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Children's Preference Patterns and Opportunities for Sensory-Led Reformulation of Chocolate Chip Cookies

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ABSTRACT

In the context of the rising prevalence childhood obesity, this study investigated children's preferences for chocolate chip cookies, a high impact food category. The objective was to explore drivers of preferences and to identify potential pathways for reformulation. A home use test was conducted in four cities in France with 151 school-aged children on eight commercial chocolate chips cookies. An external preference mapping analysis was performed using descriptive analysis data from a trained sensory panel and analyses of cookies' composition and physicochemical properties. Texture emerged as a critical driver of preference, with a majority of children favoring softer textures. Preferences were not particularly driven by sweetness, challenging the assumption that children always prefer the sweetest products. Cluster analysis revealed distinct preference patterns that were linked to children's BMI and demographic factors. Notably, children with higher BMIs showed preferences for sweeter cookies and higher sugar content.

1 | Introduction

Despite the current childhood obesity pandemic (NCD Risk Factor Collaboration (NCD-RisC) 2017) packaged foods still have excessive high levels of sugar, fat, and salt (Bonsmann et al. 2019). Food products targeting children tend to have particularly high sugar content (Moore, Sutton, and Hancock 2020; Rito et al. 2019). This is of major concern for school-aged children. Unfortunately, the food industry has made little progress so far. For example, between 2015 and 2018, most of the food companies in the UK couldn't reach the target sugar reduction set at −5% for the product categories that contribute the most to the high sugar intake (Bandy et al. 2021). Although food reformulation is seen as a possible leverage to improve food nutritional quality and consumers' diet, it has met little success over recent decades (Gressier et al. 2021; Nijman et al. 2007; Spiteri and Soler 2018). This could be explained by technological and sensory barriers to reformulation. For example, the reformulation of high sugar and high fat foods—such as cookies—is a real challenge. In addition to being strong direct drivers of children's preferences (Cooper 2017; Marty et al. 2018; Nguyen, Girgis, and Robinson 2015), sugars and fat have multiple functional properties in the food matrix (Ghotra, Dyal, and Narine 2002; Miller et al. 2017; Pareyt et al. 2009). Consequently, any decrease of sugar or fat content may change many of the cookie sensory properties and result in lower liking.

Given the complex role played by each ingredient and their impact on sensory attributes and preferences, it seems necessary to adopt sensory-led reformulation strategies. For example, instead

Practical Applications

This research provides a better understanding of children's sensory determinants of preferences for commercial chocolate chip cookies. It paves the way for cookie reformulation in the view of improving their nutritional profile and texture while maintaining high levels of liking. More generally, this study presents an approach that can help to fill the gap and limit barriers to reformulation of other foods. Application of external preference mapping modeling against combined sensory, physicochemical, and composition variables provides valuable insights for the development of healthier options for children, crucial in addressing the global challenge of childhood obesity. Moreover, considering children's interindividual preferences allows to adapt reformulation strategies more precisely to target consumers. This may lead to more successful reformulation in future.

of solely focusing on one recipe to reformulate, analyzing existing products available on the market could prove very useful to developers. Traditional sensory methods, such as external preference mapping (Schlich and McEwan 1992), associated with a systematic analysis of food properties and composition can provide a valuable understanding of the drivers or preferences and key directions for reformulation.

Studies conducted on various food categories found that children's liking patterns may depend on their individual characteristics such as weight status, gender, and age (Cox, Hendrie, and Carty 2016; Kubberød et al. 2002; Rose et al. 2004a, 2004b; Torri et al. 2021). To ensure successful reformulation, it is thus crucial to understand children's sensory drivers of preferences for considered product category and to be able to relate them to children's demographics.

The present study focuses on chocolate chip cookies. This product category has a high impact on children's diet because of its high consumption frequency and poor nutritional properties (Alessandrini et al. 2019; European Food Safety Authority 2011). In this context, the aim of this study was to gain knowledge about children's preferences for chocolate chip cookies and to derive possible pathways for future reformulation.

Eight commercial chocolate-chip cookies were selected from a representative subset of the market (18 cookies) and were evaluated for liking by a total of 151 school aged children (7–12 years old) from four different cities in France (Paris, Nantes, Toulouse, Aix-en-Provence). The hedonic test was conducted in 2020 at children's home to best account for their after-school natural snacking behavior. Home Use Tests also provide a friendly and safe environment deemed appropriate for self-administered hedonic evaluation with children aged 7–12 years (Popper and Kroll 2007).

We explored preference patterns and their potential link to children sociodemographic variables and BMI using cluster analysis. External preference mapping was used to identifying sensory drivers of liking (or dislike) (Danzart, Sieffermann, and Delarue 2004; Schlich and McEwan 1992). To provide complete and useful information for reformulation, product sensory properties—obtained by the means of a quantitative descriptive analysis—were used as explanatory variables for quadratic models, together with composition and physicochemical variables. For instrumental measurement, focus was placed on texture, which is known to be an important determinant of cookie preference (e.g., for cookies typically the degree of crispness or softness) (Chow et al. 2022; Szczesniak 2002). We therefore measured fracture and structure properties (stress and strain at rupture), as well as cookie water content, density and spread (product size and proportions).

2 | Materials and Methods

2.1 | Products

2.1.1 | Product Selection

In total, eight commercial chocolate-chip cookies were evaluated in this study (Figure 1). The products were from a larger set of cookies identified to be representative of the French market (Liechti et al. 2022). They were selected for their varied composition, sensory and physicochemical characteristics so that they would represent that initial set considering availability on the market at the time of the study. Care was taken to procure samples with similar shelf-life.

2.1.2 | Composition

Composition was estimated directly from the ingredient list on packaging. Rayner's nutrition scores (Rayner 2017) and process scores (Drewnowski 1997) were calculated from composition and recipe information (Table 1). However, the process score of products P-d and P-e could not be calculated because chocolate chips composition was missing from the ingredient list on the packaging. Besides, we conducted sensory and physicochemical analyses of these cookies as described below.

2.1.3 | Sensory Evaluation

Quantitative descriptive analysis (QDA) was used as a proxy to children perception of the products (Stone, Bleibaum, and Thomas 2020). Sensory evaluation was conducted with 12 trained panelists (seven women, five men; aged 22–32 years old), recruited at AgroParisTech in Grignon (France). In total, 20 attributes were generated and selected by the panel. The attribute intensities were measured using an unstructured scale (0 = low intensity, 10 = high intensity) with the FIZZ Acquisition 2.51 (Biosystems, France) software for sensory data acquisition. All evaluations were duplicated. The samples were coded with a random three-digit number. They were presented in a monadic way in a balanced order, following a Williams Latin Square design. Water (Evian, France) was served for palate cleansing between samples. Attribute definitions are detailed in Table S1.

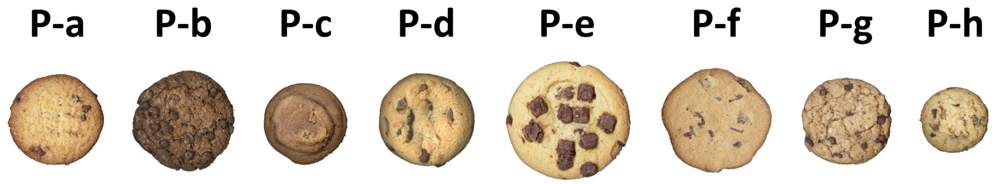

FIGURE 1 | Eight commercial chocolate-chip cookies (P-a—P-h), selected from a representative subset of the French market based on sensory, composition and physicochemical information.

TABLE 1 | Composition and scores of the eight commercial chocolate-chip cookies, with kilocalories per 100 g and fat, saturated fat, carbohydrates, sugar, fiber, protein, and salt in grams per 100 g.

	P-a	P-b	P-c	P-d	P-e	P-f	P-g	P-h
Kcal	503	504	479	485	485	511	489	514
Fat	25	23	23	24	25	25.1	24	28
Saturated fat	12	6.6	14	12	14	16.1	5.9	13
Carbohydrates	62	66	61	61	60	62.2	59	57
Sugar	27	37	35	36	33	36.9	30	34
Fiber	2.4	4.4	3.7	1.8	2.4	3.9	3.5	3.6
Protein	6.5	6.1	5.6	5.2	4.7	7	7.6	7
Salt	1.5	1.3	0.2	0.8	0.8	0.6	0.4	0.4
% Chocolate chips	5.5	30	21	31	19	28	21	33
% Cacao and Chocolate powder	0	6.6	2.6	0	0	0	0	0
Number ingredients	9	11	10	13	17	8	12	11
Number additives	3	5	4	4	7	1	2	3
Rayner score	27	20	17	24	23	26	14	24
Process score	48.4	52.1	44.5	N/A	N/A	45.5	47.3	43.5

Note: Process scores of cookies P-d and P-e were not calculated because of missing information about chocolate chips ingredients.

2.1.4 | Physicochemical Characterization

In order to estimate cookies' structure and fracture properties, we measured strain and stress at rupture using a three-point bending test carried out with a TA.HDplusC Texture Analyzer (StableMicrosystems, Surrey, UK) (Baltsavias, Jurgens, and Vliet 1997).

Water content was measured as described in Liechti et al. (2022). Cookies with a higher water content tend to be softer than cookies with lower water content (Baltsavias, Jurgens, and van Vliet 1999; Baltsavias, Jurgens, and Vliet 1997). Water content may thus indirectly drive cookie preferences (Hough et al. 2001).

Density was measured using a VolScan Profiler (Stable Micro Systems, Surrey, UK) (Mäkinen, Zannini, and Arendt 2013). Density gives an indication of cookies' volume and air fraction, which affect structure and fracture properties (Baltsavias, Jurgens, and Vliet 1997; Pareyt et al. 2009). All measures were done in triplicate.

Eventually, we determined cookies' spread ratio (final product size and proportions) by dividing cookie's diameter by cookie's height.

2.2 | Participants

All participants (or their parents in case of children) provided written informed consent and the study was approved by the University Paris-Saclay ethics committee (CER-Paris-Saclay-2020-025).

The liking study was conducted with 151 school-age children. They were recruited in four different locations in France (Paris, Aix-en-Provence, Nantes, Toulouse) by a subcontracted vendor. Their parents were contacted 2 weeks prior to the experiment using online and phone screener for their sociodemographic characteristics and consumption habits. Children included in this study had no ongoing adverse condition affecting vision, smell, and taste, no medical treatment that may influence taste and smell perception, no food allergies/intolerance for gluten, soy, lactose, legumes, nuts, seeds, nor any specific diet, and no dietary restriction.

Participants were selected using quotas for their gender, age group, household income and city (Table 2). Two subgroups of 7–9 and 10–12 years old, respectively, were selected in anticipation of differing liking patterns between younger and older children (Rose et al. 2004a, 2004b). Childrens' BMI was calculated based on their weight and height reported by their parents.

TABLE 2 | Sociodemographic and BMI data for the151 children.

Information	Groups	Counts	%
Gender	Girls	75	49.7
	Boys	76	50.3
Age groups	7–9 years	71	47
	10–12 years	80	53
Age in years	7	15	9.9
	8	27	17.9
	9	26	17.2
	10	30	19.9
	11	25	16.6
	12	28	18.5
Household income in €	0–1239 (very low)	27	17.9
	1240–1911 (low)	29	19.2
	1912–2530 (middle)	34	22.5
	2531–3778 (high)	34	22.5
	More than 3779 (very high)	27	17.9
City	Paris	52	34.4
	Nantes	32	21.2
	Toulouse	20	13.2
	Aix-en-provence	47	31.1
BMI for gender and age	Thinness/severe thinness	7	4.6
	Normal	111	73.5
	Overweight/obesity	33	21.9

Using BMI z-scores from the WHO tables "BMI for-age-boys" and "BMI for-age-girls" 5–19 years old (WHO 2007), we defined three different weight status groups: "thinness/severe thinness", "normal", and "overweight/obesity."

2.3 | Home Use Test Design and Sample Preparation

Children evaluated the cookies at home. They were asked to eat and to evaluate a different cookie variety each day following a balanced order defined with a Williams' Latin square design. The test took place over eight school days, as part of the French traditional afternoon snack ("le goûter") when coming back from school. At each consumption episode, children's responses were collected online with the sensory software RedJade.

All cookies were re-packaged in easy-to-open airtight mylar bags and were distributed to the parents in blind conditions (coded with three-digit codes). One bag containing two cookies was provided for each product. Parents were asked not to open the bags until they gave the product to their child in order to minimize the impact of air humidity on the cookies texture and flavor.

2.4 | Questionnaire

On each testing day, children were asked about their level of hunger and their willingness to eat a cookie. After having eaten one cookie, children were asked to indicate their level of liking on a 5-point facial scale. Then, after consumption, they were asked again about their level of hunger and their desire to have another cookie. The questionnaire was pre-tested with other children to ensure that questions and tasks were understandable and adapted to their age-range.

Questions were chosen in regard to literature and recommendation for children for the age 7–12 years old (Popper and Kroll 2007). We used a colored 5-point facial scale with verbal labels, ranging "1 = I don't like it at all" on the left-hand side to "5 = I like it very much" on the right-hand side, as recommended for hedonic testing with children whose reading abilities may vary even within a same age group (ASTM E2299-13 (2021); Laureati et al. 2015; Marty et al. 2018; Rannou et al. 2018). Hunger before and after the snack was evaluated using the graphic scale described by Lange et al. (2019).

Upon first connection and prior to the first session, children and their parents were asked to discuss and read the tasting instructions carefully. Few questions were asked to ensure that scales were correctly understood by the children. Children were then asked to record their own responses online but could ask their parents or guardians for help if needed. Eventually, they were asked to indicate if they ate one or both cookies.

2.5 | Data Analysis

2.5.1 | Sensory Profile

Quantitative descriptive analysis data were analyzed using a multi-way ANOVA on each attribute, with product, replicate, and panelist as the main effects and all their first-order interactions. When significant differences between products were revealed ($p < 0.05$), mean intensities were compared using Tukey HSD post hoc test. Panelists' performance was assessed based on their repeatability and ability to differentiate cookies.

To visualize and interpret the relationships between cookies sensory, composition, and physicochemical properties, we performed a Multiple factor analysis (MFA) of the three corresponding data tables (Pages 2004). Nutrition score, process score and the total number of additives and ingredients were plotted as supplementary variables. MFA's underlying principal component analyses were based on Pearson correlation coefficients. Sensory data were averaged across replicates and panelists.

2.5.2 | Hedonic Scores

Liking data were first analyzed using a mixed-model ANOVA with consumers as a random effect, product and order as fixed effects, together with the product × order interaction. A second ANOVA was then performed to test for the effect of weight status and sociodemographic variables (gender, age group, and household income). All testable first order interactions were first included in the model, but only significant interactions were eventually kept after backward elimination.

The diversity of preference patterns was explored using hierarchical cluster analysis (HCA) (Euclidean distance, Ward's criteria) on centered liking scores. Differences between clusters for weight status and sociodemographic categories were analyzed using a Fisher's exact Test.

2.5.3 | Drivers of Preferences

To relate children's preferences to the sensory properties of the cookies, we performed an external preference mapping (with quadratic model) (Danzart, Sieffermann, and Delarue 2004) using the MFA described above as basis. Each consumer's liking scores were normalized and regressed on the first two dimensions of the compromise MFA map. For comparison purposes and to gain a better understanding of preference patterns, the same procedure was also applied separately to each consumer cluster obtained from the HCA.

All univariate analyses and HCA were conducted with XLSTAT version 2018.1.1 (Addinsoft, New York, USA). All other analyses were conducted with R (version 4.3.0; R Core Team 2023), using FactoMineR for the MFA and SensoMineR for the external preference mapping.

3 | Results

3.1 | Sensory and Physicochemical Data

Sensory evaluation results show that the eight cookies differed significantly on all 20 sensory attributes ($p<0.05$; Table 3). Overall, panelists scored the attributes in a consistent and repeatable way. Repetition effects, Juge × Product, Judge × Rep, and Product × Rep interactions were not significant. Attribute-wise ANOVAs and corresponding product effects (F-ratios) indicate larger differences for aspect and texture (especially, hardness, both in-hand and in-mouth). These results are consistent with the large differences between cookies for the physical measurements (Table 3). The cookies could primarily be differentiated based on spread ratio, water content, and stress at rupture. Most of the cookies tended to have high stress at rupture, lower water content, and low density; only two cookies (P-c and P-e) had a higher water content (>6%), with P-c having higher density ($\rho=0.97$). Differences were smaller, although significant, for sweetness, butter aroma, salty aftertaste, and time in mouth.

The MFA of combined sensory, physicochemical, and composition data (Figure 5) highlights two dimensions that are highly positively correlated to texture (hardness and crispness), and negatively correlated to density and water content on the first axis. Sweet taste and chocolatey aroma are positively correlated to the second axis, together with sugar content, cacao, and chocolate chips. Overall, the score plot shows that products are well-spread over the first two dimensions, with P-c separated on the first dimension as a result of its high density and water content, and respectively, lower hardness and crispness.

3.2 | Children's Responses

A large majority of children (80%) ate both cookies in each serving, against 20% who ate only one cookie. Although the eating behavior slightly fluctuated for some children, these percentages overall did not vary significantly across products, nor across age, sex, or weight status categories. Mean liking scores ranged between 3.85 and 4.35 (on a scale from 1 = "I don't like it at all" to 5 = "I like it very much"), indicating that, overall, children liked the eight chocolate-chip cookies well. This said, significant differences among the products most were observed ($F_{(7,1043)}=6.11$; $p<0.0001$) (Figure 2). The cookie P-e was the best liked on average, whereas cookies P-g and P-c were less liked. The judge effect was significant ($F_{(150,1043)}=2.84$; $p<0.0001$) revealing differences between children in their average liking scores which are further analyzed in the light of BMI and sociodemographic data. On average, boys gave higher scores (4.23 ± 1.02) than girls (3.96 ± 1.15) ($F_{(1,1184)}=19.39$; $p<0.0001$) and younger children (7–9 years) tended to give higher scores (4.17 ± 1.10) than children in the 10–12 year old group (4.04 ± 1.09) ($F_{(1,1184)}=5.11$; $p=0.024$). Household income alone did not have any significant effect on liking scores. However, there was a significant interaction between household income and gender ($F_{(4,1184)}=3.10$; $p=0.015$) and age group ($F_{(4,1184)}=3.88$; $p=0.004$), showing notably that girls and older children (10–12 years) from highest income households tended to give lower liking scores. This might mark a social differentiation for tween girls, although the nature of that effect on liking scores is unclear.

3.3 | Children's Preference Patterns, Sociodemographic Background, and Weight Status

Regardless of the differences in average liking scores, we explored children's preference patterns using cluster analysis on centered data. Eight children gave the same score to all cookies (either all four or all five). Since they displayed no preference, they were excluded from further analyses. As a result of the HCA, we identified three groups of children (Figure 3A) with Cluster 1 accounting for nearly two thirds of the respondents ($n=95$, 66%). Children in this cluster liked the cookies differently ($F_{(7,658)}=4.11$; $p<0.001$; $\eta^2=0.03$), but they expressed much less preferences than children in Cluster 2 ($F_{(7,196)}=26.35$; $p<0.0001$; $\eta^2=0.37$) and Cluster 3 ($F_{(7,126)}=28.98$; $p<0.0001$; $\eta^2=0.53$). The three clusters essentially differ on their appreciation of products P-g (disliked by children in Cluster 2 (2.28 ± 1.00) and highly liked by children in Cluster 3 (4.79 ± 0.42)) and P-c that was strongly disliked by children in Cluster 3 (1.79 ± 0.63) (Figure 3B). Notably, cookie P-e has the best score overall (4.34 ± 0.96). It is among the best

TABLE 3 | Mean sensory and instrumental measurements for the eight chocolate chip cookies.

Measured variable	$F_{product}$	p	Eight commercial chocolate chip cookies							
			P-a	P-b	P-c	P-d	P-e	P-f	P-g	P-h
Chocolate O	28.5	**< 0.001**	1.33 c	7.60 a	8.53 a	2.10 bc	2.89 bc	3.71 b	4.13 b	2.91 bc
Hardness H	88.8	**< 0.001**	8.72 a	8.54 a	2.21 b	8.48 a	1.47 a	8.83 b	7.38 a	8.77 a
Brittleness H	22.0	**< 0.001**	2.94 bc	3.69 b	1.17 c	6.54 a	1.52 c	3.05 bc	3.84 b	6.85 a
Sweet taste T	6.5	**< 0.001**	3.75 c	7.07 a	6.80 ab	6.32 bc	4.87 abc	5.47 ab	5.53 abc	6.50 ab
Chocolate A	33.1	**< 0.001**	0.62 e	7.29 ab	8.10 a	3.27 d	3.24 d	5.57 bc	3.94 cd	3.81 cd
Butter A	7.3	**< 0.001**	5.39 a	2.63 bc	4.32 abc	4.68 a	4.82 a	4.36 ab	2.53 c	5.21 a
Chocolate At	22.2	**< 0.001**	0.71 d	7.38 a	6.84 a	2.10 cd	2.49 cd	5.13 ab	2.64 cd	3.46 bc
Salty At	2.9	**0.014**	4.37 a	3.48 ab	3.16 ab	2.75 b	2.71 b	2.90 ab	2.55 b	3.25 ab
Crispness M	60.5	**< 0.001**	7.39 a	7.74 a	0.43 c	6.65 a	2.47 b	6.68 a	7.61 a	6.71 a
Sandiness M	45.5	**< 0.001**	8.48 a	7.38 ab	1.27 d	4.97 c	1.42 d	4.63 c	7.05 ab	5.70 bc
Hardness M	44.5	**< 0.001**	5.17 b	6.48 ab	0.84 c	6.25 ab	1.98 c	5.25 ab	6.22 ab	6.65 a
Time in mouth M	6.3	**< 0.001**	3.78 c	5.94 ab	6.66 a	6.49 a	5.94 ab	4.75 abc	4.73 abc	3.98 bc
Color V	58.9	**< 0.001**	3.62 cd	8.15 a	9.13 a	2.08 de	1.40 e	4.40 bc	5.32 b	2.35 de
Visibility chocolate chips V	66.5	**< 0.001**	1.92 d	7.77 ab	1.50 d	6.07 b	8.98 a	1.55 d	6.39 b	4.50 c
Quantity chocolate chips V	66.4	**< 0.001**	1.47 c	7.89 a	1.38 c	7.47 a	5.43 b	2.61 c	5.72 b	6.82 ab
Shape chocolate chips V	33.7	**< 0.001**	1.82 e	3.76 cd	3.98 cd	4.81 bc	8.01 a	5.87 b	3.65 cd	2.67 de
Contour regularity V	33.9	**< 0.001**	7.18 ab	6.63 b	2.39 d	8.16 ab	8.07 ab	4.78 c	6.65 b	8.44 a
Cookie size V	59.0	**< 0.001**	5.85 bc	4.77 cd	4.08 d	2.64 e	7.18 a	6.41 ab	4.46 d	1.38 e
Cookie height V	78.9	**< 0.001**	2.88 d	3.98 cd	8.70 a	7.23 b	4.95 c	1.43 e	4.86 c	6.57 b
Cracks surface V	60.4	**< 0.001**	4.10 b	7.46 a	1.72 cd	3.25 bc	2.67 bc	0.37 d	7.24 a	3.25 b
Density in ρ	12.7	**< 0.001**	0.64 c	0.67 bc	0.97 a	0.66 bc	0.76 b	0.78 b	0.62 c	0.73 bc
Spread ratio in mm	31	**< 0.001**	7.23 ab	6.72 ab	3.45 c	4.41 c	7.62 a	4.33 c	5.90 b	3.28 c
Stress at rupture (σr) in kN/m2	20.7	**< 0.001**	0.08 bc	0.17 ab	0.02 c	0.15 ab	0.08 bc	0.03 c	0.13 ab	0.20 a
Strain at rupture (εr) in %	17.3	**< 0.001**	0.01 b	0.01 b	0.12 b	0.74 a	0.01 b	0.51 ab	0.55 ab	0.70 a
Water content in %	38.5	**< 0.001**	3.63 bc	2.17 c	7.87 a	4.56 b	6.82 a	2.73 c	3.65 bc	2.47 c

Note: With A = aroma, At = aroma after taste, H = texture in hand, M = texture in mouth, O = odor, T = taste, V = visual. Letters represent nonsignificant different groups row-wise according to TukeyHSD test (alpha 0.05).

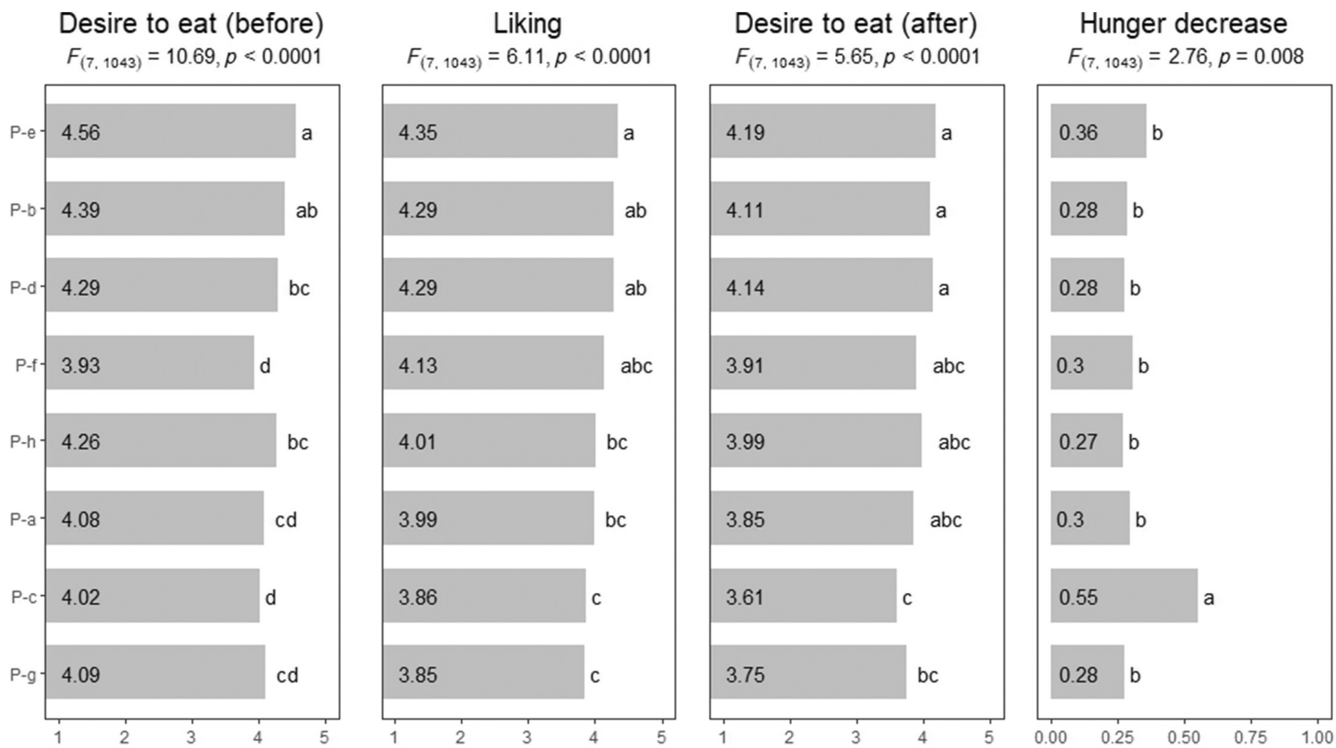

FIGURE 2 | Mean scores of the 151 children's responses to the 8 commercial chocolate-chips cookies (P-a—P-h). Letters represent Tukey HSD test groups ($p < 0.05$).

liked cookies for Cluster 1 and does not show any strong dislike from children in other clusters.

Most interestingly, these three clusters differed in their average BMI and their demographics. Cluster 1 has a proportionally higher number of "overweight/obese" children (Fisher's exact test, $p < 0.019$) and a lower number of "normal weight" children ($p < 0.017$) (Figure 4A). Conversely, Cluster 2 has proportionally fewer "overweight/obese" children ($p < 0.025$) and more "normal weight" children ($p < 0.021$). Furthermore, based on Figure 4B Cluster 1 has a lower number of children coming from families with a middle household income of €1912–€2530 (Fisher's exact test, $p < 0.049$). The clusters did not differ for children's gender and age.

3.4 | Drivers of Preferences

Figure 5 shows the overall preference mapping for the 143 children based on the multiple factor analysis of sensory, composition and physicochemical variables. The map reveals two distinct areas of higher preferences, with maximum preferences surrounding product P-e. As indicated by the loading plot in Figure 5A, this area of maximum preference is characterized by larger cookie size, higher salt content, saturated fat, fewer chocolate chips, and somewhat higher density and lower hardness and brittleness. A secondary area, reaching about 70% of predicted preferences, surrounds product P-b and is characterized by higher chocolate content, more chocolate chips and sweeter taste. Areas of lesser preferences correspond either to cookies with a more brittle, harder, crispier, and sandier texture, or to cookies with stronger chocolate flavor, and higher sugar content. To further investigate children preference patterns and underlying product and sensory variables, we plotted separate preference maps for the three clusters of children as identified with the HCA (Figure 6).

The preference map for Cluster 1 is largely consistent with the overall map, although it reveals only one—but larger—area of maximum preference that peaks around cookie P-e. In comparison with the overall preference mapping, this preference zone is shifted negatively along the first dimension, toward the left-hand side of the map (less hard and crisp, increased density and water content) and encompasses cookie P-c. This analysis indicates a negative effect of harder, crispier, and sandy textures on preferences. Furthermore, the preferences of Cluster 1 were strongly associated with a larger perceived chocolate-chip shape ($r = 0.888$) and a longer time in mouth ($r = 0.792$).

For children in Cluster 2 who dislike cookie P-g, a large rejection area was found in the center and on the right-hand side of the map. Their rejection seems to be mostly driven by harder, brittle, and sandy textures, while the analysis reveals highest preferences for larger cookie size, and more intense butter aroma. To a lesser extent, these children also favor sweeter cookies with higher sugar content (such as P-b and P-c). The preferences of Cluster 2 were strongly associated with a higher Rayner score ($r = 0.713$).

Cluster 3 is the smallest cluster ($n = 19$) which limits the scope of its results. Nevertheless, those children display an interesting preference pattern that contrasts with the other two clusters. Their preference map is mostly driven by rejection of cookie P-c, on the left-hand side of the map (higher density and water content, more intense chocolate flavor and softer

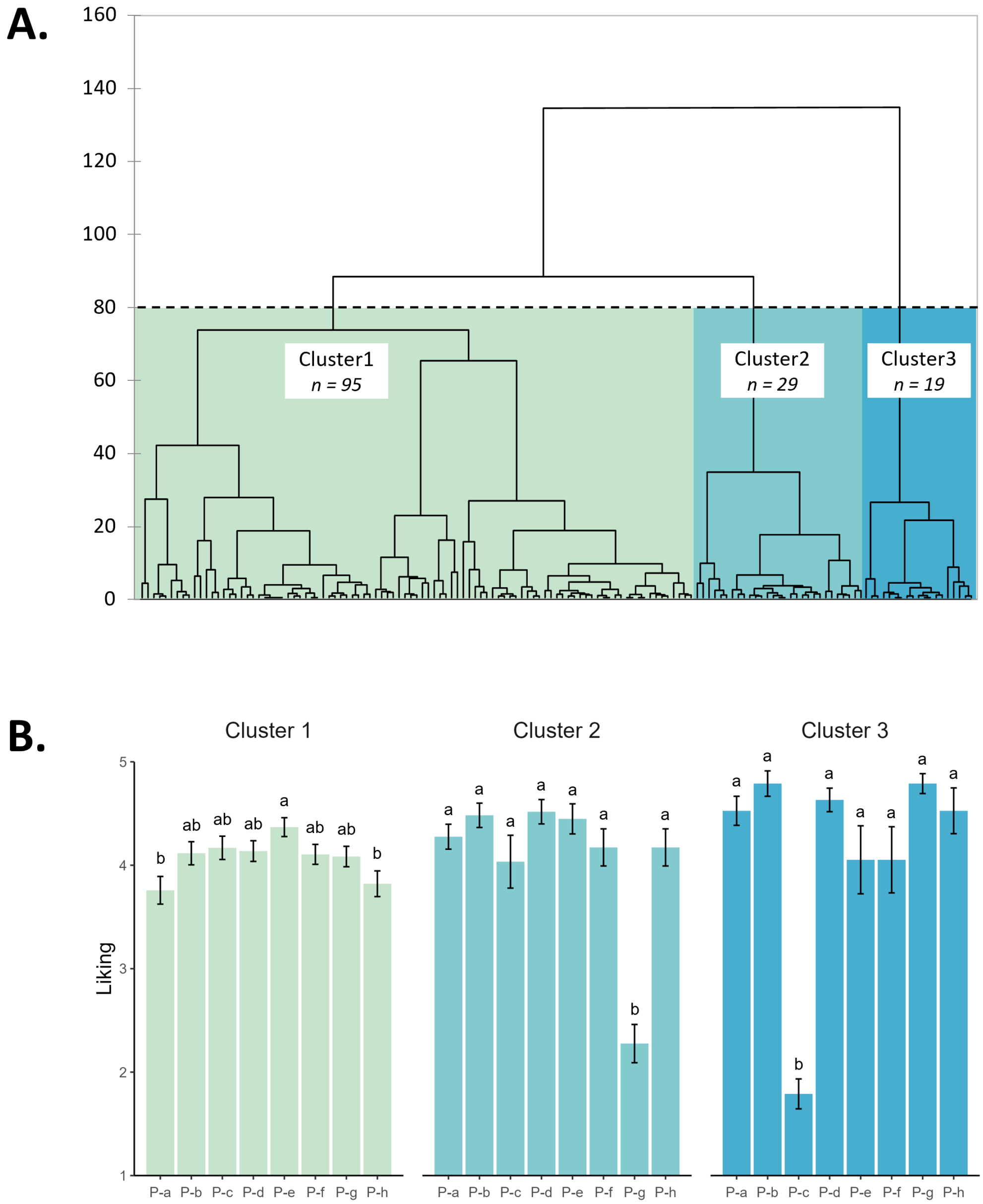

FIGURE 3 | (A) Dendrogram from the hierarchical cluster analysis of the 143 children's centered liking scores for the eight commercial chocolate-chip cookies. (B) Mean liking scores and SEM of the 8 cookies (P-a—P-h) for the resulting three clusters. Letters represent Tukey HSD test groups ($p < 0.05$) for each cluster.

texture). Conversely, Cluster 3 preferences were strongly associated with a higher crispness ($r = 0.880$) and hardness ($r = 0.850$) in mouth, more chocolate chips ($r = 0.806$), and a lower density (−0.953).

4 | Discussion

4.1 | Overall Liking and Sweet Taste

All the tested chocolate-chip cookies were overall well liked. Despite large differences in their composition, sensory, and physicochemical characteristics, none of the cookies were particularly disliked on average. This gives way for a large scope of action for reformulation among this product category while maintaining children's liking. Looking at the range of variation of cookie composition, in best case scenario, it might be possible to reduce the overall kilocalorie (−6.8%), sugar (−26.8%), and fat (−17.9%) content and increase the fiber content (+59.1%) while maintaining the liking. Further, possible improvements to reduce the Rayner score (−48.2%), the process score (−16.5%) and the number of additives (−85.7%) might be possible.

These high liking scores were expected for such a product category and are in line with earlier reports that children display high levels of liking for fatty and sweet food (Albataineh, Badran, and Tayyem 2019; Ambrosini et al. 2015; Marty et al. 2018; Moore and Fielding 2016; Nguyen, Girgis, and Robinson 2015). Accordingly, a fat and a sugar reduction in cookie dough may be expected to result in lower hedonic ratings (Biguzzi, Lange, and Schlich 2015).

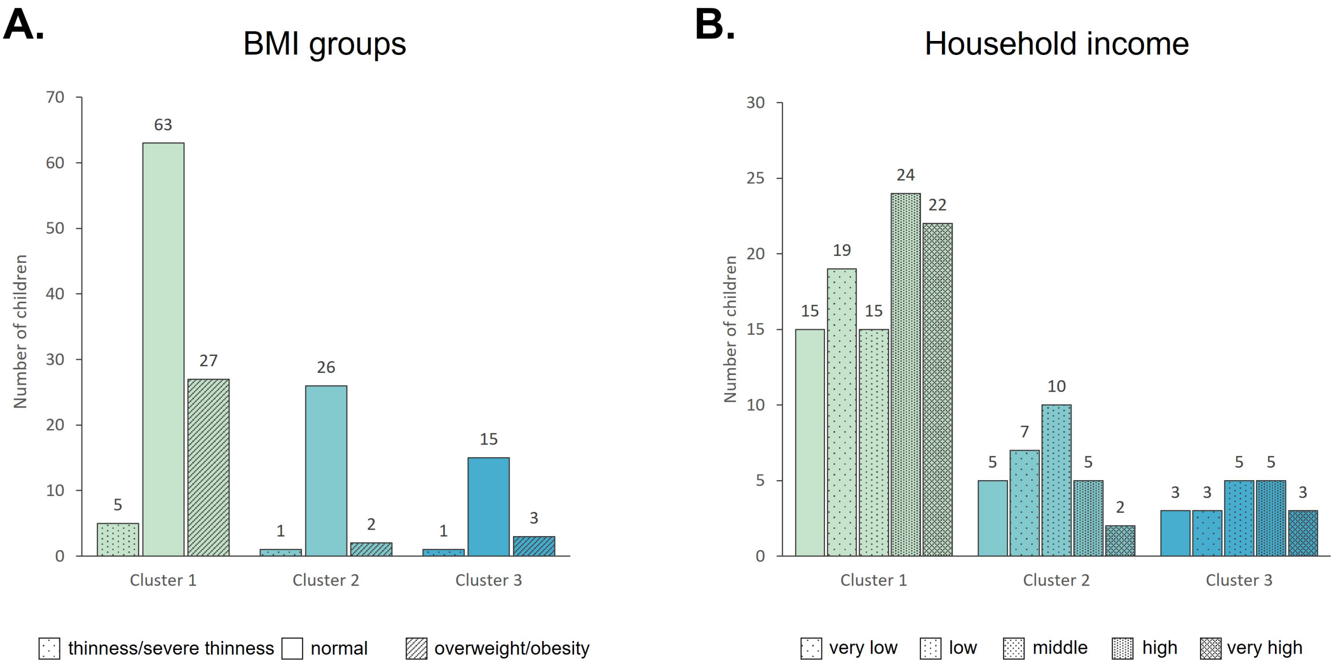

FIGURE 4 | Demographics for the three preference clusters. (A) BMI weight status categories (WHO 2007); (B) Household income.

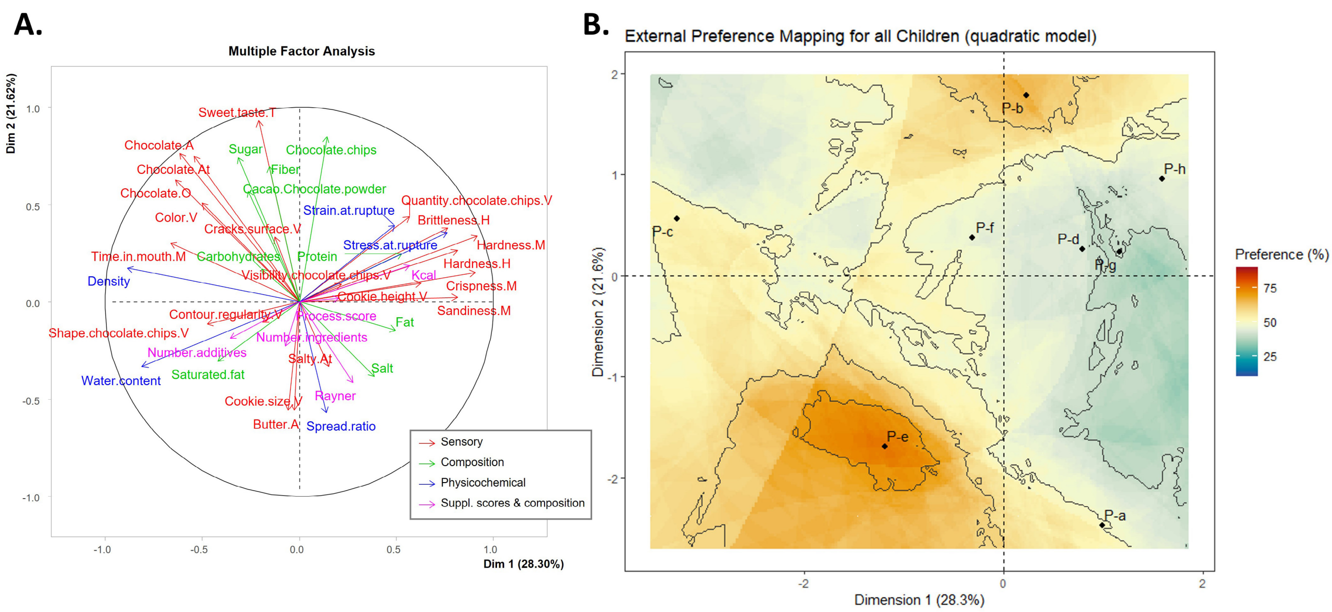

FIGURE 5 | External preference mapping, based on MFA map of sensory profile, composition and physicochemical properties. (A) Loadings of sensory, composition and physicochemical variables. (B) Overall preference mapping for the 143 children.

The cookies with the lowest sugar content (27 g/100 g, P-a) and the lowest fat content (23 g/100 g, P-b and P-c) were the least liked. However, we found that neither the cookie with the highest sugar content (37 g/100 g, P-b) nor the cookie with the highest fat content (28 g/100 g, P-h) were the most liked thereby showing that there is no simple correlation between sugar and fat content and overall liking. In fact, the preference mapping revealed that most of the children preferred cookies which tend to be less sweet, with a lower sugar, chocolate, and kilocalorie content. This result is surprising since recent studies underscored children's preferences for calorie dense and sugary food (Albataineh, Badran, and Tayyem 2019; Ambrosini et al. 2015; Marty et al. 2018; Moore and Fielding 2016; Nguyen, Girgis, and Robinson 2015). Although other factors may have been in play, we may assume that sweetest cookies (with highest levels of sugar and kilocalorie) in our product set were simply too sweet. This is an interesting finding for future reformulation work, as this shows a large frame of reformulation possibilities for a potential sugar and overall kilocalorie reduction in chocolate-chip cookies, while maintaining the liking.

Other authors reported that sugar reduction had no adverse effect on children's liking (Lima, Ares, and Deliza 2019; Reed, Mainland, and Arayata 2019; Velázquez et al. 2021, 2020).

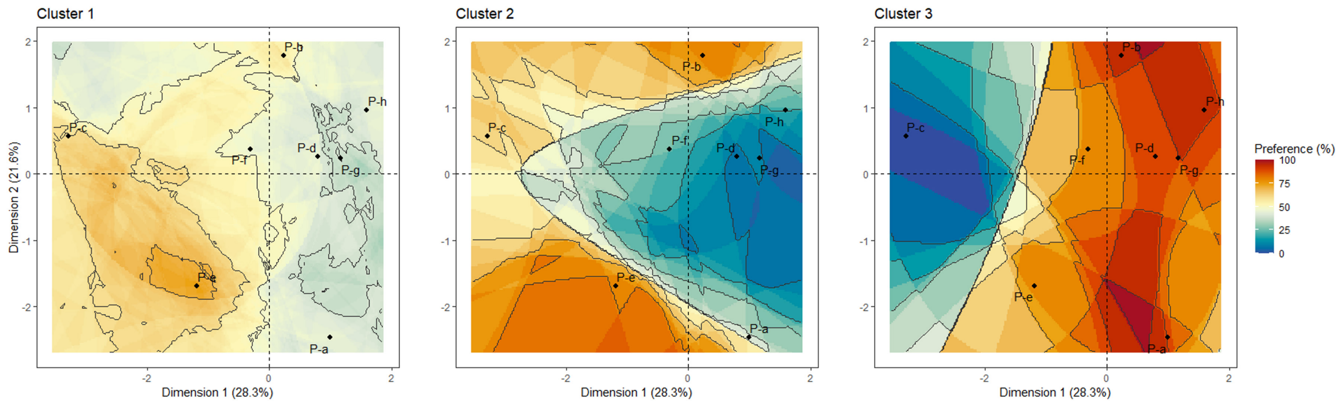

FIGURE 6 | Preference mapping for the three clusters (Cluster 1, $n = 95$; Cluster 2, $n = 29$; Cluster 3, $n = 19$).

Actually, some children even disliked the products with the highest sugar content (Velázquez et al. 2020). These authors suggest that children may not always prefer sweetest products and that, in some cases, product sweetness intensity goes beyond children's optimal level. In other words, such products are too sweet and it is therefore possible to reduce their sugar content without affecting liking (Velazquez Mendoza et al. 2021).

4.2 | Texture and Oral Processing as Important Drivers of Preferences

Our study showed that cookies texture was an important determinant of children preferences. Texture has been previously found to be a key driver of children's preferences (Lukasewycz and Mennella 2012; Rose et al. 2004a, 2004b; Szczesniak 1972; Zeinstra et al. 2010). Some textures could even trigger children's neophobia and induce rejection (Coulthard and Blissett 2009). Consistent with previous studies, we observed that most children preferred soft and uniform textures and liked clumpy or granular cookies less (Laureati et al. 2017; Szczesniak 2002; Werthmann et al. 2015; Zeinstra et al. 2010). The least liked cookie (P-c) has specific physicochemical, oral processing and sensory properties (high density and water content, longer mastication time). Its texture is stickier and chewier, with larger particle size, what requires a longer time to masticate before swallowing. Similarly, Laureati et al. (2020) had previously found that children could be either soft or hard texture lovers, or like both.

Results from the literature showed that texture preference patterns could depend on age, given the continuing growth of mouth muscles, jaw and teeth that may largely affect children's chewing capacity. For example, Rose et al. (2004a, 2004b) have found that texture and mouthfeel were more important to younger children aged 6–7 years, whereas taste and smell were more important to older children aged 10–11 years. In the present study however, we did not find any link between texture preferences and children's age although a trend could be noticed for Cluster 3 that is composed of more young children. Bearing in mind that this was the smallest cluster (19 children), it is interesting to note that those children preferred harder and crispier cookies and clearly rejected product P-c. As mentioned above, this cookie is softer, but also more challenging to process orally due to its chewiness and stickiness.

Eventually, our results show that oral processing is linked to structural and textural properties of the cookies. Indeed, denser cookies with higher water content were perceived as softer, but also chewier and thus required longer time to masticate. This result is especially interesting in the light of a recent study that showed that an increased chewiness leads to a decreased eating rate and energy intake (Bolhuis and Forde 2020). Texture, and thereby oral processing, could thus be an interesting lever to improve food healthiness.

4.3 | Preference Patterns and BMI

We observed large inter-individual differences in preferences, some of which could be related to children's BMI. According to a recent review, obese people may have a lower taste sensitivity and a higher preference and intake of fat and sweet foods, even though the latter was only to a lower extent (Spinelli and Monteleone 2021). However, studies exploring the link between obesity and children's preferences for high sweet and fat taste have led to contradictory results. Some studies report a strong relationship between fat hedonics and increased body weight (Cox, Hendrie, and Carty 2016). Similarly, Bartoshuk et al. (2006) observed an increased liking for sweetness and fattiness among obese children, compared with nonobese children. Likewise, Sobek et al. (2020) found an association between children obesity and preference for high sweet taste, but not for fat. Other studies found no difference between obese and nonobese children in their preferences for sweet taste (Bobowski and Mennella 2017). These diverging results might be explained by cultural differences. For example, in a recent study conducted in six European countries, there were no link between texture preference and children's BMI, except for Austria, where children with higher BMI preferred harder textures (Hörmann-Wallner et al. 2021).

In the present study, Cluster 1 which shows a preference for denser, softer and less crispy cookies has more children with a higher BMI (overweight/obese). Furthermore, children in this cluster do not reject any of the cookies, contrary to those in Clusters 2 and 3. However, we did not specifically used BMI as recruitment criterion for this study. In particular, very few children fell in the thinness/sever thinness group. The corresponding lack of power would prevent us to show any effect for this group. Therefore, we cannot make a direct comparison between the different BMI status groups nor draw any general conclusions from this observation.

5 | Conclusions

All cookies received high liking scores on average despite the large diversity in their composition, and in their physicochemical and sensory properties. This is promising for future reformulation, as products with a better nutritional profile were not rejected. However, detailed analysis shows that while all cookies were generally well-liked, there were notable differences between children, with three main preference patterns identified. For most children, texture emerged as a critical determinant of preference, with softer textures generally preferred. Besides, we did not observe any evident link between liking and sugar and fat content, challenging assumptions about children's preferences for sweeter, fattier products. Lastly, our data suggest potential links between preference patterns and BMI. However, sample sizes in extreme BMI groups were too low to firmly conclude on such links and further research is needed to elucidate these associations fully.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.