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Probiotic Greek yogurt: effect of the addition of prebiotic fat substitutes on the physicochemical characteristics, probiotic survival, and sensory acceptance

Research Article

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Abstract

In this research communication we evaluate the impact of the addition of prebiotic components (inulin, polydextrose, and modified starch, 40 g/l) as fat substitutes on the physicochemical characteristics, probiotic survival, and sensory acceptance of probiotic (*Lacticaseibacillus casei* 01, 10^8 CFU/ml) Greek yogurts during storage (7 °C, 28 d). All formulations had probiotic counts higher than 10^7 CFU/ml during storage and simulated gastrointestinal conditions (SGIC). The prebiotic components increased the probiotic survival to the enteric phase of the SGIC, with inulin producing the most pronounced effect. Inulin addition resulted in products with lower pH values and consistency and higher titratable acidity during storage, with negative impact on the sensory acceptance (flavor, texture, and overall impression) at the end of the storage period. Modified starch addition impacted negatively on the acceptance of the products (appearance, flavor, texture, and overall impression). Polydextrose addition resulted in products with lower consistency, but similar sensory acceptance to the full-fat yogurt. It can be concluded that it is possible to prepare potentially synbiotic Greek yogurts by desorption technique using *L. casei* as probiotic culture and inulin, polydextrose or modified starch as prebiotic components, with the utilization of polydextrose being advisable.

Greek yogurt is a dairy product of great acceptance and high commercial value, presenting higher consistency and creaminess than the traditional yogurt (Esmerino *et al.*, 2017). Different methods can be employed to obtain the desired texture, such as concentration after fermentation using membranes, addition of proteins, cream or stabilizers before fermentation or concentration of the product by desorption using cloth bags (Costa *et al.*, 2019*a*). The use of desorption technique allows for a reduction in the number of ingredients, does not require sophisticated equipment and meets consumer demand for products without a large number of ingredients and additives (Gyawali and Ibrahim, 2016). Other technological improvements have been proposed, such as the use of pectin and whey protein concentrate to reduce the production of unwanted acid whey (Uduwerella *et al.*, 2017; Gyawali and Ibrahim, 2018). However, few studies have considered the utilization of desorption technique in the preparation of Greek yogurts (Costa *et al.*, 2019*a*; Amaral *et al.*, 2020; Moineau-Jean *et al.*, 2020).

The consumption of fat has been suggested to be related to the etiology of cardiovascular diseases, which motivated the interest in low-fat or non-fat products (Ruiz-Núñez *et al.*, 2016). Prebiotics, such as inulin, polydextrose and some modified starches, are non-viable food components that confer potential health benefits on the host associated with the modulation of the microbiota (Gibson *et al.*, 2017). Inulin is commercially obtained from chicory roots (main source) and the long-chain type presents a degree of polymerization (DP) of 23. Polydextrose is a synthetic polymer prepared using sorbitol and glucose and presents a DP of 12 (Silva *et al.*, 2020). Cassava starch can be modified aiming at improving its technological properties and potentially prebiotic properties (Khaturia *et al.*, 2019).

The incorporation of prebiotic components into non-fat yogurts can improve the texture parameters, as these components are added to the product matrix, improving the interactions among different components (Costa *et al.*, 2019*a*). Furthermore, they can promote a sensation in the mouth similar to that of fat. This characteristic is the result of the ability to form microcrystals when mixed with milk, which are not perceived in the mouth, but interact to form a fine creamy texture (Pimentel *et al*., 2012).

Probiotics are living microorganisms that may have a beneficial effect to the individual, when administered in adequate amounts (Hill *et al*., 2014). In order to have a beneficial impact on health, probiotic cultures must be alive in the product for the entire shelf life and must retain some degree of viability in the gastrointestinal tract (>10^6 CFU/ml) (Costa *et al*., 2019*b*). The desorption process for preparing Greek yogurts can result in the decrease of the probiotic viability in the products, as the microorganism could be carried out with the serum. As far as the authors know, there are no studies with probiotic Greek yogurts prepared by desorption methodology and using prebiotic components as fat substitutes. Thus, the objective of this study was to evaluate the effect of the addition of prebiotic fat substitutes (inulin, polydextrose or modified starch) on the physicochemical characteristics, probiotic survival, and acceptance of probiotic Greek yogurts during storage.

Materials and methods

Five formulations of probiotic Greek yogurts were prepared: WHOLE (whole milk), SKIM (skimmed milk), INUL (skimmed milk + inulin), POLY (skimmed milk + polydextrose), and STAR (skimmed milk + modified starch), according to Costa *et al.* (2019*b*). Whole milk or skimmed milk (Líder®, Lobato, Brazil) was added with sucrose (120 g/l, União®, Sertãozinho, Brazil) and the prebiotic components (inulin [Orafti® HP, DP > 23, Mannheim, Germany], polydextrose [STA-III, Tate & Lyle®, DP = 9–10, London, United Kingdom], or modified cassava starch [Indemil®, Paranavaí, Brazil, 40 g/l). The mixture was pasteurized at 85 °C for 30 min in a water bath (Marconi®, Piracicaba, Brazil) and cooled to 42 °C. Then, 30 ml/l of the starter culture (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*, YF-L812, Christian Hansen®, Valinhos, Brazil) and 0.2 g/l of the probiotic culture (approximately 10^8 CFU/ml, *L. casei*-01, Christian Hansen®) were added, and the mixture was incubated at 42 °C for 8 h. The preparation of the starter culture is provided in the online Supplementary File. After fermentation, the curd was cooled to a temperature of 5 °C and transferred to previously sterilized cotton bags, drained for 2 h, packaged in polypropylene plastic packages with 80 mL capacity, and stored at 7 °C for 28 d. The concentrations of the starter culture and prebiotic components, fermentation time, and desorption time were determined in preliminary tests.

The chemical composition (moisture, protein, lipid, ash, and carbohydrates) was evaluated according to AOAC (2005). The pH of the products was determined using a pH meter (MS Tecnopon Instrumentation, mPA210, Piracicaba, Brazil). The titratable acidity (TA) was measured according to AOAC (2005). The total soluble solids (TSS) content was determined using a refractometer (Instruterm®, São Paulo, Brazil). A colorimeter (Minolta®, model CR400) was used for instrumental color evaluation (L^*, a^* and b^* parameters). The texture parameters (firmness, consistency, and cohesiveness) were determined on a TAXT Plus texturometer (Stable Microsystems®) according to Januário *et al.* (2018). The *L. casei* was enumerated according to Tharmaraj and Shah (2003) using Man Rogosa and Sharp agar supplemented with 2 mL/l of a 0.05% (w/v) vancomycin solution and incubation at 37 °C for 72 h. The survival of the probiotic culture to SGIC was carried out according to Minekus *et al.* (2014).

The acceptance test (appearance, aroma, flavor, texture and overall impression) was performed using a 9-point hedonic scale (1 = disliked very much, 9 = liked very much) and the purchase intention test was performed using a 5-point scale (1 = would certainly not buy, 5 = would certainly buy). Furthermore, for the formulations that the consumers disliked (scores <5), they were asked to provide the reason. The panel was composed of 100 consumers (53 women and 47 men), ranging in age from 15 to over 50 years, with majority (60 individuals) aged 15–25 years. The project was approved by the Ethics Committee involving human beings (CAAE: 54928016.4.0000.5688; opinion number: 1.616.735).

The physicochemical characteristics and probiotic survival in the product were evaluated on days 1, 7, 14, 21 and 28 of storage. The sensory acceptance and the probiotic survival to SGIC were evaluated on days 1 and 28 of storage. The chemical composition was evaluated on day 1 of storage. The analyses were performed in triplicates and the experiment was repeated twice. The experimental design was a split-plot, in which the main factor was the yogurt formulations and the second factor was the storage time. The results were submitted to Analysis of Variance (ANOVA) and Tukey test ($P = 0.05$) using the XLSTAT software (Adinsoft®, Paris, France).

Results and discussion

Greek yogurts presented chemical composition in the following range (g/100 g): moisture (72.98–79.55), protein (3.85–4.92), ash (0.75–0.79), lipid (0.91–5.44), and carbohydrates (14.90–20.44) (online Supplementary Table S1). The reduction of the fat content resulted in products with higher moisture content, with a consequent decrease in the protein, lipid, and carbohydrate contents ($P < 0.05$). The addition of the prebiotic components resulted in decrease in the moisture content, with a consequent increase in protein and carbohydrate contents ($P < 0.05$). The lowest moisture contents were observed for POLY and STAR formulations, suggesting that these formulations lost more serum during the desorption process. The presence of the polydextrose and modified starch in the matrix could have decreased the interactions between the milk proteins, resulting in a higher serum expulsion from the curd (Cruz *et al*., 2013). On the other hand, inulin presents hydroxyl groups that are more able to interact with water, increasing the water holding capacity, and resulting in a lower serum expulsion (Gyawali and Ibrahim, 2016).

Greek yogurts presented pH values of 4.14–4.34, TA of 1.00–1.29% lactic acid, and TSS values of 15.52–20.48°Brix (Table 1) during the storage time. The reduction of the fat content and the addition of the prebiotic components had no effect ($P > 0.05$) on the TSS values (day 1). Furthermore, there was no effect of the reduction in fat content and the addition of polydextrose on the pH and TA values ($P > 0.05$). The addition of inulin or modified starch resulted in products with a lower pH and higher TA in all storage days ($P \leq 0.05$). Inulin or modified starch probably promoted the growth of starter culture during the fermentation process, resulting in greater production of lactic acid. The greater acidity can protect the products from the development of spoilage microorganisms, increasing the shelf life. However, it can change the sensory characteristics and/or decrease the probiotic viability (Januário *et al*., 2018). Future studies should enumerate the starter cultures to prove the positive impact of inulin and modified starch on their viability.

Table 1. Physicochemical characteristics of the Greek probiotic yogurt formulations

Parameter	Storage time (days)	WHOLE	SKIM	INUL	POLY	STAR
pH	1	4.31^{aA} ± 0.09	4.35^{aA} ± 0.03	4.23^{bA} ± 0.06	4.30^{aA} ± 0.02	4.21^{bA} ± 0.03
	7	4.26^{aA} ± 0.06	4.26^{aA} ± 0.04	4.18^{bA} ± 0.10	4.23^{aA} ± 0.08	4.18^{bA} ± 0.05
	14	4.27^{aA} ± 0.11	4.28^{aA} ± 0.14	4.18^{bA} ± 0.13	4.22^{aA} ± 0.16	4.18^{bA} ± 0.06
	21	4.33^{aA} ± 0.17	4.34^{aA} ± 0.21	4.22^{bA} ± 0.20	4.27^{aA} ± 0.20	4.21^{bAA} ± 0.05
	28	4.32^{aA} ± 0.03	4.28^{aA} ± 0.06	4.19^{bA} ± 0.09	4.29^{aA} ± 0.05	4.14^{bA} ± 0.05
Titratable acidity (% lactic acid)	1	1.01^{bB} ± 0.01	1.02^{bC} ± 0.05	1.21^{aB} ± 0.02	1.00^{bB} ± 0.02	1.18^{aB} ± 0.02
	7	1.03^{B} ± 0.03	1.04^{C} ± 0.02	1.22^{AB} ± 0.04	1.05^{AB} ± 0.01	1.21^{AB} ± 0.04
	14	1.05^{B} ± 0.03	1.08^{B} ± 0.01	1.22^{AB} ± 0.02	1.05^{AB} ± 0.10	1.25^{A} ± 0.10
	21	1.09^{AB} ± 0.05	1.12^{B} ± 0.05	1.26^{A} ± 0.01	1.09^{A} ± 0.03	1.27^{A} ± 0.02
	28	1.11^{A} ± 0.03	1.15^{A} ± 0.02	1.28^{A} ± 0.01	1.12^{A} ± 0.02	1.29^{A} ± 0.02
TSS (°Brix)	1	17.32^{aBC} ± 0.85	17.90^{aBC} ± 0.73	16.72^{aB} ± 0.54	17.65^{aB} ± 0.79	16.63^{aAB} ± 1.33
	7	16.80^{aC} ± 0.86	16.93^{aC} ± 0.29	16.43^{aB} ± 0.88	16.77^{aB} ± 1.50	15.52^{aB} ± 0.44
	14	18.94^{aAB} ± 0.47	20.00^{aA} ± 0.93	20.10^{aA} ± 1.50	18.72^{aAB} ± 3.02	18.37^{aA} ± 0.98
	21	19.65^{abA} ± 1.04	19.58^{abAB} ± 1.01	17.63^{bB} ± 1.20	20.48^{aA} ± 1.54	18.20^{bA} ± 1.38
	28	16.75^{aC} ± 0.41	17.52^{aC} ± 0.83	16.38^{aB} ± 0.95	17.40^{aB} ± 2.57	15.98^{aB} ± 1.92
*L**	1	85.55^{aA} ± 0.35	85.47^{aA} ± 0.99	85.51^{aA} ± 0.91	84.91^{aA} ± 0.43	85.50^{aA} ± 3.78
	7	84.07^{aA} ± 0.28	84.28^{aA} ± 0.54	84.43^{aA} ± 0.91	83.39^{aA} ± 0.71	83.70^{aA} ± 5.16
	14	82.42^{aA} ± 0.63	83.54^{aA} ± 314.59	84.39^{aA} ± 0.13	82.90^{aA} ± 1.02	82.12^{aA} ± 5.32
	21	81.87^{aA} ± 1.33	82.40^{aA} ± 0.78	82.26^{aA} ± 0.92	81.67^{aA} ± 1.19	82.11^{aA} ± 5.42
	28	77.18^{aB} ± 0.40	76.17^{aB} ± 0.33	75.36^{aB} ± 3.38	75.70^{aB} ± 0.94	76.26^{aB} ± 5.31
*a**	1	−2.43^{aB} ± 0.37	−2.56^{aB} ± 0.27	−2.21^{aB} ± 0.41	−2.09^{aBC} ± 0.88	−2.30^{aB} ± 0.30
	7	−1.78^{aB} ± 0.35	−2.16^{aB} ± 0.51	−1.85^{aBC} ± 0.39	−2.00^{aBC} ± 0.78	−2.24^{aB} ± 0.39
	14	−2.67^{aB} ± 0.44	−2.31^{aB} ± 0.60	−2.31^{aB} ± 0.37	−2.31^{aB} ± 0.60	−2.31^{aB} ± 0.86
	21	−1.55^{aC} ± 0.41	−1.66^{aC} ± 0.39	−1.47^{aC} ± 0.50	−1.57^{aC} ± 0.57	−1.57^{aC} ± 0.56
	28	−3.83^{aA} ± 0.43	−3.93^{aA} ± 0.69	−3.72^{aA} ± 0.31	−3.53^{aA} ± 0.41	−3.27^{aA} ± 0.58
*b**	1	10.30^{aA} ± 0.47	10.21^{aA} ± 0.73	10.52^{aA} ± 0.39	10.17^{aA} ± 0.55	9.98^{aA} ± 1.56
	7	9.03^{aA} ± 0.38	9.19^{aA} ± 0.52	9.44^{aA} ± 0.51	8.81^{aA} ± 0.59	8.78^{aA} ± 1.76
	14	9.09^{aA} ± 0.59	9.16^{aA} ± 0.44	9.66^{aA} ± 0.51	9.27^{aA} ± 0.62	8.82^{aA} ± 2.15
	21	10.68^{aA} ± 0.32	10.78^{aA} ± 0.14	11.01^{aA} ± 0.85	10.27^{aA} ± 0.60	10.50^{aA} ± 26.32
	28	6.29^{aB} ± 0.41	6.14^{aB} ± 0.38	6.49^{aB} ± 0.85	6.96^{aB} ± 0.61	7.07^{aB} ± 1.37
Firmness (g)	1	218.6^{aAB} ± 48.2	194.7^{aA} ± 39.1	244.2^{aAB} ± 48.1	243.2^{aA} ± 62.9	203.2^{aA} ± 40.8
	7	259.7^{aA} ± 31.4	197.0^{abA} ± 39.8	152.1^{bB} ± 46.6	145.5^{bA} ± 36.4	140.5^{bA} ± 32.1
	14	119.5^{aB} ± 10.7	156.3^{aA} ± 41.5	127.4^{aA} ± 10.6	128.4^{aA} ± 19.1	150.7^{aA} ± 8.2
	21	130.5^{aB} ± 7.4	158.8^{aA} ± 6.3	189.3^{aAB} ± 11.4	128.6^{aA} ± 6.7	119.9^{aA} ± 9.7
	28	165.1^{aB} ± 10.8	113.3^{aA} ± 10.4	104.2^{aB} ± 20.9	116.1^{aA} ± 16.4	139.0^{aA} ± 18.1
Consistency (g)	1	1360.8^{aB} ± 53.7	1178.7^{aA} ± 12.81	1684.7^{aAB} ± 30.0	862.3^{bA} ± 35.7	1265.1^{aA} ± 73.8
	7	2382.1^{aA} ± 40.6	1344.0^{bA} ± 61.2	1115.4^{bBC} ± 37.8	677.9^{cA} ± 44.1	1053.2^{bcA} ± 48.4
	14	878.6^{bB} ± 44.1	1082.2^{bA} ± 45.2	2110.8^{aA} ± 70.2	986.1^{bA} ± 35.6	1239.2^{abA} ± 53.9
	21	955.9^{abB} ± 15.8	1128.2^{aA} ± 34.3	1385.1^{aABC} ± 59.6	735.4^{bA} ± 35.0	895.2^{bA} ± 63.7
	28	1112.8^{aB} ± 20.5	739.1^{bB} ± 32.7	706.4^{bC} ± 41.2	833.5^{bA} ± 25.0	914.5^{aA} ± 53.7
Cohesiveness	1	84.88^{aA} ± 7.32	72.74^{aAB} ± 5.71	78.23^{aA} ± 8.48	78.88^{aA} ± 10.68	79.14^{aA} ± 6.01
	7	87.18^{aA} ± 3.41	80.00^{aA} ± 8.31	82.84^{aA} ± 6.26	78.24^{aA} ± 13.28	73.90^{aA} ± 3.23
	14	81.66^{aA} ± 2.05	68.64^{bB} ± 6.11	71.98^{aA} ± 4.37	71.23^{aA} ± 11.75	58.95^{bB} ± 9.87
	21	83.63^{aA} ± 3.87	74.23^{aA} ± 9.76	75.52^{aA} ± 8.11	80.85^{aA} ± 3.59	74.89^{aA} ± 18.82
	28	84. 97^{aA} ± 5.08	48.16^{bC} ± 4.34	44.87^{bB} ± 5.39	79.62^{aA} ± 2.53	52.23^{bB} ± 17.19

Means ± standard deviation in the same column followed by different capital letters indicate statistically significant differences at $P \leq 0.05$ for each formulation affected by the storage time ($n = 6$). Means ± standard deviation on the same line followed by different lowercase letters indicate statistically significant differences at $P \leq 0.05$ between formulations ($n = 6$). L^* ranging from 0 (black) to 100 (white), a^* ranging from red ($+a^*$) to green ($-a^*$) and b^* ranging from yellow ($+b^*$) to blue ($-b^*$). TSS: Total Soluble Solids. Formulations: WHOLE (with whole milk), SKIM (with skimmed milk), INUL (with skimmed milk + inulin), POLY (with skimmed milk + polydextrose), and STAR (with skimmed milk + modified starch).

Table 2. Sensory acceptance of the probiotic Greek yogurts

Attribute	Storage time (days)	WHOLE	SKIM	INUL	POLY	STAR
Appearance	1	$7.18^{aA} \pm 1.81$	$7.02^{aA} \pm 1.75$	$6.89^{abA} \pm 1.74$	$7.22^{aA} \pm 1.73$	$6.18^{bA} \pm 2.25$
	28	$7.45^{aA} \pm 1.57$	$7.60^{aA} \pm 1.51$	$7.08^{abA} \pm 1.79$	$7.76^{aA} \pm 1.36$	$6.50^{bA} \pm 2.08$
Aroma	1	$7.08^{aA} \pm 1.68$	$6.86^{aA} \pm 1.63$	$6.77^{aA} \pm 1.57$	$7.25^{aA} \pm 1.40$	$6.49^{aA} \pm 1.79$
	28	$7.15^{aA} \pm 1.64$	$7.35^{aA} \pm 1.49$	$6.65^{aA} \pm 1.75$	$7.23^{aA} \pm 1.53$	$6.54^{aA} \pm 1.84$
Flavor	1	$7.37^{aA} \pm 1.71$	$7.14^{aA} \pm 1.76$	$6.72^{abA} \pm 1.70$	$7.66^{aA} \pm 1.82$	$6.26^{bA} \pm 1.95$
	28	$7.62^{aA} \pm 1.56$	$6.96^{abA} \pm 1.80$	$6.11^{bcA} \pm 2.02$	$7.16^{aA} \pm 1.72$	$5.78^{cA} \pm 2.29$
Texture	1	$7.16^{aA} \pm 1.88$	$6.87^{aA} \pm 1.81$	$6.52^{abA} \pm 1.85$	$7.21^{aA} \pm 1.69$	$5.78^{bA} \pm 2.31$
	28	$7.62^{aA} \pm 1.39$	$7.47^{abA} \pm 1.36$	$6.65^{bcA} \pm 1.89$	$7.63^{aA} \pm 1.39$	$6.16^{cA} \pm 2.08$
Overall impression	1	$7.29^{aA} \pm 1.65$	$7.04^{abA} \pm 1.55$	$6.77^{abA} \pm 1.63$	$7.49^{aA} \pm 1.27$	$6.29^{bA} \pm 2.03$
	28	$7.66^{aA} \pm 1.36$	$7.21^{abA} \pm 1.58$	$6.46^{bcA} \pm 1.86$	$7.33^{aA} \pm 1.50$	$5.98^{cA} \pm 2.11$
Purchase intention	1	$3.92^{aA} \pm 1.03$	$3.67^{abA} \pm 1.01$	$3.42^{abA} \pm 1.21$	$3.86^{aA} \pm 0.98$	$3.16^{bA} \pm 1.23$
	28	$4.17^{aA} \pm 0.98$	$3.80^{abA} \pm 1.27$	$3.41^{bcA} \pm 1.27$	$3.97^{aA} \pm 1.20$	$3.05^{cA} \pm 1.39$

Means ± standard deviation in the same column followed by different capital letters indicate statistically significant differences at $P \le 0.05$ for each formulation affected by the storage time ($n = 100$). Means ± standard deviation on the same line followed by different lowercase letters indicate statistically significant differences at $P \le 0.05$ between formulations ($n = 100$). Hedonic values (appearance, aroma, flavor and overall impression) are 1 = disliked very much; 9 = liked very much. Purchase intention values are 1 = certainly would not buy; 5 = certainly would buy. Formulations: WHOLE (with whole milk), SKIM (with skimmed milk), INUL (with skimmed milk + inulin), POLY (with skimmed milk + polydextrose), and STAR (with skimmed milk + modified starch).

During the storage period, all yogurts showed similar behavior, with an increase in TSS values in the intermediate periods and a subsequent decrease, an increase in TA values ($P \le 0.05$), and maintenance of pH values ($P > 0.05$). The starter and probiotic cultures remain metabolic active even at refrigerated storages, resulting in the hydrolysis of the lactose in their monosaccharides (galactose and glucose), fermentation of the sugars, and production of lactic acid (Pimentel *et al*., 2012; Januário *et al*., 2018). During the first 14 d of storage there was probably some lactose hydrolysis but no significant fermentation, resulting in increased TSS values and maintenance of TA values. From 14–28 d of storage, the microorganisms used the sugars and produced lactic acid, with a consequent decrease in the TSS values and increase in TA. The maintenance of the pH values may be associated to the buffering capacity of the yogurts (Pimentel *et al*., 2012).

Greek yogurts presented a light-yellow color ($L^* = 75.36–85.55$; $a^* = -1.47–3.93$; $b^* = 8.78–11.01$, Table 1). The reduction of the fat content and the addition of the prebiotic components had no effect ($P > 0.05$) on the color parameters of the products (day 1). The maintenance of the color is important, as a white or light-yellow color is expected by consumers for non-flavored yogurts (Costa *et al*., 2019*b*). During the storage period, all yogurts became darker and with a lower yellow color intensity, as increases in the a^* values and decreases in the L^* and b^* values ($P \le 0.05$) were observed. The alteration of the color could be related to proteolysis, as the white color of milk is related to the presence of casein, and proteolysis promotes breakdown of the casein (Costa *et al*., 2019*b*). The alterations were observed, mainly, on the 21st and 28th days of storage, which can be related to the highest increase in the TA of the products (Table 1). The lactic acid produced may have impacted on the proteins, facilitating their hydrolysis, and resulting in color alterations (Rezaei *et al*., 2019).

Greek yogurts presented firmness values of 104.2–259.75 g, consistency of 677.99–2382–1 g s, and cohesiveness of 44.87–87.18 during the storage time. The reduction of the fat content and the addition of the prebiotic components had no effect ($P > 0.05$) on the texture parameters of the products (day 1, except polydextrose for consistency). The results suggest that the yogurts presented similar texture characteristics even though they had different chemical composition (moisture, protein, and fat contents) (online Supplementary Table S1) and acidity (pH and TA) (Table 1). During the storage period, the firmness was similar in all formulations on comparing in between the products on their 1st and 28th days of storage ($P > 0.05$), and consistency was decreased only in the SKIM and INUL products ($P < 0.05$). For cohesiveness, the SKIM, INUL and STAR formulations had lower values than the WHOLE and POLY formulations on the 28th day of storage ($P < 0.05$). Inulin with high DP can disperse among the components of the food matrix, interfering in the interactions and resulting in products with lower consistency (Pimentel *et al*., 2012). Polydextrose can promote a greater number of intermolecular interactions between product components, providing greater cohesiveness (Silva *et al*., 2020). Therefore, the prebiotic components modified the texture characteristics of the yogurts during the storage period, which may impact on the sensory acceptance of the products.

Greek yogurts received scores between 5.78 and 7.76 on a 9-point scale, indicating that the consumers neither liked nor disliked some formulations and liked moderately other formulations (Table 2). The reduction of the fat content and the addition of polydextrose as a prebiotic component had no effect ($P > 0.05$) on the sensory acceptance of the products. Therefore, the full-fat, non-fat, and polydextrose-added products had similar acceptance on the evaluated attributes (appearance, aroma, flavor, texture, and overall impression). This result corroborates those of physicochemical characteristics, as the addition of polydextrose had no impact on the acidity and color of the products. Furthermore, it indicates that the lower consistency of POLY was not perceived negatively by consumers. The addition of inulin had no impact on the sensory acceptance on day 1; however, on day 28, the INUL product presented lower acceptance ($P < 0.05$) than the full-fat yogurt (flavor, texture, and overall impression). The results suggest that the higher acidity and lower consistency of the

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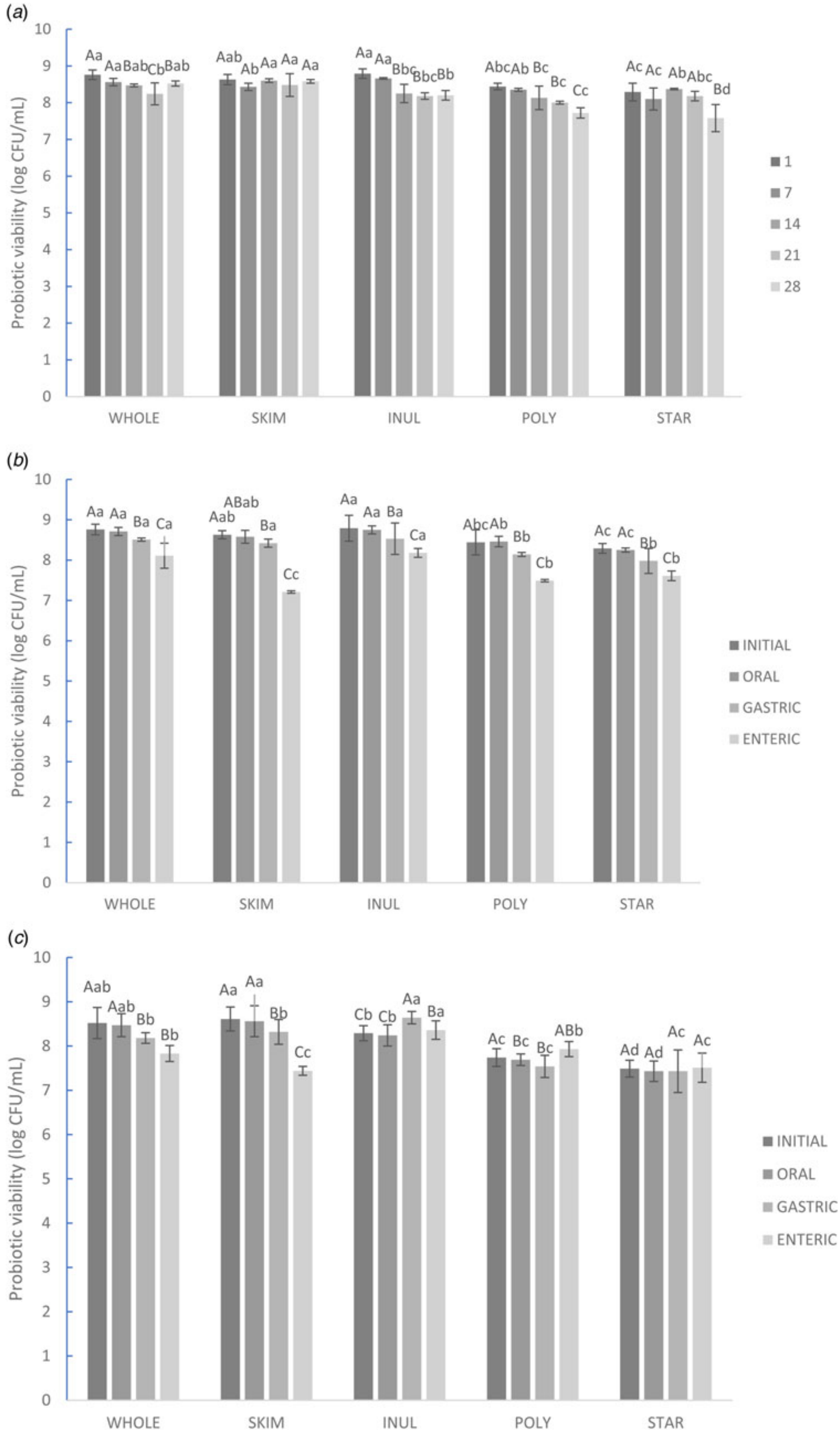

Fig. 1. Probiotic viability (log CFU/ml) in the product during storage (a) and in the simulated gastrointestinal conditions (oral, gastric and enteric steps) on days 1 (b) and 28 (c) of storage. The error bars represent the standard deviation ($n = 6$). Different capital letters indicate statistically significant differences at $P \leq 0.05$ for each formulation affected by the storage time ($n = 6$). Different lowercase letters indicate statistically significant differences at $P \leq 0.05$ between formulations for the same storage day ($n = 6$). Formulations: WHOLE (with whole milk), SKIM (with skimmed milk), INUL (with skimmed milk + inulin), POLY (with skimmed milk + polydextrose), and STAR (with skimmed milk + modified starch).

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inulin-added products were perceived as negative characteristics by consumers.

The addition of modified starch as prebiotic component decreased the acceptance of the products on appearance, flavor, texture, overall impression, and purchase intention in both evaluated storage time ($P < 0.05$). These results could be associated with the higher acidity and lower cohesiveness of this product. The consumers reported that the drivers of dislike for this yogurt were heterogeneity (appearance and texture), and bitter taste. Therefore, the effect of starch addition on the TA values and texture parameters impacted negatively on the acceptance of the products by consumers. The results indicate that consumers of Greek yogurt prefer products with low acidity and texture similar to the full-fat product.

All yogurt formulations had *L. casei* counts higher than 10^7 CFU/mL during storage (Fig. 1a) and SGIC (Fig. 1b, c), that is higher than the minimum count needed to consider a product as probiotic (10^6 CFU/ml, Costa *et al.* 2019*b*). Thus, regardless of the reduction of fat content or addition of prebiotic components, all formulated yogurts could be considered probiotic after 28 d of refrigerated storage (7 °C). Furthermore, in all formulated yogurts, probiotics could survive to the SGIC.

The addition of polydextrose and modified starch resulted in lower probiotic counts on the 1st day of storage of the products ($P < 0.05$, Fig. 1a). Probably, these formulations lost more probiotic microorganisms in the serum during the desorption process. This result is corroborated by the moisture content of the products (online Supplementary Table S1), as POLY and STAR formulations presented the lowest moisture contents. The addition of the prebiotic components resulted in an increase in the probiotic survival to enteric phase, as higher probiotic counts were observed for yogurts added with modified starch (only day 1), polydextrose (days 1 and 28), and inulin (days 1 and 28) compared to the skimmed yogurt ($P < 0.05$), indicating that these components acted as prebiotic components. Inulin had a better performance, providing the highest probiotic survival among all formulations, mainly on day 28 of storage ($P < 0.05$). Modified starch, polydextrose and inulin are substrates available for probiotic metabolism, being a carbon source for the maintenance of their cells. Furthermore, they provide a physical protection from damage caused by the environment and prevent injuries caused by acidity and bile salts (Costa *et al.*, 2019*b*).

It can be concluded that it is possible to prepare potentially synbiotic Greek yogurts by desorption technique using *L. casei* as probiotic culture and inulin, polydextrose or modified starch as prebiotic components, preferably with the utilization of polydextrose. Inulin and modified starch acted as prebiotic components, increasing the probiotic survival to the SGIC, however, they changed the acidity and texture parameters during storage of the products, resulting in decreased acceptance by consumers. Polydextrose acted as a prebiotic component by increasing the probiotic survival to the SGIC and did not impair the physicochemical and texture parameters of the products, resulting in similar acceptance to the full-fat product.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029921000121.

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