LWT - Food Science and Technology 80 (2017) 59–66

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Enrichment of yoghurt with insoluble dietary fiber from triticale – A sensory perspective

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ARTICLE INFO

Article history:
Received 10 November 2016
Received in revised form
23 January 2017
Accepted 5 February 2017
Available online 8 February 2017

Keywords:
Descriptive analysis
Preference mapping
Mean drop analysis
Quality rating

ABSTRACT

Fortification of fermented dairy products with insoluble dietary fiber is an interesting way to increase consumers' fiber intake. The objective of this study was to evaluate the sensory characteristics and consumer acceptance of low-fat unsweetened yoghurt, fortified at levels of 15 and 30 g/kg, with insoluble triticale, wheat or oat fibers. The addition of insoluble triticale fiber resulted in yellowish-brown color, grainy flavor, and pronounced sandiness/grittiness of the fortified yoghurts. The products were classified into the 'very good' quality category, despite the lower quality scores given to the 30 g/kg fiber-fortified yoghurts, caused primarily by a gritty/sandy texture and some bitterness. Three distinct consumer subgroups were revealed by the clustering analysis, one of which showed a preference for the triticale-yoghurts. Insoluble dietary fiber from triticale showed promising potential to be used as a fortifying ingredient in the production of fiber-enriched fermented dairy products such as yoghurt.

1. Introduction

For the past 20 years, much attention has been paid to developing functional food and food ingredients with increased health benefits and acceptable sensory properties. Consumer demands in this field are still rising, with special concern about the nutritional aspect of the food. In general, adding value to food products is a customer-oriented concept where a producer expects consumers will perceive value-added foods as having more quality (Grunert, 2005). Food fortification, defined as the addition of one or more essential nutrients to a food for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population (Bonner, Warwick, Barnardo, & Lobstein, 1999, pp. 1–115), is a way of enhancing the nutritional value of food.

Milk is a rich source of nutritive compounds which can be enriched and/or further modified, and also fortified (Saxelin, Korpela, & Mäyrä-Mäkinen, 2000). Fortification of dairy products with dietary fiber is of increasing interest in creating functional foods with health benefits and improving their initial functionality (AACC International, 2003). Dietary fiber consists of remnants of plant cells (hemicelluloses, cellulose, lignin, pectins, gums and waxes), and is resistant to hydrolysis (digestion) by human alimentary enzymes (Rodríguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006). Based on their simulated intestinal solubility, dietary fibers are either classified as insoluble or soluble (Rodríguez et al., 2006). Diets with a high dietary fiber content play a significant role in the prevention of several diseases. Insoluble dietary fibers (IDF) increase stool weight and decrease colonic transit time (Müller-Lissner, 1988). These characteristics lead to prevention of colonic diverticulosis and constipation (Slavin, 2005). IDFs have an antioxidant potential that comes from phenolics, and enhance certain health benefits (Mazza & Kay, 2009). A food can be considered a source of fiber and labeled as such where the product contains at least 1.5 g of fiber per 100 kcal (418.68 kJ), while product containing at least 3 g of fiber per 100 kcal (418.68 kJ) can be classified as a high fiber food (EU., 2006).

IDF can be extracted from a great variety of raw materials, such as fruits, vegetables, cereals, corn, sugar beet, leguminous plants, etc. (Larrauri, 1999). Triticale is a hybrid crop developed by crossing wheat (*triticum*) and rye (*secale*), and its by-products, such as bran and straw, show promise as a source of valuable phenolics and dietary fibers for future functional foods (Hosseinian & Mazza,

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http://dx.doi.org/10.1016/j.lwt.2017.02.008
0023-6438/

2009). Although triticale can be a suitable grain for the human diet, its application in the food industry is still very limited when compared with other types of grain such as wheat and oats (Peña, 2004).

Triticale is a good source of different phenolics with antioxidant activity, alkylresorcinols, phytoestrogens, but also has vitamins, amino acids and microelements (Fraś et al., 2016; Jonnala, Irmak, MacRitchie, & Bean, 2010; Villegas, McDonald, & Gilles, 1970). The great potential of triticale utilization lays in the dietary fiber content (around 15%), which is normally at an intermediate level compared to its rye and wheat parents, but greater than in other cereals of commercial importance, including wheat and oats (Rakha, 2011; Rakha, Åman, & Andersson, 2011). The usage of triticale in the bakery industry is limited, due to the high alpha-amylase activity, and weak rheological properties of the dough and low gluten content (Fraś et al., 2016); however, its great functional properties might be still exploited in the dairy industry.

Besides nutritional enhancement, addition of IDF to fermented dairy products such as yoghurt affects the sensory properties of final products. Furthermore, dairy products with a reduced fat content, aimed at lowering the daily energy intake, may lack the mouthfeel associated with higher fat products (Kip, Meyer, & Jellema, 2006). Low-fat yoghurt, in terms of fat content, contains between 0.5% and 2% milk fat and not less than 8.25% milk solids not fat (Tribby, 2009).

Addition of IDF can influence the sensory characteristics of yoghurt both positively and negatively. As reported by Fernández-García and McGregor (1997), addition of these 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 grainy flavor and a gritty texture were intense in all samples except in those made with oat fiber. Their subsequent research showed that addition of 1.32% insoluble oat fiber improved the body and texture of unsweetened plain yoghurts but lowered overall scores for body and texture in yoghurts sweetened with sucrose (Fernández-García, McGregor, & Traylor, 1998).

Since global trends in food consumption and nutrition are still focusing on lowering the energy intake, there is an increased market demand for yoghurt with reduced content of both fat and sugar, while, at the same time, many consumers expect the sensory quality to be similar to the “original” product (Johansen, Næs, Øyaas, & Hersleth, 2010). Considering consumer acceptance of yoghurt enriched with different types of dietary fiber, Hoppert et al. (2013) reported that acceptance was significantly lower for reduced-sugar yoghurt with visible fiber than for reduced-sugar yoghurt with inulin, that the interaction between the perception of sweetness and flavor could be used to increase the acceptability of fiber-enriched yogurt, and that in yoghurt with visible fiber, it was mainly the size of incorporated fiber that should be considered in product optimization. Staffolo, Bertola, Martino, and Bevilacqua (2004) reported that the addition of 1.3% insoluble dietary fiber to supplement yogurts appears to be a promising avenue for increased fiber intake, with relatively high consumer acceptability.

Wheat and oat IDF are frequently used in the dairy industry (Fernández-García et al., 1998; Staffolo et al., 2004), while the application of triticale fiber is less common. There is a scarcity of scientific articles reporting fortification of dairy products with triticale insoluble dietary fiber (IDFT), which has the technological potential to be used as a fortifying ingredient.

The aim of this study was to investigate the sensory and affective aspects of utilizing IDFT in yoghurt fortification. For that purpose, sensory characteristics and consumer acceptance of low-fat unsweetened yoghurt fortified with IDFT were evaluated and compared with yoghurts fortified with wheat and oat IDF.

2. Materials and methods

2.1. Dietary fibers

IDF from three different cereal sources (triticale, wheat, and oats) were used in the study (Table 1). IDFT was obtained by innovative technology based on the autohydrolysis properties of triticale (Dojnov, Vujčić, Margetić, & Vujčić, 2016). Triticale has been used previously for bioethanol (Pejin et al., 2009) and fungal amylase production (Dojnov, Grujić, Perčević, & Vujčić, 2015), and it has its own α-amylases that can hydrolyze all starch present in the grain. This characteristic has also been used in insoluble dietary fiber production technology. IDF from wheat (IDFW) (SANACEL® wheat 90) and oats (IDFO) (SANACEL® oat 90) were locally purchased as commercial products manufactured by CFF GmbH & Co. KG (Gehren, Germany). Particle sizes and proportions of different fractions were determined by sieving samples of IDF through standard laboratory sieves (Table 1).

Chemical analysis of IDFT showed the presence of relatively small amounts of proteins (cca. 2.0 mg/g IDFT), starch (cca. 0.8 mg/g IDFT) and reducing sugars (cca. 2.3 mg/g IDFT), indicating the negligible calorific value of this fiber. No phytates were found. Elemental microanalysis showed that IDFT was relatively rich in essential elements (such as Na, K, Fe, Mn, Mg, Ca, Co) and macrominerals (such as Ca = 6.4 mg/g IDFT, Mg = 3.5 mg/g IDFT, K = 1.0 mg/g IDFT, approx. values). Yoghurt enriched with IDFT showed enhanced antioxidant capacity, mainly due to the significant presence of different phenolic fractions in IDFT (total phenolic content: bound phenolics = 990 μg/g IDFT, free phenolics = 50 μg/g IDFT, phenolics dissolved in the aqueous phase = 113 μg/g IDFT).

2.2. Yoghurt preparation and fortification

Low-fat unsweetened yoghurts were prepared using pasteurized and homogenized milk containing 15 g/kg milk fat. IDFs were added at the levels of 15 g and 30 g per 1 kg of milk (15 g/kg and 30 g/kg) before milk heat treatment. The control yoghurt was not fiber-fortified. Starter culture (0.2 g/kg of Yoflex 812) (Chr. Hansen, Nieuwegein, The Netherlands) was added. Fermentation was set at 43 °C until pH 4.6 was reached. Yoghurts were mixed and cooled during 24 h at 4–7 °C and then analyzed.

The 15 g/kg and 30 g/kg fiber-fortified yoghurts fulfilled the conditions of being ‘a source of fiber’ (>1.5 g of fiber per 418.68 kJ) and ‘high in fiber’ (>3 g of fiber per 418.68 kJ), respectively (EU., 2006). All the yoghurts were labeled with random 3-digit codes.

2.3. Sensory analysis

Descriptive analysis and quality grading were conducted by a sensory panel that consisted of 10 staff members from the University of Belgrade – Faculty of Agriculture – who were experienced in dairy product quality judging. The panel evaluated all of the yoghurts in two replications.

Consumer acceptance tests were performed by 100 students from the university. The students (18–25 years old) were randomly selected and were chosen if they were regular yoghurt consumers.

The sensory tests were performed in the sensory testing laboratory at the University of Belgrade. Low sodium bottled water was used for palate cleansing. No strict instructions were given to the panelists whether to swallow or expectorate individual samples.

2.3.1. Descriptive sensory evaluation

Over a period of three weeks, two 2.5-h training sessions were performed using yoghurts prepared in the laboratory with experimental cereal extracts and commercially available yoghurts with

Table 1
Technical specifications for the insoluble dietary fibers (IDF) used in the study.

Characteristics	Triticale-IDF (IDFT)[a]	Wheat-IDF (IDFW)[b]	Oat-IDF (IDFO)[b]
Appearance	light brown fibrous powder	white fibrous powder	cream-white fibrous powder
Odor and taste	neutral	neutral	neutral
Roughage content (%)	100	>96.0	>96.0
Water binding capacity (g water/g)	4.7	ca.4.7	ca. 6.0
Oil absorption (g oil/g)	2.0	ca. 2.6	ca. 3.0
Bulk density (g/l)	–	>200	<280
Particle size (mm)	Proportion (g/100 g)		
	IDFT[c]	IDFW[c]	IDFO[c]
>0.40	0.68 ± 0.02	0.00	0.00
0.25–0.40	5.67 ± 0.15	19.00 ± 0.85	18.80 ± 0.79
0.16–0.25	23.73 ± 0.96	45.60 ± 1.75	46.00 ± 1.43
0.12–0.16	20.96 ± 0.78	17.34 ± 0.66	17.07 ± 0.74
0.09–0.12	43.50 ± 1.65	2.53 ± 0.05	2.73 ± 0.07
0.05–0.09	5.50 ± 0.15	13.82 ± 0.42	13.90 ± 0.33
<0.05	0.00	1.68 ± 0.03	1.50 ± 0.06

[a] IDFT were obtained in the framework of this research.
[b] Manufacturing specifications (SANACEL® wheat 90 and SANACEL® oat 90, CFF GmbH & Co. KG, D-98708 Gehren, Germany).
[c] Values are the arithmetic mean ± standard error of measurement ($N = 3$).

cereals. Commercial products ($n = 5$) were used to help in both the training of panelists and the anchoring of minimum and maximum levels of individual sensory attributes. The list of 18 sensory attributes with their definitions (Table 2) was generated during the training sessions. The selected sensory attributes were scored with respect to their intensities using 15 cm line scales within paper ballots. The scales had verbal anchors at both ends (Table 2) and the panelists were given free choice in using them. All seven yoghurts were presented to each panelist at the same time using the Latin Square order 7 design. The panelists evaluated the intensities of selected attributes by comparing the yoghurts with each other.

2.3.2. *Sensory quality rating*

Apart from the descriptive training, over a period of two weeks, two 2-h quality rating training sessions were performed using the same products. Quality grading was performed using a 5-level quality scoring method as follows: excellent quality (quality score > 4.5); very good quality (3.5 < score ≤ 4.5); good quality (2.5 < score ≤ 3.5); poor/unsatisfactory quality (1.5 < score ≤ 2.5); very poor quality (0.5 ≤ score ≤ 1.5); spoiled product/not for human nutrition (0 ≤ mean score < 0.5). Overall sensory quality was assessed by evaluating four initially selected characteristics: appearance, odor (orthonasal olfaction), oral texture and flavor. According to the individual impact on overall quality, the selected characteristics were assigned appropriate coefficients of importance (CI): 3, 2, 9, and 6, respectively. The selected sensory characteristics were rated using a category scale with minimum 0 to maximum 5 score range. Each of the five integer quality scores (1–5) was divided into fourths, to obtain a category scale with 20 alternative responses. The assessors rated the quality of the selected characteristics by subtracting an appropriate number of scale score-points from the maximum value of 5 depending on the defect level, according to the internal laboratory guidelines for yoghurt quality judging but modified for yoghurt fortified with cereals. In order to calculate the overall quality score for each panelist, individual scores given to the selected sensory

Table 2
Definitions of the attributes used in descriptive sensory analysis of yoghurts fortified with insoluble dietary fibers.

Attribute	Definition
APPEARANCE	
Color description	The color of the sample from *white* to *brown*.
Color evenness	The evenness of distribution of color (*uneven – even*).
Viscosity (visual) [a]	The viscosity of the sample. The speed at which a sample flows down the glass-wall (*thin - thick*).
Grain-particles size (visual)	The relative size of the particles originating from cereals (*small – large*).
Uniformity of grain-particles	Degree of uniformity of the particles originating from cereals (*nonuniform - uniform*).
ODOUR	
Overall odor intensity[a]	The intensity of overall product odor (*none - intensive*).
Lactic acid odor	The intensity of odor associated with sour milk, i.e. lactic acid (*none - intensive*).
Grainy odor	The intensity of odor associated with cereals (*none - intensive*).
FLAVOR	
Overall flavor[a]	The intensity of overall product flavor (*none - intensive*).
Yoghurt flavor	The intensity plain yoghurt flavor (*none - intensive*).
Grainy flavor	The intensity of flavor associated with cereals (*none - intensive*).
Sourness[a]	The taste stimulated by acids (*none - intensive*).
Bitterness	The taste stimulated by substances such as quinine or caffeine (*none - intensive*).
Sweetness[a]	The taste stimulated by sugars (*none - intensive*).
TEXTURE	
Viscosity (oral) [a]	Internal rate of flow across tongue or force used to draw sample from spoon between lips (*thin - thick*).
Grittiness/Sandiness	The amount of abrasive (sandy) pieces in the mass (*none – very many*).
Grain-particles size (oral)	The relative size of the particles originating from cereals (*small – large*).
RESIDUAL	
Mouth coating	The amount of film/particles left on the mouth surfaces (*none – much*).

[a] Excluded from further dimension reduction analysis.

characteristics were first multiplied by the corresponding CI, and then the sum of corrected score-values was divided by the sum of CI. The yoghurts were presented to the panelists monadically in random order.

2.3.3. Consumer testing

Fortified yoghurts were evaluated for liking of 'product as a whole', 'color', and 'flavor' using the 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely), and also, using 9-point just-about-right (JAR) scales (1 = too little, 5 = JAR, 9 = too much), for intensity of 'color' (*too white*–JAR–*too brown*), 'thickness' (*too thin*–JAR–*too thick*), 'sandiness' (JAR–*too sandy*), 'grainy flavor' (*not enough*–JAR–*too much*), 'sweetness' (*not sweet enough*–JAR–*too sweet*), 'sourness' (*not sour enough*–JAR–*too sour*). The control yoghurt was assessed for both overall and flavor acceptance using the hedonic scale, and for intensity of thickness, sandiness, and sourness using the JAR scale.

2.4. Statistical analysis

2.4.1. Descriptive data and PREFMAP

In order to perform multivariate (MANOVA) and univariate (ANOVA) analysis of variance, raw descriptive data for each variable for each assessor were first standardized. One-way MANOVA with 'yoghurts' as the main effect (fixed factor) was applied in order to test for the significance of multivariate effect for yoghurt samples. To identify sensory attributes that significantly discriminate among yoghurts, three-way analysis of variance (ANOVA) was applied to standardized data with main effects of 'yoghurts', 'assessors' and 'replications' and all two-way interactions ('yoghurts' = fixed factor; 'assessors' and 'replications' = random factors). Tukey's honestly significant difference (Tukey's HSD) test was used to separate the mean values for yoghurts. Six sensory attributes that did not significantly discriminate among yoghurts were excluded from subsequent statistical analysis (Table 2). The rest of the attributes were subjected to Generalized Procrustes Analysis (GPA) and Principal Component Analysis (PCA) on the correlation matrix (corr-PCA). GPA was applied to original (raw) data divided into 20 personal construct grids (10 assessors x 2 replications). The consensus data matrix (7 rows/yoghurts and 12 columns/attributes) that resulted from GPA was subjected to PCA. Extracted principal components were used as explanatory variables (predictors) in further linear multiple regression analysis (the vector model) against the overall acceptance (hedonic) data. This technique is referred to as external preference mapping (PREFMAP) (McEwan, 1996). The regression coefficients were segmented using K-means cluster analysis.

2.4.2. Quality data

Sensory quality data were first analyzed separately by 3-way ANOVA that included 'yoghurts' as fixed factor, and 'assessors' and 'replications' as random factors. In the second iteration, original data for fortified yoghurts were subjected to 3-way ANOVA that included 'fiber origin' and 'fiber content' as fixed factors, and 'assessors' as a random factor. Both ANOVA models included main effects and all 2-way interactions. Tukey's HSD test was used to separate the mean quality scores.

2.4.3. Consumer data

Raw hedonic acceptance data, grouped into clusters that resulted from K-means cluster analysis of consumer PCA-scores (PREFMAP), were analyzed by one-way ANOVA in order to examine differences between the clusters (within the experimental yoghurts), and between the yoghurts (within the clusters), separately.

Mean Drop analysis was performed by combining the JAR data with the overall hedonic data, as described by Schraidt (2009), in order to assess the potential impact of being off from *just-about-right* on the overall acceptability of the yoghurts. Raw JAR scores were grouped into three categories as follows: 1, 2 and 3 = 'below JAR'; 4, 5 and 6 = 'at JAR'; 7, 8 and 9 = 'above JAR'. Then the mean overall hedonic rating was calculated for each category. Mean drops were calculated by subtracting the mean liking of each non-JAR category from the mean of the JAR category. The JAR-categories overall hedonic means were compared by ANOVA and Tukey's HSD test. Minimum percentage skew for 'Not Just Right' (the cutoff) was set at 20% of the total consumer panel.

2.4.4. Software

Data standardization, GPA and PCA were completed using Idiogrid software version 2.4/2008 (Grice, 2002). The rest of the statistical analyses were performed using SPSS Statistics 17.0. The level of statistical significance was set at 0.05.

3. Results and discussion

3.1. Descriptive and acceptance testing (PREFMAP)

Standardized descriptive data of 18 sensory attributes were initially subjected to MANOVA which revealed a significant multivariate effect for 'yoghurts'. Subsequent 3-way ANOVA showed that 6 out of 18 attributes (Table 2) did not significantly discriminate among the yoghurts ($p > 0.05$). Those six attributes were excluded from further dimension reduction analysis. None of the 12 attributes left after removal of the 6 showed a statistically significant difference between replications. Also, the 'yoghurt by panelist' interactions were not significant, indicating that the panelists were scoring the yoghurts in the same order.

Raw descriptive data, derived from the 12 sensory attributes which discriminated among the yoghurts, were subjected to GPA. The results yielded a consensus proportion of 0.94 (statistically significant at the 0.05 level) which indicated strong agreement among the individual measurements. Individual isotropic scaling values (Grice & Assad, 2009) were relatively close to unity (they ranged from 0.81 to 1.20), indicating that individual differences in overall variability of the grids were relatively small. The consensus data matrix, obtained by GPA, was further subjected to corr-PCA. Only the first two extracted principal components (PC) had eigenvalues larger than 1 (9.9 and 1.3, respectively) and, therefore, according to the Kaiser criterion (Stevens, 2009, pp. 1–651), were retained for describing objects in the new 2-dimensional PC-space. The two PCs explained 93.8% of the variance in the data matrix values. The un-rotated solution was left since it showed the best arrangement of the loading values in comparison with Varimax, Equamax and Quartimax rotations. PCA on the covariance matrix (cov-PCA), which was performed simultaneously with corr-PCA, resulted in PCA-plots highly similar to the plots obtained by corr-PCA (data not shown).

Fig. 1 shows attribute-loadings and yoghurt&consumer-scores plots of the first two extracted PCs. Both 15 g/kg and 30 g/kg triticale-yoghurts (15-IDFT and 30-IDFT), on the far right side of the scores plot, were characterized by yellowish-brown color, grainy odor and flavor, large non-uniform grain particles, and also by highly pronounced sandiness, especially 30-IDFT. Lactic acid odor and yoghurt flavor in these yoghurts were masked by the presence of grainy odor and flavor. Pronounced sandiness was also a characteristic of 30 g/kg oat (30-IDFO) and 30 g/kg wheat (30-IDFW) yoghurts. According to sandiness/grittiness, the yoghurts were grouped in four homogenous subsets ($\alpha = 0.05$) without overlaps (ANOVA-data not shown), with increasing sandiness in the

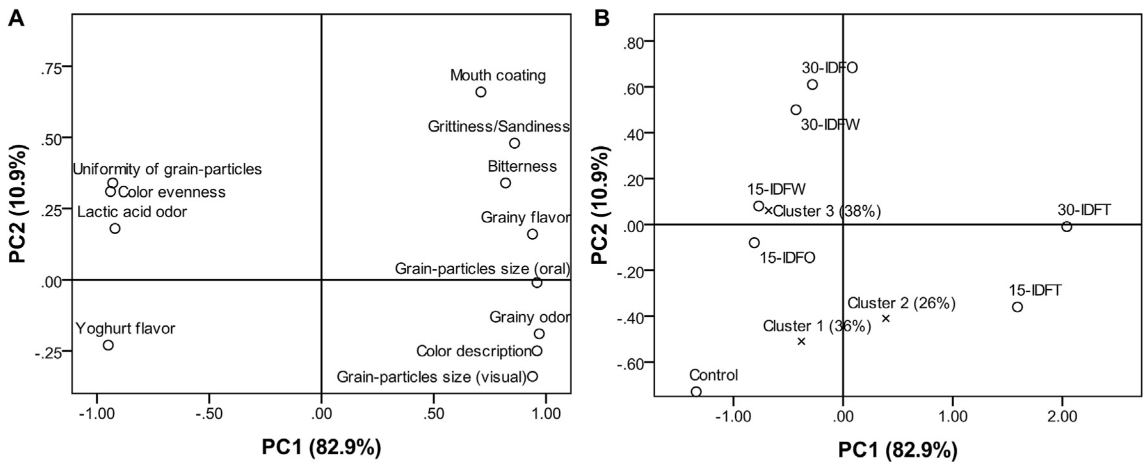

Fig. 1. Attribute-loadings (A) and yoghurt&consumer-scores (B) plots of the first two principal components extracted by applying Principal Component Analysis (unrotated solution) on consensus data matrix obtained by applying Generalized Procrustes Analysis on descriptive data (10 assessors x 2 replications) of yoghurts fortified with insoluble dietary fibers (triticale, wheat, or oats). Consumers (N = 94) are grouped in three clusters. Abbreviations for yoghurt types: 15 = 15 g IDF/kg yoghurt; 30 = 30 g IDF/kg yoghurt; IDF = insoluble dietary fiber, T = triticale, W = wheat, O = oats.

following order: (i) Control; (ii) 15 g/kg oat and wheat (15-IDFO and 15-IDFW); (iii) 30-IDFO, 30-IDFW, and 15-IDFT; and (iv) 30-IDFT. All three 30 g/kg fiber-fortified yoghurts had a more pronounced mouth coating characteristic compared with their 15 g/kg counterparts. All of the oat and wheat yoghurts were characterized by white color, small uniform grain-particles, lactic acid odor and absence of grainy odor (Tukey's HSD $p > 0.05$ for this last characteristic). Considering grainy flavor, yoghurts were grouped in three distinct homogenous subsets ($\alpha = 0.05$). Placed in the same homogenous subset, the wheat and oat yoghurts were significantly different from the control (absence of grainy flavor), while IDFT yoghurts had the most grainy flavor ($p < 0.05$). Beside the control yoghurt, yoghurt flavor was more pronounced in 15-IDFO and 15-IDFW yoghurts compared with the rest, which was also confirmed by 3-way ANOVA and Tukey's HSD test ($p < 0.05$). Examining the influence of 1.32% insoluble dietary fiber (soy, rice, oat, corn or sugar beet) on the sensory quality of sweetened plain yoghurt, Fernández-García and McGregor (1997) found that the grainy flavor was significantly more intense in all fiber-fortified yoghurts, except those fortified with oat fiber, as compared with controls. They also reported that the overall texture quality was most affected by fiber-fortification and that the low scores were primarily due to the grittiness effect. Again, yoghurts made with oat fiber had the lowest grittiness intensity scores, as compared with the rest. Fernández-García et al. (1998) reported that adding insoluble oat fiber (1.32%) improved body and texture of unsweetened yoghurt, while the presence of sucrose led to lower body and texture scores. The same authors also found that the effect of oat fiber addition on body and texture of yoghurt depended on the sweetening agent used and concluded that fiber appears to affect body and texture less than if added to yogurts containing fructose or those made with hydrolyzed milk than if added to yogurts containing sucrose.

After removal of six outliers, individual consumer overall hedonic scores (94 in total) were regressed against the two PCs. The PC1-PC2 plot of the standardized regression coefficients showed three relatively distinct clouds of plotted data. Regression coefficients were then clustered using K-means clustering and averaged across the clusters (Fig. 1b). Three clusters numbered from 1 to 3, each with ≥20% of respondents (36%, 26%, and 38%, respectively), were identified for consumer responses. Table 3 shows consumer hedonic scores averaged across the three clusters. The consumers within Cluster 1 (36%) showed a preference for the yoghurts with sensory characteristics close to the sensory profile of plain yoghurt, i.e. the yoghurts with a distinctive yoghurt flavor and lactic acid odor, white color, low level of grainy flavor and low levels of grittiness/sandiness and residual mouth coating (Fig. 1). The control, 15-IDFW and 15-IDFO yoghurts fulfilled these criteria (mean hedonic scores between 6.7 and 7.8; Table 3). Similar to Cluster 1, the consumers in Cluster 3 (38%) also liked 15-IDFO and 15-IDFW yoghurts with a distinctive yoghurt flavor and lactic acid odor, white color, and low level of grainy flavor, but they also found 30-IDFW and 30-IDFO yoghurts were acceptable; these, among other characteristics, are characterized by pronounced sandiness. Mean acceptance scores of these latter two yoghurts were within the range of 6.0–7.4 for Cluster 3 (Table 3). In contrast to cluster 1 and 3 consumers, those within Cluster 2 (26%) showed a preference for the triticale-yoghurts, both 15 g/kg and 30 g/kg (mean hedonic scores between 7.0 and 7.5), which were characterized by sensory attributes associated with commercial yoghurts with cereals, such as yellowish-brown color, grainy odor and flavor, large nonuniform grain-particles, and grittiness to a certain extent.

3.2. Mean drop analysis

The results of Mean Drop analysis are shown only for the triticale-yoghurts (Fig. 2). A point in the plot that shows a large (statistically significant) mean drop and a large percentage (above the cutoff point) is a cause for concern and suggests that the product be modified in the appropriate direction (Lawless & Heymann, 2010, pp. 1–596). Fig. 2 for 15-IDFT yoghurt shows that there were three large consumer groups (≥20%) with significant mean drops, one of which felt the product was 'not sweet enough' (33%), one that the product had a 'too strong grainy flavor' (37%), and one who felt the product was 'too sandy' (60%). Similar to 15-IDFT, consumers felt 30-IDFT yoghurt was 'too thick' (31%), 'too sandy' (68%), and with a 'too strong grainy flavor' (52%). Both 15 g/kg and 30 g/kg wheat-yoghurts were also rated as 'not sweet enough'. All of the experimental yoghurts were prepared without sugar added, and it was expected that the products could be perceived by the consumers as 'not sweet enough' since the most of the commercial fermented dairy products with cereals/fibers contain sugar or other sweeteners, and consumers are accustomed to the sweet taste of such products. On the other hand, 30-IDFT and

Table 3
Consumer ratings for yoghurts fortified with insoluble dietary fibers on a 9-point hedonic scale.

Yoghurt types[1]	Hedonic score[2] (Mean ± Sd)	Consumers ($N = 94$)		
		Cluster 1 (36%)	Cluster 2 (26%)	Cluster 3 (38%)
15-IDFT	Overall	5.1 ± 2.7 $^{a/\alpha}$	7.5 ± 1.8 $^{b/\alpha}$	3.9 ± 2.5 $^{a/\alpha}$
	Color	5.1 ± 2.3 ^{a}	7.1 ± 2.1 ^{b}	4.9 ± 2.7 ^{a}
	Flavor	5.3 ± 2.5 ^{a}	7.4 ± 2.0 ^{b}	4.1 ± 2.1 ^{a}
30-IDFT	Overall	5.2 ± 2.2 $^{a/\alpha}$	7.0 ± 2.1$^{b/\alpha,\beta}$	3.8 ± 2.6 $^{a/\alpha}$
	Color	5.6 ± 2.4 ^{a}	7.2 ± 2.3 ^{b}	4.0 ± 2.5 ^{c}
	Flavor	5.4 ± 2.2 ^{a}	7.2 ± 1.8 ^{b}	4.2 ± 2.5 ^{a}
15-IDFW	Overall	7.5 ± 1.6 $^{a/\beta}$	5.5 ± 2.3 $^{b/\beta,\gamma}$	7.4 ± 1.5 $^{a/\beta}$
	Color	7.8 ± 1.4 ^{a}	7.1 ± 2.2 ^{a}	7.8 ± 1.4 ^{a}
	Flavor	7.4 ± 1.8 ^{a}	6.1 ± 2.3 ^{b}	7.0 ± 2.2 ^{a,b}
30-IDFW	Overall	4.4 ± 2.5 $^{a/\alpha}$	4.3 ± 2.2 $^{a/\gamma}$	6.4 ± 2.1 $^{b/\beta}$
	Color	7.0 ± 1.9 ^{a}	6.6 ± 1.9 ^{a}	7.4 ± 2.3 ^{a}
	Flavor	5.1 ± 2.6 ^{a}	4.8 ± 1.9 ^{a}	6.9 ± 2.2 ^{b}
15-IDFO	Overall	6.7 ± 1.6 $^{a,b/\beta}$	6.1 ± 2.1 $^{a/\alpha,\beta}$	7.5 ± 1.9 $^{b/\beta}$
	Color	7.5 ± 1.3 ^{a,b}	6.8 ± 1.8 ^{a}	7.9 ± 1.6 ^{b}
	Flavor	7.0 ± 1.6 ^{a,b}	6.3 ± 2.0 ^{a}	7.5 ± 1.8 ^{b}
30-IDFO	Overall	4.1 ± 2.2 $^{a/\alpha}$	5.8 ± 1.9 $^{b/\alpha,\beta,\gamma}$	6.3 ± 2.2 $^{b/\beta}$
	Color	6.3 ± 2.0 ^{a}	6.6 ± 1.9 ^{a,b}	7.4 ± 1.7 ^{b}
	Flavor	4.5 ± 2.1 ^{a}	5.5 ± 2.1 ^{a,b}	6.0 ± 2.1 ^{b}
Control	Overall	7.9 ± 1.2 $^{a/\beta}$	6.4 ± 2.2 $^{b/\alpha,\beta}$	7.2 ± 1.5 $^{a,b/\beta}$
	Flavor	7.6 ± 1.2 ^{a,b}	6.8 ± 2.0 ^{a}	7.7 ± 1.4 ^{b}

1 Abbreviations: 15 = 15 g IDF/kg yoghurt; 30 = 30 g IDF/kg yoghurt; IDF = insoluble dietary fiber, T = triticale, W = wheat, O = oats.
2 Values marked with the same Roman letter within the same row are not statistically different ($\alpha = 0.05$). Values marked with the same Greek letter within the same column (overall acceptance only) are not stat. different ($\alpha = 0.05$).

30-IDFO were not perceived as 'not sweet enough'. Both yoghurts, especially the triticale one, were characterized by a 'grainy flavor' (Fig. 1), and both of them were perceived by consumers as products with a 'too strong grainy flavor' (52% and 36% of respondents, respectively), so it could be that these flavor notes masked the lack of a sweet taste. These results are in accordance with findings of Hoppert et al. (2013), who concluded from acceptance data, and from results obtained by the just-about-right rating, that adapting the flavoring concentration might be an appropriate tool to mask sugar reduction, i.e. that elevating flavor might be helpful to increase the general acceptance of reduced-sugar products. In the current study, all of the evaluated fiber-fortified yoghurts were assessed as 'too sandy'. This was expected, since the cereal fiber products used for preparation of the yoghurts are all insoluble in water. Performing consumer acceptance testing of yoghurt fortified with passion fruit fiber, Espírito-Santo et al. (2013) found that, even though the particle size of fibers was less than 17.7 μm, the products were scored as having a sandy mouthfeel, which was ascribed not only to the amount or size of fiber particles in yoghurts but also to the shape of fibers, which had edges like stones and were capable of sensitizing the mouth more than if they had had a spherical and smooth shape. Hoppert et al. (2013) reported that when fiber-enrichment through cereals is desired, special emphasis should be placed on the size of the particles that are incorporated in the

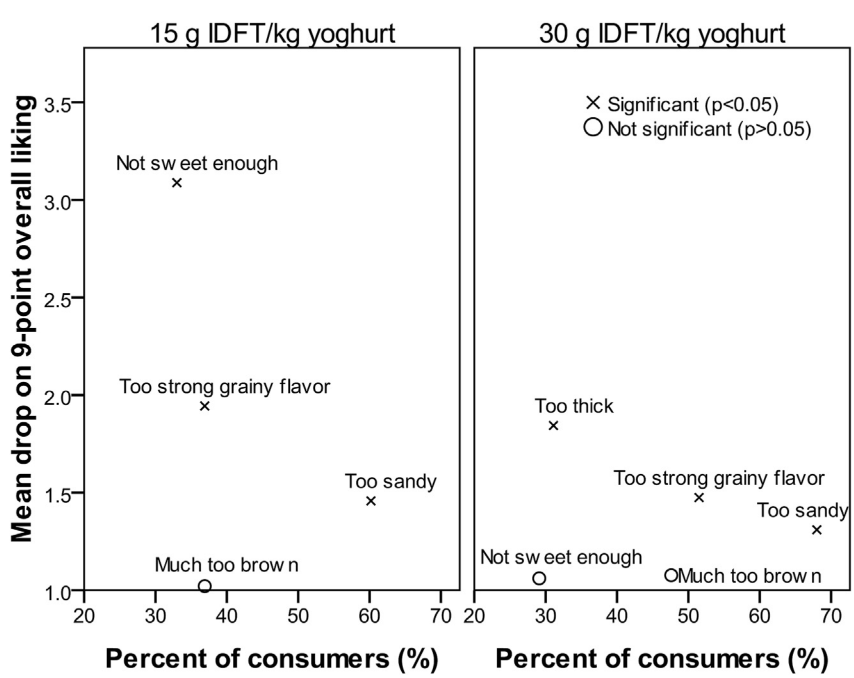

Fig. 2. Mean Drop analysis for yoghurts fortified with triticale insoluble dietary fiber (IDFT) (N = 94 respondents in total).

Table 4
Sensory quality scores for yoghurts fortified with insoluble dietary fibers.

Yoghurt types[1]	Overall quality[2]	Appearance[2]	Odor[2]	Flavor[2]	Texture[2]
15-IDFT	4.3 ± 0.6 [a]	4.4 ± 0.5 [a,b]	4.5 ± 0.5 [a,b]	4.3 ± 0.7 [a,b]	4.3 ± 0.8 [a]
30-IDFT	3.7 ± 0.7 [b]	4.0 ± 1.0 [a]	4.3 ± 0.4 [a]	3.6 ± 0.9 [c,d]	3.6 ± 1.0 [b]
15-IDFW	4.4 ± 0.6 [a]	4.7 ± 0.8 [b,c]	4.7 ± 0.4 [a,b]	4.3 ± 0.8 [a,b]	4.1 ± 0.8 [a]
30-IDFW	3.8 ± 0.7 [b]	4.7 ± 0.6 [b,c]	4.4 ± 0.8 [a,b]	3.6 ± 0.8 [c,d]	3.4 ± 1.1 [b]
15-IDFO	4.2 ± 0.8 [a]	4.6 ± 0.8 [b,c]	4.5 ± 0.9 [a,b]	4.0 ± 1.1 [a,c]	4.2 ± 0.7 [a]
30-IDFO	3.6 ± 0.8 [b]	4.7 ± 0.5 [b,c]	4.3 ± 0.9 [a]	3.2 ± 1.1 [d]	3.5 ± 0.8 [b]
Control	4.8 ± 0.4 [c]	4.9 ± 0.3 [c]	4.8 ± 0.3 [b]	4.8 ± 0.3 [b]	4.6 ± 0.9 [a]

[1] Abbreviations: 15 = 15 g IDF/kg yoghurt; 30 = 30 g IDF/kg yoghurt; IDF = insoluble dietary fiber, T = triticale, W = wheat, O = oats.
[2] Values are the arithmetic mean ± standard deviation ($N = 20 = 10$ assessors x 2 replications). Values marked with the same letter within the same column are not statistically different ($\alpha = 0.05$).

product, and that in yoghurt with visible fiber, the size of incorporated fiber is the main factor that should be considered in product optimization.

3.3. Sensory quality testing

Three-way ANOVA applied on overall quality scores showed that only the 'fiber content' as a main effect was statistically significant ($p < 0.05$), influencing, in general, higher quality scores in the case of 15 g/kg fiber-fortified yoghurts. Similar results were obtained for individual evaluated sensory attributes. 'Fiber origin' effect was significant only for *appearance* (mean quality scores for the triticale-yoghurts were slightly lower as compared to the wheat and oat yoghurts). This was mostly due to mosaic-like surface appearance of the triticale-yoghurts, with bright and dark yellowish-brown color shades deriving from triticale-fiber particles, which were relatively large in size, planar in shape (in the form of very small flakes with sharp edges), and brown in color, compared to the wheat and oat fiber extracts which were white in color and in the form of fine powder. The 'Replication' effect and all two-way interactions were not statistically significant.

The results of sensory quality judging are shown in Table 4. Mean overall quality scores were all >3.5, i.e. within the ranges of 'very good' and 'excellent' quality (only the control was excellent). Despite that, 30 g/kg fiber-fortified yoghurts had significantly lower ($p < 0.05$) overall quality scores (3.6–3.8) compared with 15 g/kg fiber-fortified yoghurts (4.2–4.4), all of which were classified in the 'very good' quality category. The score-lowering factors in the case of 30 g/kg fiber-fortified yoghurts were primarily gritty/sandy texture, bitter taste (to some degree), as well as the mosaic-like surface appearance found in triticale yoghurts. Grainy flavor, which was more intensive in the triticale-yoghurts compared with those fortified with wheat or oat fiber, was described as a flavor which is pleasant and typical for cereal-rich yoghurt. Also, the yellowish-brown color of the yoghurt matrix in the triticale-yoghurts was described as typical for these kinds of dairy products. Bitterness influenced the flavor quality scores of 30 g/kg fiber-fortified yoghurts (3.2–3.6), which were scored at significantly lower levels ($p < 0.05$) compared with their 15 g/kg counterparts (4.0–4.3). Texture was the sensory attribute most negatively affected by the presence of the insoluble fiber extracts used in the study. Mostly due to perceived grittiness/sandiness, the texture quality scores of 30 g/kg fiber-fortified yoghurts (3.4–3.6) were significantly lower ($p < 0.05$) than those of the 15 g/kg fiber yoghurts (4.1–4.3).

4. Conclusion

IDF from triticale showed promising potential to be used as a fortifying ingredient in production of fiber-enriched yoghurt, according to the results of the sensory evaluation conducted. The yellowish-brown color, grainy odor and flavor, and highly pronounced sandiness/grittiness of triticale-fiber fortified yoghurt did not result in poor quality scores. Therefore, the resulting yoghurt, a new type of functional food, could be a suitable choice for those wishing to consume the high-fiber product as a meal in itself. Since the product was not assessed as 'not sweet enough' by the consumers, it also showed potential to be part of low sugar or sugar free diets. By introducing a completely new source of IDF in a frequently consumed product such as yoghurt, the currently inadequate daily intake of this type of dietary fiber could be increased without affecting eating habits significantly.

Acknowledgements

This study was supported by the Serbian Ministry of Education, Science and Technological Development (projects grant numbers ON 172048 and 451-03-2082-Tip 1/75).

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