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Nutritional, rheological, sensory characteristics and environmental impact of a yogurt-like dairy drink for children enriched with lupin flour

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ABSTRACT

Studies have demonstrated that the addition of pulses to foods can make them more nutritious. We hypothesize that lupin flour adds nutritional benefits to yogurts. This study aimed to characterize a lupin-enriched yogurt in nutritional, rheological, and sensorial terms by a trained panel and assess its environmental impact using the life cycle assessment (LCA) approach. For comparison, natural yogurt and a commercial formula were used as controls. The developed yogurt is "high in protein" (7g/100g), "source of fiber" (1.9g/100g), and "source of omega 3" (53 mg/100g). The lupin yogurt was the stiffest with the highest viscosity than controls according to rheological parameters. There were no significant sensory differences between the lupin-enriched yogurt and the controls, although some undesirable sensory characteristics, such as bitterness, granularity, and after-taste, were observed. The environmental impact per 100 g serving was similar to natural yogurt and slightly worse regarding commercial yogurt but better when expressed per Nutritional Density Unit (NDU). Using lupin flour to enrich yogurts for children can be an alternative to producing more nutritious products.

1. Introduction

The functional food market is one of the fastest-growing segments in the food product development category, as an increasing number of consumers are concerned about health-related issues (Paul et al., 2020; Asioli et al., 2017). Pulses have a high potential to be used in functional foods, as they are good stabilizers, sources of protein, dietary fiber, minerals, vitamins, polyunsaturated fatty acids (linoleic and linolenic), minerals, and phytochemicals, which are all important for human health (Foschia et al., 2017). Considering the current European Union legislation, using pulses as a food ingredient may also allow some nutrition claims, especially regarding fiber and protein (Watson and Brandt, 2017). One way to classify food products' nutritional quality is using Nutri-Score, a nutrition label that is shown on the front pack and that establishes the nutritional characteristics using a five-letter code (A, B, C, D, and E) in different colors (Ferreiro et al., 2021). Studies in several European countries have highlighted that the Nutri-Score generally follows public health nutritional recommendations (Hercberg et al., 2021).

Beyond favorable nutritional composition, pulses are affordable and benefit soil health maintenance (Boeck et al., 2021). Investing in food innovations that diversify the use of pulses may promote their cultivation in sustainable cropping systems while improving products' nutritional quality (Bresciani and Marti, 2019). Several new pulse-based products have appeared in the market in recent years, especially innovations enriching cereal products with pulses (Bresciani and Marti, 2019; Magrini et al., 2018). Nevertheless, overall consumer acceptance of products with pulses is still a challenge (Binou et al., 2020). Considering this, product innovations could prioritize incorporating pulses in animal foods (Magrini et al., 2018) and preferentially target younger consumers whose taste preferences have not yet been established (Lartey et al., 2016). According to dietary recommendations, pulses should be introduced into infant feeding before the first year of life. Due to their nutritional density, pulses' inclusion in children's diets can increment

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nutrient intake, helping reach nutritional demands and may prevent overweight (Vieira et al., 2021).

Market research suggests that parents are looking for innovative ways to incorporate vegetables and healthy proteins into their children's food patterns while contributing to environmental sustainability (Austen, 2018). Products' environmental impact is widely evaluated by the Life Cycle Assessment (LCA) approach, which quantifies resource use and environmental emissions of all inputs and outputs associated with the production process, from extraction to disposal (Dai et al., 2020). The LCA processes have been standardized by ISO 14040 (2006) and ISO 14044 (2006) norms and have been shown to be a useful tool for evaluating the environmental impact of foods and diet patterns (Heller et al., 2013). Recent LCA studies evidenced that pulse-based products present a lower environmental impact while offering higher nutritional density than similar products available in the market (Saget et al., 2020, 2021). Thus, developing new children's foods enriched with pulses seems to be the right direction to take.

The dairy industry has invested in making its foods more nutritious and functional beyond conventional milk products (Paul et al., 2020). Yogurts are popular fermented foods produced by fermentation of milk by dairy cultures of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*. Evidence is accumulating that yogurt consumption as part of a healthy diet is related to healthier metabolic profiles in children and adults (Moore et al., 2018). Often present in the infant diet, yogurts can contribute significantly to babies' and children's daily nutrient intake, providing substantial amounts of protein and essential micronutrients such as calcium, potassium, zinc, phosphorus, and magnesium (Marette and Picard-Deland, 2014). The addition of pulses in yogurts can increment their nutritional profile with nutrients that are missing in conventional formulations, such as fibers and polyunsaturated fatty acids. Lupin (*Lupinus albus*), a pulse crop that grows in the Mediterranean region, is highly nutritive, has a low number of anti-nutrients, and provides beneficial functional, antioxidant, and prebiotic properties (Porres et al., 2006; Gullón et al., 2015). Furthermore, lupin is rich in minerals such as iron, zinc, and manganese (Villarino et al., 2016), which are particularly important for children's cognitive and motor development (Beal, 2021). We hypothesize that lupin flour adds nutritional benefits to yogurts. This study aimed to develop an enriched lupin yogurt, characterizing it in nutritional, rheological, and sensorial terms and assessing its environmental impact using the LCA approach.

2. Materials and methods

2.1. Yogurt development

The yogurt was prepared as described in Fig. 1. Organic semi-skimmed milk (Milhafre®, Azores, Portugal) was mixed with 6% (6.8 g/100 ml) of skimmed milk powder (Molico®, Nestlé Portugal) and enriched with 4% (4.16 g/100 ml) of de-hulled organic lupin flour originated from the European Union. The nutritional composition of lupin flour is available in Table 1. The mixture of milk and lupin flour was homogenized and heated to 90 °C for 3.5 min. After cooling to 40 °C, the preparation was inoculated with an organic powder preparation for yogurt (Natali®, France) containing *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*. After inoculation, the milk enriched with lupin flour was fermented in a water bath at 42 °C for approximately 6 h (until pH reached 4.6–4.5). After fermentation, the yogurt was gradually cooled and stored at 4 °C for 24 h until the analyses were carried out or frozen in the case of nutritional analyses.

Two controls were used in the current study: i) a natural yogurt (NY), in which the preparation followed the same steps as the lupin enriched yogurt (LEY), except for the addition of lupin flour, and a commercially available infant yogurt formula (CY) (Table 2). The differences between the developed yogurt and commercial formula may limit some comparations, but this was chosen because it was the product targeted to infants more similar to yogurts. The three products were characterized concerning nutritional, physical, and sensory aspects.

2.2. Yogurt characterization

2.2.1. Nutritional characterization

The nutritional composition was determined in terms of macronutrients and minerals. The total protein content of the yogurt samples was obtained by the determination of total nitrogen by the Kjeldahl method, with a nitrogen-to-protein conversion factor of 6.25 (AOAC- Association of Official Analytical Chemists, 1995). Moisture was determined in a vacuum oven using AOAC 925.09, and ash content was determined as a percentage after muffle incineration at 550 °C for 5 h (AOAC- Association of Official Analytical Chemists, 1995). Total fat was determined by the Gerber Method (Badertscher et al., 2007), in which the separated fat is measured directly in a calibrated butyrometer. Fatty acids were quantified by gas chromatography coupled to a flame ionization detector (GC-FID) based on ISO 12966–1:2014; 12966–2:2011; 12966–3:2016 (ISO, 2016, 2014, 2011). The carbohydrate content was determined by differences based on protein, fat, moisture, and ash percentages. The conversion values for the macro-nutrients in European regulation (European Union, 2011) were considered for calculating the

Table 1
Nutritional information of lupin flour.

Energy/Nutrient	In 100 g of the product
Energy (kcal)	358
Total fat (g)	12
Saturated fat acids (g)	1.5
Carbohydrates (g)	9.0
Fiber (g)	27
Protein (g)	40

Source: Product's label

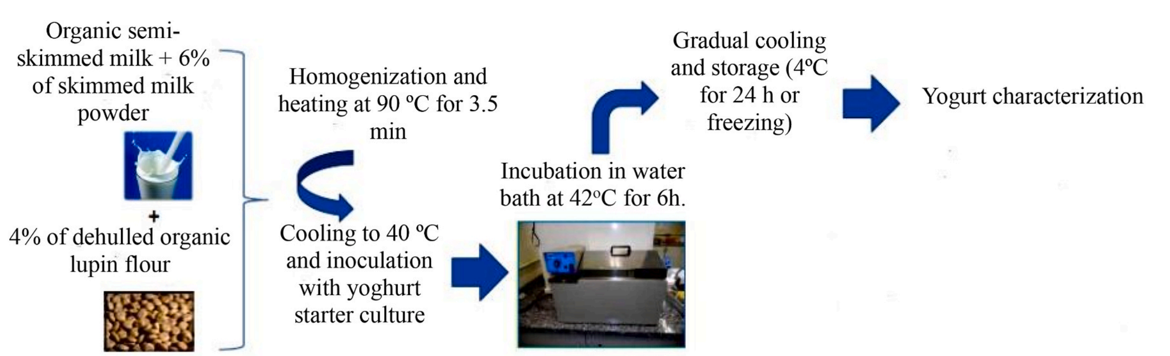

Fig. 1. General workflow followed for the lupin-enriched yogurt production.

Table 2
The three yogurt formulations used in the current study and their ingredient lists.

Yogurt type	Ingredients
Lupin-enriched yogurt (LEY)	Organic semi-skimmed milk (90%), skimmed milk powder (6%), organic dehulled lupin flour (4%), and organic yogurt starter bacteria.
Natural yogurt (NY)	Organic semi-skimmed milk (94%), skimmed milk powder (6%), organic yogurt starter bacteria.
Commercial yogurt (CY)	Fermented milk (88.1%) [organic milk (60%[a]), water (24.1%[a]), organic skimmed milk powder (3%[a]), thickener (pectin) (1%[a]), yogurt starter bacteria], water (3.6%[a]), corn starch (2.3%[a]), rice starch (2%[a]), organic butterfat (3%[a]), organic rice semolina (1%[a])

[a] Estimated percentages.

energy value. The gravimetric enzymatic methods (AOAC 991.43 and AOAC 985.29) were applied to determine the total dietary fiber (AOAC-Association of Official Analytical Chemists, 2007).

Mineral analyses for iron (Fe), zinc (Zn), magnesium (Mg), manganese (Mn), copper (Cu), calcium (Ca), phosphorus (P), sodium (Na), and potassium (K) were performed using 200 mg of sample, analyzed in triplicate, mixed with 6 mL of 65% HNO_3 and 1 mL of 30% H_2O_2 in a Teflon reaction vessel heated in a SpeedwaveTM MWS-3+ (Berghof, Germany) microwave system. Digestion procedures were conducted in five steps, consisting of different temperature and time sets: 130 °C/10min, 160 °C/15min, 170 °C/12min, 100 °C/7min, and 100 °C/3min. Mineral concentration determination was performed using the inductively coupled plasma optical emission spectrometer (ICP-OES) Optima 7000 DV (PerkinElmer, USA) with a radial configuration.

The Nutri-Score was calculated to determine the overall nutritional quality of the products. This calculation was performed using a table available on the French public health website (https://www.santepubliquefrance.fr/media/files/02-determinants-de-sante/nutrition-et-activite-physique/nutri-score/tableur-calcul-nutri-score-en).

2.2.2. Physical characterization

Rheology was performed to evaluate the yogurts' physical properties. A rotational rheometer (Bohlin Instruments, United Kingdom), coupled with a Peltier unit for temperature control, was used, and assays were conducted at 12 °C, in triplicate, using a cone-and-plate geometry probe ($\alpha = 4°$; $d = 40$ mm). Samples were gently stirred for homogenization and then transferred to the measurement plate. Two distinct oscillatory assays were performed, namely, amplitude and frequency sweeps, in which the elastic (storage) and viscous (loss) moduli and the complex viscosity were assessed. Amplitude sweep was conducted at a constant frequency of 1 Hz, and the strain varied from 0.001 to 0.1 Pa. Besides providing information regarding the different yogurt samples, this test allowed us to determine the linear viscoelastic region (LVER) of each sample type (LEY, NY, CY). The frequency was then varied (sweep) from 0.1 to 10 Hz, using a strain value that was required to be within the LVER of all the different yogurt types. Based on the results obtained in the amplitude sweeps, the strain value selected to be used in the frequency sweeps was 0.005.

2.2.3. Sensory analysis

The sensory analysis was performed in two phases. Firstly, a triangular test was performed by 14 trained panelists to identify adding lupin flour (4%) could produce perceptive sensory alterations in the yogurt. For the triangular test, the two samples (LEY and NY) were presented to the panelists in sets of three, in identical containers coded with 3-digit random numbers. The samples were randomized, so each panelist had an equal chance of receiving any of the serving orders. The samples were presented in the order selected for each panelist who will be required to evaluate them from left to right. The results were analyzed using a one-tailed binomial test for significance, as a sample is known to be different. The number of tasters correctly identifying the different samples is totaled, and the total is tested for significance using a reference table (Watts, 1989). After that, a quantitative descriptive sensory analysis was carried out by seven trained panelists. The panelists answered a specific questionnaire for set yogurt (CIDIL, 1995), adapted for the present study. The panel was instructed to score the intensity of attributes related to the samples' appearance, aroma, texture, and taste on a scale of 0–5, with 5 being the maximum score.

2.2.4. Statistical analysis

Statistical analyses were performed using the SPSS 17.0 software (SPSS, Chicago, IL, USA). The normality of the data was evaluated using Shapiro-Wilk's test. Data following normal distribution were analyzed using One-Way ANOVA coupled with Tukey's posthoc test when comparing the three samples (LEY, NY, and CY) or the t-student test when comparing two samples (LEY and CY). The data that did not comply with normality requirements were evaluated using the Kruskal-Wallis test associated with Dunn's posthoc test for three sample comparations or the Wilcoxon-Mann-Whitney test in the case of two samples. The differences between means were considered significant for p-values below 0.05.

2.3. Environmental impact assessment

2.3.1. Goal, scope, and boundary definition

An LCA screening was undertaken for the LEY, NY, and CY for benchmarking purposes. A cradle-to-gate scope was considered, representing the production and distribution of all ingredients for the respective yogurts (Table 2), according to the ILCD handbook recommendation (European Commission, 2010). The manufacturing process and end-of-life stages were assumed to be similar for all three products and were therefore excluded from the analysis. The open-source software OpenLCA v1.10.2 (GreenDelta, 2020) was used to calculate the environmental footprint of the three products, using product (ingredient) data from Agrifootprint 3.0 (Durlinger et al., 2017) and Ecoinvent 3.7.1 (Wernet et al., 2016) databases.

2.3.2. Functional units

Considering that nutritional delivery is a primordial function of food, and therefore it needs to be considered to correctly assess the environmental impact (Miller et al. 2021), two functional units (FU) were used: 100 g of yogurt, and the Nutrient Density Unit (NDU), calculated as the formula below, developed by Van Dooren (2016). NDU is a useful formula because it requires few nutritional analyses and correlates with more extensive nutritional indices (Saget et al., 2021).

$$NDU = \frac{\frac{EFA}{DV_{EFA}} + \frac{Protein}{DV_{Prot}} + \frac{Fibre}{DV_{fibre}}}{3\ x\ \frac{S_i}{2000\ kcal}}$$

where:

EFA is the amount of essential fatty acids in 100g of product, expressed in grams.

Protein is the amount of protein in 100g of product, expressed in grams.

Fiber is the amount of fiber in 100g of product, expressed in grams.

DV EFA is the recommended daily value intake of essential fatty acids, expressed in grams = 12,4g†

DV prot is the recommended daily value intake of protein, expressed in grams = 50g*

DV fiber is the recommended daily value intake of fiber, expressed in grams = 25g*

Si is the amount of kilocalories in 100g of product, expressed in kilocalories.

*Based on the US Food and Drug Administration's recommendations.

†Based on the Institute of Medicine's DRI of EFA.

2.3.3. Inventories

The main differences between the LEY, NY, and CY were milk quantity and the presence of starches (Table 2). Ingredients data for the CY were collected from the label, and quantities were estimated based on the nutritional composition shown. Global market product data were extracted from Ecoinvent v3.7.1, representing the average global market mix, therefore ensuring broad applicability. Some ingredients in Table 2 were not available in Ecoinvent v3.7.1, so proxies were used, notably: rice in place of rice semolina, chickpea in place of lupin flour, and potato starch in place of pectin.

2.3.4. Impact assessment

The environmental footprints of the three yogurts were assessed across the sixteen environmental impact categories recommended in the Product Environmental Footprint (PEF) Category Rules Guidance (European Commission, 2018). To assist in the interpretation of environmental burdens across several categories, results were normalized by global person equivalents with the PEF recommended factors to generate comparable normalized scores across impact categories (European Commission, 2018).

3. Results and discussion

3.1. Nutritional characterization

Table 3 shows the nutritional information and Nutri-Score of the three yogurts. Observing the general nutritional profile and the Nutri-Score, it is possible to notice that LEY presented advantages compared to the other two products. In the LEY, the addition of lupin flour enabled an increase in protein (40%), fiber (90%), and omega 3 (+353%) when compared to its natural counterpart (NY). According to European standards (European Union, 2006, 2010), it is permitted to claim that LEY is "high in protein" (at least 20% of energy value provided by protein), "source of fibers" (at least 3g/100g) and "source of omega 3" (at least 0, 3g of linolenic acid/100g). In fact, an increase in protein and dietary fiber is usually observed in food products enriched with pulses (Binou et al., 2020).

The high protein content (7g/100g) in the LEY yogurt allows offering the appropriate nutrient contribution for young children in smaller portions. Also, the fiber content can be advantageous since it can contribute to adequate fiber intake. Fiber is usually associated with children's health benefits, such as improving bowel function, preventing, and treating childhood obesity, maintaining normal blood glucose and blood pressure values, and reducing the risk of developing chronic diseases in the future (Korczak et al., 2017). The presence of alpha-linolenic acid, an omega-3 fatty acid, represents an additional gain. Several studies have linked the consumption of this essential fatty acid with brain development and positive effects on cognitive development, especially in the first years of life (Shahidi and Ambigaipalan, 2018).

Table 4 shows the mineral composition of the three yogurts. Fe was not detected in any of the three samples, and Mg was just detected in the LEY. Zn, Mn, and Cu presented higher levels in the LEY, although the differences were not statistically significant concerning NY. CY tended to show lower mineral levels compared with the other products, especially Zn, Mn, Ca, P, Na, and K ($p < 0,05$).

Although lupin is rich in minerals (Ruiz et al., 2019), the mineral variation in LEY was not significant compared with NY, probably because lupin addition was not enough to promote an increase in mineral content. On the other hand, LEY presented a better mineral profile compared with CY. When discussing improved food mineral profile by adding pulses, bioavailability is always a question to be considered. In the case of lupin, an experimental study with rats found high bioavailability of P, Ca, and Mg in diets composed of lupin (*Lupinus albus*) flours (Porres et al., 2006). Nevertheless, more bioavailability studies are necessary to make conclusions about the presented formulation.

Despite nutritional benefits, using pulses in food formulations can present some limitations that need to be circumvented. One of the considerable challenges is the presence of anti-nutritional factors (Bresciani and Marti, 2019). One of the main disadvantages of adding lupin to products would be alkaloids, the allergic potential of this food (Kouris-Blazos and Belski, 2016), and the presence of oligosaccharides that may cause flatulence such as α-galactosides (Martínez-Villaluenga et al., 2008). Regarding alkaloids, their presence represents a concern for safe consumption since their ingestion can cause intoxication. The domestication process selected low alkaloid varieties for animal and human consumption (Ruiz et al., 2019). In addition, strategies such as soaking, cooking or fermenting, and dilution by incorporating another food matrix reduce alkaloids to safe levels in the final product (Singh, 2017). Hence, the risks associated with these substances are reduced in LEY yogurt. Concerning the allergic potential, the consumption of LEY should not be recommended to those who are allergic to peanuts since they are more likely to develop a reaction to the lupin (Kouris-Blazos and Belski, 2016). In relation to the oligosaccharides, the fermentation process can sharply reduce their content in the yogurt (Binou et al., 2020; Martínez-Villaluenga et al., 2008), and the remnants compounds may be beneficial for the gut microbiota (Gullón et al., 2015).

3.2. Physical characterization

The storage modulus (G′), the loss modulus (G″), and the complex viscosity (η*) determined for all three yogurts (LEY, NY, and CY) are

Table 3
Nutritional information in 100g of lupin-enriched yogurt (LEY), natural yogurt (NY), and commercial yogurt (CY).

Energy/Nutrient	In 100 g of the product		
	LEY	NY	CY
Energy (kcal)	86	70	79
Total fat (g)	1.9	1.9	3.4
Saturated fat acids (g)	1.1	1.2	1.5
Unsaturated fat acids (g)	0.8	0.7	1.9
Omega 3 (mg)	53[a]	15	<10
Omega 6 (mg)	91	43	84.7
Carbohydrates (g)	9.3	7.7	8.9
Fiber (g)	1.9[b]	1	1
Protein (g)	7[c]	5[c]	3
Moisture (g)	78.3	83.2	83
Ash (g)	1.6	1.2	0.6
Nutri-Score	A (−3)	A (−3)	B (0)

[a] Source of omega 3 [Regulation (EC) N° 116/2010].
[b] Source of fibers [Regulation (EC) N° 1924/2006].
[c] High in protein (per 100 kcal) [Regulation (EC) N° 1924/2006].

Table 4
Mineral composition of lupin-enriched yogurt (LEY), natural yogurt (NY), and commercial yogurt (CY).

Mineral	mg/L		
	LEY	NY	CY
Fe	*nd*	*nd*	*nd*
Zn	0.18 ± 0.01[b]	0.16 ± 0.00[b]	0.09 ± 0.00[a]
Mg	5.03 ± 0.61[b]	4.76 ± 0.08	2.15 ± 0.33[c]
Mn	0.95 ± 0.11	*nd*	*nd*
Cu	0.01 ± 0.00	0.005 ± 0.00	0.007 ± 0.00
Ca	43.68 ± 4.16[b]	50.41 ± 1.25[b]	25.51 ± 0.86[a]
P	31.04 ± 4.66	36.86 ± 0.45[b]	20.66 ± 0.42[a]
Na	13.83 ± 1.67[b]	17.48 ± 0.54[b]	9.11 ± 0.36[a]
K	67.48 ± 7.75[b]	71.87 ± 2.52[b]	37.43 ± 1.36[a]

nd - not detected.
[a] significant difference ($p < 0,05$) according to Tukey's posthoc test.
[c] significant difference ($p < 0,05$) according to Dunn's posthoc test.

presented in Fig. 2 (a and b, respectively). Rheological properties of experimental and control yogurt samples revealed important physical differences with respect to total solids content and nature. As shown in Fig. 2a, the yogurt with skimmed milk powder (6%) and lupin flour (4%) added (LEY) showed the highest values of G' and G" compared with the other two control yogurts without lupin flour (NY, CY) and with a lower skimmed milk powder content (3%) (CY). Similar behavior was observed concerning η* (Fig. 2 b).

The elastic modulus (G′) is related to the stiffness of the network and translates the solid-like characteristics of the sample, while the viscous modulus (G″) is related to the viscous component of the yogurt and reflects liquid-like features (Steffe, 1996). The amplitude sweep allows the determination of the LVER, the region in which the viscoelastic properties are not dependent on the strain applied and, consequently, the elastic and viscous moduli are constant throughout. Results showed that the LVER was narrower in the yogurts with higher G′ and G″ since the point when those parameters began to decrease occurred at a lower strain than in the remaining yogurts. The largest LVER was reported for CY since the corresponding G′ began to decrease at a higher strain than the other yogurts (G″ remained constant throughout the entire amplitude sweep). Complex viscosity also varied similarly, with a decrease starting earlier in LEY, followed by NY, and finally CY, which was the last to begin to decrease. In order to perform frequency sweep tests, a strain value within the LVER must be selected and, as such, 0.005 was the strain chosen.

The dependence of G′ and G″ and η* on frequency is presented in Fig. 3a and b, respectively. When varying the frequency, for all three yogurts, both moduli increased with increasing frequency, and G′ was always higher than G'' (Fig. 3a), which reflects a solid-like behavior of the samples. As such, yogurts can be characterized as being viscoelastic solids. Such trend, regardless of lupin/skimmed milk supplementation, denotes a weak viscoelastic behavior characteristic of yogurt, in general. Furthermore, both G′ and G″ increased with increasing frequency. Results showed significant differences ($p < 0.05$) between the yogurts prepared with the distinct formulations. Regarding all parameters, significantly ($p < 0.05$) higher values were obtained for LEY samples than for NY and CY, which means that LEY presents/detains a more prominent solid-like behavior. Concerning NY and CY, only G″

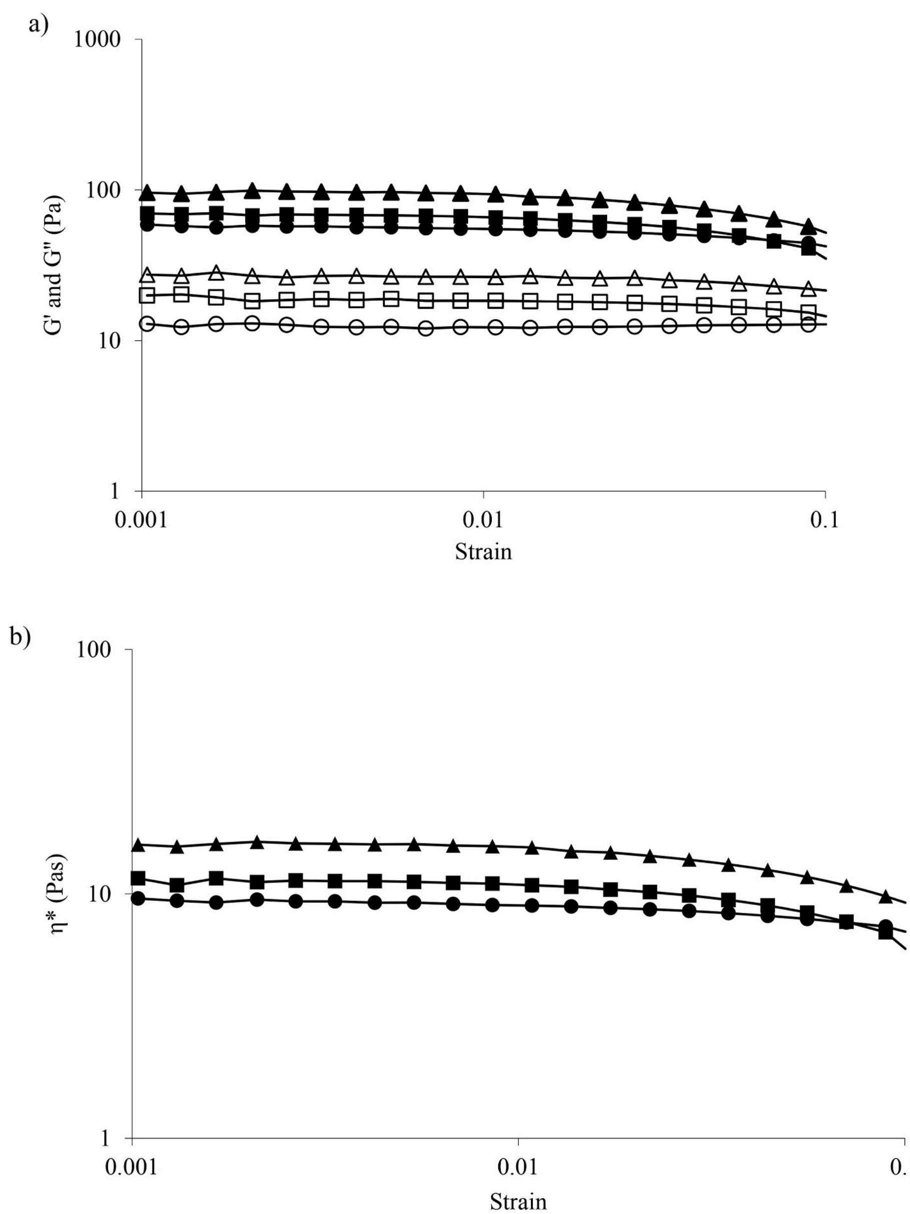

Fig. 2. (a) Elastic and viscous moduli (filled symbols - G'; open symbols - G″) and (b) complex viscosity (η*) of the lupin-enriched LEY (Δ), natural NY (□), and commercial CY (○) yogurts.

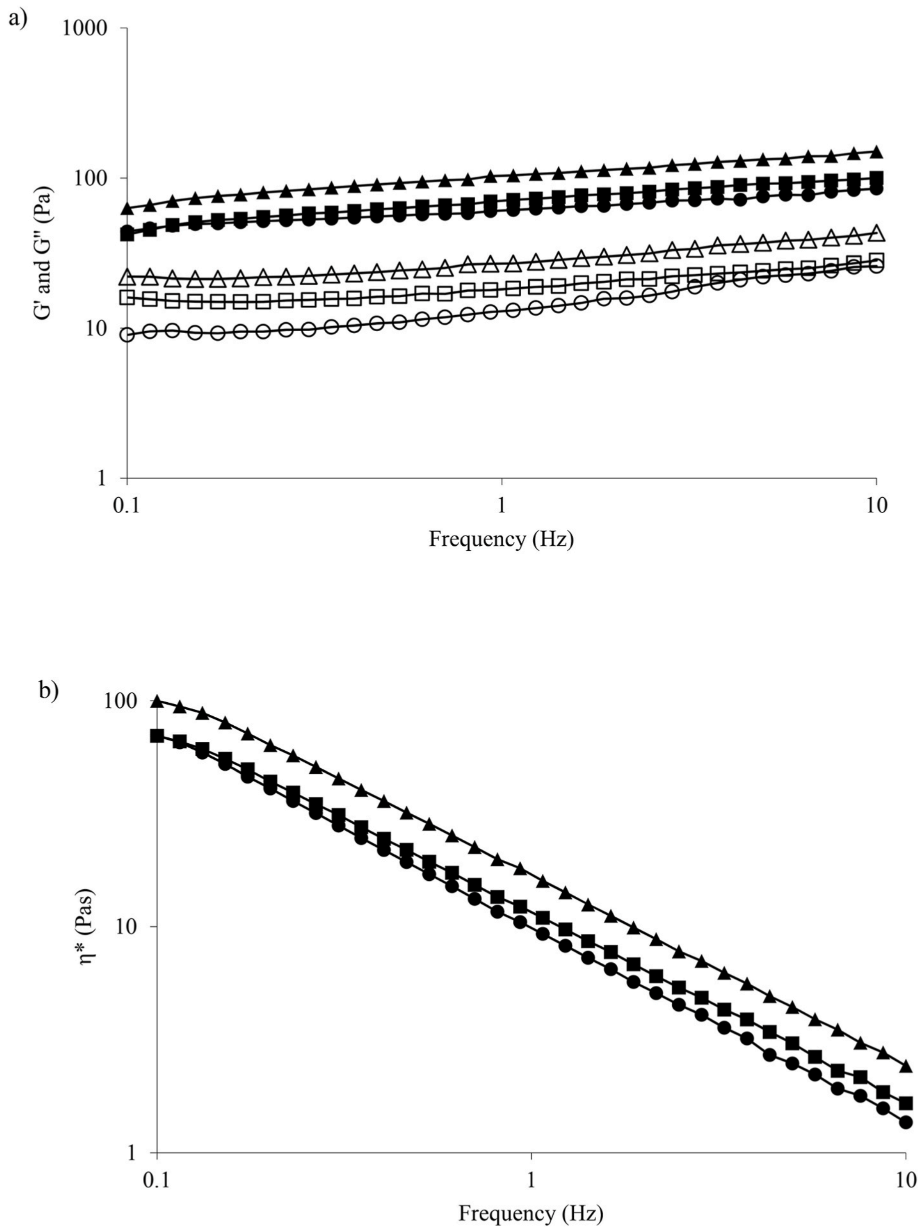

Fig. 3. (a) Elastic and viscous moduli (filled symbols - G'; open symbols - G″) and (b) complex viscosity as a function of frequency of the lupin-enriched LEY (Δ), natural NY (□), and commercial CY (○) yogurts.

presented significant differences ($p < 0.05$) between the two types of yogurts, while both G' and η* did not ($p > 0.05$). This indicates similarity between the yogurts in terms of physical properties.

Concerning complex viscosity (Fig. 3b), values decreased with increasing frequency, which was expected for such matrices, as at higher frequencies, the matrices become more fluid.

The results evidenced that LEY was the stiffest yogurt with the highest viscosity, whereas NY presented intermediary results, and CY presented the most increased fluidity and lowest viscosity. Yogurt structure is strongly influenced by the total solids content, especially in what concerns protein content. An increase in protein content results in linear increases in the elastic modulus and apparent viscosity (Divyang et al., 2016). The supplementation of yogurt with skimmed milk powder and with lupin flour led to a higher total solids content which increased the capacity to establish crosslinking bridges between milk casein micelles and other added proteins. In fact, some components present in lupin and other pulses, such as proteins with a more significant number of hydroxyl groups and fiber, have a higher capacity for water binding, which is related to viscosity (Bresciani and Marti, 2019; Villarino et al., 2016). These components also give greater stability to foods, improving product shelf-life (Foschia et al., 2017). In a recent study, Saleh et al. (2020) found that chickpea starch is a good stabilizer used in low-fat yogurts, maintaining the texture after 15 days of storage. Similarly, Raza et al. (2021) showed that the addition of 3–5% roasted chickpea flour to yogurt milk improved final product physicochemical, rheological, and sensory characteristics while providing essential nutrients of value for several target groups. In the case of the developed LEY yogurt, additional studies are required to evaluate formula stability during storage.

3.3. Sensory analysis

The triangular test revealed no significant sensory differences between the NY and LEY. Thus, the descriptive sensory test was performed with LEY and CY. Fig. 4 displays the intensity of sensory attributes in both yogurts. Regarding appearance, CY was brighter ($p < 0.05$) and had

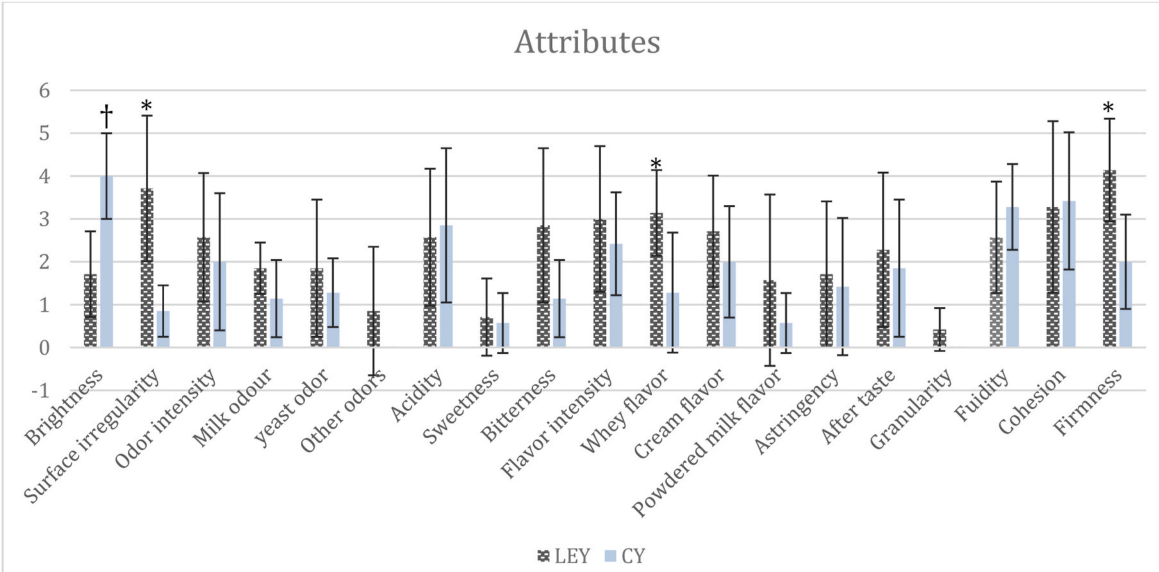

Fig. 4. Quantitative descriptive analysis of sensory attributes of the lupin-enriched (LEY) and commercial (CY) yogurts.
The values presented correspond to the average score of each characteristic.
*Significant difference ($p < 0.05$) according to Wilcoxon-Mann-Whitney test.
†Significant difference ($p < 0.05$) according to t-student test.

a more regular surface ($p < 0.05$) than LEY. Yogurts showed similar scores for most attributes in terms of smell and taste, except for whey flavor, which tended to be higher in LEY ($p < 0.05$). Although without statistical significance, LEY also presented more bitterness, granularity, and after-taste, which are unexpected attributes in the case of yogurts. Concerning texture parameters, LEY tended to be less fluid and firmer, showing a more significant difference in the latter attribute ($p < 0.05$). These results agree with the rheological parameters.

A significant limitation of adding lupin flour to food products is its sensory acceptability (Bresciani and Marti, 2019). Additionally, a persistent after-taste is a recurrent problem in products with lupin, which is the primary sensory obstacle to using it in different formulations (Villarino et al., 2016). The residual alkaloids and the formation of Maillard products during the heating of amino acids and sugars can be related to this finding. A detailed problem analysis, followed by adaptations in the processing, may outline sensory questions (Singh, 2017). The use of more refined ground flour, rigorous time and temperature control during processing, and a deep chemical evaluation to observe undesirable compounds in order to reduce or even remove them, are measures that can be adopted to minimize undesirable characteristics.

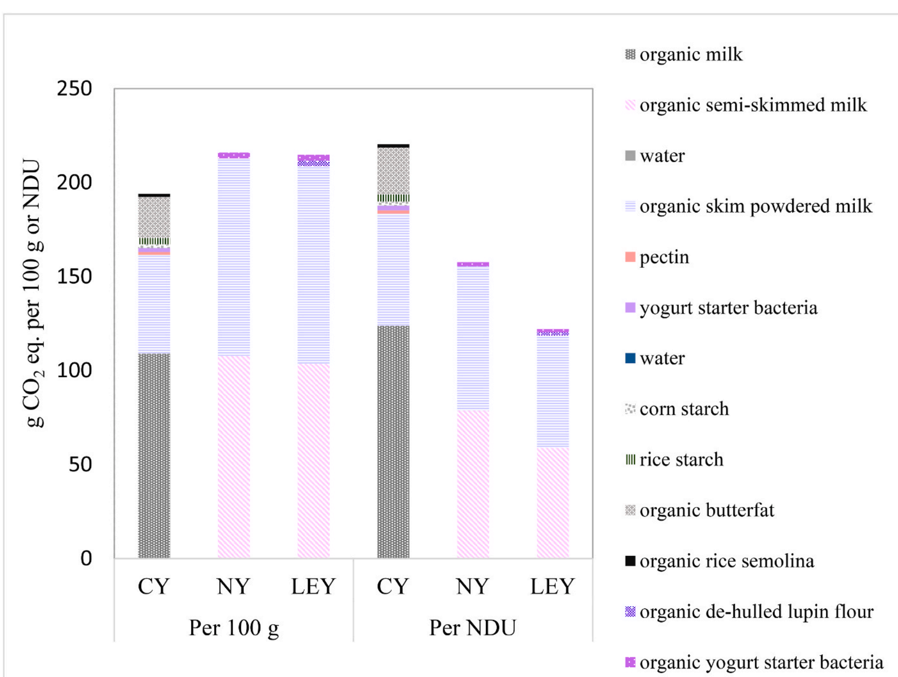

Fig. 5. Contribution of ingredients to global warming potential expressed as g CO_2 eq. per 100 g or per NDU for the commercial (CY), natural (NY), and lupin-enriched (LEY) yogurts.

Furthermore, some consumers are more likely to choose a product perceived as more healthy, even if it presents some sensory defect (Maruyama et al., 2021).

3.4. Environmental impact

The global warming potential (GWP), or "carbon footprint", of a serving (100g) of LEY is similar (1% smaller) than for the NY, but 11% larger than for the CY (Fig. 5), largely because of a greater input of powdered milk (5.4 vs. 2.7 g per 100 g). However, owing to higher nutrient density, the LEY carbon footprint is approximately half that of the CY per NDU, and 23% smaller than for the NY on an NDU basis (Fig. 5). Despite a wide range of ingredients, especially for the CY, footprints are dominated by milk-derived products: organic milk, organic semi-skimmed milk, skim milk powder, and organic butterfat.

The Environmental Footprint impact assessment methodology applied generates results across 16 impact categories. Fig. 6 shows the normalized scores (divided by per capita burdens) across all categories. Per 100 g serving, LEY and NY normalized scores are similar across almost all impact categories, whilst the CY has slightly lower normalized scores than the LEY for all impact categories except for dissipated water (DW), where rice starch and rice-derived semolina contribute towards 40% of the DW footprint for CY. Normalized scores for DW burdens are at least an order of magnitude higher than for other impacts, suggesting that the ingredients considered here make a large contribution to water consumption compared with other food and activities – via bovine

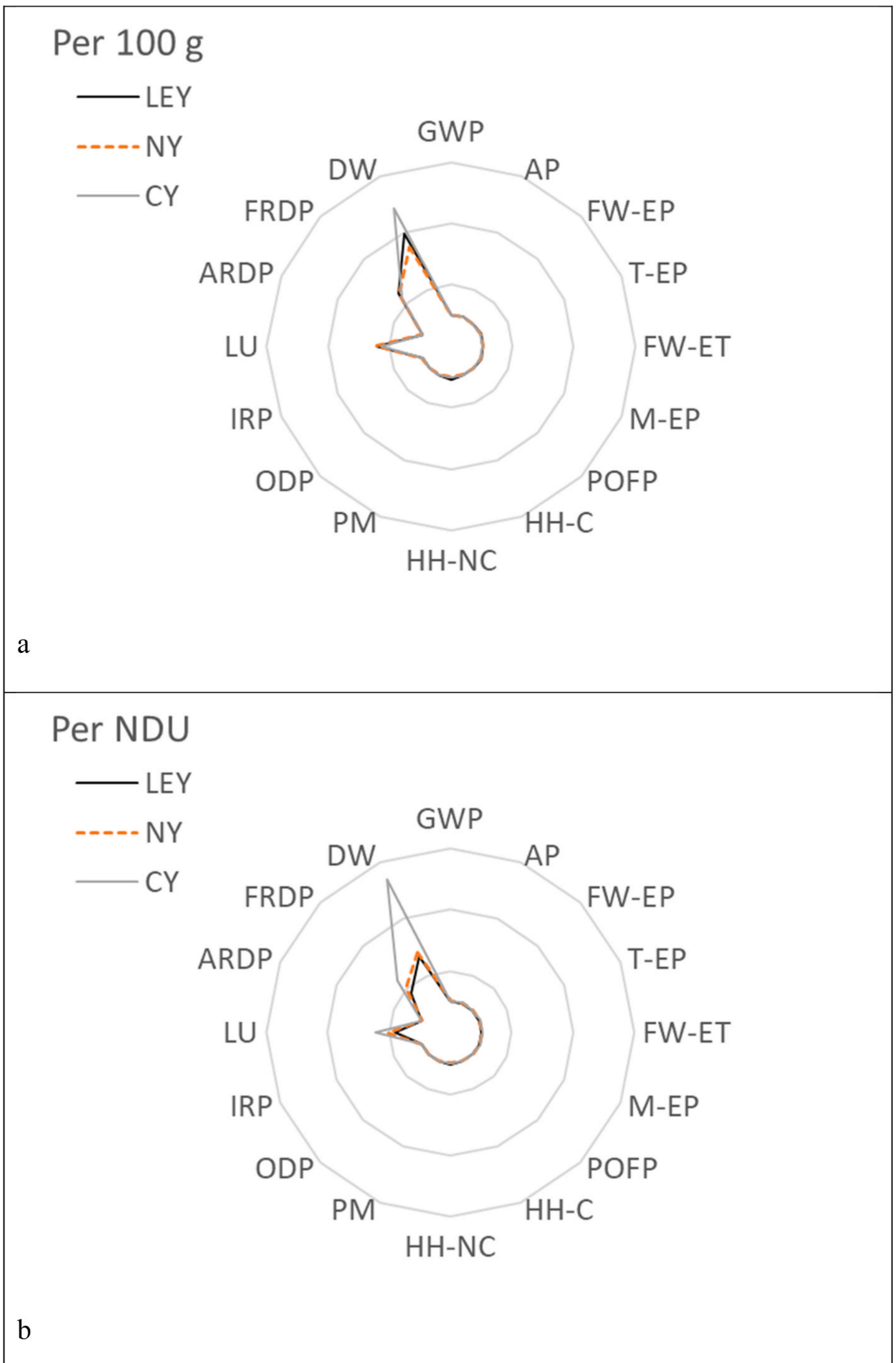

Fig. 6. Normalized environmental scores across 16 impact categories for the lupin-enriched (LEY), natural (NY), and commercial (CY) yogurts, expressed per 100 g of yogurt (a) and per NDU (b). Impacts are shown, clockwise from the top: global warming potential (GWP), acidification potential (AP), freshwater eutrophication potential (FW-EP), terrestrial eutrophication potential (T-EP), freshwater ecotoxicity (FW-ET), marine eutrophication potential (M-EP), photochemical ozone formation potential (POFP), human health cancer & non-cancer effects (HH–C & HH-NC), particular matter (PM), ozone depletion potential (ODP), ionizing radiation potential (IRP), land use (LU), abiotic resource depletion potential (ARDP), fossil resource depletion potential (FRDP), and dissipated water (DW).

production and rice cultivation. When expressed per NDU, the LEY has lower normalized scores than both the NY and the CY yogurts across all categories, apart from the human-health non-cancer category where NY has the lowest score (Fig. 6).

The LCA screening undertaken here indicates that LEY has a similar environmental footprint to NY but a slightly higher environmental footprint compared with CY, per 100 g serving, because of the higher skimmed milk powder content. Evaluating the environmental impact of yogurt production González-García et al. (2013) also found a remarkable contribution of milk powder in the main impact categories. On the other hand, the higher protein, fiber, and fatty acid contents of LEY result in a smaller environmental impact per unit of nutritional density compared with the other yogurts, especially compared with the CY – corroborating other recent assessments of legume-derived products (Saget et al., 2020, 2021). Proxy data were required for some ingredients, introducing some uncertainty. As an alternative, it could be possible to reduce to some extent the percentage of skimmed milk powder in LEY, reducing the environmental impact without significantly compromising nutritional, physicochemical, and sensory aspects. In any case, the greatest contribution to improving the understanding of the environmental sustainability of LEY would be to consider the crop rotation changes that could be associated with new large-scale demand for lupin driven by LEY commercialization. Past work has indicated that legume grains can play an important role in driving the overall environmental sustainability of entire crop rotations by, *inter alia*, delivering biologically fixed nitrogen to following crops and acting as a break crop (Costa et al., 2021). In further evaluation, a consequential LCA of commercial LEY deployment could consider which kinds of crop rotations would be modified by this increased demand for lupin, alongside the consequences of reduced demand for, *inter alia*, rice-derived products.

4. Conclusion

The addition of lupin flour to yogurt conferred nutritional advantages to the product. Also, lupin flour adds more rigidity and viscosity to the product. There were no significant sensory differences between LEY and NY, and most of the sensory attributes of LEY were similar to those of CY. However, undesirable sensory characteristics such as bitterness, granularity, and after-taste were observed. These may be overcome with processing adaptations such as using more refined ground flour and rigorous time and temperature control during processing. Further studies are required to evaluate mineral bioavailability, the presence of antinutritional factors, and formula stability during storage. Regarding environmental impact, LEY has similar normalized scores to NY and slightly worse normalized scores compared with CY for most impact categories per 100 g serving. However, environmental scores for LEY are better than for the other yogurts when expressed per unit of nutrition. Using lupin flour to enrich yogurts for children can be an alternative to producing more nutritious and functional products. Infant commercial formulations would benefit using lupin to replace some texture ingredients.

Implications for gastronomy

Lactic fermentation is a process described and documented throughout history. Yogurt is an ancient food traditionally consumed by different human populations. However, with the change from the artisanal way to a more industrial way of processing food, some aspects related to the quality and health benefits of this product were harmed. More and more consumers are concerned about issues related to the health, origin, and sustainability of products. Thus, food producers must adapt to new demands for more "natural" ingredients with less processing. For this reason, it is essential for those working in food science and gastronomy fields to research and develop ingredients e techniques aligning with health, nutrition, and sustainability trends. In this study, we used lupin, a healthy and sustainable pulse crop from the Mediterranean region, to enrich a yogurt nutritionally, possibly adding other functional properties. Lupin is a nutritious ingredient that may be used in gastronomy for various applications, from texture agents to bakery products, among others. This study can open pathways for several investigations in the gastronomy area.

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CRediT authorship contribution statement

Evla D.F. Vieira: Conceptualization, Methodology, Investigation, Formal analysis, writing. **David Styles:** Methodology, Investigation, Formal analysis, writing. **Sérgio Sousa:** Investigation, Formal analysis, writing. **Carla Santos:** Investigation, Resources. **Ana M. Gil:** Methodology, Supervision. **Ana M. Gomes:** Conceptualization, Methodology, Project administration. **Marta W. Vasconcelos:** Conceptualization, Methodology, Resources, Supervision, Project administration.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijgfs.2022.100617.

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