containing CG with TBS was the least viscous *(k* = 0.23). These values of k are in line with the apparent viscosity and yield stress data for the samples. After 7 days of storage at a cold temperature, all of the samples exhibited an improved k with the exception of CG with SPS, so that CPS > CG > CS > control > SPS > TBS. This increase in k indicated that the added polysaccharides (CG and starches) had positively interacted with the casein network in the yogurt gels. However, it should be noted that the amylose content of the starch is not the only factor that contributes to the stability of yogurt gels under short-term storage, even though the addition of TBS gave the lowest value of *k,* and that the viscous nature of yogurt does not always indicate a firmer gel (Saleh et al., 2020b). A greater change in *k* over time was observed in the sample containing CG alone, indicating that CG interacted favorably with the casein network and improved the gel stability under storage.

Overall, based on the *n* and *k* values, it can be concluded that the addition of CG with CPS is a good choice for producing a high-viscosity yogurt. Saleh et al. (2020b) previously reported the suitability of using potato starch to produce better yogurt after 2 weeks of storage. Some reports have also suggested that the use of milk solids in yogurt preparation can improve the maintenance of gel viscosity (Gün & Işıklı, 2007). However, starch is a less expensive additive and can provide thicker yogurt at a similar solids content. It has also been shown that acetylated crosslinked starch performs better than the native starches in yogurt in terms of improving the yield stress, apparent viscosity, consistency, and thixotropy (Isleten & Karagul-Yuceer, 2006).

3.2 Viscoelastic properties

Dynamic viscoelastic behavior is estimated to predict the extent and strength of the internal structure of a sample (Sendra et al., 2010). Yogurt is basically a viscoelastic gel system in which the interactions between casein micelles at the molecular level confer elastic properties while weaker intermolecular interactions and attractions confer viscose properties. Generally, dynamic viscoelastic measurements include parameters such as the elastic or storage modulus (G'), loss or viscous modulus (G"), complex viscosity (η*), and phase angle (tan δ). All of the yogurt samples had a weak gel character (G' > G") in the examined stress range of 0.1 to 50 Pa.s, while LVR was established using a stress range of 0.1 to 10 Pa.s. Consequently, the frequency sweep test was conducted at a stress of 1 Pa.s. The obtained frequency data are supported by the findings of a previous report in which inulin-enriched yogurt was prepared (Paseephol et al., 2008). When LVR was extended in a stress sweep experiment, G' was found to be independent of the applied stress and the samples exhibited a solid-like behavior. However, the LVR of each yogurt sample was dependent on the type of starch added. Similar dependent behavior for LVR was also observed by Saleh et al. (2020a).

The viscoelasticity profiles of the samples (plotted as G' vs. frequency) are shown in Figure 2. At 0 days, G' ranked as

Table 1. Flow behavior index (*n*, dimensionless) and consistency index (k, Pa) values of yogurts containing cress seed gum and different starches after 0 and 7 days of storage.

Sample	0 days			7 days		
	n	*k (Pa)*	R^2	*n*	*k (Pa)*	R^2
Control	0.38 ± 0.01	0.38 ± 0.01	0.99 ± 0.02	0.31 ± 0.01	0.40 ± 0.01	0.99 ± 0.02
Y.CG	0.38 ± 0.00	0.47 ± 0.01	0.99 ± 0.01	0.41 ± 0.03	0.56 ± 0.04	0.99 ± 0.01
Y.CG.SPS	0.35 ± 0.01	0.65 ± 0.02	0.99 ± 0.01	0.40 ± 0.03	0.37 ± 0.01	0.99 ± 0.00
Y.CG.CS	0.38 ± 0.01	0.47 ± 0.02	0.99 ± 0.02	0.31 ± 0.03	0.54 ± 0.01	0.97 ± 0.04
Y.CG.CPS	0.40 ± 0.03	0.54 ± 0.03	0.99 ± 0.01	0.35 ± 0.03	0.71 ± 0.02	0.98 ± 0.03
Y.CG.TBS	0.45 ± 0.02	0.23 ± 0.02	0.99 ± 0.02	0.30 ± 0.03	0.36 ± 0.01	0.97 ± 0.01

Control = plain yogurt, Y.CG = yogurt with cress seed gum, Y.CG.SPS = yogurt with cress seed gum and sweet potato starch, Y.CG.CS = yogurt with cress seed gum and corn starch, Y.CG.CPS = yogurt with cress seed gum and chickpea starch, Y.CG.TBS = yogurt with cress seed gum and Turkish bean starch.

follows for the yogurt samples: CPS > TBS > CS > SPS > CG > control. Thus, the yogurt containing CG together with CPS had the most elastic gel. After 7 days of cold storage, this sample became firmer, which could be attributed to CPS having a higher amylose content but this being degraded during storage, imparting a greater firmness to the yogurt. However, this was still the most elastic gel. The G' values for the samples containing CG together with CS and SPS were almost overlapping at 0 days, whereas the sample containing CG with CS superimposed the sample containing CG with TBS after 7 days, indicating the enhanced firmness of CS-containing yogurt after cold storage. Yogurt containing CG alone and the control sample (without any additive) had softer gels. At the beginning of storage (0 days), there was very little physical gap among CS, SPS, and CG, whereas after storage, a greater gap was noticed due to an increased firmness of CS followed by SPS and CG. The control sample had the softest gel at 0 days and became firmer with increased storage time at a low temperature. In a previous study, yogurt containing CPS alone or in combination with okra pod gum showed a greater G' than yogurt containing tuber starches (Saleh et al., 2020a). Together, these findings indicate that all of the yogurt gels attained time-dependent firmness after 7 days of storage, which was clearly portrayed by the higher G' and increased physical gaps among samples in the profiles. Thus, gels without any additives (starch or CG) had the lowest G' and could be ascribed as the weakest gel, while the yogurt containing CPS had the firmest gel structure, indicating that the addition of CPS should be adopted for the production of stronger yogurt gels. The complex viscosity (η*) data measured at a frequency of 0.3 rad/s also indicated that the sample containing CPS had the highest viscosity.

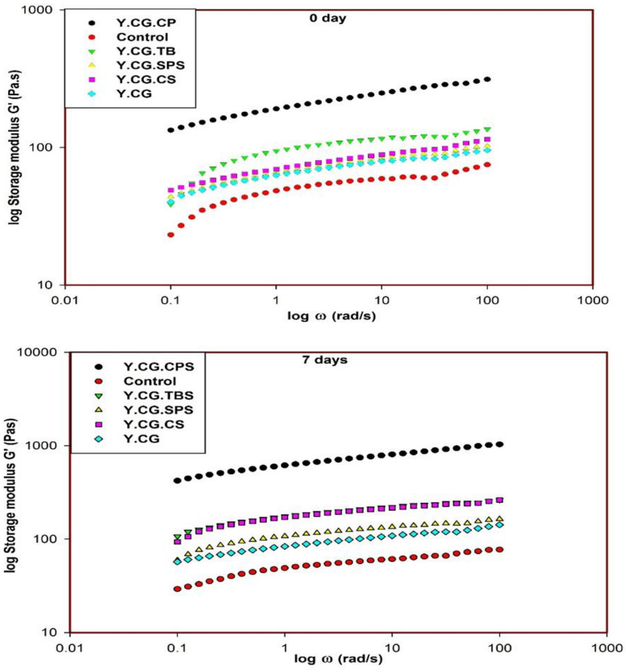

Figure 2. Viscoelasticity profiles (storage modulus vs. frequency) of the yogurt samples after 0 and 7 days of storage. Control = plain yogurt, Y.CG = yogurt with cress seed gum, Y.CG.SPS = yogurt with cress seed gum and sweet potato starch, Y.CG.CS = yogurt with cress seed gum and corn starch, Y.CG.CPS = yogurt with cress seed gum and chickpea starch, Y.CG.TBS = yogurt with cress seed gum and Turkish bean starch.

3.3 Texture

The texture of yogurt is closely related to the inner structure of the gel, which typically results from the physical interactions between casein micelles (Peng & Guo, 2015), and dictates the overall quality of the final product. The texture is generally assessed by measuring parameters such as hardness, cohesiveness, and adhesiveness. The texture data for the yogurt samples investigated in the present study are presented in Table 2. At the beginning of storage (0 days), yogurt containing CG together with SPS had the highest hardness (26.0 g), while the samples containing CG alone or in combination with CS had statistically similar hardness values. The softest gel was observed for the control sample with no additives, supporting the rheological data in which the control yogurt showed the lowest value of G'. The increased hardness of samples containing additives suggests that CG interacted with the casein micelles synergistically, while the addition of starches manipulated this interaction, with a pronounced reduction in hardness being observed in the yogurts that included CS, CPS, and TBS. Similarly, it has previously been shown that the hardness of yogurt decreases when starches from tubers and beans are added alongside okra pod gum (Saleh et al., 2020a). The hardness of the samples was between 21 g and 26 g at 0 days and between 24 g and 30 g at 7 days, indicating that storage increased the firmness of all of the samples, including those containing starch, possibly due to degradation of the leached amylose. At 7 days, the highest

Table 2. Effects of the addition of cress seed gum and different starches on the texture of yogurt after 0 and 7 days of storage.

Sample	0 days			7 days		
	Hardness (g)	Adhesiveness (mJ)	Cohesiveness	Hardness (g)	Adhesiveness (mJ)	Cohesiveness
Control	21.00 ± 1.50d	0.47 ± 0.10c	0.351 ± 0.020d	24.00 ± 1.00c	0.33 ± 0.06c	0.460 ± 0.011b
Y.CG	25.30 ± 1.01ab	0.80 ± 0.10a	0.422 ± 0.010c	30.33 ± 0.58a	0.33 ± 0.06c	0.471 ± 0.001b
Y.CG.SPS	26.00 ± 2.00a	0.20 ± 0.06e	0.492 ± 0.020a	26.33 ± 1.53b	0.60 ± 0.10a	0.453 ± 0.011c
Y.CG.CS	24.02 ± 2.00ab	0.57 ± 0.06b	0.462 ± 0.020b	26.33 ± 1.53b	0.47 ± 0.06b	0.494 ± 0.000a
Y.CG.CPS	21.40 ± 1.00cd	0.29 ± 0.01d	0.491 ± 0.010a	26.33 ± 0.58b	0.47 ± 0.06b	0.464 ± 0.011b
Y.CG.TBS	21.33 ± 0.58cd	0.77 ± 0.06a	0.453 ± 0.010b	26.67 ± 0.58b	0.40 ± 0.00bc	0.494 ± 0.011a

Means followed by different letters within a column are significantly different ($p \leq 0.05$). Control = plain yogurt, Y.CG = yogurt with cress seed gum, Y.CG.SPS = yogurt with cress seed gum and sweet potato starch, Y.CG.CS = yogurt with cress seed gum and corn starch, Y.CG.CPS = yogurt with cress seed gum and chickpea starch, Y.CG.TBS = yogurt with cress seed gum and Turkish bean starch.

hardness value was observed in the sample containing CG alone, which may have been due to an improved interaction with casein micelles under cool storage. By contrast, the control yogurt gel remained the softest. Thus, the addition of CG alone rather than in combination with starch is favorable for maintaining the texture of yogurt under cool storage. Similarly, Saleh et al. (2020a) reported that non-fat yogurt gel had the highest hardness after 15 days of storage when okra gum was added.

Adhesiveness is the force of attraction between the food and a solid that is in contact with it and is generally measured to help determine the stickiness of the food. The yogurt containing CG was the stickiest among all other yoghurt samples. By contrast, the yogurt containing CG with SPS had the lowest adhesiveness. In general, gels with greater adhesion have a softer texture (Saleh et al., 2020b). However, this generality is not valid in the current case, as the SPS-containing yogurt had the greatest textural hardness (Table 2). Interestingly, after 7 days of storage, the sample containing SPS had the highest adhesion value, while the control and the sample containing CG alone had the least coherence and the softest texture. Thus, the addition of CG could provide a soft gel with low adhesion during a longer storage period.

Cohesiveness is the total force of internal bonds that stabilize the yogurt gel and influences the extent of deformation during the deformation test. At the beginning of storage (0 days), the yogurt samples containing CG with SPS or CPS had the highest cohesiveness, whereas the control showed the highest degree of deformation and weakest internal structure. This low stability of the control yogurt at the beginning of storage supports the hardness data, which showed that this yogurt had the softest texture. However, after 7 days of storage, the yogurt containing SPS had the least cohesive nature, while that containing TBS had the most cohesive gel structure.

In summary, the texture data showed that a firm and hard gel could be obtained by adding CG together with SPS, but that CG with CPS should be selected for longer storage. Sandoval-Castilla et al. (2004) similarly reported that the addition of polysaccharides to yogurt as a fat replacer increased the hardness of the yogurt without significantly affecting its adhesiveness or cohesiveness.

3.4 Whey separation

The whey separation data for the yogurt samples are presented in Table 3. The spontaneous separation of whey, irrespective of any external applied stress, is an indicator of the fragile nature of the yogurt gel, which is correlated with the rearrangement of the three-dimensional casein network. Wheying-off in yogurt is commonly caused by a low milk solids content, low pH, long incubation time, imbalance in the whey to casein ratio, and physical shock during transportation and storage. To mitigate whey separation, various stabilizers are incorporated in yogurt, such as native and modified starches, soluble fibers, and gelatins (Isleten & Karagul-Yuceer, 2006; Ramirez-Santiago et al., 2010; Saleh et al., 2020a; Saleh et al., 2020b). In the present study, wheying-off was between 12% and 17% for all samples at the beginning of storage (0 days). The control sample had a significantly higher wheying-off value than all other samples (p ≤ ple), whereas there were no significant differences among the other yogurt gels regardless of whether CG was added alone or in combination with starch. However, the maximum reduction in wheying-off (28%) was observed when CG was added in combination with CS or CPS, whereas whey separation was greater for the samples in which only CG was added. Thus, the presence of starches further reduced the level of wheying-off, though this was not significant. Similarly, Saleh et al. (2020a) reported a non-significant reduction in the wheying-off of yogurt gels in which okra gum had been added in combination with starches. After 7 days of storage, the control sample still had the highest level of wheying-off (27%), which represented an almost 10% increase compared with the value at the beginning of the storage. The samples containing CG alone or in combination with the various starches had similar wheying-off values to each other after 7 days, all of which were significantly lower than that of the control sample, indicating that wheying-off represented a time-dependent rearrangement in the casein network that was independent of the type of starch added. Thus, the partial gelatinization of starch during processing may help to form larger casein flocs that prevented wheying-off. Zuo et al. (2008) proposed that the presence of starch in non-fat yogurt absorbs the water from the continuous phase by swelling and increases the effective concentration of the milk proteins, minimizing the separation of whey from the casein micelles. In addition, starch has the ability to form an interpenetrating network with whey proteins and to augment the water retention ability of the yogurt gel (Considine et al., 2011). By contrast, the sample containing CG alone had the lowest level of wheying-off after 7 days of storage. It has been reported that chemically modified starch imparts positive attributes to yogurt compared with native starches, decreasing syneresis and improving the rheology (Alakali et al., 2008; Singh & Byars, 2009).

Table 3. Effects of the addition of cress seed gum and different starches on the whey separation from yogurt after 0 and 7 days of storage.

Sample	0 days	7 days
Control	16.67 ± 0.58a	27.00 ± 1.00a
Y.CG	13.51 ± 0.51b	17.33 ± 0.57c
Y.CG.SPS	12.67 ± 1.16b	18.31 ± 1.53bc
Y.CG.CS	12.00 ± 1.00b	18.27 ± 0.46bc
Y.CG.CPS	12.00 ± 1.00b	17.67 ± 0.58bc
Y.CG.TBS	12.67 ± 0.58b	18.00 ± 1.00bc

Means followed by different letters within a column are significantly different ($p \leq 0.05$). Control = plain yogurt, Y.CG = yogurt with cress seed gum, Y.CG.SPS = yogurt with cress seed gum and sweet potato starch, Y.CG.CS = yogurt with cress seed gum and corn starch, Y.CG.CPS = yogurt with cress seed gum and chickpea starch, Y.CG.TBS = yogurt with cress seed gum and Turkish bean starch.

3.5 Sensory properties

Sensory analysis is a powerful tool that allows the correlation between microstructural data and consumer preference for the developed food product to be determined (Sass et al., 2021; Torres et al., 2020). The sensory and nutritional properties of yogurt are highly influenced by the initial composition, processing conditions, starter culture, and additives (Bonczar et al., 2002).

Table 4. Effects of the addition of cress seed gum and different starches on the sensory properties of yogurt.

Sample	Viscosity	Creaminess	Flavor	Color	Overall acceptability
Control	5.40 ± 1.07c	6.33 ± 1.34c	6.80 ± 1.39b	8.00 ± 1.33	5.90 ± 0.99c
Y.CG	8.80 ± 0.42ab	8.81 ± 0.42ab	6.90 ± 1.50b	8.40 ± 0.52	8.80 ± 0.40ab
Y.CG.SPS	8.60 ± 0.70bc	8.62 ± 0.79a	8.60 ± 0.79a	7.60 ± 0.85	8.70 ± 0.67ab
Y.CG.CS	8.40 ± 0.69bc	8.41 ± 0.70bc	8.00 ± 0.94a	8.50 ± 0.70	8.60 ± 0.69ab
Y.CG.CPS	8.40 ± 0.84bc	8.31 ± 0.69bc	8.30 ± 0.82a	8.40 ± 0.70	8.30 ± 0.67ab
Y.CG.TBS	7.90 ± 0.87b	7.71 ± 0.67b	8.00 ± 0.94a	8.00 ± 0.82	7.90 ± 0.87b

Means followed by different letters within a column are significantly different ($p \leq 0.05$). Control = plain yogurt, Y.CG = yogurt with cress seed gum, Y.CG.SPS = yogurt with cress seed gum and sweet potato starch, Y.CG.CS = yogurt with cress seed gum and corn starch, Y.CG.CPS = yogurt with cress seed gum and chickpea starch, Y.CG.TBS = yogurt with cress seed gum and Turkish bean starch.

Among the various parameters that are assessed, yogurt texture is the key attribute that determines consumer acceptability and sensory quality and is estimated either directly by the tongue or indirectly by employing a spoon (Saleh et al., 2020b). In general, a viscose yogurt is difficult to swallow and stays on the tongue for longer, while yogurt flowability is visually assessed by slanting the spoon for some time. The subjective data resulting from the sensory evaluation of the yogurt samples examined in the present study are tabulated in Table 4. In terms of the viscosity and creaminess, the samples containing CG alone or together with SPS, CS, or CPS were equally preferred by the panelists and better accepted than the sample containing CG with TBS and the control. Similar positive effects on sensory attributes were reported when quinoa extract was used in the production of goat milk yogurt (El-Shafei et al., 2020). In terms of flavor, the yogurts containing the various starches had a similar richness, while the sample containing CG alone and the control were the least preferred. Conversely, the color attribute was ranked the same for all of the samples by the panelists. Finally, the samples containing CG alone or in combination with SPS, CS, or CPS ranked equally in terms of overall acceptability, whereas the sample containing CG with TBS was slightly less acceptable and the control sample was the least acceptable. It is interesting to note that the sample containing CG alone was found to have an equivalent hedonic score for acceptability to the starch-containing yogurts, while the control sample was disliked and ranked lowest for the organoleptic scores and acceptability. Similarly, Yekta & Ansari (2019) reported that the addition of jujube mucilage did not distort the sensory quality of yogurt. Therefore, while consumer preferences vary across the globe, it appears that the addition of starches to non-fat yogurt can augment its texture and enhance its hedonic properties.

4 Conclusion

CG and various starches were added to non-fat yogurt as polysaccharide-based stabilizers to improve its rheological, textural, and sensory properties. The results suggested that the viscosity of the yogurt was most improved when CG was added in combination with SPS or CPS, but all of the samples exhibited a shear thinning behavior. Yogurt containing CG with CPS also formed a more solid-like and stronger gel based on its higher G´ value, while that containing CG with SPS had the highest textural hardness. The addition of any of the starches significantly reduced wheying-off compared with the control. Furthermore, while the origin of the starch (tuber, cereal, or beans) and the storage time had different effects on the yogurt quality, the addition of CG and any of the starches enhanced the hedonic properties of the final product. Therefore, further studies should be conducted to explore the effects of CG and modified starches on the quality of non-fat yogurt.

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