Quality assessment of yogurt enriched with different types of fibers
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ABSTRACT
This study evaluated the effect of the addition of four different types of dietary fibers on the rheological, physicochemical and sensory characteristics of yogurt. The four types of fibers (inulin, pea, oat and wheat) were added in the yogurt formulation in different proportions (1%–2.5%) using classical technology adapted to laboratory conditions. The obtained results showed that, the most viscous samples were obtained with wheat fibers addition (1% and 1.5%), while the best viscous characteristics were obtained for the samples with oat fibers addition (2% and 2.5%). The lowest syneresis value (38.86 ± 0.2) were observed for the samples with 1.5% pea fibers addition. Yogurt samples with the highest acceptance scores were samples with 2% wheat fibers and respectively with 2.5% pea fibers addition. All the tested fibers were compatible with the yogurt-manufacturing process. Therefore, the fibers addition in yogurt could be considered an alternative to incorporate dietary fibers in the human diet.

1. Introduction
Yogurt is one of the most consumed healthy and nutritious foodstuff worldwide (Shi et al., 2017; Zhi et al., 2018). Yogurt has a better digestibility of proteins than milk and many latent positive effects on health by providing the human body prebiotic and probiotic bacteria. Additionally, by incorporating fibers in yogurt, researchers have achieved a mean of increasing fibers consumption in all sectors of the populace and they have developed a functional food with an extensive array of beneficial effects. Several studies reported prebiotic fortification by adding dietary fibers in yogurt. Consumption of high-fiber yogurt may prevent or reduce obesity, diabetes, cancer, hypercholesterolemia, gastrointestinal disorders, colonic diverticulosis and constipation, ulcerative colitis, hyperlipidemia, hypertension, coronary artery disease, but also promote intestinal microflora and gastrointestinal immunity (Dello Staffolo, Sato, & Cunha, 2017; Dhingra, Michael, Rajput, & Patil, 2012; Hoppert et al., 2013; Ramirez-Santiago et al., 2010; Sah, Vasiljevic, McKechnie, & Donkor, 2016; Tomic et al., 2017).

Since it is known that a lack of fibers in the diet can be the cause of many nutrition-associated illnesses, the European Food Safety Authority (EFSA) has been forced to recommend an average daily fibers intake of 25 g (EFSA, 2010). Fibers are found in the cell wall of vegetables, fruits or cereals. They include polysaccharides (pectins, cellulose and hemicelluloses) and lignin. Although both soluble and insoluble fibers are available, usually the insoluble fibers are used with food fortifying intents (Dönmez & Gökmen, 2017; Bertolino et al., 2015; Hashim, Khalil, & Afifi, 2009; Sah, Vasiljevic, McKechnie, & Donkor, 2015; Sendra et al., 2008, 2010; Tejada-Ortigoza, García-Amezquita, Serna-Saldivari, & Welti-Chanes, 2016).

Many researchers reported that the rheological properties of yogurt are affected differently depending on the type of fiber source (Luana et al., 2014; Raju & Pal, 2014; Dello Staffolo, Bertola, Martino, & Bevilacqua, 2004; Hashim et al., 2009). The role in increasing the water holding capacity, in stabilization of high fat yogurt, in enhancing viscosity characteristics and the gel forming ability are properties of fibers...
that allow the development of fiber-enriched yogurt with improved texture and reduced syneresis (Dello Staffolo et al., 2017; Balthazar et al., 2016; Lazaridou, Serafeimidou, Billaderis, Moschakis, & Tsanetakis, 2014; Espírito-Santo et al., 2013). According to Gilbowksi and Rybak (2015), the inulin addition in skimmed yogurt contributed in obtaining an yogurt with similar texture properties when compared with control full-fat yogurt. Sanz, Salvador, Jiménez, and Fiszman (2008) reported that yogurt fortification with oat fibers allowed the development of a product with no significant diminution in the sensorial quality, but with slight diminution in texture quality. However, Hashim et al. (2009) reported that the addition of 0.5% oat β-glucan or inulin and guar gum were effective in improving serum retention and viscoelastic properties of yogurt.

Oat and wheat fibers are the most frequently used auxiliary materials in the dairy industry, leading to fortified finished products. Oat fibers (containing β-glucan, an indigestible polysaccharide) were proven to increase immunity, to improve anticancer activity and lower blood cholesterol, lipids and blood glucose. Adding oat fibers in yogurt fostered the creation of a good fermented product, with insignificant drop in flavour quality and only a minor decline in texture quality (Dello Staffolo et al., 2004; Sanz et al., 2008).

According to the EFSA (2010), “...hewat fibers help to accelerate intestinal transit.” Wheat bran is extremely rich in fibers, as well as in minerals such as potassium, phosphorus and magnesium. Wheat dextrin, extracted from wheat starch, is widely used to add fibers in processed foods especially for its contribution in lowering cholesterol (low-density lipoprotein [LDL] and total cholesterol) and in reducing the risk of type 2 diabetes and coronary heart disease. Wheat fibers improve the products quality characteristics in dietetic foods, meat products, pasta, bread, baked goods, cheese and other dairy products (Krasaekoopt & Watcharapoka, 2014).

Inulin is an indigestible carbohydrate which is a natural prebiotic agent, obtained industrially mainly from chicory and Jerusalem artichoke (Delgado & Bañón, 2018). In the dairy industry, inulin has been used to replace fat, while improving taste and texture of low-fat/non-fat dairy products. The texture achieved by using inulin is attributed to its propensity to form small aggregates of microcrystals that seal a great amount of water, thus leading to a fine creamy texture (Crispin-Isidro, Lobato-Calleros, Espinosa-Andrews, Alvarez-Ramírez, & Vernon-Carter, 2015; Tseng & Zhao, 2013).

Trying to create functional foods with improved functionality and health benefits has become of great interest for researchers worldwide, fortifying yogurt with pea fibers being an appealing alternative. Pea fibers (insoluble dietary fibers extracted from pea hulls) are proved to ensure significant cardiovascular benefits, predominantly via cholesterol reducing means. It promotes satiety thus helping in weight-loss. Pea fibers blend wonderfully with other ingredients and they are good bulking agents. Due to their quality, they have the potential to be used in a wide range of applications: from bakery products to dairy industry. Their high dietary fiber content may increase the nutritional profile of the finished product, thus, by fortifying yogurt with pea fibers it completes its healthy properties (Bitaraf, Khodaiyan, Mohammadifar, & Mousavi, 2012; Cueva & Aryana, 2008; Dahl, Foster, & Tyler, 2012; Moreira et al., 2017; Repín, Scanlon, & Fulcher, 2012; Stone, Avaramenko, Warkentin, & Nickerson, 2015; Zare, Champagne, Simpson, Orsat, & Boye, 2012).

Manufacturers are directly interested in using natural ingredients as an alternative to chemical stabilizers in making dairy products. Taking into account this fact the one of the goals of this study was to determine the type and amount of fibers which can be recommended for the industrial production of yogurt in order to improve the quality of the final product.

The aim of this study was to evaluate the effect of the addition of four types of fibers (inulin, pea, oat and wheat) on the rheological, physicochemical and sensory characteristics of yogurt.

2. Materials and methods

2.1. Materials

The yogurt samples were obtained in laboratory conditions, using the following raw materials: cow’s milk with 3.5% fats, 4.5% carbohydrates, 3% proteins; lactic bacteria cultures (Lactobacillus bulgaricus and Streptococcus thermophilus) were supplied by Danisco Romania S.R.L. The different fibers used in the experiments were provided by Enzymes & Derivates Romania: inulin fibers (I), pea fibers (P), oat fibers (O) and wheat fibers (W). Inulin fibers (I) are presented as a white homogeneous powder with min. 95% fibers, max. 8% moisture and low energetic value (1.3 kcal/g). We used the long-chain type inulin (high performance, highly polymerised, HP). Pea fibers (P) are presented as a white powder with min. 48% fibers, 39% starch, min. 7% protein, max. 8% moisture. Oat fibers (O) are presented as a dark white homogeneous powder with min. 96% fibers, max. 8% moisture and the water retention capacity of 4.8 g H2O/g. Wheat fibers (W) are presented as a white homogeneous powder with min. 97% fibers, max. 8% moisture and the water retention capacity of 4.9 g H2O/g."

2.2. Experimental conditions for yogurt samples preparation

For the yogurt production, the cow’s milk was first pasteurized at 90°C for 5 minutes and cooled to 45°C. After cooling, the milk was inoculated with the starter culture. In all samples, milk was directly inoculated with 0.02% (w/v) starter culture of Lactobacillus bulgaricus and Streptococcus thermophilus. After a strong stirring for the evenly distribution of the culture, the inoculated samples were transferred over the inulin, pea, oat and, respectively, wheat fibers, which were previously dosed directly into the yogurt jars in varying proportions from 1% to 2.5%. The fermentation process was carried out at 43°C, until a pH of 4.6 was reached. Subsequently, the finished products were stored at 4°C – 6°C for the next 24 h.

2.3. Physicochemical analysis

The titratable acidity of yogurt samples was expressed in Thörner degrees, after sample titration with NaOH 0.1N. The portable F2 Standard METTLER TOLEDO pH-meter was used for the pH measurement in different stages of samples preparation: during fermentation, in finished product and during storage.

Colour has been determined using a Konica CR400 Chromameter (Konica Minolta, Japan). The samples were measured against a white spectrum. The colour intensity,
hue angle and \( \Delta E^* \) were calculated using the following equations:

\[
C_{ab} = \sqrt{a^2 + b^2} \quad (1)
\]

\[
h^* = \tan^{-1} \left( \frac{b^*}{a^*} \right) \quad (2)
\]

\[
\Delta E^* = \sqrt{\Delta L^2 + (\Delta a^2 + \Delta b^2)} \quad (3)
\]

where: \( L^* \) (100 = white; 0 = black), \( a^* \) (+, red, – green), \( b^* \) (+yellow; – blue), \( C_{ab} \) – chroma, \( h^* \) – hue angle and \( \Delta E^* \) – colour difference.

The syneresis determination was performed by the means of a Spin MPW 223E Centrifuge, with respect to the method used by Gengatharan, Dykes, and Choo (2017): 10 ml of sample volume; sample centrifugation at 639 × g for 10 min, at 4 ± 1°C; the clear supernatant scaling and applying the below formula for obtaining the syneresis percent of samples:

\[
\text{Syneresis(\%)} = \frac{\text{Weight of supernatant}}{\text{Weight of yogurt sample}} \times 100
\]

All analyses were carried out in triplicate.

2.4. Rheological analysis

The Modular Advanced Rheometer System (Thermo Haake Mars) was used to study the rheological properties of yogurt samples. The samples were allowed to rest for 10 minutes at 8°C on the Ti40mm geometry plate, before conducting the analyses. The samples were subjected to frequency dependency experiments from 0.1 to 10.0 Hz, at 8°C. The storage modulus (\( G' \)), the loss modulus (\( G'' \)), the loss tangent (\( \tan \delta \)) and the complex viscosity modulus (\( |\eta^*| \)) at 1 Hz frequency were monitored. Also, there were conducted viscosity tests depending on the shear rate (0.02 to 100 s\(^{-1}\)) and depending on time (10 minutes at a constant shear rate of 100 s\(^{-1}\)). The rising curves of viscosity at different shear rates, from 0.02 to 100 s\(^{-1}\), for the yogurt samples, were adjusted to Bingham, Ostwald de Weale, Casson and Herschel-Bulkley models. Three determinations of each test were conducted for every sample (Mathias, Carvalho Junior, Carvalho, & Sérvulo, 2011). The Haake RheoWin Data Manager software was used for obtaining the graphical representation of viscosity curves and the values in the tables.

2.5. Sensory analysis

For the sensory analysis, the yogurt samples were evaluated by a consumer panel formed by students and academic staff of the Food Engineering Faculty from ‘Stefan cel Mare’ University of Suceava. Each sample was equally dosed (30 mL) in a glass beaker. The glasses were presented to tasters at 10 ± 1°C, with their coding number. The scoring method was used as a quality assessment system, according to SR 6345:1995, on a scale of 0–20 points. Thereby, there were attributed points from 0 to 5 with their weighting factor (importance coefficient) to each sensorial feature. The weighting factor of 0.5 was assigned to appearance, colour, consistency and smell and the importance coefficient was assigned to taste. For each characteristic, there was calculated the non-weighted average score, by adding the points given by the tasters to the arithmetic mean. Afterwards, by multiplying each non-weighted average score of each sensory feature with the corresponding weight factor, there was calculated the weighted average score. By summing all weighted average scores corresponding to the sensory attributes of each analysed sample, the total weighted average score was obtained. The sensory assessment of samples’ quality was performed on the basis of the overall average score, on a scale of 0–20 points and compared to control sample.

3. Results and discussion

3.1. The effect of fibers addition on the rheological properties of yogurt

The most important information on the yogurt samples structure was given by the conducted viscoelasticity tests. Four groups of experiments (yogurt with inulin, pea, oat and wheat fibers) were subjected to measurements at different frequencies for assessing the elastic modulus (\( G' \)), the viscous modulus (\( G'' \)), the phase angle (\( \tan \delta \)) and the complex viscosity (|\( \eta^* | \)). In Table 1, there are presented the values of \( G' \), \( G'' \), \( \tan \delta \) and |\( \eta^* | \) at 1 Hz for the yogurt samples.

The highest consistency, gel firmness and dynamic viscosity modules were observed for \( I_2 \) sample (yogurt with 2.5%
inulina adición). Nuestros resultados están en concordancia con los obtenidos por Crispín-Isidro et al. (2015) quienes reportaron que el poder firmeza aumenta a un nivel de 2–4% inulina adición. Esto puede ser debido al hecho de que las fibras están actuando como un ‘lleno’ entre los componentes de yogur. Menor concentración de fibras resultó en valores G’ y G” mayores, debido a las interacciones con la caseína en concordancia con los datos presentados en la literatura (Crispin-Isidro et al., 2015; Delloye Staffolo et al., 2017; Lazairdou et al., 2014; Sanz et al., 2008).

Cuando se evalúa la consistencia u otras propiedades predominan en muestras de yogur, no se observaron variaciones significativas (p > 0.05) en comparación con el control, mostrando que la incorporación de inulina, avena, y trigo en yogur no sustancialmente modifican el modelo de organización estructural en muestras. La Tabla 2 muestra los valores del coeficiente de regresión r para modelos ajustados para el comportamiento de viscosidad de las muestras de yogur.

La pequeña correlación más baja, r = 0.3373, fue observada para la muestra 1 (yogur con 1% inulina fibra), de acuerdo con Bingham model. Los mayores valores de r, r = 1, fueron mostrados por O4 muestra (yogur con 2.5% avena fibras) según el modelo de Herschel-Bulkley, que describe el comportamiento plástico y viscoso (no-newtoniano, ley de la fuerza que actúa). El r > 0.99 valores confirman la adecuación del modelo para caracterizar el comportamiento rheológico de yogurts. Figuras 1–4 muestran el representación gráfica de las muestras' viscosidad versus time.

3.2. El efecto de la adición de fibras sobre las propiedades físico-químicas de yogur

Los resultados obtenidos para los propiedades físico-químicas de los yogur muestran, como la acidez, pH y syneresis se incluyen en la tabla 3.

La acidez y el pH no variaron mucho para muestras con diferentes fibras adición, probablemente debido al hecho de que los ácidos grasos libres son liberados y consumidos por el cultivo de fermentacion. Un nivel mayor de aminoácidos en productos fermentados con adición de inulina fue reportado por Zhu, Miller, Nelson, and Glahn (2008). La acidez permaneció prácticamente invariable (p > 0.05) para yogur con inulina. Esto también fue reportado por Crispín-Isidro et al. (2015), quienes reportaron que la acidez no cambió independientemente de la inulina concentración (2–6%) debido a un efecto de buffer del proteína. La syneresis tuvo un mayor tamaño, de 8.21 unidades, el valor más pequeño (38.86 ± 0.2) (p ≤ 0.05) for P2 sample (yogur con 1.5% pease fibras adición) and the highest value (47.07 ± 0.01) (p ≤ 0.05) for W2 sample (yogur con 1.5% wheat fibras adición). Como se puede observar, un nivel mayor de añadido de fibras adición lleva a una disminución en el syneresis valores, debido a la capacidad de agua de los fibra que absorben la whey liberada por el gel estructura. Una disminución de este valor comparado con control muestras fue también reportado por Raja y Pal (2014). Además, según Rinaldoni, Campederróss, y Pérez-Padilla (2012) y Crispín-Isidro et al. (2015), la syneresis se mejoró comparado con el control muestra, debido a la mayor capacidad de interacción de los fibra con los casquete lactasicos.
Figure 2. Viscosity curves of yogurt with 1.5% fibers (inulin, pea, oat and wheat) additions and control samples.

Figure 2. Curvas de viscosidad del yogur con la adición de 1.5% de fibras (inulina, arveja, avena y trigo) y muestras de control.

Figure 3. Viscosity curves of yogurt with 2% fibers (inulin, pea, oat and wheat) additions and control samples.

Figure 3. Curvas de viscosidad del yogur con la adición de 2% de fibras (inulina, arveja, avena y trigo) y muestras de control.

Figure 4. Viscosity curves of yogurt with 2.5% fibers (inulin, pea, oat and wheat) additions and control samples.

Figure 4. Curvas de viscosidad del yogur con la adición de 2.5% de fibras (inulina, arveja, avena y trigo) y muestras de control.
Table 3. Physicochemical characteristics of enriched and control yogurt samples.

| Yogurt with fibers: | Acidity [°T] | pH | Syneresis [%] |
|-------------------|--------------|----|--------------|
| 0% Control sample | 128.6 ± 0.1  | 4.04 ± 0.01 | 46.75 ± 0.1 |
| 1% Inulin         | 128.5 ± 0.2  | 4.04 ± 0.01 | 43.25 ± 0.2 |
| 1% Pea            | 128.5 ± 0.2  | 4.04 ± 0.01 | 44.53 ± 0.1 |
| 2% Oat            | 128.4 ± 0.1  | 4.05 ± 0.01 | 40.73 ± 0.1 |
| 1.5% Wheat        | 128.5 ± 0.2  | 4.04 ± 0.01 | 43.33 ± 0.1 |
| 2.5% Wheat        | 128.5 ± 0.2  | 4.04 ± 0.01 | 44.01 ± 0.1 |

3.3. The effect of the fibers addition on the sensorial properties of yogurt

The sensory analysis complements the quality evaluation of the studied yogurt samples. The tasters’ panel was formed by 9 persons who were previously trained. The final results of the sensorial evaluation of the yogurt samples are shown in Figure 5.

Yogurt samples with the highest acceptance scores, 18.8 and 19, were W3 (2% wheat fibers) and respectively P3 (2.5% pea fibers). The research of Crispín-Isidro et al. (2014) demonstrated an improvement in taste and texture for yogurt with inulin, while Kip, Meyer, and Jellema (2006) observed that inulin can be used to improve creaminess. Our results showed that yogurt with oat fibers received lower scores for sensorial analysis from the panel consumers in comparison with the yogurt enriched with the other fibers, confirming by the results presented in the study of Raju and Pal (2014). Hashim et al. (2009) studied the effect of fortification with date fiber and observed that the yogurt fortified with 3% date fiber resulted with similar sourness, sweetness, firmness, smoothness and overall acceptability as the control yogurt. As both fiber and yogurt are well known for their beneficial health effects, together will constitute a functional food with commercial applications. The results of Hashim et al. (2009) are corroborated, since 1.32% oat fibers addition improved the body and texture of unsweetened yogurt and decreased the overall flavour quality. Tomic et al. (2017) found that addition of fibers from different sources (soy, rice, oat, corn, and sugar beet), at the level of 1.32%, in general led to lower overall flavor and texture scores – a gravy flavour and a gerrty texture were intense in all samples except in those made with oat fiber. However, fiber size is also an important factor in yogurt formulation because of their impact on general acceptance.

The principal component analysis (PCA) has been conducted to evaluate the influence of different fibers on yogurt physicochemical, sensory and rheological parameters, from a descriptive point of view. The scores and compound loadings of the PCA are presented in Figures 6 and 7.

The two principal components (PC) explained 100% of the variations in data set, the PC1 explained 99%, while the PC2 explains 1%. It can be observed in the Figure 6 that the control sample (CS) is placed in the same dial with the sample with inulin; this fact reveals that the final product is not influenced significantly (p > 0.05) by the addition of inulin. The samples with wheat fibers are placed in opposition with the control sample, so that samples have different characteristics. Regarding the loadings, the parameters like G’, acidity, h°, L* and syneresis have the biggest influence on the samples loadings. The G’ is influencing strongly the PC1, while acidity is influenced by the acidity.

4. Conclusions

This study evaluated the influence of the yogurt enrichment with total dietary fibers from inulin, pea, oat and wheat on its rheological, physicochemical and sensory characteristics. The four studied types of fibers (inulin, pea, oat and wheat) were added in the yogurt formulation in different proportions (1%–2.5%), with the classical production technology adapted to laboratory conditions. The most viscous samples were those with wheat fibers addition at low concentrations (1% and 1.5%), while for higher concentrations (2% and 2.5%) the best viscous characteristics were obtained for the samples with oats fibers addition. The acidity and the pH did not vary significantly for samples with different fibers addition. The lowest syneresis values were observed for the samples with 1.5% pea fibers addition, while the highest

Figure 5...
Figure 5. Graphical representation of the sensory evaluation of yogurt samples with fibers addition: a) yogurt with inulin fibers addition; b) yogurt with pea fibers addition; c) yogurt with oat fibers addition; d) yogurt with wheat fibers addition.

Figura 5. Representación gráfica de la evaluación sensorial de muestras de yogurt a las que se adicionaron fibras: a) yogurt con fibras de inulina; b) yogurt con fibras de arveja; c) yogurt con fibras de avena; d) yogurt con fibras de trigo.

Figure 6. Principal component analysis scores of yogurt with fibers (inulin, pea, oat and wheat) additions in different concentration and control samples.

Figura 6. Puntajes del análisis de los componentes principales del yogurt con fibras (de inulina, arveja, avena o trigo) adicionadas en distintas concentraciones y muestras de control.
syneresis values were determined for the yogurt with 1.5% wheat fibers addition. Sensory speaking, yogurt samples with the highest acceptance scores were samples with 2% wheat fibers and respectively with 2.5% pea fibers addition.

The results showed that, different types of fibers incorporated in yogurt significantly affect its rheological properties as well as its composition, flavour and other sensory characteristics.

All the tested fibers were compatible with the yogurt-manufacturing process. Therefore, this study opens the way for testing other types of fibers obtained as a by-product of industrial food processing to obtain enriched yogurts and could be considered an alternative to incorporate fibers in the human diet.

Due to its nutritional properties, yogurt is one of most consumed healthy and nutritious foodstuffs worldwide. By incorporating fibers in yogurt, researchers have achieved a mean to increase fibers consumption in all sectors of the populace and they have developed a functional food with an extensive array of beneficial effects.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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