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Effect of nutrition, sensory education and healthy food exposure interventions on adolescent food habits and attitudes

Lara Fontana [a], Perla Degli Innocenti [b], Cinzia Franchini [b], Leonardo Menghi [c,d], Beatrice Biasini [b,*], Alice Rosi [b], Luana Bontempo [a], Francesca Scazzina [b], Isabella Endrizzi [a], Flavia Gasperi [d,a]

[a] Research and Innovation Centre, Fondazione Edmund Mach, Via E. Mach, 1, San Michele All'Adige, TN, 38098, Italy
[b] Department of Food and Drug, University of Parma, Medical School, Building A, Via Volturno 39, 43125, Parma, Italy
[c] Department of Green Technology, University of Southern Denmark, Campusvej 55, 5230, Odense, Denmark
[d] Center Agriculture Food Environment, University of Trento, Via Edmund Mach 1, San Michele all'Adige, TN, 38098, Italy

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ABSTRACT

Adolescents are increasingly moving away from the Mediterranean Diet (MD), raising concerns for their long-term health. Since adolescence is crucial for shaping eating habits, school-based interventions offer an opportunity to promote healthier choices. Nutrition and sensory education can influence food attitudes and behaviors, but their combined effects are not well understood. This study tested school-based nutrition and sensory education programs, alone or combined, with daily exposure to a healthy, unfamiliar snack, on Italian adolescents' food knowledge, attitudes, and behaviour. A total of 197 students (aged 14–17) were assigned to one of four groups: Control, Nutrition, Sensory, or Nutrition and Sensory. Over four weeks, participants received targeted lessons and were offered a healthy snack each day. Data were collected at baseline, post-intervention, and at a two-month follow-up. Key outcomes included nutritional knowledge, adherence to the MD (KIDMED), food neophobia, picky eating, food choices, and acceptance of healthy snacks. Nutrition education improved nutritional knowledge and the ability to identify MD foods, with partial retention at follow-up. However, daily dietary habits showed little changes. Sensory education increased snack consumption and willingness to try unfamiliar foods. No significant changes were observed in food neophobia or picky eating. These findings highlight the value of integrating diverse, experience-based strategies into school settings to support the development of food knowledge and healthier food choices in adolescence.

1. Introduction

The Mediterranean Diet (MD) is widely recognized for its contribution to long-term well-being (Godos et al., 2024; Guasch-Ferré & Willett, 2021). It prioritizes the intake of nutrients from plant-based over animal sources, which collectively support cardiovascular and metabolic health (D'Innocenzo et al., 2019; Tresserra-Rimbau et al., 2013). Beyond nutrition, the MD supports a healthy lifestyle and promotes sustainable farming, biodiversity, and seasonality (Dernini & Berry, 2015; Serra--Majem et al., 2020). It also embodies cultural and social values, including conviviality and intergenerational traditions, which anchor the identity of Mediterranean basin countries (Bach-Faig et al., 2011). These distinctive features led to its recognition as UNESCO Intangible Cultural Heritage in 2010 (Trichopoulou, 2021).

Despite its well-documented health benefits, adherence to the MD has been steadily declining (Damigou et al., 2023; Godos, 2023; Obeid et al., 2022), particularly among younger generations (Rosi et al., 2019, 2024a,b). The reasons are multifactorial, as framed by contemporary Social Ecological Models, which view dietary choices as the outcome of interacting influences operating at multiple levels, from societal drivers such as marketing and public policies to social environments shaped by peers and family, and individual factors including knowledge and preferences (Oudat et al., 2025). At the societal level, the progressive westernization of eating habits has increased the consumption of meat

* Corresponding author. Via Volturno 39, 43125, Parma, Italy.
E-mail addresses: lara.fontana94@hotmail.it (L. Fontana), perla.degliinnocenti@unipr.it (P. Degli Innocenti), cinzia.franchini@unipr.it (C. Franchini), leom@igt.sdu.dk (L. Menghi), beatrice.biasini@unipr.it (B. Biasini), alice.rosi@unipr.it (A. Rosi), luana.bontempo@fmach.it (L. Bontempo), francesca.scazzina@unipr.it (F. Scazzina), isabella.endrizzi@fmach.it (I. Endrizzi), flavia.gasperi@unitn.it (F. Gasperi).

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and discretionary foods rich in sugar and sodium but poor in nutrients (Ares et al., 2024; Grosso & Galvano, 2016). Modern lifestyles further reinforce this tendency by encouraging sedentary routines and prolonged screen time (Boniel-Nissim et al., 2024; Rakić et al., 2024) and by favouring the consumption of processed and pre-packaged foods that, while convenient, familiarise adolescents with highly palatable products, with potential negative effects on health and the environment (Garcia et al., 2023; Popkin et al., 2012; Forde & de Graaf, 2022). Over time, such exposures may shape food preferences in which taste and convenience often prevail over healthfulness (Daly, O'Sullivan, & Kearney, 2022) and reduce openness to new foods, resulting in monotonous and nutritionally poor diets (Mustonen et al., 2009) that contribute to higher risks of obesity and metabolic disorders in adulthood (Ruiz et al., 2019). Lastly, increasing autonomy from parents and the reduced frequency of family meals may weaken conviviality, which has recently been identified as a key determinant of MD adherence among youth in the Mediterranean basin (Rosi, Scazzina, Giampieri, Álvarez-Córdova, et al., 2024b). Taken together, these dynamics point to the urgent need for early and context-specific strategies focusing on active skill-building and experiential learning that help adolescents develop healthier and more conscious food choices sustained by knowledge and awareness.

In this context, schools represent an ideal setting for promoting healthy and sustainable food habits, as they provide a structured environment where students can access healthier food options, nutrition education, and engage in social interactions that reinforce positive behaviours (FAO, 2020). Higher levels of nutrition knowledge have been associated with healthier dietary choices (Scalvedi et al., 2021; Spronk et al., 2014). As an example, a short-term nutrition education intervention involving over 2000 early adolescents (aged 10–12) in Croatia has led to sustained improvements in nutritional knowledge, nutritional status, diet quality, and lifestyle, observed after 6 and 9 months (Jovanovic et al., 2023). School-based nutrition education interventions have also proven effective in increasing fruit and vegetable consumption and reducing overweight and obesity risk among children and adolescents (see for review Silveira et al., 2011). Moreover, studies on food education consistently show that developing a preference for certain foods is associated with the frequency of exposure to them, which leads to increased consumption of these foods (Cooke, 2007). School intervention programs support this finding. For example, handing out fruit and vegetable portions every day at the same time in the classroom, as a consistent repeated behaviour, helps students form intentional habits that behaviour increased such consumption (Reinaerts et al., 2008). Early introduction of fruit and vegetables or other healthy foods is also crucial for promoting their long-term consumption (Meleleo et al., 2021).

Similarly, developing sensory skills is a valuable tool for improving food quality assessment and supporting more conscious food choices. It enhances awareness of taste and smell and encourages the exploration of unfamiliar foods, both contributing to a more varied and balanced diet (Wahl & Majchrzak, 2019). Engaging with food through the senses in a positive social environment helps develop healthy eating habits (Meleleo et al., 2021), encompassing varied dietary choices that ensure adequate intake of nutrients (Di Nucci et al., 2023). However, food neophobia, defined as the unwillingness to try novel and/or unfamiliar foods (Pliner & Hobden, 1992), and picky eating, a selective eating behaviour not necessarily related to food familiarity (Taylor et al., 2015), can hinder this variety. These selective and restrictive eating behaviours are often driven by aversions to specific sensory attributes of food, such as taste, smell, texture, visual appearance, complexity, intensity, or unfamiliarity (Menghi et al., 2022), which can reduce exposure to certain foods. Sensory education has proven effective in promoting dietary variety by enhancing the willingness to try (Battjes-Fries & Haveman-Nies, 2014; Mustonen et al., 2009) and accept (Reverdy et al., 2008) unfamiliar foods, improving taste recognition (Wahl & Majchrzak, 2019), and reducing food neophobia (Mustonen & Tuorila, 2010).

Children tend to base their food preferences and dietary choices primarily on the sensory qualities of food (Mustonen et al., 2009), whereas adults are generally more aware of the health implications associated with different food options (Drewnowski, 2000). Adolescents lie in an intermediate developmental stage, which makes it essential to assess how educational interventions operate within this specific age group. Notably, evidence indicates that involving the entire school community, including teachers, principals, and food service staff, enhances programme adherence and sustainability. Teachers' participation in discussions about fruits and vegetables has been associated with greater student engagement and acceptance, while institutional support improves coordination and helps maintain activities over time (Ismail et al., 2020). However, despite growing recognition of the value of multi-component interventions, studies integrating complementary forms of literacy-based education within a unified school context remain limited.

Specifically, although various studies have investigated the impact of nutrition or sensory education in schools, several important gaps remain. First, few studies use designs that evaluate both the individual and combined effects of different educational interventions over time. Most interventions focus on a single approach, either nutritional (Chaudhary et al., 2020) or sensory education (Mustonen et al., 2009; Reverdy et al., 2008), which makes it difficult to compare strategies within the same framework. Second, while repeated exposure to foods promotes acceptance (Ismail et al., 2020), food distribution programs are rarely combined with educational interventions that enhance nutritional knowledge or sensory awareness (Chaudhary et al., 2020).

Against this backdrop, this study aimed to investigate the effectiveness of combined interventions: nutrition education, sensory education, and exposure to a newly formulated healthy bar on adolescents' eating behaviours. Specifically, changes in nutritional knowledge, adherence to the MD (KIDMEDscore), food neophobia, and picky eating traits have been monitored. Additionally, a food choice task (Fontana et al., 2025) was conducted to evaluate adolescents' willingness to select among foods with different characteristics in terms of alignment with MD principles and familiarity, simulating real-life decision-making scenarios.

The role of the following interventions has been assessed within the same research design.

1. Nutrition education to enhance knowledge and awareness of healthy eating principles.
2. Sensory education to reduce selective eating behaviours and encourage dietary variety.
3. A healthy bar distribution program to promote habitual exposure to healthier alternatives.

We hypothesized that the combined interventions would have led to greater improvements in food attitudes and behaviours compared to the application of a single disciplinary intervention. Furthermore, the frequency of healthy bar consumption during the intervention period has been assessed to verify whether it could be a predictor of positive changes in food choice behaviours. Given that previous studies indicate a decline in the long-term retention of educational effects (Battjes-Fries & Haveman-Nies, 2014; Reverdy et al., 2008), this research provided a follow up data collection two months after the end of the intervention. The rationale for this shorter interval was to assess the immediate retention of the effects and to explore the potential for reinforcing exposure within a more condensed time frame, before the benefits might decrease over time.

2. Material and methods

This intervention study was carried out from January to April 2024 within the PROmedLIFE project (https://PROmedLIFEproject.eu/),

supported by the European Union (PRIMA 2021; GA n°2132), which seeks to counteract the decline in adherence to the MD pattern using a multi-actor approach. The work received approval from the Research Ethics Committee of the University of Trento, Italy (Protocol 2023-048, approved on September 14, 2023) and was conducted in accordance with the Declaration of Helsinki (World Medical Association; last amendment in 2013 - Fortaleza, Brasil). Written informed consent was obtained from the parents or legal guardians of each participant, and written assent was obtained directly from the students.

2.1. Participants and study design

Participants were invited to take part in the study through a series of informative events addressed to both students and their parents and held at a high school in San Michele all'Adige (Trento, Italy). Following agreement with the school board, the project was integrated into the yearly educational programme of the first- and second-year classes (n = 213, 14–17 years old). Participation was conditional on written informed consent from parents or legal guardians and assent from the students. Students who eventually reported allergies or intolerances to ingredients in the bar distributed during the intervention or in the samples used for sensory education (see section 2.2) were exempted from tasting but still benefited from all educational activities. No additional exclusion criteria were applied.

A post hoc power analysis was performed using *G*Power version 3.1* (Faul et al., 2009) for an *F test family* (ANOVA: repeated measures, between factors) with a medium effect size ($f^2 = 0.25$), as observed in comparable school-based behavioural interventions (O'Brien et al., 2021). With $\alpha = 0.05$, power $(1-\beta) = 0.95$, and an expected 5 % dropout rate due to the longitudinal design, the analysis indicated that 188 participants would have been sufficient to detect similar effects, thus supporting the adequacy of the final sample size.

Further support for the representativeness and generalizability of the sample came from a cross-check of health-related data collected from the same group within a previous study conducted shortly before the start of the present project, suggesting that participants could reasonably be considered part of the healthy adolescent population, with no evidence of ongoing treatments likely to affect mood or taste function (Menghi et al., 2025).

As depicted in Fig. 1, the total sample was divided into four groups whereof one control group and three education intervention groups: one receiving nutrition education (Nutrition Group) one receiving sensory education (Sensory Group), and one receiving both (Nutrition and Sensory Group). For logistical reasons, participants were grouped by class, which was assigned to a single condition.

Data were collected at baseline (T0), at the end of the four-week intervention (T1), and at 12 weeks after the start of the study (T2). At each time point, participants were invited to the sensory laboratory of the Edmund Mach Foundation (San Michele all'Adige, Trento, Italy) on school days before the mid-morning snack. They were instructed to refrain from smoking, eating, or drinking (except water) for at least 2 h before testing. During these laboratory sessions, conducted in an ISO-compliant sensory laboratory, equipped with individual booths to facilitate simultaneous testing in a controlled setting, participants first rated their liking for four healthy and unfamiliar snacks developed within the PROmedLIFE project (see section 2.3.4) and a Food Choice Task (Fontana et al., 2025) to assess their food attitudes. Then, they completed a series of questionnaires (see sections 2.3.1 and 2.3.3), which were administered in a classroom setting at their own desks. Each experimental session lasted about 80 min. All data, including sensory evaluations, the food choice task, and the questionnaires, were collected using the EyeQuestion software (Logic8 BV, Elst, The Netherlands).

2.2. Interventions

Depending on the group, students received either the nutrition education intervention, the sensory educational intervention, both combined, or neither. All activities were carried out during school hours. Throughout the four-week intervention (T0–T1), all participants received a daily healthy bar as a mid-morning snack. Both educational interventions consisted of four 2-h lessons, delivered once per week.

The nutrition education aimed to increase students' knowledge of healthy and sustainable diets, using the MD as the reference model. Lessons were delivered by schoolteachers, who were provided with a toolkit developed by the Human Nutrition Unit of the University of Parma (Italy). The toolkit consisted of four PowerPoint presentations

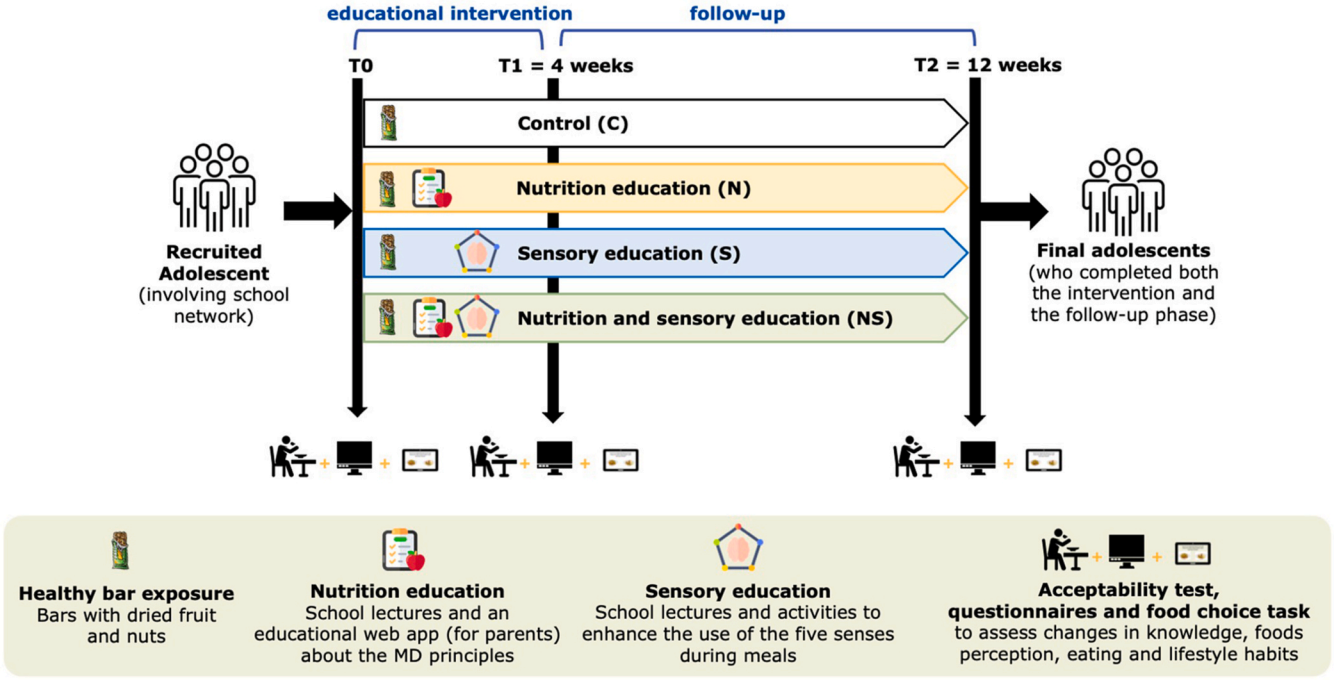


Fig. 1. Intervention study timeline.

and education games inspired by the MD principles, covering the following topics: *Diet and nutrients, Food groups, Balanced meals, and Healthy and sustainable diets*. Pre-recorded lessons and detailed transcripts were provided to assist teachers in lesson preparation. Finally, the key messages of each topic were summarized in infographics to be delivered to the students. The contents were adaptable by the teachers to the needs and knowledge level of each class. In addition, students' families received access to nutrition education materials and an example of a MD-inspired weekly food plan via a dedicated web-application. To develop the education program, partially realized based on the experience and knowledge gained from ongoing local (i.e., Giocampus, https://www.giocampus.it/it/) and previous European projects (i.e., MED4Youth, GA n°: 818318, https://med4youth.eu/; Strength2Food, GA n°: 678024, https://www.strength2food.eu/), the three phases/components that define nutrition education (Contento, 2008), were considered: the motivational phase (explaining the meaning of healthy and sustainable diets and associated benefits); the action phase (providing practical advice and recommendations on how to adopt such dietary patterns and lifestyle) and the environmental component (students' commitment was supported by engaging teachers and their families). Such structure is consistent with the COM-B Model of behaviour, a theory of behaviour change according to which an individual put in action a particular behaviour only when it has the capability and opportunity to engage in that behaviour and is more motivated to enact that behaviour than any other behaviours (Michie et al., 2011). Additional information about the nutrition education program can be retrieved from Supplementary Table S1.

The primary objectives of the sensory lessons were to enhance students' familiarity with their sensory experiences, improve their ability to differentiate between senses, refine their sensory perceptions, and broaden their descriptive and expressive skills. The sensory lessons were conducted by sensory experts in the sensory laboratory of the Edmund Mach Foundation (San Michele all'Adige, Trento, Italy). Teaching materials, developed by the Sensory Quality Unit of the Edmund Mach Foundation and the Sensory quality and Consumer Behaviour group of the University of Trento, focused on the five senses with specific emphasis on their role in food consumption. Each lesson addressed a specific sensory modality in the following order: taste, smell, touch, and a combined module on vision and hearing. The course followed an experiential approach, with each lesson combining direct sensory trials and theoretical explanations. Practical activities were followed by class discussions that allowed students to compare and reflect on their sensory perceptions. Each module concluded with an individual sensory test and a short homework assignment to be completed before the next session. The contents of sensory lessons are described in detail in Supplementary Table S2.

The healthy bar exposure involved integrating a daily snack into the students' routine across all participating classes during the four-week intervention (from T0 to T1), irrespective of group assignment. This snack consisted of a dried fruit and nut bar with a high fibre content, made with dates, almonds, coconut, cashews, sesame, and cacao powder (nutritional values per 47 g: Energy: 155 Kcal; Fat: 8 g, of which saturated: 2.2; Carbohydrate: 19 g, of which sugars: 14 g; Fibre: 3 g; Protein: 3 g; Salt: 0 g). This bar, produced for the project by a Tunisian company, represented a novel and unfamiliar product for Italian adolescents due to its composition and texture. Bars were distributed to students at the same time each day to establish a consistent routine. Teachers and staff members assisted with the distribution by ensuring that each student received the snack and were encouraged to consume it together with them.

2.3. Data collection

Alongside socio-demographic questions adapted from the Health Behaviour in School-aged Children (HBSC) 2017/18 survey (Inchley et al., 2018), data were collected to explore nutritional knowledge, adherence to the MD, eating and lifestyle habits, as well as attitudes and perceptions towards food. In addition, data on the liking of four PROmedLIFE snacks and the Food Choices Task were recorded. A detailed description of the tools employed is provided below.

2.3.1. Nutritional knowledge

The Nutritional Knowledge was assessed through a 19-item questionnaire with four options including one correct answer and one "*I do not know*". This tool was designed *ad-hoc* for the study based on the contents of nutritional modules (Annex 1). A total nutritional knowledge score (0–19 points) was calculated by assigning 1 point for correct answers and 0 for incorrect or "*I don't know*" answers. The overall internal consistency of the questionnaire was satisfactory (Cronbach's $\alpha = 0.79$).

2.3.2. Food choice task

The Food Choice Task consisted of two phases. In Phase 1, participants were shown ten pairs of food images including both familiar and unfamiliar healthy options in line with the MD, as well as MD versus non-MD familiar foods. Pairings were based on familiarity ratings from a prior study (Fontana et al., 2025) and each pair contrasted items according to compliance with MD principles. Participants were asked to choose the food they preferred from each pair of images in a real-scenario context (e.g., "*You had a hearty breakfast and now you're at school feeling a bit hungry, what would you choose for a snack?*").

In Phase 2, participants rated the same 15 food images previously presented in Task 1 (i.e., 10 MD foods and 5 non-MD foods) for liking (9-point labelled hedonic scale; 1 = "*dislike extremely*" to 9 = "*like extremely*"), arousal (i.e., the level of emotional activation elicited by a food stimulus; 7-point Likert scale from 1 = "*relaxed*" to 7 = "*anxious*"; Jaeger et al., 2023), familiarity (5-point Likert scale from 1 = "*I do not recognize it*" to 5 = "*I regularly eat it*"; Tuorila et al., 2001), and adherence to MD principles (9-point Likert scale from 1 = "*Not in line*" to 9 = "*Extremely in line*").

For the latter, an MD food identification score was calculated by assigning a positive (+) or negative (−) value to each rating depending on whether the item belonged to the MD. Thus, the total score ranged from −35 (worst case; i.e. rating all non-MD foods '-9′ and MD foods '-1′) to 85 (best case; rating all MD foods '9′ and non-MD foods '1′). Participants received different images across sessions to prevent early familiarization (see Supplementary Table S3). For a full description of the task and image details, refer to Fontana et al. (2025).

2.3.3. Adherence to the Mediterranean diet, lifestyle habits, food-related behaviours

To investigate adherence to the MD, we used the Italian version of the KIDMED questionnaire (Serra-Majem et al., 2004), which was designed for children and young people aged 2–24 years. The questionnaire consists of 16 yes/no items (Serra-Majem et al., 2004), where negative answers were scored as 0. Positive responses were scored either as +1 or −1, depending on whether the question aligned with MD principles (e.g., using olive oil at home) or not (e.g., skipping breakfast). The total score, ranging from 0 to 12 points, was derived by summing the responses. Based on the result, MD adherence could be classified as poor ($\leq$3), average (4–7), or good ($\geq$8).

Information about the frequency of intake of different food groups, habits of during meals, alcohol consumption, body perception, physical activity, and digital tool use was collected using the latest Italian version of the HBSC questionnaire (Inchley et al., 2018). The Food Frequency Questionnaire (FFQ) section was expanded with items covering additional food groups (milk and dairies, breakfast cereals, cheese, nuts, white and red meat, and fish) to complement the original foods included (i.e, fruit, vegetables, sweets, sugary and carbonated soft drinks, salty snacks, cereals, legumes). Habitual consumption was reported on a 7-point Likert scale, ranging from 1 ("*never*") to 7 ("*more than once a day*").

An FFQ-derived score was developed by adapting a procedure used

in a previous study (Grant & Rossi, 2022), considering both weekly food consumption frequencies and breakfast habits during the school week and on Sunday. As reported in Table S4, scoring was based on adherence to the Italian guidelines for adolescents aged 11–14 and 15–17 (CREA Alimenti e Nutrizione, 2019). Each food category was assigned a score from 0 to 2 points: +2 points if completely in line with the guidelines, +1 points if moderately aligned, and 0 if substantially deviating. Accordingly, the total score could range from 0 to 34 points. In some cases, if the food group is prototypical of a healthy diet, such as the MD, a full score was given even if the reported intake was higher than suggested (e.g., legumes).

Lifestyle-related questions from the HBSC survey were also recodified according to the Italian HBCS report (HBSC Italia, 2022) and the HBSC data browser referring to the 2021/22 survey (HBSC, n.d.). Physical activity was considered by rating adolescents according to meet recommendations or not of engaging in at least 60 min of moderate to vigorous physical activity daily and vigorous physical activity three or more times per week. Body perception was evaluated by asking adolescents how they perceived their body size, using the original options (1 = "definitely too thin", 2 = "a bit too thin", 3 = "about the right size", 4 = "a bit too fat", 5 = "definitely too fat"). Responses were then dichotomised into "yes" (4–5, feeling too fat) and "no" (1–3, all other responses).

Time spent on electronic devices (video games, computer/tablet, or phone) was assessed using options ranging from "none" to "more than 7 h per day" and then grouped into two categories: less than 2 h per day or 2 h or more per day.

The unwillingness to try novel and/or unfamiliar foods was measured via the Italian version of the food neophobia scale (Laureati et al., 2018). The scale consists of 10 items rated on a 7-point Likert scale ranging from 1 ("*strongly disagree*") to 7 ("*strongly agree*"). Before analysis, scores for five items that indicated neophilic food attitudes were reversed. The total food neophobia score, obtained from summing all item scores, ranged from 10 to 70, with higher scores indicating stronger aversion to new food experiences. The Italian food neophobia score was originally validated for adults aged 20–60 years (Laureati et al., 2018), while a shortened version exists for Italian children aged 6–9 years (Laureati et al., 2015). Although neither version specifically targeted adolescents, the adult version was employed, as more commonly used in adolescent samples (Appleton et al., 2019; Roβbach et al., 2016; Sorokowska et al., 2022). The internal reliability of the scale in this study was acceptable (Cronbach's α = 0.79), slightly below that reported for adult populations (α = 0.87; Laureati et al., 2018).

Lastly, multiple dimensions of picky eating were assessed using the 20-item Adult Picky Eating Questionnaire (APEQ; Ellis et al., 2017; He et al., 2019). Participants were instructed to assess how well a statement about picky eating reflected their own behaviour using a 5-point Likert scale ranging from 1 ("*Never*") to 5 ("*Always*"). A composite score was then calculated as the mean of all responses, with higher scores indicating a greater propensity for picky eating. For this study, we used the Italian validated version by Menghi et al. (2022). Although originally validated in adults aged 18–75 years, preliminary evidence of its psychometric validity in adolescents has recently been demonstrated in a slightly larger sample that also included our participants (Menghi et al., 2025). In this study, the internal reliability of the measure was acceptable (Cronbach's α = 0.79).

2.3.4. Acceptability test

The purpose of the acceptability test was to determine whether the new products developed under the PROmedLIFE project aligned with adolescents' preferences and whether these could increase after targeted interventions. The four products tested were supposed to be innovative snacks (hereafter referred to as "PROmedLIFE snacks") produced with ingredients and recipes from the Mediterranean area. Participants tasted the following products: 1) dried tomato chips covered with breadcrumbs and oregano; 2) a spreadable cream made from almonds, honey, and argan oil (Amlou, a traditional Moroccan product) served on toasted bread; 3) a date and almond bar; 4) sour milk (a partially skimmed fermented milk) with spruce tip syrup. As date bar and sour milk developed for the project were not available at the time of the test, similar commercial products were used instead of them. Participants sampled one product at a time, served in an anonymous 80 cc. cups labelled with 3-digit numerical codes, and rated their liking under white light using the Labelled Affective Magnitude scale (0 = "*Greatest imaginable dislike*", 100 = "*Greatest imaginable like*" Schutz & Cardello, 2001). The tasting order was fixed among participants, starting with the chips, then moving to the spreadable cream, followed by the bars, and finally the sour milk. Prior to tasting, participants rinsed their mouths with water and consumed a piece of plain cracker to cleanse the palate. Each step of the assessment was preceded by a detailed explanation to ensure participants were familiar with the tasting procedure and scale usage according to standard practices (Schutz & Cardello, 2001).

2.3.5. Diary of bar consumption

During the intervention students were asked to complete a daily diary to record their bar consumption. They were prompted to indicate whether they had eaten the entire bar, half of it, just tasted (a bite), or not eaten it at all. Based on this daily record, a Bar Intake Index was scored as 1 for an entire bar, 0.5 for half, 0.25 for a taste, and 0 for not consumed. We then averaged each student's responses to get a total score (Total Bar Intake Index) that could range from 1 (eaten all bar every day) to 0 (never eaten the bar any day).

2.4. Statistical analyses

Statistical analyses were performed using RStudio (version April 1, 1103, Boston, MA, United States; RStudio Team, 2016) and SPSS Statistics (version 29.1, Armonk, NY: IBM Corp). Differences between groups were investigated using parametric one-way ANOVA with Bonferroni post hoc for continuous variables and Pearson Chi-square tests (χ^2) for categorical variables.

To evaluate changes over time in response to the intervention, separate linear mixed-effects models (LME) were computed using the lme4 package in RStudio (Bates et al., 2018). Dependent variables included nutrition knowledge, MD food identification, KIDMED score, FFQ-derived score, food neophobia score, picky eating score, Total Bar Intake Index, and liking of the four PROmedLIFE snacks. For binary outcomes such as choice for unfamiliar vs. familiar foods or MD vs. non-MD foods, generalised linear mixed-effects models (GLMM) were employed. Time of data collection (T0, T1, T2) and group (Sensory, Nutrition, Nutrition and Sensory, Control) or Total Bar Intake Index were included as independent variables (fixed effects), while participants were included as a random effect to account for individual variability. Model selection was based on likelihood ratio tests, considering the model with the lowest Akaike Information Criterion (AIC) as the best fit, with relative evidence assessed using AICRL = exp(ΔAIC/2) (Fontana et al., 2022). All models were fitted using maximum likelihood estimation.

The piecewise SEM package (Lefcheck, 2016) was used to estimate marginal (R^2m) and conditional (R^2c) R^2, reflecting the variance explained by fixed effects alone and by both fixed and random effects. Variables showing significant differences in the LME analyses were further explored using general linear model (GLM) repeated measures, comparing changes across times (i.e., T0, T1, T2).

Finally, descriptive analyses were reported for different times by group as mean and standard deviation (SD) or absolute number and percentages (%), with all tests being two-tailed and statistical significance set at $p < 0.05$.

3. Results

Out of a total of 201 students enrolled, four participants were absent

on one of the three days of data collection and were excluded from the analysis. The final sample included 197 students, distributed across the intervention groups as follows: Control (n = 56), Sensory (n = 54), Nutrition (n = 50) and Nutrition and Sensory (n = 37). Additionally, due to food allergies, five adolescents did not participate in tasting one or more PROmedLIFE products, resulting in different missing data for each snack (i.e., Chips: 6, Amlou: 6, Bar: 7, Sour milk: 2, across all three time points). Accordingly, analysis of PROmedLIFE snack liking were conducted on 192 subjects.

3.1. Participants' characteristics at baseline

As shown in Table 1, most participants were boys (64 %), Italian (99 %) and attending the first year of secondary school (58 %). The distribution between first- and second-year classes, and consequently the mean age, differed significantly among the groups ($p < 0.001$ and $p = 0.002$, respectively), although overall mean age remained comparable. About one-fifth of the sample (17 %) reported living in a boarding school away from home. Half of the sample (51 %) indicated that they had a family of 4 members, while most families had 2 minor children (45 %).

Table S5 shows the results from the items of the HBSC questionnaire related to anthropometric and lifestyle variables. Briefly, the majority of subjects had a normal weight status (73 %) and engaged in vigorous physical activity at least three times a week (69 %). However, only 6 % reported at least 60 min/day of moderate to vigorous physical activity and two-thirds spend at least 2 h a day using electronic devices like video games (78 %), PCs/tablets (67 %) and TVs (76 %). Less than a fifth of the sample reported smoking (14 %) and nearly half (48 %) have tried alcoholic beverages in the last 30 days. Regarding eating habits, almost all participants followed an omnivorous food pattern (97 %), and did not perceive themselves in need of a diet, perceiving their weight as adequate (51 %). Moreover, students reported having meals with their families everyday (45 %) or most days (39 %). Overall, no statistically significant differences were found among the groups for any of the variables presented in Table S5.

With regards to eating habits (Table S6), more than half of the students reported having breakfast during school days (62 %) and on Sundays (75 %), with 12 % consuming breakfast cereals daily. However, the intake of most food groups did not align with the recommendations of the Italian dietary guidelines. In brief, despite recommendations for daily consumption of 2 portions, most of the sample consumed grains (73 %), vegetables (79 %), fruit (85 %), and milk and dairy products (87 %) once a day or less. Most of the participants consumed fish (79 %) and nuts (64 %) less than the recommended 3 times per week. Conversely, red meat was consumed more than once a week (60 %), while more than half (61 %) reported eating white meat 2 or more times per week. Regarding discretionary foods, 70 % and 51 % of students met the guidelines for carbonated soft drinks and salty snacks, respectively, while 65 % had sweet intake aligned with the recommendations. No statistically significant differences were found among the groups in eating habits, except for nut intake, which showed a significant association with group membership ($p = 0.015$). The compliance with Italian dietary recommendations is shown in detail in Supplementary Table S6.

3.2. Effect of educational interventions

3.2.1. Overall impact of the multiple interventions

To summarize the main results (see Table 2), linear mixed-effects models revealed a significant main effect of Time on several outcomes, including nutrition knowledge, MD food identification, FFQ-derived score, food choice preferences, liking of the four PROmedLIFE snacks ($p < 0.001$ for all), and the KIDMED score ($p = 0.011$). These findings indicate overall improvements over time. Significant differences between groups were also observed for nutrition knowledge ($p < 0.001$), MD food identification ($p = 0.006$), FFQ-derived score ($p = 0.004$), and food choice preferences (preferences for unfamiliar foods only) ($p = 0.027$), indicating that these outcomes differed across groups regardless of time. Interaction effect of Time and Group was significant only for the nutrition knowledge score ($p < 0.001$), showing that changes in nutritional knowledge over time varied among groups. Conversely, no significant main or interaction effects were found for food neophobia and picky eating, suggesting that these traits remained stable throughout the study. Descriptive statistics for all variables across the three data collections and by group are reported in Supplementary Table S7.

3.2.2. Changes in nutrition knowledge, food attitude, and food habits

The significant changes identified through the linear mixed effects model analysis (Table 2) were further examined by calculating the differences from baseline scores (Δ). The variations in the variables of interest over time (T0, T1, and T2) for each group are illustrated in Fig. 2.

Overall, the GLM repeated measures approach for nutrition knowledge revealed a significant ($p < 0.001$) single and interaction effect of Time and Group ($\eta^2_p = 0.092$; 0.170; 0.113, respectively), (Fig. 2, panel A). Post hoc comparisons showed that nutrition knowledge in the groups which received nutrition education differed significantly compared to control and/or sensory education group both after the intervention (T1) ($p < 0.001$) and at the follow up (T2) ($p = 0.005$). In parallel, a statistically significant higher nutrition knowledge score was observed in the nutrition education groups over time both between T0 - T1 and T0 - T2 compared to the other groups ($p < 0.001$). Hence, although nutrition

Table 1
Socio-demographic characteristics reported for total sample, and by group.

Item		All (n = 197)	C group (n = 56)	S group (n = 54)	N group (n = 50)	NS group (n = 37)	*p* value
Age (years)[1]	Mean (SD)	14.5 (0.6)	14. 4 (0.5)[b]	14.4 (0.6)[b]	14.8 (0.6)[a]	14.6 (0.5)[ab]	**0.002**
Gender[2]	Boys	128 (65.0)	37 (66.1)	35 (64.8)	33 (66.0)	23 (62.2)	0.980
	Girls	69 (35.0)	19 (33.9)	19 (35.2)	17 (34.0)	14 (37.8)	
Country of origin[2]	Italy	194 (98.5)	56 (100.0)	54 (100.0)	48 (96.0)	36 (97.3)	0.526
	Other (RU, AT)	3 (1.5)	0 (0.0)	0 (0.0)	2 (4.0)	1 (2.7)	
School year[2]	1st year	114 (57.9)	39 (69.6)	39 (72.2)	19 (38.0)	17 (46.0)	**<0.001**
	2nd year	83 (42.1)	17 (30.4)	15 (27.8)	31 (62.0)	20 (54.1)	
Boarding school[2]	Yes	34 (17.3)	13 (23.2)	11 (20.4)	8 (16.0)	2 (5.4)	0.141
	No	163 (82.7)	43 (76.8)	43 (79.6)	42 (84.0)	35 (94.6)	
Family members[2]	3	21 (10.7)	7 (12.5)	2 (3.7)	8 (16.00)	4 (10.8)	**0.035**
	4	101 (51.3)	27 (48.2)	28 (51.9)	32 (64.00)	14 (37.8)	
	5 or more	75 (38.1)	22 (39.3)	24 (44.4)	10 (20.00)	19 (51.4)	
Family minors[2]	1	69 (35.0)	16 (28.6)	18 (33.3)	24 (48.0)	11 (29.7)	0.415
	2	89 (45.2)	27 (48.2)	27 (50.0)	20 (40.0)	15 (40.5)	
	3	30 (15.2)	10 (17.9)	8 (14.8)	4 (8.0)	8 (21.6)	
	4	9 (4.6)	3 (5.4)	1 (1.9)	2 (4.0)	3 (8.1)	

Data are presented as mean (SD) for continuous variables and as absolute number (%) for categorical variables. [1] One-way ANOVA test. Different letters in the same line indicate significant differences among groups. [2] Pearson Chi-square test. C: Control. S: Sensory. N: Nutrition. NS: Nutrition and Sensory.

Table 2
Main and interaction effects of time and group on each dependent variable.

Dependent variable	Independent variable	Likelihood Ratio Test	*p* value[#]	AIC_{RL}	R^2m	R^2c
Nutrition knowledge score	Time	$\chi^2(1) = 26.549$	**< 0.001**	>100	0.019	0.597
	Group	$\chi^2(1) = 39.252$	**< 0.001**	>100	0.129	0.569
	Time*Group	$\chi^2(1) = 47.441$	**< 0.001**	>100	0.178	0.643
MD foods Identification	Time	$\chi^2(1) = 13.264$	**0.001**	>100	0.008	0.637
	Group	$\chi^2(1) = 12.513$	**0.006**	25.961	0.046	0.624
	Time*Group	$\chi^2(1) = 9.1842$	0.164	4.087	0.060	0.645
Choice preference (MD vs. non-MD)	Time	$\chi^2(1) = 21.206$	**< 0.001**	>100	0.008	0.176
	Group	$\chi^2(1) = 4.135$	0.247	2.541	0.005	0.166
	Time*Group	$\chi^2(1) = 5.3471$	0.500	27.839	0.016	0.178
KIDMED score	Time	$\chi^2(1) = 9.0343$	**0.011**	12.393	0.004	0.714
	Group	$\chi^2(1) = 5.0658$	0.167	1.595	0.020	0.707
	Time*Group	$\chi^2(1) = 0.0297$	0.917	>100	0.025	0.715
FFQ derived score	Time	$\chi^2(1) = 18.641$	**<0.001**	>100	0.012	0.629
	Group	$\chi^2(1) = 13.217$	**0.004**	36.917	0.048	0.611
	Time*Group	$\chi^2(1) = 2.2606$	0.894	>100	0.062	0.631
Choice preference (Unfamiliar vs. Familiar)	Time	$\chi^2(1) = 87.938$	**< 0.001**	>100	0.051	0.173
	Group	$\chi^2(1) = 9.1731$	**0.027**	4.887	0.011	0.117
	Time*Group	$\chi^2(1) = 4.5014$	0.609	42.492	0.065	0.176
PROmedLIFE snacks Liking	Time	$\chi^2(1) = 31.672$	**< 0.001**	>100	0.007	0.322
	Group	$\chi^2(1) = 1.5443$	0.672	9.280	0.003	0.313
	Time*Group	$\chi^2(1) = 4.4116$	0.621	44.444	0.011	0.323
Food neophobia	Time	$\chi^2(1) = 3.2031$	0.202	1.490	0.001	0.772
	Group	$\chi^2(1) = 3.5889$	0.309	3.339	0.015	0.770
	Time*Group	$\chi^2(1) = 5.0611$	0.536	32.118	0.018	0.775
Picky eating	Time	$\chi^2(1) = 2.1476$	0.342	2.525	0.001	0.626
	Group	$\chi^2(1) = 1.2187$	0.749	10.921	0.005	0.624
	Time*Group	$\chi^2(1) = 3.5622$	0.736	67.956	0.008	0.630

Note: [#] generalised linear mixed effect models (GLMM) with bold *p* values denoting statistical significance if < 0.05. * = Multiple comparisons. AIC_{RL} = exponent of the difference between the AIC (Akaike information criterion) of the models; R^2_m = marginal effect size; R^2_c = conditional effect size. FFQ: food frequency questionnaire; MD: Mediterranean Diet.

knowledge score in these two groups decreased during follow-up (T2), the difference from baseline remained significant.

Moreover, changes have been observed in the ability to recognize MD foods (Fig. 2, panel B), as well as hypothetical choice of MD food (Fig. 2, panel C), with a significant overall Time effect ($p < 0.001$, $\eta^2_p = 0.040$) in both nutrition education groups which improved the MD food recognition from T0 to T2 (Nutrition Group: $p = 0.018$; Nutrition and Sensory Group: $p = 0.009$) and from T1 to T2 ($p = 0.041$) in the Nutrition and Sensory Group.

Dealing with MD foods choice, the results showed an overall Time effect ($p < 0.001$, $\eta^2_p = 0.051$), with an increase between T0 and T1 and a decrease from T1 to T2 in all groups. However, significant differences from T0 to T1 ($p = 0.030$) and from T1 to T2 ($p = 0.004$) were found only in the N group. However, when considering dietary habits in terms of adherence to the MD (i.e., KIDMED score), an overall significant Time effect was highlighted ($p = 0.022$, $\eta^2_p = 0.20$), with no significant differences among each time and between groups (Fig. 2, panel D).

In parallel, the eating habits explored through the FFQ-derived score (Fig. 2, panel E) revealed an overall significant Time effect ($p < 0.001$, $\eta^2_p = 0.049$). Specifically, the group with both nutrition and sensory education reported the greatest improvement from T0 and T1 compared to the other groups. However, the only significant change occurred in Nutrition and Sensory Group, with a decrease in the score between T1 - T2 ($p = 0.021$).

Focusing on the unfamiliar hypothetical food choice (Fig. 2, panel F), an overall significant Time effect has been highlighted ($p < 0.001$, $\eta^2_p = 0.214$), with a generalised increase in the scores. Particularly, all groups showed statistically significant differences at T2 comparing both T0 and T1, with a $p < 0.001$ for both times except for sensory group (T0 - T2: $p = 0.001$; T1 - T2 $p = 0.023$).

Finally, the liking of the PROmedLIFE snacks was evaluated and reported as the mean of liking score trend derived from the 4 snacks (Fig. 2, panel G). A significant overall time effect was found ($p < 0.001$, $\eta^2_p = 0.108$). Except for the Nutrition and Sensory Group which had a slight increase without reaching significance, all other groups showed a significant ($p < 0.05$) increase from T0.

For conciseness, Liking, Arousal and Familiarity ratings for familiar vs. unfamiliar foods and MD vs. non-MD foods are presented as detailed results in the Supplementary Materials (Tables S8 and S9).

3.2.3. *Effect of healthy bar exposure*

Based on the results, the changes over time in food choice (either MD foods and unfamiliar foods), KIDMED score, PROmedLIFE snacks Liking do not seem to be group-specific. Thus, we hypothesized that the bar consumption, common to all groups, might have contributed to these changes. As shown in Fig. 3 and reported in Table 3, the Bar Intake Index, which reflects the amount of snack consumed, decreased over time ($p < 0.001$), with reductions observed only in Nutrition and Control groups. Differences between groups were also detected, with the S group showing higher bar consumption than the Nutrition Group ($p = 0.011$).

To further explore this, we re-analysed food choice data, KIDMED score and PROmedLIFE snacks Liking including the Total Bar Intake Index as an independent variable (Table 4). The main effect of the Total Bar Intake Index on the preference for unfamiliar foods was found to be statistically significant ($p = 0.032$), indicating that participants who consumed more bars tended to choose unfamiliar foods more often. Although this relationship did not vary significantly over time, at T2 follow-up higher bar consumption remained associated with a greater preference for unfamiliar products (Fig. 4, panel A). In contrast, bar consumption was not significantly related to the choice of MD foods, and no consistent pattern was observed across time points (Fig. 4, panel B). Concerning the KIDMED score, bar consumption did not influence the degree of adherence to MD or its change over time (Fig. 4, panel C).

Finally, for liking of PROmedLIFE snacks, participants who consumed more bars tended to report higher liking ratings overall, although daily consumption did not lead to a further increase in liking during the study period (Fig. 4, panel D).

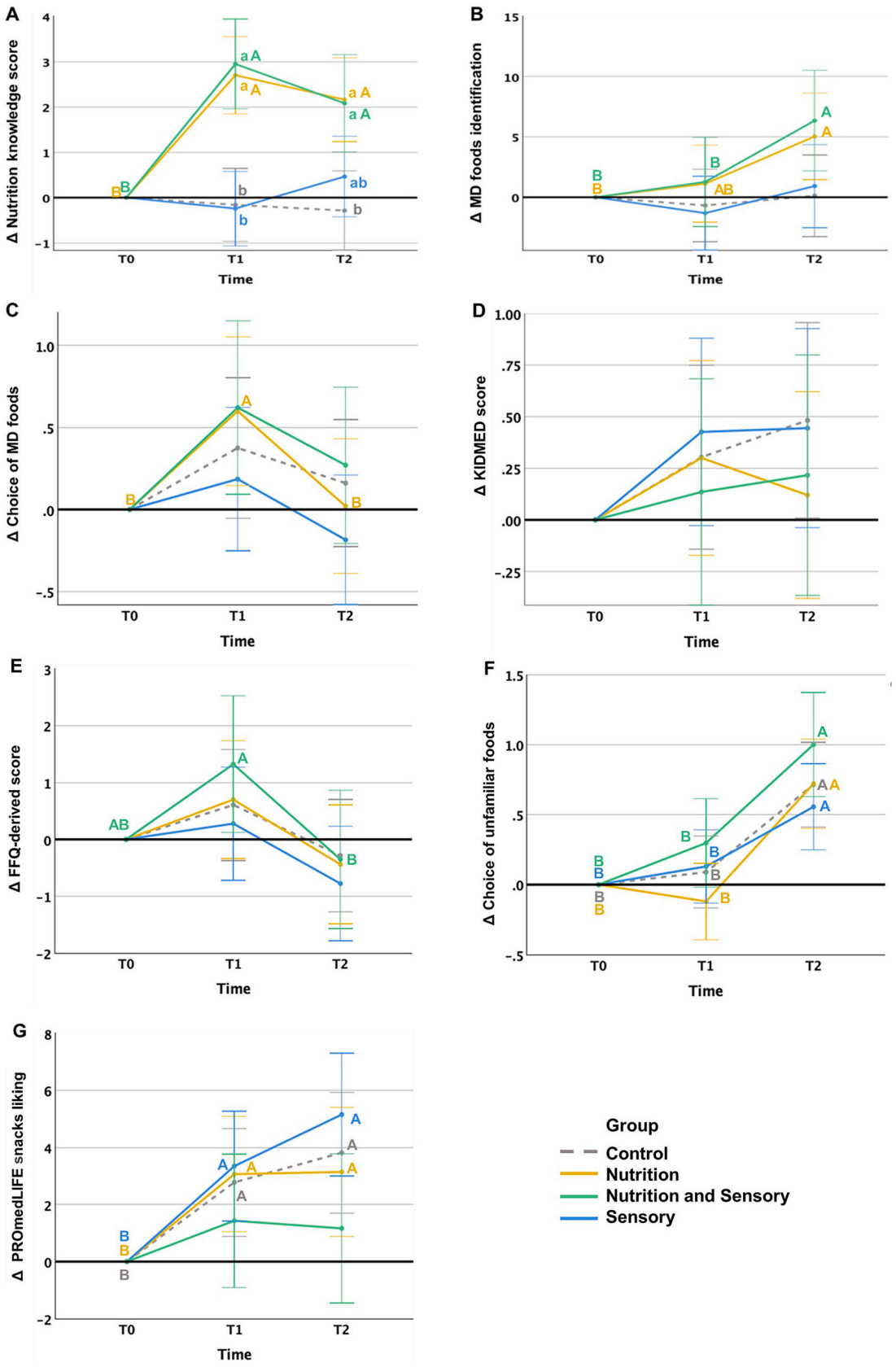


Fig. 2. Changes in each dependent variable among times (T0, T1 and T2) for each group. Data are expressed as mean (SD). Different upper-case letters indicate statistically significant differences between the times in each group. Different lower-case letters indicate statistically significant differences among the groups at each time. MD: Mediterranean Diet.

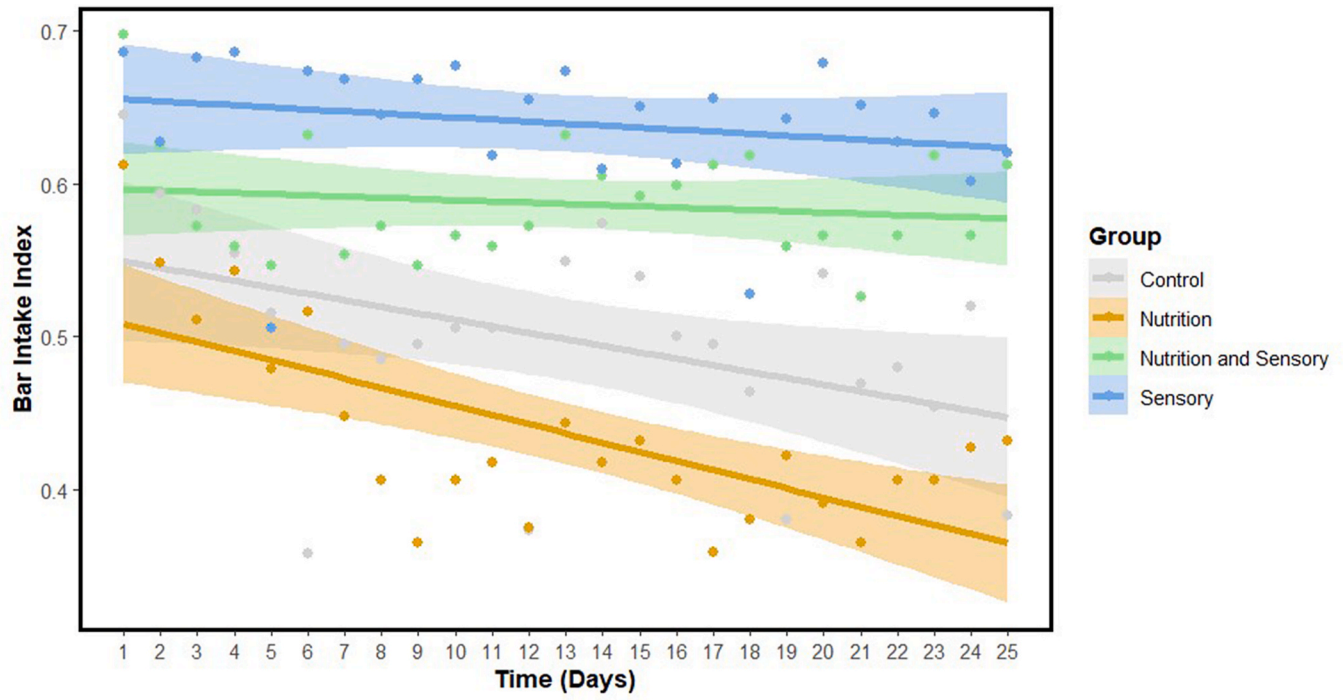


Fig. 3. Bar Intake Index over time for each group. The dots depict the mean at each trial. The shaded area around the regression line indicates the 95 % confidence interval.

Table 3
Main and interaction effects of time and group on bar intake index.

Independent variable	Estimate	Likelihood Ratio Test	*p* value[#]	AIC_{RL}	R^2m	R^2c
Time		$\chi^2(1) = 44.576$	**< 0.001**	>100	0.003	0.654
Group		$\chi^2(1) = 10.98$	**0.012**	12.059	0.037	0.651
C - N[a]	0.054		0.853			
C - NS[a]	−0.094		0.554			
C - S[a]	−0.150		0.098			
N - NS[a]	−0.143		0.173			
N - S[a]	−0.204		**0.011**			
NS - S[a]	−0.056		0.862			
Time[a]Group		$\chi^2(1) = 24.974$	**< 0.001**	>100	0.042	0.657
S[b]	−0.001	$\chi^2(1) = 0.7263$	0.394	1.891	<0.001	0.579
N[c]	−0.006	$\chi^2(1) = 32.946$	**< 0.001**	>100	0.011	0.599
NS[d]	−0.001	$\chi^2(1) = 1.0361$	0.309	0.618	<0.001	0.809
C[e]	−0.005	$\chi^2(1) = 25.814$	**< 0.001**	>100	0.008	0.637

Note: [#] generalised linear mixed effect models (GLMM) with bold *p* values denoting statistical significance if < 0.05.
[a] Multiple comparisons.
[b] Effect of Time for Group S.
[c] Effect of Time for Group N.
[d] Effect of Time for Group NS.
[e] Effect of Time for control group. C: Control; N: Nutrition; NS: Nutrition and Sensory; S: Sensory.

4. Discussion

The study presents one of the few examples integrating nutrition and sensory education with exposure to a healthy bar prepared with MD ingredients, alongside longitudinal assessments of literacy, behavioural, and perceptual outcomes within a school-based intervention designed to promote healthier eating behaviours among adolescents.

At the baseline, despite most of participants reporting a daily breakfast consumption, adolescents' eating habits were not consistent with most of the Italian dietary recommendations (CREA Alimenti e Nutrizione, 2019). Plant-based foods were especially poorly consumed, while meat and discretionary foods exceeded optimal consumption frequencies. Our results are in line with the latest national survey conducted within the HBSC study in 2022. Indeed, most Italian adolescents are used to consuming breakfast daily and exceed the consumption of unhealthy foods. At the same time, low percentages consume fruit and vegetables more than once a day and legumes more than twice a week (HBSC Italia, 2022).

Consistent with previous studies (Medeiros et al., 2022), nutrition intervention appeared to be successful in enhancing knowledge, at least in the short term. Our results show that providing theoretical information about the MD also improves the ability to recognize MD-aligned foods in image-based, real-life-like scenarios. The increased nutritional knowledge also makes participants more likely to choose healthier, MD-consistent products in a hypothetical selection task, linking improved understanding directly to better decision-making.

The intervention(s) and snack exposure did not however improve the KIDMED score, suggesting that translating knowledge into lasting

Table 4
Main and interaction effects of time and total bar intake index on each dependent variable.

Dependent variable	Independent variable	Estimate	Likelihood Ratio Test	*p* value[#]	AIC_{RL}	R^2m	R^2c
Choice preference (Unfamiliar vs. Familiar)	Time		$\chi^2(1) = 82.405$	**<0.001**	>100	0.051	0.172
	T0 - T1[a]	−0.184		0.372			
	T0 - T2[a]	−1.029		**<0.001**			
	T1 - T2[a]	−0.844		**<0.001**			
	Total Bar Intake Index		$\chi^2(1) = 4.5869$	**0.032**	3.645	0.006	0.117
	Time*Total Bar Intake Index		$\chi^2(1) = 3.001$	0.223	1.648	0.059	0.173
	T0[b]	0.061	$\chi^2(1) = 0.0382$	0.845	2.667	<0.001	0.083
	T1[c]	0.462	$\chi^2(1) = 1.6689$	0.196	1.180	0.006	0.222
	T2[d]	0.660	$\chi^2(1) = 7.9966$	**0.005**	20.052	0.015	0.059
Choice preference (MD *vs.* non-MD)	Time		$\chi^2(1) = 18.912$	**<0.001**	>100	0.008	0.176
	T0 - T1[a]	−0.378		**<0.001**			
	T0 - T2[a]	−0.005		0.999			
	T1 - T2[a]	0.373		**<0.001**			
	Total Bar Intake Index		$\chi^2(1) = 0.0795$	0.778	2.612	<0.001	0.167
	Time[a]Total Bar Intake Index		$\chi^2(1) = 6.0236$	**0.049**	2.751	0.010	0.179
	T0[b]	−0.351	$\chi^2(1) = 1.8583$	0.173	1.073	0.004	0.140
	T1[c]	0.242	$\chi^2(1) = 0.879$	0.349	1.752	0.002	0.152
	T2[d]	0.291	$\chi^2(1) = 1.1335$	0.287	1.542	0.003	0.175
KIDMED	Time		$\chi^2(1) = 7.1467$	**0.028**	0.408	0.004	0.714
	T0 - T1[a]	−0.297		**0.044**			
	T0 - T2[a]	−0.342		**0.017**			
	T1 - T2[a]	−0.044		0.931			
	Total Bar Intake Index		$\chi^2(1) = 5.4320$	0.170	2.450	0.008	0.718
	Time[a]Total Bar Intake Index		$\chi^2(1) = 0.9027$	0.637	6.564	0.012	0.721
PROmedLIFE snacks Liking[e]	Time		$\chi^2(1) = 26.377$	**< 0.001**	>100	0.008	0.323
	T0 - T1[a]	−2.760		**<0.001**			
	T0 - T2[a]	−3.520		**<0.001**			
	T1 - T2[a]	−0.760		0.546			
	Total Bar Intake Index		$\chi^2(1) = 30.213$	**<0.001**	>100	0.049	0.319
	Time[a]Total Bar Intake Index		$\chi^2(1) = 0.3568$	0.836	0.245	0.057	0.328

Note: [#] generalised linear mixed effect models (GLMM) with bold *p* values denoting statistical significance if < 0.05.
[a] Effect of Time for Group S.
[b] Effect of Time for Group N.
[c] Effect of Time for Group NS.
[d] Effect of Time for Group C.
[a] Multiple comparisons.
[b] Effect of Total Bar Intake Index for time T0.
[c] Effect of Total Bar Intake Index for time T1.
[d] Effect of Total Bar Intake Index for time T2.
[e] Referred to the PROmedLIFE snacks actually tasted during the acceptability test. MD: Mediterranean Diet.

healthy eating habits likely requires longer interventions and greater family involvement (Murimi et al., 2017; Samad et al., 2024). Such result reflects the well-documented attitude/intention-behaviour gap, intended as the failure to translate positive attitudes or intentions into action (Aschemann-Witzel & Niebuhr Aagaard, 2014; Green et al., 2025). To narrow this gap, understanding enables and barriers influencing the behaviour change is essential, while contributing factors (e.g., capability, self-efficacy, opportunity, motivation, etc.) can be strengthened by grounding intervention strategies on behaviour change theories (Wu et al., 2025).

Also considering the adherence to Italian guidelines (i.e., FFQ-derived score) a significant positive trend between baseline (T0) and the end of the intervention (T1) was found regardless of the group. In addition, there was a significant tendency for FFQ-derived scores to decrease over time, but within groups comparison was significant only in the group that received both nutrition and sensory education, probably due to the greatest improvement in this group during the intervention phase. Overall, these results did not highlight the effect of the intervention itself as found for the KIDMED score. However, although the Italian dietary recommendations on which the FFQ-derived score is based align with the principles of MD, the two tools have some differences which could explain the discrepancies observed. For instance, only the KIDMED questionnaire assesses olive oil consumption, and, unlike the FFQ, it does not include questions about red and white meat intake over the week.

Furthermore, it is important to mention that adherence to the Italian dietary guidelines was derived from answers available in the FFQ with some adaptations. Thus, the derived score may have limitations in assessing changes in habits with respect to the recommendations (e.g., overall meat consumption according to the recommendations should be 3 times per week; for the FFQ, the answers "2–4 days per week" for white meat and "1 time per week" for red meat were considered compliant). Despite the aforementioned inherent limitation, the use of FFQ score was necessary to provide a summary measure of participants' eating habits in line with the outcomes of the other questionnaires (i.e., KIDMED, food neophobia score, APEQ), besides the descriptive value of this tool. Clearly, it is not only important to choose healthy products, but also to vary the selection of different foods. This means not being afraid of unfamiliar foods but instead being open to trying a wide variety of different foods. This is where sensory education comes into play, aiming to reduce the fear of tasting new foods (i.e., food neophobia) or those with unusual textures and appearances (Battjes-Fries & Haveman-Nies, 2014; Mustonen et al., 2009), potentially fostering healthier eating behaviours (Reverdy et al., 2008; Wahl & Majchrzak, 2019). Although some studies in children have shown that sensory education can reduce food neophobia (Mustonen & Tuorila, 2010), the present study found that this trait, along with picky eating behaviours, remained stable in adolescents regardless of the intervention received. This aligns with previous research in adults, which suggests that these traits tend to be relatively stable over time (Hazley et al., 2022).

However, all participants, regardless of group assignment, showed an increase in the selection of unfamiliar foods at T2. This could reflect changes in familiarity levels due to pictures selection and, consequently, in liking and arousal. Although the familiarity at T2 changes at a

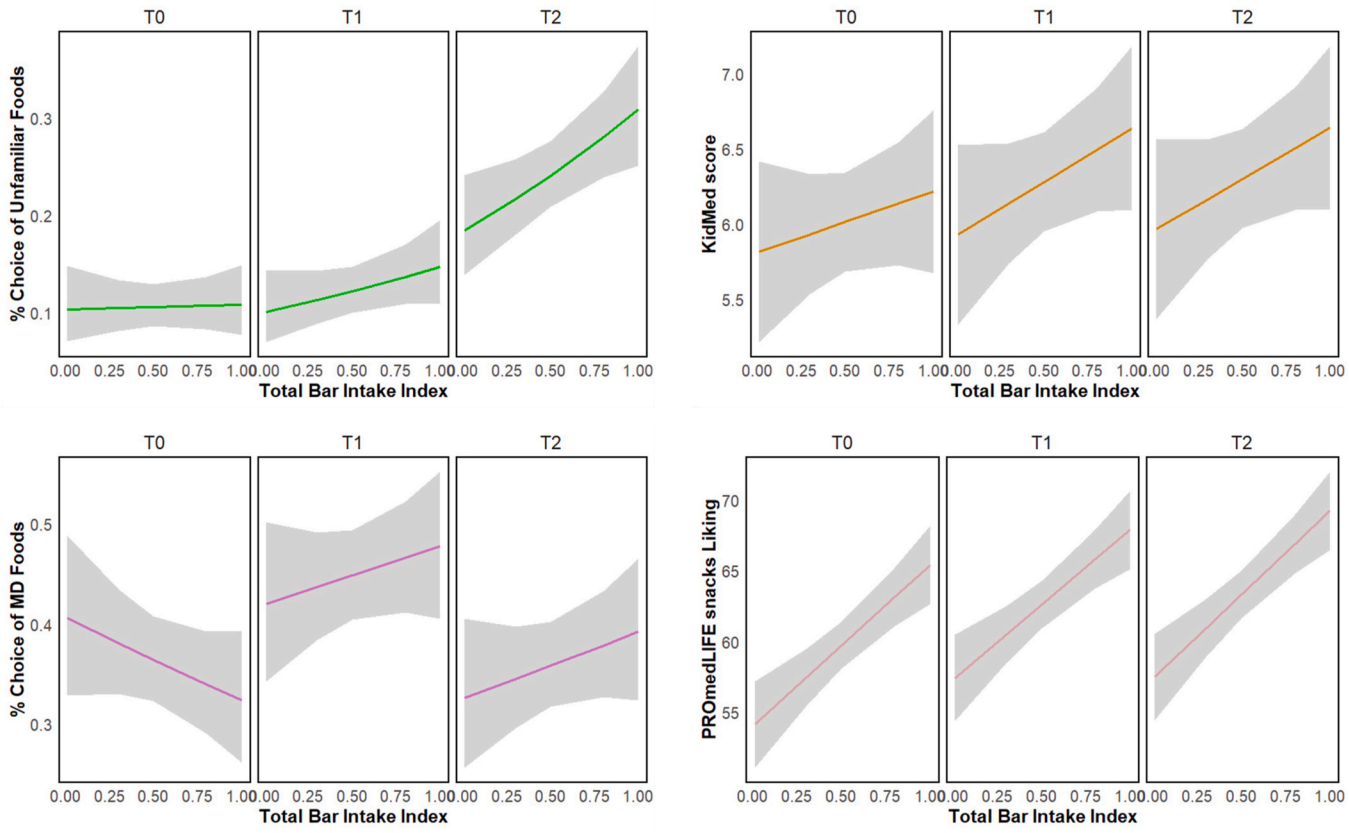


Fig. 4. Choice frequency of unfamiliar foods (Panel A) and MD foods (Panel B) as well as KidMed score (Panel C) and PROmedLIFE snacks Liking (Panel D) based on the Total Bar Intake Index at T0, T1 and T2. MD: Mediterranean Diet.

significant level compared with T0, familiar foods maintained a mean score of approximately 4 on a 5-point scale, while unfamiliar foods averaged around 2. Liking and arousal ratings aligned with these findings, with familiar foods rated higher in liking and lower in arousal, and the opposite pattern observed for unfamiliar foods. This suggests that the difference observed at T2 is unlikely to be attributable to the images selected at T2. Hence, the observed increase might be partly explained by a shared intervention across groups, namely the exposure to the healthy bar. Our findings suggest that adolescents with a higher consumption of the healthy and innovative bar during the exposure period were also more likely to choose unfamiliar foods in the food choice task. While this association may reflect an increased familiarity with new flavours and textures (Reinaerts et al., 2008), it should be noted that the assumption that exposure to one novel ingredient generalizes to a broader openness toward unfamiliar foods warrants further investigation Moreover, the groups that participated in sensory education maintained a steady and higher consumption of the bar throughout the exposure period compared to Nutrition and Control groups. This suggests that sensory education allowed these students to better appreciate the bar's innovative characteristics, whose consumption as a snack may contribute to meeting the recommended daily fibre intake (Reverdy et al., 2008). On this matter, our findings suggest that individuals who consumed a greater quantity of the healthy bar were also those who showed a higher appreciation for other unfamiliar and innovative PROmedLIFE snacks during the acceptability test. This pattern was not influenced by the education intervention, but those who have a greater preference for unfamiliar and innovative foods are more likely to consume them when offered.

Therefore, it could be suggested that each type of intervention implemented in this project may have contributed differently to the outcomes obtained. Thereby, a multidimensional approach may be useful in achieving different competences functional to establish an appropriate dietary lifestyle. This finds confirmation from the literature. In their study, Scazzocchio and colleagues (2021) affirm the importance of applying more notional approaches together with practical ones (e.g. cooking) to increase food literacy within the school environment. Similarly, in the present study, nutritional aspects were targeted through lectures and educational handouts whereas the sensory dimension was addressed through frontal lesson, and practical activities (e.g. with the laboratories). However, it is important not to generalize and tailor the interventions based on the social and food environment to which adolescents are exposed (Ares et al., 2024).

Despite the positive outcomes of the project, some study inherent limitations must be considered. To begin with, the intervention phase lasted four weeks. A short time like this may not be enough to significantly impact participants' dietary behaviours. Indeed, an educational curriculum integrated into the annual school program could be more effective in promoting knowledge and healthy eating habits. In addition, participants' parents showed limited interest in the project, as evidenced by the low engagement with the web app containing educational materials. Therefore, identifying effective strategies to involve families is essential, alongside exploring ways to implement interventions within the school setting. Although progressive autonomy is gained during adolescence, parental support remains crucial in helping them develop the necessary competencies for effective diet management. Parents play a key role in fostering these competencies. Furthermore, including a group without snack exposure was not feasible in the school setting, as students shared spaces and recess times, which could have led to exchange or peer influence. Finally, although the nutrition education content aligned with the COM-B model of behaviour, the study was not designed to formally test a behavioural theory, which limited our ability to disentangle the specific drivers of food choices.

Beyond the limitations inherent to the tools and design employed, it is also important to consider the potential influence of self-presentation bias. Recruitment via promotional school events may have introduced a potential selection bias, as students who voluntarily participated could differ in motivation or interest in healthy eating compared to the general adolescent population. However, it is worth noting that participation in the study was integrated into the school's program, which likely reduced the impact of self-selection. Moreover, nutrition and, in particular, sensory science are not subjects typically included in their curriculum, which further mitigates the likelihood that prior familiarity influenced students' engagement or biased the results." Given the educational context and the involvement of teachers known to the students, participants may have felt inclined to respond in a socially desirable manner, particularly in the intervention groups.

It is also important to consider that nutrition intervention was delivered by the teachers of the class, while sensorial education was conducted by external researchers. This difference in familiarity and pre-existing trust may have influenced students' engagement and responsiveness, leading to different effects among outcomes assessed. Future studies should take into account such relational dynamics, possibly by balancing teacher-student familiarity across conditions. Furthermore, the study was conducted on a limited number of students and in an agricultural high school, where students may already have a predisposition toward food-related topics. Different educational settings might yield varying results, highlighting the need for proposing intervention strategies that consider diverse academic backgrounds and levels of prior knowledge.

In parallel, the absence of a qualitative data collection focusing on each component of the intervention did not allow to understand which of them were most effective or acceptable to participants. For these reasons, drawing general conclusions about the impact of this intervention should be made with caution. Future studies will be crucial to fill the gaps pointed by our research and to strengthen the promising results obtained. In particular, further research should explore the optimal duration, frequency, and mode of delivery of the interventions that allow for a more precise evaluation of causal effects. Additionally, the development and use of more sensitive and complete tools for assessing food consumption over time, such as the food diary, would enhance the accuracy of the analysis. Similarly, creating instruments to evaluate food avoidance behaviours could be valuable. For instance, tasks modelled after the food choice paradigm could compare responses to stimuli that are more or less likely to elicit rejection in picky eaters, such as foods with uncommon versus familiar textures, or spicy versus non-spicy items.

5. Conclusions

The present study assessed the impact of a school-based multidimensional intervention on adolescents' nutritional knowledge, food attitudes, and food choices in both hypothetical and real contexts. While the nutrition-focused intervention successfully increased participants' understanding of healthy eating principles and their ability to recognize MD foods, these gains did not translate into actual food behaviours. Sensory education appeared to enhance engagement with the healthy bar, supporting more stable consumption during the intervention period and a greater willingness to try unfamiliar foods. These findings suggest that knowledge alone may not be sufficient to drive long-term behavioural change, highlighting the need for longer interventions that combine education, repeated exposure, and sensory experiences. Future school-based programs should consider integrating structured nutritional and sensory activities throughout the school curriculum, actively involving school staff and, importantly, families, in order to foster lasting improvements in adolescents' dietary behaviours. This underscores the need for systemic, theory-driven interventions that are carefully designed and evaluated for effectiveness, and that can be sustainably incorporated into school curricula. Such approaches could inform policymakers and educational institutions aiming to promote food literacy, healthier food choices, and sustainable eating habits among young populations.

CRediT authorship contribution statement

Lara Fontana: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Perla Degli Innocenti:** Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation. **Cinzia Franchini:** Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation. **Leonardo Menghi:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Beatrice Biasini:** Writing – review & editing, Methodology, Conceptualization. **Alice Rosi:** Writing – review & editing, Methodology, Conceptualization. **Luana Bontempo:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Francesca Scazzina:** Writing – review & editing, Methodology, Conceptualization. **Isabella Endrizzi:** Writing – review & editing, Methodology, Conceptualization. **Flavia Gasperi:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Ethical statement

This study was approved by the Research Ethics Committee of the University of Trento (Protocol 2023-048, approved on September 14, 2023) and was conducted in accordance with the Declaration of Helsinki (World Medical Association; last amendment in 2013). All participants were asked to sign a written consent form to take part in the experiment.

Declaration of generative AI in scientific writing

During the preparation of this work the authors used ChatGPT (version 5) in order to improve grammar and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2025.108388.

Data availability

Data is available from the corresponding authors upon reasonable requests.

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