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Promoting Healthy and Sustainable Eating Behaviors: Multidimensional Interventions Across Childhood and Young Adulthood

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Coordinator:
Prof. Elena CAVALLINI

Doctoral candidate:
Dr. Sara BASILICO

Tutor:
Prof. Hellas CENA

Co-tutors:
Prof. Juana Esther CUADRADO SOTO
Prof. Androniki NASKA

For all important changes, we must take a leap of faith

— *William James*

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Abbreviations

The following abbreviations are used in this thesis:

ACP	Average consumption percentage
ASD	Autism Spectrum Disorder
BAMBI	Brief Autism Mealtime Behavior Inventory questionnaire
BMI	Body Mass Index
COSI	Childhood Obesity Surveillance Initiative
CREA	Centro di Ricerca Alimenti e Nutrizione
CRF	Case Report Form
DVM	Dosso Verde Milano
DVP	Dosso Verde Pavia
Edisu	Ente per il diritto allo Studio Universitario
FS	Food Selectivity
IMN	Istituto di Ricerche Farmacologiche Mario Negri IRCCS (IMN)
KIDMED	Mediterranean Diet Quality Index for children and adolescents
LDNC	Laboratory of Dietetics and Clinical Nutrition
LIVELY	MuLtidimensional school-based and family Involved interVentions, to promote a hEalthy and sustainable LifestYle for the childhood obesity primary prevention
MCA	Multiple Correspondence Analysis
MD	Mediterranean Diet
MedQ-Sus	New Validated Short Questionnaire for the Evaluation of the Adherence of Mediterranean Diet and Nutrition Sustainability questionnaire
NCDs	Non communicable diseases
OSA	Office for Sustainable Actions
P.I.	Principal Investigator
PDAT	Pictorial Dietary Assessment Tool
SD	Standard deviation
SDGs	Sustainable Development Goals
STEP	Screening Tool for Feeding Problems questionnaire
TP	Fondazione Tiglio Onlus
UNESCO	United Nations Educational, Scientific and Cultural Organization
WC	Waist circumference
WHO	World Health Organization
WHtR	Waist-to-height ratio

Abstract

Introduction: Unhealthy and unsustainable dietary patterns represent a major public health challenge, contributing to the rising burden of obesity, non-communicable diseases, and environmental degradation. Access to healthy and sustainable diets is shaped by complex interactions between individual, social, and environmental determinants, which vary across the life course and across contexts. Evidence increasingly shows that isolated, individual-focused interventions are insufficient to produce equitable and lasting changes in dietary behaviors, highlighting the need for context-specific and multidimensional strategies.

Aim: This thesis aims to explore how multidimensional, context-adapted interventions can promote access to healthy and sustainable eating behaviors across different life stages and population groups. Specifically, it examines the feasibility, acceptability, and implications for policy of interventions implemented in school settings (childhood), university food environments (young adulthood), and collective catering contexts for individuals with clinical and functional vulnerabilities.

Methods: Three applied intervention studies were conducted. The LIVELY project implemented a school-based nutrition education program with family involvement in a multicultural, low socioeconomic urban setting. The FOOD-HACK project tested environmental nudging strategies in a university cafeteria to promote healthier and more sustainable food choices. The AUT-MENU project evaluated the feasibility of sensory-informed, nutritionally tailored menu adaptations combined with caregiver education in collective catering settings for individuals with autism spectrum disorder. Quantitative and qualitative data were collected using anthropometric measures, questionnaires, food consumption assessments, and acceptability evaluations, depending on the context.

Results: Across the three studies, interventions were feasible and generally well accepted by participants and stakeholders. While short-term changes in dietary behaviors and consumption were modest and context-dependent, all interventions demonstrated the potential to improve food environments without compromising acceptability. School-based education enhanced nutrition knowledge and engagement; nudging strategies influenced food selection toward healthier and more sustainable options; and sensory-informed menu

adaptations supported the inclusion of nutritionally relevant foods in vulnerable populations. Structural and contextual factors, including institutional constraints, cultural diversity, and sensory sensitivities, strongly influenced outcomes.

Discussion: Taken together, the findings indicate that improving access to healthy and sustainable diets requires flexible, context-sensitive, and integrated approaches rather than uniform solutions. The evidence supports a shift from isolated educational actions toward multidimensional strategies that combine education, environmental modification, and policy support across the life course. These results provide a basis for informing food policies that prioritize feasibility, equity, and sustainability, and that can be adapted and scaled across diverse institutional settings to promote healthier and more inclusive food environments.

Preface

One Health [1]. Health for all. A concept that goes beyond the individual and embraces a vision of well-being that is equitably distributed and deeply interconnected with the environment and animals. Human health cannot be considered in isolation; it is part of a complex system in which ecosystems, production chains, and social dynamics are interdependent. Within this perspective, sustainability becomes an essential prerequisite, not only environmental, through the preservation of ecosystem functions over time, but also economic, to ensure stability and growth, and social, to guarantee equity in well-being, safety, education, and health across genders and socio-economic groups.

Despite these principles, strongly reaffirmed by the 2030 Agenda and its 17 Sustainable Development Goals (SDGs) [2], today's food system is facing a profound crisis. It overuses environmental and animal resources beyond their regenerative capacity, struggles to provide safe and nutritionally adequate food for a growing population, and contributes substantially to climate change, accounting for nearly one-third of global greenhouse gas emissions. At the same time, a striking paradox persists: more than 700 million people experience hunger, while nearly one-third of the food produced worldwide is wasted.

This crisis affects not only ecosystems and economies but also, and increasingly, public health. Its most tangible manifestation is the coexistence of multiple forms of malnutrition: on one side, undernutrition and food insecurity; on the other, a dramatic rise in obesity. Obesity, in particular, represents one of the most pervasive public health challenges of modern times [3] [4], a chronic, multifactorial condition that mirrors the contradictions of an unsustainable food and information system.

Several factors contribute to this trajectory, including the ongoing nutrition transition. Across regions, traditional dietary models such as the Mediterranean diet (MD), recognized by United Nations Educational, Scientific and Cultural Organization (UNESCO) as part of the world's intangible cultural heritage, are progressively being replaced by Westernized dietary patterns rich in ultra-processed foods, refined sugars, and saturated fats [4,5]. Initially observed in high-income countries, this transition is now widespread in low- and middle-income settings,

further increasing the global burden of obesity and diet-related non-communicable diseases [6].

This transition is closely intertwined with broader lifestyle changes. Daily routines have become increasingly sedentary, with declining levels of physical activity, particularly among children and adolescents [7–9]. At the same time, digital technologies have profoundly reshaped food environments. Beyond their contribution to sedentary behaviors, digital media expose children and young people to pervasive marketing of unhealthy foods and to persuasive, algorithm-driven content that shapes food preferences from an early age [10,11].

If obesity and malnutrition are complex and multifactorial conditions, one critical determinant deserves particular attention: the environments in which food-related information is produced, disseminated, and interpreted. In an era of unprecedented access to information, individuals are increasingly confronted with contradictory, simplified, or commercially driven messages about nutrition. This information overload often exceeds individual capacity for critical appraisal, contributing to confusion rather than informed choice.

In this context, relying solely on individual responsibility or nutritional knowledge is insufficient. When information environments are fragmented and food environments systematically promote unhealthy choices, even well-informed individuals may struggle to translate knowledge into practice. This highlights the need for approaches that go beyond information provision and address the structural, social, and environmental conditions that shape everyday food choices.

These challenges set the background for the present thesis, which focuses on food environments and access to healthy and sustainable diets across the life course, exploring how context-specific, multidimensional interventions can contribute to more equitable and sustainable food systems from childhood to young adulthood.

Chapter 1.

Introduction.

1. Global food systems and health equity

1.1. Food systems and their role in shaping diets

Food systems encompass the complex network of actors, activities, environments, and policies involved in the production, processing, distribution, consumption, and disposal of food [12,13]. Rather than being neutral mechanisms that simply deliver food from farm to plate, food systems are powerful determinants of dietary patterns, nutritional status, and health outcomes at population level [14,15]. In this sense, diets are not merely the result of individual preferences but the product of systemic structures that influence what foods are available, affordable, accessible, and socially acceptable.

Over the past decades, global food systems have undergone profound transformations driven by urbanization, globalization, technological innovation, and economic pressures [16]. These changes have increased food availability and reduced hunger in many regions; however, they have also contributed to the widespread adoption of unhealthy and unsustainable dietary patterns [17]. Energy-dense, ultra-processed foods have become increasingly prevalent, often replacing traditional diets rich in minimally processed, plant-based foods [4,5]. This global dietary shift has been closely associated with the rising burden of non-communicable diseases, obesity overall, and diet-related health inequalities [18,19].

Food systems do not affect all population groups equally. Socio-economic position, geographic location, age, and health status interact with food system characteristics to create unequal opportunities for accessing healthy and sustainable diets [20–22]. Populations experiencing economic disadvantage are often disproportionately exposed to food environments characterized by limited availability of fresh foods and a high density of inexpensive, unhealthy options [20–22]. Similarly, children, young adults, and individuals with specific clinical or functional vulnerabilities may be particularly sensitive to environmental cues and structural barriers embedded within food systems [20–22].

Afar health outcomes, food systems are also major drivers of environmental degradation, contributing significantly to greenhouse gas emissions, biodiversity loss, water use, and land degradation [23–25]. The environmental impacts of current food systems threaten their long-term capacity to provide adequate and nutritious food, thereby reinforcing a feedback loop

between ecological unsustainability and compromised human health [23,26]. As a result, the concept of healthy diets can no longer be disentangled from that of sustainability, requiring a systemic perspective that considers both human and planetary health [23].

Recognizing the central role of food systems in shaping diets shifts the focus from individual responsibility toward shared accountability across sectors, including agriculture, education, public health, urban planning, and policymaking. This perspective underscores the necessity for integrated, context-specific interventions that can effectively address the structural determinants of food choice across various settings and life course stages.

1.2. Sustainable Development Goals: Zero Hunger, Good Health and Well-being and Responsible Consumption and Production

The adoption of the 2030 Agenda for Sustainable Development by the United Nations marked a pivotal moment in global efforts to address interconnected challenges related to health, food security, and environmental sustainability [2]. Among the 17 SDGs, SDG #2 (Zero Hunger), SDG #3 (Good Health and Well-being), and SDG #12 (Responsible Consumption and Production) are particularly relevant to the transformation of food systems and the promotion of healthy and sustainable diets [2].

SDG #2 aims to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture [2]. While historically focused on undernutrition and food availability, contemporary interpretations of SDG #2 increasingly emphasize diet quality, equity in food access, and the sustainability of food production systems. Evidence suggests that achieving food security without addressing nutritional adequacy and environmental sustainability may paradoxically exacerbate the global burden of obesity and non-communicable diseases [19,27]. Thus, SDG #2 cannot be considered in isolation, but must be aligned with broader health and sustainability objectives.

SDG #3 recognizes unhealthy diets as a major modifiable risk factor for global morbidity and mortality [2]. Diet-related risks are among the leading contributors to the global burden of disease, highlighting the need for upstream interventions targeting food environments and food systems rather than individual behavior alone [28].

SDG #12 addresses the environmental externalities of current production and consumption patterns [2]. Food production and consumption are key contributors to climate change and resource depletion, with animal-based and ultra-processed foods exerting a disproportionate

environmental impact [23,29]. Dietary shifts toward healthier and more plant-forward patterns are therefore increasingly framed as strategies capable of delivering co-benefits for health and sustainability.

Crucially, the intersection of SDG #2, SDG #3, and SDG #12 underscores the need for integrated approaches that address nutrition, health, equity, and sustainability as interdependent outcomes of food systems. Recent frameworks emphasize that healthy diets are not only a matter of nutrient adequacy, but also of affordability, cultural acceptability, and environmental impact [30]. This integrated vision challenges traditional policies and calls for coordinated actions across agriculture, health, education, and social protection sectors.

1.3. The nexus between food security, food safety, food access, sustainability and health

The concepts of food security, food safety, food access, sustainability, and health are deeply interconnected. Together, they form a complex nexus that shapes dietary patterns, health outcomes, and social equity across populations and life stages.

Food security is defined as a condition in which all people have physical, social, and economic access to sufficient, safe, and nutritious food [31]. In high-income countries, however, food insecurity increasingly manifests as poor diet quality and limited access to healthy foods rather than insufficient caloric intake [20]. As a result, food insecurity has been paradoxically associated with both undernutrition and obesity, particularly among socio-economically disadvantaged groups [32,33].

Food access represents a critical operational component of food security, encompassing economic affordability, physical availability, and social and cultural acceptability of foods [34,35]. Economic constraints remain one of the most powerful barriers to healthy eating, as nutrient-dense and environmentally sustainable diets often have higher monetary costs compared to energy-dense, ultra-processed alternatives [36,37].

Food safety represents a foundational component of food security and public health. Unsafe food contributes substantially to the global burden of disease and disproportionately affects vulnerable populations, including children [38]. Climate change and environmental degradation further threaten food safety, strengthening the link between sustainability and health [39,40]. Sustainability adds a further layer of complexity to this nexus by introducing environmental considerations.

Current food systems are simultaneously failing to ensure healthy diets for all and exceeding planetary boundaries [23]. Diets high in animal-based products and ultra-processed foods are associated with both adverse health outcomes and substantial environmental impacts, including greenhouse gas emissions, land use, and water consumption [23,29,41]. Conversely, dietary patterns rich in plant-based foods have the potential to deliver co-benefits for human health and environmental sustainability, provided that issues of affordability and cultural acceptability are adequately addressed. Health outcomes emerge from the cumulative interaction of these dimensions. Poor access to safe, affordable, and sustainable foods increases the risk of obesity and non-communicable diseases, while ill health can in turn limit food access and utilization. This bidirectional relationship highlights the importance of integrated, system-oriented strategies capable of addressing multiple dimensions of the food system simultaneously [42,43].

2. Determinants of access to healthy and sustainable diets

Access to healthy and sustainable diets is shaped by a complex interplay of economic, environmental, and knowledge-related determinants. These factors operate at multiple levels, individual, household, community, and systemic, and interact with broader food system structures to influence dietary behaviors and health outcomes. Importantly, barriers to access are not evenly distributed across populations, but disproportionately affect vulnerable groups across the life course, reinforcing existing health and social inequalities. Understanding these determinants is essential for designing effective, context-specific interventions capable of improving diet quality in real-world settings.

2.1. Economic and socio-economic determinants: food poverty and the cost of a healthy diet

Economic constraints represent one of the most significant barriers to accessing healthy and sustainable diets [44]. Food poverty, broadly defined as the inability to secure adequate and nutritious food due to financial limitations, affects a substantial proportion of households even in high-income countries [20,45]. Rising food prices, income instability, and widening social inequalities have further exacerbated this phenomenon, increasing reliance on low-cost, energy-dense foods with poor nutritional profiles [32].

Unfortunately, healthier dietary patterns are consistently more expensive than less healthy alternatives [46]. Diets rich in fruits, vegetables, whole grains, and high-quality protein sources are associated with higher monetary costs, while ultra-processed foods offer a low-cost means of meeting energy needs [32,47]. Similarly, environmentally sustainable diets, particularly those aligned with plant-forward recommendations, may entail higher upfront costs, posing additional challenges for low-income households [48]. These economic barriers constrain food choice and limit the feasibility of dietary guidelines for large segments of the population.

Socio-economic status influences not only purchasing power, but also exposure to food insecurity and diet-related stressors [49,50]. Individuals experiencing economic disadvantage often face trade-offs between food expenditure and other essential needs, such as housing, healthcare, and education [51]. These trade-offs are particularly salient during sensitive life stages, including childhood and young adulthood, when economic dependence and transitional living conditions may further restrict food access. In such contexts, interventions that fail to account for affordability risk reinforcing inequalities rather than reducing them.

2.2. Environmental determinants: nutrition transition, food systems and the obesogenic environment

Environmental determinants play a central role in shaping access to healthy and sustainable diets, operating through the broader transformation of food systems and food environments. One of the most influential processes underlying these changes is the global nutrition transition, characterized by a shift from traditional dietary patterns toward Westernized diets high in energy density, animal-based products, added sugars, fats, and ultra-processed foods [4,5]. This transition has occurred rapidly across both high- and middle-income countries and has profoundly altered the contexts in which food choices are made [52].

The Westernization of dietary patterns has been closely linked to urbanization and globalization of food markets. Traditional, minimally processed foods are increasingly displaced by standardized, highly palatable products designed for convenience, long shelf life, and aggressive marketing [53,54]. As a result, dietary behaviors are increasingly driven by environmental exposure rather than individual preference alone [53,54]. Ultra-processed foods (UPFs) represent a defining feature of contemporary obesogenic food environments [55]. Characterized by high levels of industrial processing, additives, and low nutritional quality, UPFs are widely accessible across school, workplace, and food service settings [56–59]. A

substantial body of evidence links high consumption of UPFs to poorer diet quality, increased energy intake, obesity, and cardiometabolic risk [56,60].

At the same time, digital food environments have emerged as powerful and increasingly influential determinants of dietary behavior [61,62]. Social media platforms, food delivery apps, and digital advertising ecosystems expose individuals, particularly children and young adults, to continuous marketing of unhealthy food products [61,63]. Digital marketing strategies often rely on personalized content, influencers, gamification, and emotional appeals, blurring the boundaries between advertising and entertainment [64,65]. Evidence indicates that exposure to digital food marketing is associated with increased preferences for and consumption of energy-dense, nutrient-poor foods, reinforcing unhealthy dietary norms [62,66].

Taken together, the nutrition transition, the proliferation of ultra-processed foods, and the expansion of digital food environments illustrate how contemporary food systems systematically shape dietary behaviors. Addressing these environmental determinants requires multi-level and context-sensitive approaches capable of reshaping food environments in ways that promote healthy and sustainable choices across the life course.

2.3. Knowledge determinants: the role of food literacy and education

While structural factors play a central role, knowledge and skills related to food and nutrition also influence access to healthy diets [67]. Food literacy encompasses a broad set of competencies, including the ability to plan meals, interpret nutrition information, prepare food, and critically evaluate food-related messages [68]. Higher levels of food literacy have been associated with better diet quality and healthier eating behaviors across diverse life stages [69–72].

However, knowledge alone is rarely sufficient to overcome economic and environmental barriers. Educational interventions that focus exclusively on individual responsibility risk placing undue burden on individuals while neglecting the structural constraints that limit choice [22,73,74]. This limitation is particularly evident among populations facing socio-economic disadvantage or clinical vulnerabilities, where knowledge may not translate into behavior change in the absence of supportive environments [73,75].

Effective strategies therefore integrate food literacy within broader, multi-level interventions that address affordability and availability alongside education. School-based programs,

family-involved interventions, and context-specific educational approaches have demonstrated potential to improve dietary behaviors when embedded within supportive food environments [76]. Such integrated models are particularly relevant for childhood and young adulthood, where educational settings offer unique opportunities to promote long-term healthy and sustainable eating patterns.

3. Vulnerabilities across the life course

Access to healthy and sustainable diets is not uniform across the population but varies substantially across the life course, reflecting differences in biological, social, cognitive, and environmental susceptibility [77]. Certain life stages represent periods of heightened vulnerability, during which food environments and structural determinants exert a particularly strong influence on dietary behaviors and long-term health trajectories [78,79]. Adopting a life-course perspective is therefore essential for understanding how inequalities in food access emerge, accumulate, and persist, and for designing interventions that are both effective and equitable.

3.1. Childhood as a critical window

Childhood represents a critical window for the development of dietary preferences, eating behaviors, and metabolic health [80–82]. Early-life nutrition has lasting effects on growth, cognitive development, and the risk of obesity and non-communicable diseases later in life [83,84]. During this period, children are highly dependent on their immediate environments, including family, school, and community food settings, which strongly shape food exposure and consumption patterns [85,86].

Modern food environments pose several challenges for children. The widespread availability of ultra-processed foods, combined with pervasive marketing exposure through traditional and digital media, has normalized dietary patterns characterized by high energy density and low nutritional quality [61,63]. Children are especially susceptible to marketing strategies due to limited cognitive ability to recognize persuasive intent, making them a key target of unhealthy food promotion [64,65,87]. These environmental pressures interact with socio-economic constraints, increasing the risk of unhealthy diets among children from disadvantaged backgrounds [88].

Schools represent a central setting for influencing children's diets, as they provide regular meals and opportunities for nutrition education while reaching diverse socio-economic groups [89–91]. School-based interventions that integrate food environment modifications with educational components have demonstrated potential to improve diet quality and reduce inequalities [92,93]. Importantly, interventions implemented during childhood may yield long-term benefits by shaping food preferences and behaviors that track into adolescence and adulthood.

3.2. Young adulthood and the transition to college

Young adulthood represents another vulnerable life stage characterized by increasing autonomy, identity formation, and major lifestyle transitions. Once individuals enter adult life, dietary patterns tend to stabilize and track over time [79,94]. Early adulthood may therefore represent a critical transition period between adolescence and adulthood, offering a key window of opportunity for the establishment of high-quality dietary patterns that can prevent Non communicable diseases (NCDs) later in life [95].

This life stage, typically spanning from late adolescence to the third decade of life (approximately 16–30 years), is marked by multiple and often simultaneous transitions [78,79]. These include moving out of the parental home, gaining financial independence, and navigating new educational or occupational pathways, such as entering university or the workforce [78,79]. Such transitions profoundly reshape food-related environments and behaviors. Leaving the family home, in particular, alters the domestic food environment and grants young people greater autonomy in food choices, often accompanied by reduced structure and support [96]. At the same time, young adults experience increased exposure to new institutional food environments. University campuses and workplaces often prioritize convenience, affordability, and palatability over nutritional quality and sustainability, with widespread availability of fast food, sugar-sweetened beverages, and ultra-processed products [97–99]. Consistent evidence indicates a deterioration in diet quality during this period, characterized by reduced consumption of fruits and vegetables and increased intake of fast food and energy-dense foods [100,101]. Despite these challenges, young adulthood also represents a strategic opportunity for intervention. During this phase, individuals are actively shaping long-term habits, values, and identities, including growing awareness of sustainability, health, and social responsibility [77,102]. Interventions targeting university

food environments, particularly those based on environmental modification and nudging strategies, have shown promise in supporting healthier and more sustainable food choices while preserving individual autonomy [103–106]. Such approaches are especially relevant for addressing the structural determinants of diet during this critical transitional period and form the basis for the intervention strategies explored in this thesis.

3.3. Clinical and functional vulnerabilities: the case of autism spectrum disorder

Beyond age-related vulnerabilities, certain populations experience heightened dietary challenges due to clinical or functional conditions. Autism spectrum disorder (ASD) represents a paradigmatic example of how neurodevelopmental characteristics interact with food environments to shape food access and dietary behaviors [107]. Individuals with ASD frequently experience food selectivity (FS), sensory sensitivities, and rigid eating patterns, which can limit dietary variety and nutritional adequacy [108,109]. Food-related challenges in ASD are not solely attributable to individual characteristics but are strongly influenced by environmental and contextual factors [109,110]. Limited availability of acceptable foods in institutional settings, lack of tailored nutritional support, and insufficient caregiver guidance may exacerbate existing vulnerabilities [107,111]. These challenges can persist across the life course, affecting not only nutritional status but also quality of life [112]. Interventions targeting food access in ASD therefore require highly specialized and individualized approaches that account for sensory, behavioral, and environmental constraints [113,114]. Multidisciplinary strategies involving caregivers, educators, and healthcare professionals are essential to support healthier eating patterns while respecting individual needs [113–115]. Addressing clinical and functional vulnerabilities within food systems highlights the importance of inclusive and adaptable interventions capable of reaching diverse population groups.

Chapter 2.

Rationale

1. Context-Specific Interventions: why no single strategy is sufficient

The growing burden of diet-related diseases and the persistence of inequalities in access to healthy and sustainable diets highlight the limitations of single-component and individual-focused interventions [116,117]. Despite widespread dissemination of dietary guidelines and nutrition education programs, improvements in population diet quality have remained modest, particularly among vulnerable groups [118]. This gap between knowledge and behavior underscores the need to move beyond reductionist approaches and to address the structural and contextual determinants that shape food choice.

Food systems and food environments are inherently complex, operating through interconnected economic, environmental, social, and cultural mechanisms [12,13,119]. As a result, no single strategy, whether educational, environmental, or policy-based, is sufficient to produce meaningful and equitable changes in dietary behaviors across diverse populations and settings [19,120]. Interventions that fail to account for context risk limited effectiveness, poor scalability, or unintended consequences, including the exacerbation of health inequalities [121].

Context-specific interventions recognize that food choices are embedded within everyday environments and life circumstances. Children, young adults, and individuals with clinical or functional vulnerabilities experience distinct barriers and opportunities related to food access, autonomy, and exposure to food environments [21]. School settings, university campuses, and clinical or specialized contexts differ substantially in terms of institutional structures, stakeholder involvement, and leverage points for change [122]. Consequently, effective interventions must be tailored to these contexts while remaining grounded in a shared conceptual and theoretical framework.

Multi-level and systems-based approaches that combine environmental modifications, behavioral insights, and educational components seem more effective [122,123]. School-based interventions integrating food provision changes with nutrition education and family involvement, nudging strategies that reshape choice architecture in food service settings, and tailored interventions addressing the specific needs of vulnerable populations all demonstrate the potential of context-sensitive strategies to improve dietary behaviors [92,106,113,124].

Importantly, these approaches shift responsibility away from individuals alone and toward shared accountability across systems, institutions, and policies. Multidimensional interventions are particularly well suited to simultaneously address health, sustainability, and equity objectives. By targeting food environments and structural determinants, such interventions can improve diet quality, reduce environmental impact, and promote fair access to healthy diets.

2. Thesis Aim

This thesis's main goal is to examine how multifaceted, context-specific interventions can encourage sustainable and healthful eating habits by enhancing access to wholesome food and altering eating environments at key life stages. These phases are thought of as an ongoing cycle of vulnerability and opportunity where eating habits are gradually molded by shifting degrees of autonomy, exposure to the environment, and structural limitations while still being heavily impacted by past experiences and situations.

Specifically, this thesis focuses on three complementary population groups and settings:

- Childhood, through a school-based, family-involved intervention aimed at promoting healthy and sustainable dietary behaviors and preventing obesity in early life.
- Young adulthood, through an environmental and nudging-based intervention within a university food environment designed to support healthier and more sustainable food choices during a key transitional period.
- Clinical and specialized settings, through a tailored intervention addressing food access and dietary challenges among individuals with autism spectrum disorder.

Rather than being conceived as independent research projects, these three studies are intentionally framed as complementary examples of multidimensional interventions. When taken as a whole, they show how various scenarios of vulnerability, and environment necessitate different but conceptually related intervention strategies, such as early preventive action, environmental support during transitional phases, and customized adaptations when functional or clinical constraints are present.

Each study addresses specific configurations of structural, environmental, and behavioral determinants of food access across the life course. Across these contexts, the thesis seeks to address the following objectives:

- To examine how modifications of food environments can influence dietary behaviors;
- To assess the feasibility and effectiveness of interventions that integrate education, health, and equity considerations;
- To identify common drivers and context-specific mechanisms that shape access to healthy and sustainable diets across the life course.

By adopting a life-course and food systems perspective, this thesis contributes to the growing body of research emphasizing the need for integrated approaches to nutrition and public health.

Chapter 3.

Experimental Part

1. Study 1 - Childhood: The LIVELY Project

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1.1. Introduction: The School Environment in Health Promotion and obesity prevention

Childhood obesity is recognized as a chronic and multifactorial condition, resulting from the interaction of genetic, behavioral, and environmental determinants [125]. Its prevalence has increased substantially worldwide over recent decades, making it one of the most pressing public health challenges [3]. Children with obesity are at higher risk of developing metabolic, cardiovascular, and psychological complications, with long-term consequences that often persist into adulthood [126,127]. Consequently, effective prevention strategies must move beyond individual behaviors and address the broader environments in which children live and grow [128,129].

In this context, the school environment has been widely identified as a key setting for health promotion and obesity prevention. Schools reach children during a critical developmental window, provide daily exposure to food and physical activity opportunities, and offer a structured context in which health-promoting behaviors can be supported across socio-economic groups. According to the World Health Organization (WHO), approximately 25% of children aged 7 to 9 years in the European region are affected by overweight or obesity [130]. In Italy, prevalence remains particularly high, approaching 40%, with marked regional inequalities that disproportionately affect southern areas [131,132].

School environments are embedded within broader societal changes that have reshaped children's dietary and lifestyle patterns. The global nutrition transition has led to a progressive shift from traditional dietary models, such as the MD, toward Westernized diets rich in ultra-processed foods, added sugars, and unhealthy fats [4–6]. At the same time, modern lifestyles have become increasingly sedentary, with reduced physical activity and increased screen time among children, contributing to higher obesity risk and adverse effects on mental health and academic performance [7–11,133].

In parallel, schools are increasingly characterized by cultural and socio-economic diversity, reflecting migration flows and social inequalities. Differences in cultural food practices,

combined with limited access to healthy foods and greater exposure to obesogenic environments, may further hinder the adoption of healthy dietary behaviors, particularly among children from disadvantaged or migrant backgrounds [21,22,73,74,134,135].

These dynamics highlight the need for school-based interventions that are inclusive and sensitive to social and cultural determinants of health.

Nutrition education represents a core component of school-based health promotion strategies [89,90]. Accordingly, numerous interventions have been implemented worldwide, demonstrating improvements in nutrition knowledge, dietary behaviors, and physical activity levels when programs are culturally tailored and context-specific [91,136–138]. In Italy, although national initiatives have promoted the inclusion of nutrition education within school curricula, implementation remains heterogeneous [139,140]. Several projects targeting primary school children have shown promising results, including improvements in nutritional knowledge, eating habits, and lifestyle behaviors [92,124,139,141].

In this context, the LIVELY project (MuLtidimensional school-based and family Involved interVentions, to promote a hEalthy and sustainable LifestYle for the childhood obesity primary prevention) was developed as a multidimensional intervention centered on the school environment and reinforced by family involvement. By integrating structured nutrition education within schools and extending its influence to the family context, LIVELY aimed to promote healthy and sustainable eating behaviors and to provide a scalable model for childhood obesity prevention.

1.2. Study Design and Methodology

1.2.1. Study design and setting

The LIVELY project was a single arm pre -post study (without control) conducted by a multidisciplinary team consisting of researchers from the Istituto di Ricerche Farmacologiche Mario Negri IRCCS (IMN) of Milan and the Laboratory of Dietetics and Clinical Nutrition (LDNC) of the University of Pavia [142]. The study was carried out at Istituto Comprensivo "Luigi Cadorna", a public primary school with a strong multiethnic component in the North-West of Milan, Italy, from October 2023 to October 2024. The study was approved by the Fondazione IRCCS Istituto Neurologico Carlo Besta Ethics Committee (protocol 11) in January 2023. The timeline of the study is shown in **Figure 1**.

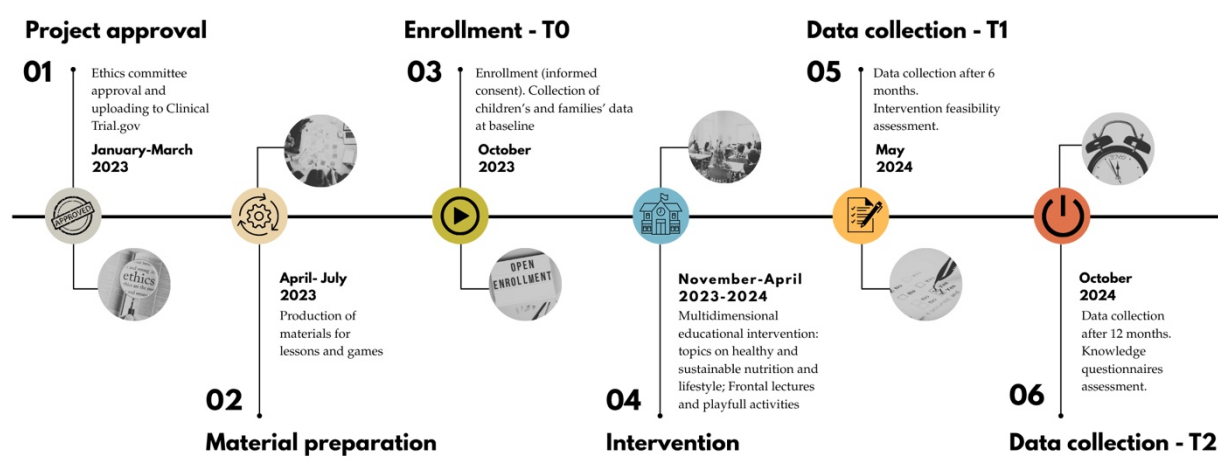


Figure 1. Timeline of LIVELY project

1.2.2. Study objectives

The primary objective of this study was to assess the prevalence of overweight and obesity among primary school children and identify the key determinants related to their lifestyle habits, family socioeconomic status, and environmental influences.

The secondary objective was to evaluate the feasibility of a structured multidimensional educational intervention in terms of participant satisfaction, learning outcomes, and organizational impact within the school environment. Furthermore, the project aimed to examine potential changes in children's dietary and lifestyle habits, as well as shifts in family behavioral attitudes, at 6- and 12-months post-intervention.

1.2.3. Selection criteria and enrollment

The target population consisted of children aged 5 to 12 years, of both sexes and any ethnicity, with no exclusion criteria. In June 2023, during the final teaching board meeting, the research team presented the project to the school dean and teachers. Fourteen classes approved participation and formally included the intervention within the school curriculum for the 2023–2024 academic year.

In October 2023, informed consent and privacy forms were distributed to parents. Participation in data collection was voluntary, and only children whose parents returned the signed consent were enrolled in the study and included in anthropometric assessments and questionnaires.

However, as the educational intervention was embedded within a mandatory curricular subject (Civic Education) and delivered during school hours between November 2023 and

April 2024, all children attending the participating classes were involved in the educational activities and were assessable for the evaluation of learning outcomes and project appreciation, regardless of their participation in data collection.

1.2.4. Educational intervention

The educational intervention was structured into six thematic modules, interspersed with a multimedia workshop. A detailed description of the modules is reported in **Table 1** (page 78). Each lesson was delivered every four weeks, lasted approximately two hours, and was divided into two parts:

- a frontal lesson of 30–40 minutes supported by interactive slides, and
- a practical session of 80–90 minutes consisting of age-appropriate, playful activities.

The intervention was delivered by trained professionals, including nutritional biologists and registered dietitians. Teaching materials were developed in accordance with the 2018 Centro di Ricerca Alimenti e Nutrizione (CREA) Guidelines [143], WHO Guidelines [144], and the Harvard Kid's Healthy Eating Plate [145].

After the first five lessons, which focused on the principles of healthy and sustainable eating, a multimedia workshop was conducted in collaboration with the Officine Creative of the University of Pavia. The workshop aimed to consolidate previously acquired knowledge through creative expression, peer discussion, and collaborative storytelling.

MULTIMEDIA WORKSHOP

During the multimedia workshop, children were divided into small groups of 5–6 participants. Each group selected a food item from a bag using touch alone; foods could be either fresh or packaged. Following group selection, the class collectively voted to choose one food item to be further developed.

Each group then created a character based on the selected food by completing a character profile, including name, personality traits, mood, special abilities, and a distinctive action (**Figure 2a**). The food item was subsequently illustrated in a humanized form (**Figure 2b**).

Narrative elements were introduced through “story-creator” cubes, which determined the setting, helper character, magical object, and an unexpected event. Using these elements, each group developed a short story featuring the food character as the protagonist. Selected drawings were later processed and animated using augmented reality techniques (**Figure 2c**).

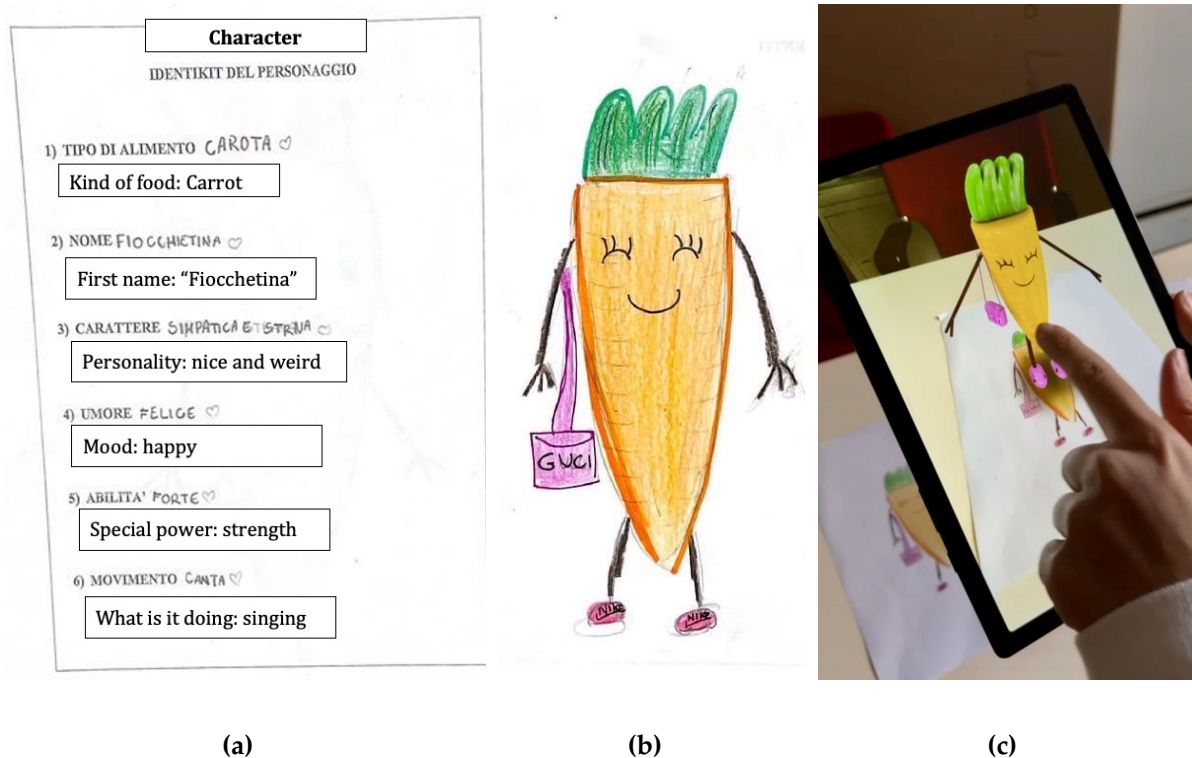


Figure 2. Example of a character realized during the multimedia workshop and animated using augmented reality techniques. (a) Description of the main features of the depicted fantasy character; (b) Humanized carrot drawn by a fourth-grade class; (c) Animation through a tablet.

FAMILY ENGAGEMENT

Family involvement was an integral component of the intervention. After each lesson, a summary slide of the content covered was shared with parents to reinforce learning at home (**Figure S1**, page 91).

At the end of the school year (T1), a multicultural celebration was organized, during which families were invited to bring a traditional dish from their country of origin.

Two educational deliverables were distributed during this event. The first included, on one side, the healthy plate model presented during the intervention (Module 5), and on the other side, practical tips for preparing a balanced breakfast (Module 6) (**Figure S2**, page 92).

In addition, children, with the support of their families, contributed a healthy traditional recipe from their country of origin. Recipes were collected, categorized, and compiled into a digital recipe book, with brief comments highlighting nutritional value and suggestions for healthier and more sustainable adaptations [<https://backend.onfoods.it/sites/default/files/2024-06/Ricettario%20multietnico%20Progetto%20LIVELY.pdf>].

1.2.5. Data collection

Referring teachers distributed an ad-hoc Case Report Form (CRF), in paper format, to each child whose parents signed the informed consent and then took charge of collecting them once they were filled out by the parents. The questionnaires were translated in different languages (Italian, Arabic and English) due to the high multiethnicity of the school. Researchers at the IMN reported the data into an electronic, web-based CRF (eCRF) implemented using the REDCap software platform and specifically made for this study [146]. Each participant was assigned a unique code to link their data securely while protecting their identity. Anthropometric measures and all the other questionnaires were collected at baseline (October 2023, T0), at 6 months (May 2024, T1), and at 12 months after intervention delivery (October 2024, T2).

1.2.6. Primary outcome

ANTHROPOMETRIC MEASURES

Children's anthropometric measurements were assessed by a team of trained nutritionists.

Children's weight was measured using the same digital scale (Tanita BC545N) and it was recorded to the nearest 0.1 kilogram. Height was measured using a portable altimeter (Seca 213) and recorded to the nearest centimeter. All children were measured without shoes and wearing light clothing. In addition, the type of clothing worn at the time of measurement was recorded for each child. Waist circumference (WC) was measured with an inelastic tape placed midway between the lower rib and the iliac crest and recorded to the closest 0.5 cm; the measurement was taken while the child was standing upright, with feet together and arms hanging down at the sides. The circumference of the non-dominant bicep was measured with an inelastic tape placed between the acromion process and the olecranon with the forearm flexed 90°, and recorded to the closest 1.0 cm

Body Mass Index (BMI) was calculated as kg/m^2 and expressed as BMI z-score by referring to the growth curves by sex and age proposed by the WHO that classify children as having underweight (BMI -2 standard deviation, [SD], below the median BMI) normal weight (BMI between -2 and +1SD), overweight (BMI +1SD, above the median BMI, equivalent to BMI 25 kg/m^2 at 19 years) or obesity (BMI +2SD, equivalent to BMI 30 kg/m^2 at 19 years) [147]. The software Anthro® and AnthroPlus® was used to calculate BMI z-score [148]. In addition, waist-to-height ratio (WHtR) was calculated as WC divided by height, both expressed in

centimeters. For the definition of central distribution of adiposity, the discriminatory value of 0.5 for WHtR was adopted [149,150]. Children were divided into two groups: the first one included children with WHtR<0.5 (normal distribution of adiposity), while the second one included children with WHtR≥0.5 (central obesity).

SOCIODEMOGRAPHIC INFORMATION

Data concerning the families (household composition, ethnicity, parents' education, and lifestyle) and the children (age, attended class, health conditions and food habits within the family) were collected through a structured questionnaire. The latter included information about whether meals were consumed with family members, the use of electronic devices (TV or smartphones) during meals, the availability and use of sweets (e.g., as rewards), and the frequency of fast-food consumption.

EATING BEHAVIORS AND LIFESTYLE

Specifically, the KIDMED questionnaire (Mediterranean Diet Quality Index for children and adolescents) [151,152] was used to assess adherence to the MD and to get an overview of the child's consumption of the main food groups (fruits, vegetables, pasta and cereals, legumes, fish, meat, and dairy products). The KIDMED questionnaire consists of yes/no items, with positive responses scored +1 and negative dietary behaviors scored -1. Adherence to MD was rated as low (score ≤4), medium (score between 5 and 7), and high (scores ≥8). To complete the questionnaire, information was requested regarding the number of meals consumed, whether children ate in the school cafeteria, whether they used sweeteners in tea or milk (e.g., sweetened cocoa, sugar, or honey), and whether they consumed whole foods. In addition, consumption of ultra-processed foods (according to the NOVA classification) was evaluated using a separate questionnaire specifically developed to assess the frequency of intake of selected ultra-processed food categories [56,153]. In addition, children's hydration levels were assessed based on the 2018 CREA Guidelines while type and load of physical activity, sleep habits, and screen time were assessed following WHO Guidelines [143,144].

1.2.7. Secondary outcome

EVALUATION OF THE EDUCATIONAL INTERVENTION

The feasibility of the multidimensional educational intervention at school was assessed, through an ad-hoc questionnaire at T1, in terms of "satisfaction" (by children, families, and teachers) and "organizational" impact in the work context (by teachers). The overall

satisfaction and organizational impact of the interventions explored the following issues: usefulness (definition and consistency/congruence of the multidimensional interventions with the project objectives, usefulness of the interventions and materials prepared), didactics (competence and appropriateness of the teaching techniques of the study teams addressed to the subjects, support received by the study teams during the implementation of the activities), organization and services (timing, facilities and appropriateness of the schools' premises). In addition, teachers were asked to refer to the reproducibility of the intervention in other classrooms or schools. All items in the questionnaire were rated on a Likert-type scale.

EVALUATION OF CHILDREN'S KNOWLEDGE

The assessment of children's knowledge on the topics covered during the nutrition education intervention was conducted using a structured questionnaire at T2. This questionnaire included true/false questions, multiple-choice items, and fill-in-the-blank exercises, with specific questions assigned to each topic. For each topic, children got a score from 1 to 10; the final score was calculated as the sum of the scores across these six topics, with a maximum possible score of 60. A passing score was defined as correctly answering at least 60% of the questions, equivalent to a minimum score of 36. This threshold was chosen based on common educational standards, where 60% is typically considered the minimum level of basic competence. It reflects a sufficient understanding of the key concepts delivered during the intervention, while allowing for some margin of error, especially given the young age of the participants and the novelty of some of the content

1.2.7. Statistical methods

SAMPLE SIZE CALCULATION

We expected to enroll about 300 to 350 children aged between 6 and 12 years from 15 to 20 classes (in primary school and in the first class of secondary school) based on the availability-willingness of teachers to participate and the resources [142]. This would have allowed us to estimate the prevalence of overweight and obesity between 23% and 24%, with a 20% relative precision and within a 95% CI [142]. These data are in line with those observed in the Okkio alla Salute 2019 survey in the Lombardy region [131].

STATISTICAL ANALYSIS

Continuous variables were expressed as mean and SD or median and interquartile range (IQR) as appropriate, and categorical variables as frequencies and percentages. Continuous variables

were compared using a T-test and categorical variables were compared with a Chi-square test. Main determinants of overweight/obesity among children have been investigated among dietary patterns and lifestyle habits, evaluated at the baseline, by means of logistic regression models. Two separate models have been fitted: the first adjusted for sex, ethnic group and dietary habits (i.e. adherence to MD and hydration), the second adjusted for sex, ethnic group and lifestyle habit (i.e. physical activity, screen time and sleeping habit). Results were expressed as Odds ratio (OR) and corresponding 95% confidence interval (95% CI). Changes in dietary and lifestyle habits in children, behavioral attitudes in their families and children's anthropometric measurements have been assessed at 6 months starting from baseline.

Although 12-month follow-up data were collected, it was not possible to perform reliable analyses due to substantial attrition and the resulting risk of bias. Consequently, long-term effects could not be evaluated. To investigate appreciation of the interventions, the frequencies of Likert-scores for each item of the questionnaires have been calculated and the distributions presented according to their frequency.

1.3. Results of the educational intervention

Fourteen classes (1 second grade, 5 third grade, 2 four grades and 6 fifth grade) with a total of 275 children, joined the educational intervention. No first-grade class took part in it. Of these, 227 children, whose parents approved and signed the informed consent, were enrolled in the study data collection. Finally, 205 children returned the questionnaires and were included in the analyses.

1.3.1. Demographic and anthropometric characteristics

Main characteristics of the 227 children enrolled are shown in **Table 2** (page 79). The mean (SD) age was 8.9 years (1.2 years), 48% (n=110) were males.

At baseline (T0) among the overall sample, 41 children (18.1%, 95% CI: 13.3%-23.7%) presented overweight, while 12 (5.3%, 95% CI: 2.8%-9.1%) presented obesity. Prevalence of overweight (including obesity) was almost similar between males and females (23.6% vs 23.1%), instead males had higher prevalence of obesity than females (9.1% vs 1.7%, p=0.03 respectively).

Differences among ethnic groups were observed: the highest prevalence of overweight was observed among Hispanic children (n=9, 29.0%), followed by African children (n=21, 24.4%), while the lowest among Caucasian (n=6, 7.3%), although obesity was almost similar among them, **Table S1** (page 104). The overall prevalence of central obesity was 33.9%, with no

significant difference between male and female (30.9% vs 36.8%). Difference exists among ethnic group, with Hispanic children showing the highest prevalence (58.1% respectively vs Caucasian 24.4%), **Table S1** (page 104).

By comparing children's measured BMI categories with parents' perception of their child's weight status (underweight, normal weight, overweight), it was found that nearly 60% of parents classified their child's weight status correctly. However, among children with overweight or obesity, parents were much more likely to underestimate their child's condition, doing so in 80.6% of cases for children with overweight and 90.0% of cases for children with obesity. Among parents, the prevalence of overweight and obesity was notably high, with 168 (82.0%) children having at least one parent presenting overweight (including obesity): 37.8% of mothers and 50.3% of fathers with overweight, and 17.6% of mothers and 10% of fathers with obesity. Additional data related to parents are presented in **Table S2** (page 104).

1.3.2. Eating behaviors and lifestyle habits

Data regarding eating behaviors and lifestyle habits at baseline are reported in **Table 3** (page 80). Out of 205 children with assessable data, most children (n=111, 55.2%) are moderately adherent to MD, only 29 (14.4%) were poorly adherent. The low adherence was mainly driven by eating few vegetables (N=122, 61.0%), not eating enough nuts (N=138, 68.3%), and dairy food (N=140, 69.6%), **Table S3** (page 105). No significant difference emerged among ethnic groups, nor among sex, although higher frequency of males showed good adherence to MD respect to females (36.4% vs 24.5%). The most consumed ultra-processed foods (more than 4 times per week) were biscuits (44.3.0%), followed by fruit juices (37.5%), and milk-based beverages (35.9%), **Table S4** (page 106).

Regarding physical activity, 9% of the children did not engage in any physical activity, while 93 (46%) and 40 (20%) reported doing a sport 1-2 or 3 times or more per week, respectively, with a median of 2 hours/week (IQR: 2-3), without addressing the WHO recommendations.

Regarding screen time, nearly 11% of respondent children spent 3 or more hours per day in front of a screen. As for sleep duration, most of the sample (67%) met the recommended guidelines by sleeping more than 9 hours per night.

1.3.3. Models

Results of the regression model were reported in **Table S5** (page 106). Among the investigated risk factors, only the ethnic group turned out to be significantly associated with BMI, in

particular African children were almost three times more likely to present overweight (or obesity) with respect to the Caucasian (OR=3.08, 95%CI: 1.29-7.34 in the first model, and almost similar results in the second one), also other ethnic group (Asiatic, Hispanic and mixed) showed higher risk. Participants with medium adherence to the MD showed a lower estimated odds of presenting overweight or obesity (OR = 0.44, 95% CI: 0.17–1.14), while those with high adherence had a similar direction of association (OR = 0.83, 95% CI: 0.31–2.26); however, neither association reached statistical significance.

1.3.4. Data after six months (T1)

ANTHROPOMETRIC MEASURES

Comparison among anthropometric measures between the baseline and six-month follow-up are shown in **Table 4** (page 80). A not significant shift in BMI classes was noted with a slight reduction of children in the obesity and overweight classes in favor of the normal-weight class. Also, according to WHtR, there was a slight reduction in the prevalence of central obesity.

EATING BEHAVIORS AND LIFESTYLE HABITS

Table 5A (page 81) shows the data regarding eating behaviors at T0 and T1 (n=186). No change was observed at T1 in MD adherence, while improvement, although not significant, in daily hydration was observed, with a higher percentage of children drinking at least 1.5L per day (13.4% vs 17.2%). However, a decline in the consumption of breakfast and whole cereals emerged. The same consumption preference for ultra-processed foods observed at T0 remained similar at the 6-month follow-up (T1), although with a slight decrease, **Table S6** (page 107).

Table 5B (page 81) shows the data about lifestyle at T0 and T1 (n=178). At T1 a favorable trend was observed in decreasing prevalence of children who did not enjoy any physical activity, while increasing that of children who enjoy planned physical activity. An improvement was also observed in the number of children who slept recommended 9 hours or more. On the other hand, screen time seems increased, although not significantly.

1.3.4. Educational intervention evaluation

CHILDREN'S KNOWLEDGE QUESTIONNAIRE

Learning questionnaires have been compiled by children at the beginning of the following school year (T2). All in all, 168 (61.1%) questionnaires out of 275 children attending the participating classes were collected. Results were provided for children who attended at least

4 out of 6 lessons (N=161, 95.83%). Overall, 85 children (52.8%) achieved a passing score based on the total lesson score, while only 11 children (6.8%) met the sufficiency in every individual topic, with higher prevalence among females in both cases.

The prevalence, instead, was lower among children attending the 2nd grade (22.2%), where no children reached the passing score in each topic. **Table 6** (page 81) reported the average score attained in each topic. The most challenging topics for children to grasp were macronutrients and micronutrients, with average scores of 4.07 (SD 2.60) and 3.92 (SD 2.54), respectively. In contrast, the most well-understood topics were the food pyramid, the healthy plate, and lifestyle, all of which had average scores exceeding 7.

CHILDREN'S SATISFACTION QUESTIONNAIRES

A total of 244 questionnaires were collected. Overall, 93.9% of children gave a positive evaluation of the educational intervention (question 1, Q1), and 92.1% found the proposed activities interesting and enjoyable (Q2). Additionally, 86.6% considered the language used appropriate for understanding the lesson (Q10), while 90.2% deemed the teaching materials suitable (Q11). On the other hand, 30% of participants reported difficulties in working with their classmates during the activities (Q7). Nevertheless, 89% expressed the desire for the project to be repeated, highlighting a high level of overall satisfaction (Q14).

Other than the playful activities, which were the most appreciated by more than half of the sample (n = 134, 54.9%), the most voted lesson was that on the "Food pyramid" (n = 102, 41.8%), while "Micronutrients" was the less (n=40, 16.4%). The results are shown in **Table S7** (page 108).

PARENTS' SATISFACTION QUESTIONNAIRES

A total of 164 families returned the completed questionnaire. Among them, 75.3% expressed great satisfaction with their child's participation (Q1), thinking their children improved their knowledge about nutrition and healthy lifestyle. The results are shown in **Table S8** (page 108).

TEACHERS' SATISFACTION QUESTIONNAIRES

The questionnaire for teachers was completed by all participants (n=18). All teachers (100%) agreed that the educational intervention objectives were well-defined (Q1). Additionally, 94.4% believed that initiatives like this could have a positive impact on public health, beyond benefiting individual children (Q2), and all respondents (100%) considered the proposed activities effective in raising children's awareness of the importance of a healthy diet (Q13).

The language and materials used received positive feedback from 72% of the teachers (Q9). However, some concerns were raised about the educational intervention ability to integrate into daily school activities (Q14), with 11% rating this aspect as “low”. Nevertheless, 77.9% expressed the desire for the project to be repeated (Q16). The results are shown in **Table S9** (page 109).

1.4. Discussion

Within the broader aim of this thesis to explore multidimensional interventions promoting healthy and sustainable eating behaviors across the life course, the LIVELY project represents a case example focused on childhood. Specifically, LIVELY was designed to evaluate the feasibility and potential impact of a school-based nutrition education intervention, integrated within the curricular context and reinforced through school and family involvement, in a multicultural primary-school setting.

The project involved 14 classes and engaged 275 children in the educational activities, with 227 children included in data collection related to overweight and obesity. The multiethnic composition of the sample, with a high representation of children of Northern African and South American origin, reflects the demographic reality of many contemporary school environments and underscores the relevance of schools as strategic settings for addressing health inequalities. The high prevalence of overweight and obesity observed in the LIVELY sample was in line with national and regional data [131,132], with higher rates among African and Hispanic children, in line with evidence on ethnic disparities in childhood obesity [154–156]. These findings highlight how childhood obesity is strongly shaped by social, cultural, and environmental determinants, reinforcing the need for interventions that go beyond individual behaviors and explicitly address equity.

To better capture adiposity in this heterogeneous population, WHtR was used alongside BMI. WHtR identified a higher prevalence of central obesity and revealed marked differences across ethnic groups, supporting the use of complementary anthropometric indicators in multiethnic pediatric populations [157,158].

In parallel, parental underestimation of children’s weight status emerged as a relevant issue, particularly among children with overweight or obesity. This phenomenon, widely reported in the literature [159–161], underscores the potential role of schools as neutral and trusted settings for obesity prevention and awareness.

After six months, favorable trends toward lower BMI categories and reduced central adiposity were observed, although changes were not statistically significant. These results are consistent with previous evidence indicating that short-term school-based interventions often initiate positive trajectories, while measurable anthropometric changes typically require longer follow-up and sustained exposure [61,62].

Dietary behavior analysis showed a moderate adherence to the MD, with low consumption of vegetables, nuts, and dairy products contributing to suboptimal scores, in line with previous findings [162]. No significant association between BMI and adherence to the MD was observed, supporting the view that anthropometric outcomes in childhood are influenced by multiple socio-demographic and environmental factors beyond diet alone [163,164]. Lifestyle behaviors further confirmed the multidimensional nature of obesity risk, with low adherence to WHO recommendations for physical activity and sleep and excessive screen time [143,144]. Together, these findings reinforce the need for integrated interventions addressing diet, physical activity, and broader lifestyle behaviors.

A central strength of the LIVELY project lies in its multidimensional design. The combination of formal nutrition education, experiential and playful activities, and structured family involvement aimed to create a supportive environment for behavior change. Family engagement initiatives, including culturally sensitive activities and shared events, are consistent with evidence showing that parental involvement enhances the effectiveness of childhood obesity prevention programs [165,166]. Similar whole-school and family-oriented approaches have been adopted in other European and Italian interventions, reporting favorable trends despite limited short-term effects [167,168].

Children's nutritional knowledge showed moderate overall levels, with better performance among older children and girls. Lower scores among younger pupils highlight the importance of age-appropriate educational strategies and raise considerations regarding the optimal timing and tailoring of nutrition education interventions [169].

The LIVELY project faced several methodological and implementation challenges which should be acknowledged. First, the study did not reach the planned sample size, limiting the statistical power to explore risk factors associated with overweight and obesity. In addition, a substantial loss to follow-up at 12 months reduced the ability to assess changes in dietary and lifestyle behaviors over time and may have introduced attrition bias. Loss to follow-up was primarily driven by the non-return of parental questionnaires. Linguistic, cultural, and social

barriers likely affected families' ability to complete study materials, particularly in a multiethnic school context. While collecting additional information from non-responders could have provided further insights into adherence and feasibility, this was not feasible given the existing difficulties in questionnaire return. Importantly, attrition itself may reflect structural challenges in engaging families in real-world school-based interventions. Baseline comparisons showed that families who did not complete the 12-month follow-up had a higher prevalence of overweight and obesity, suggesting a possible selective attrition pattern. Weight-related stigma and concerns about social identity, as previously described in the literature [170–172], may have contributed to reluctance in continued participation. These barriers also limited parental engagement and reduced opportunities to reinforce educational content beyond the classroom. Second, the intervention was conducted in a single primary school in Northern Italy and did not include a control group, limiting generalizability and causal inference. Therefore, findings should be interpreted as proof-of-concept evidence regarding feasibility and acceptability rather than definitive evidence of effectiveness. Finally, the relatively short follow-up period may not have been sufficient to detect meaningful behavioral or anthropometric changes. Previous research indicates that sustained, multi-level, and longer-term interventions, particularly those involving families, are more likely to produce lasting effects. Despite these limitations, LIVELY demonstrated high acceptability and feasibility within the school context. Children's engagement was high, interactive and digital tools were well received, and teachers expressed strong interest in replicating the intervention. Overall, the LIVELY project provides proof-of-concept evidence supporting the role of schools as strategic platforms for multidimensional interventions aimed at promoting healthy and sustainable eating behaviors in childhood, contributing to the life-course perspective developed in this thesis.

2. Study 2 - Young Adulthood: The FOOD-HACK Project

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2.1. Introduction: the role of the university food environment in promoting healthy and sustainable eating

The simultaneous crises of obesity, diet-related non-communicable diseases, and climate change form a global syndemic that highlights the urgent need to address the shared

determinants of human and planetary health [19]. Unhealthy dietary patterns contribute not only to the rising prevalence of obesity but also to environmental degradation and social inequalities, reinforcing the need for integrated and sustainable approaches to food systems and food environments. Young adulthood represents a critical life stage characterized by profound physiological, psychological, and social transitions [173]. During this period, individuals often experience increased autonomy and responsibility over food choices, alongside constraints related to limited budgets, time pressures, and reduced cooking skills. These factors frequently lead to unbalanced dietary patterns and increased reliance on processed and ultra-processed foods [101]. University students, in particular, show low adherence to healthy and sustainable dietary models such as the MD [174], while dietary habits established during this phase tend to track into later adulthood, influencing long-term health outcomes [175].

Evidence consistently shows that university students consume fewer recommended portions of key food groups, including fruits, vegetables, whole grains, legumes, and dairy products, while favoring energy-dense and sugary foods [100]. These patterns are associated with increased risk of obesity, metabolic syndrome, and other non-communicable diseases, underscoring the importance of early interventions capable of promoting healthier behaviors during this transitional period [101,176]. Importantly, early adulthood also represents a window of opportunity in which dietary trajectories may still be reshaped before becoming consolidated over time. Within this context, nudging strategies grounded in behavioral economics have emerged as promising tools to influence food choices without restricting individual freedom [176,177]. By modifying the choice architecture of food environments, nudging leverages cognitive shortcuts and decision-making biases to encourage healthier and more sustainable selections [178]. A growing body of evidence demonstrates the effectiveness of nudging techniques in food service settings, including among university students [179–182]. Common approaches include enhancing the visibility and accessibility of healthy options, using salient labels or symbols, and providing simple educational prompts at the point of choice [103,106,177,182,183].

University cafeterias represent particularly relevant settings for the application of these strategies. Many students rely on campus food services for one or more daily meals [97], making cafeterias influential environments for shaping dietary behaviors at scale. Cafeterias offer a controlled context in which relatively small environmental modifications can produce

measurable shifts toward healthier and more sustainable choices [182]. Moreover, these settings provide an opportunity to align health promotion with environmental sustainability objectives. Dietary frameworks such as the Harvard Healthy Eating Plate [184] and the Planetary Health Diet proposed by the EAT-Lancet Commission [23] emphasize plant-forward dietary patterns that benefit both human health and the environment. Expanding the availability and visibility of plant-based options has been shown to significantly increase their selection and reduce the environmental impact associated with food consumption [23,104,185,186]. Within this background, the Food-Hack Project (“One small nudge for a cafeteria, one giant impact for students”) was developed as a pilot intervention at the University of Pavia (Italy). The project aimed to explore whether subtle, cafeteria-based nudging strategies could promote healthier and more sustainable food choices among university students. Drawing inspiration from the Harvard Healthy Eating Plate [184] and the Planetary Health Diet [23], the intervention sought to increase the selection of plant-based MD components and to support the composition of nutritionally balanced meals aligned with both human and planetary health principles. Changes in food selection patterns were assessed using a pre-post design over 12 non-consecutive days, with the broader goal of informing scalable and context-sensitive interventions within university food environments.

2.2. Study Design and Methodology

2.1. Study objective

The primary aim of this study was to design and implement a cafeteria-based intervention using nudging strategies to promote healthier and more sustainable lunch choices among university students. The intervention specifically targeted an increased selection of MD plant-based components (e.g. vegetables, legumes, whole grains, and fresh fruit) and encouraged the composition of balanced meals consistent with the Harvard Healthy Eating Plate and the Planetary Health Diet frameworks [23,184].

2.2. Partnership

The current pilot study was implemented at one of the cafeterias (Polo Cravino) of the University of Pavia. The cafeteria was selected based on practical considerations, including its accessibility and logistical feasibility for implementing the intervention. The study was designed by the LDNC in collaboration with the Office for Sustainable Actions (OSA) of the University of Pavia and with Edisu, Ente per il diritto allo Studio Universitario (the Regional

Agency for the Right to Higher Education) and Markas Italia s.r.l., leading companies in collective catering services.

2.3. Study population and setting

The selected cafeteria operates daily from 12:00 p.m. to 2:00 p.m., offering 200 seats and serving an average of 350–400 meals per day. The primary users are university students, although professors and administrative staff may also access the facility. For this study, only individuals who consumed their meals on-site were included in the sample, while those who purchased food for take-away were excluded.

2.4. Experimental design

The present pilot study employed a pre–post design with two distinct phases. The independent variable was the implementation of nudging strategies during the post phase, selected to assess intervention effects while preserving routine canteen operations. The primary outcome was the selection of predefined target foods, one for each course of a typical Italian meal (including first course, second course, side dishes, bread, and fruit/dessert). Conducted in real-world setting, this design enabled evaluation of effectiveness with high practical relevance and transferability to similar contexts. The study timeline is reported in Figure 3.

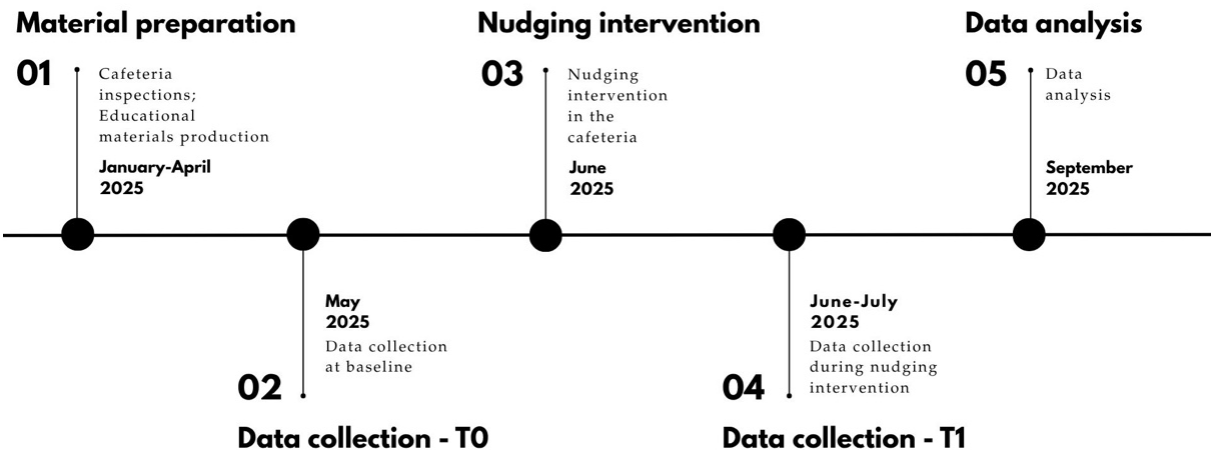


Figure 3. Timeline of the FOOD-HACK project.

DATA COLLECTION (T0 AND T1)

The observational phase, both at T0 and at T1, was carried out on Mondays, Wednesdays, and Fridays over four weeks (12 service days) from 5 May to 30 May 2025 and from 23 June to 18 July, respectively. Non-consecutive days were deliberately chosen to ensure variability in meal options and consumption patterns, thereby providing a more representative overview of

students' dietary behaviors across the week. During each observation day, two trained researchers stationed at the point of sale (adjacent to the cashier) systematically photographed diners' trays immediately after meal selection and before consumption, yielding 200 usable tray photographs at T0 and at T1. Images excluded any personal identifiers; no individual-level demographic data were recorded.

All photographs were imported into a dedicated database and coded according to a pre-specified data dictionary. For each tray, every visible component was recorded and assigned to one of six categories reflecting a typical Italian meal structure: first course; second course; side dish; bread; fruit/dessert; and beverage [187]. After the first data collection (T0), the nudging intervention was implemented in the canteen space. The second data collection (T1) started three weeks after the implementation to allow students to adapt to the new environment. The project targeted the summer four-week rotating menu offered by the cafeteria. Pre- and post-intervention data were collected using the same menu, with no changes in food availability or pricing, thereby minimizing potential confounding related to seasonality or economic factors. **Table S10** (page 110) shows the full menu available during the data collection days (Mondays, Wednesdays, and Fridays). Typically, two to three options were available for first courses, second courses, and side dishes, and four options for the end-of-meal course. In addition, a few fixed alternatives were always offered (e.g., plain pasta or rice, grilled meat, fish, or vegetables). To better clarify the composition of a typical Italian meal, **Figure 4** shows an example of a tray.



Figure 4. Example of tray with an Italian meal composition.

According to the menu (**Table S10**, page 110) and the cafeteria policy, a tray can be composed as follows:

- Option 1: One dish of first course, one dish of second course, one or more side dishes, bread and one or two servings of either fruit or dessert.
- Option 2: Two first courses, one or more side dishes, bread and one or two servings of either fruit or dessert.
- Option 3: Two second courses, one or more side dishes, bread and one or two servings of either fruit or dessert.
- Option 4: Pizza, one or more side dishes, and one or two servings of either fruit or dessert.

Each customer could compose their tray among the options (option 1- option 4) listed above. Since trays were registered at the cashier upon payment, it was inferred that each tray corresponded to a single customer's meal.

DATA CODIFICATION

Category-specific coding criteria captured dish composition (e.g., dominant protein/source and cereal type) and preparation features where discernible. For first courses, items were classified by dominant ingredient into meat-based, fish-based, vegetable-based, or legume-based preparations; pasta/grain type (whole-grain vs. refined) was additionally noted when visually ascertainable.

Second courses were classified by primary protein source (meat, fish/seafood, eggs, cheese, or plant-based/legume-derived). Side dishes were coded for vegetable presence (yes/no) while bread was coded by grain type (whole-grain vs. refined; whole-grain defined as predominantly whole-meal flour). Fruit/dessert was recorded for presence (yes/no), and beverages were categorized as water or sugar-sweetened (containing caloric sweeteners).

Two independent raters performed coding following a brief calibration on a sample set; a random 10% of records were double coded to assess inter-rater reliability (Cohen's κ), with discrepancies resolved by consensus and, when necessary, adjudication by a third reviewer. Quality control included periodic checks for internal consistency and completeness before database lock. Based on the aforementioned category-specific criteria, tray-level dietary patterns were identified as follows: omnivore (e.g. any selection containing meat, fish/seafood, or other animal-source foods), vegetarian (e.g. no meat or fish/seafood selected, but eggs

and/or dairy permitted), and vegan (e.g. no animal-source items selected, i.e., excludes meat, fish/seafood, eggs, and dairy). This classification was derived directly from the observed composition and preparation features recorded for each tray.

As a gold standard for the ideal tray composition, we referred to the optimum meal composition of the Harvard Healthy Eating Plate [184] and to the principles of the and the EAT-Lancet Planetary Diet [23]. Together, these models emphasize the importance of a balanced and sustainable meal consisting of approximately 50% fresh fruits and vegetables, 25% cereals (preferably whole grains), and 25% healthy protein sources, with particular attention to increasing the proportion of plant-based proteins. Accordingly, trays were considered compliant with these models [23,184] if they included one source of carbohydrates (pasta, bread, or potatoes), one source of protein (meat, fish, legumes, eggs, or cheese), and at least one serving of vegetables and fresh fruit. Additionally, based on these guidelines, six negative dietary quality indicators were defined:

- Excessive animal protein: trays containing both meat and fish, or double portions of either.
- Absence of protein: trays lacking any protein source (meat, fish, legumes, eggs, cheese).
- Absence of vegetables: trays without a vegetable side dish.
- Excessive carbohydrate sources: trays including pasta or rice together with bread and potatoes.
- Absence of fruit: trays without fruit at the end of the meal.
- Absence of water: trays without water (tap or bottled), where only other beverages were selected.

Pizza orders were placed directly at the cashier, after which customers collected their pizzas at the oven station. As a result, at the time of photographing the trays, the pizzas were not yet present, making it impossible to determine the type of toppings added (e.g., plain margherita, or with additional ingredients such as cured meats or fries). For this reason, trays containing pizza were excluded from analyses concerning dietary patterns and adherence to both the Harvard Healthy Eating Plate [184] and the EAT-Lancet Planetary Diet models [23].

NUDGING STRATEGIES IMPLEMENTATION

The nudging strategies aimed to promote the selection of the plates to compose a healthy and sustainable meal, enhancing the consumption of vegetables, fresh fruit and plant-based

proteins. To incentivize the selection of the healthiest choice, three integrated nudging approaches were implemented as follows:

- 1) Increasing ease/convenience (choice architecture): the central counter, previously displaying desserts (fresh fruit and sweet items together), was reorganized to present only fresh fruit. Sweet desserts remained available but were relocated to a separate, less prominent area.
- 2) Providing disclosures (salient labelling): plant-based dishes (**Figure S3**, page 93) and legumes (**Figure S4**, page 93) were flagged with distinctive tags to enhance salience and encourage uptake. Tags for plant-based items read “Best Choice: plant-based and sustainable”; legume dishes were labelled “Reminder: legumes are the protein source of your dish, not a side dish”.
- 3) Priming (educational prompts): posters, flyers, and “talking” placemats highlighting the benefits of the MD and sustainable eating were positioned along queue lines and adjacent to targeted items. Materials were displayed in Italian; each poster also included a QR code (“Scan me for the English version”) linking to an English translation to ensure accessibility for non-Italian-speaking students.

Concerning the educational materials realized, along the diner’s path, the team positioned a coordinated set of educational prompts to guide choices without interrupting service flow. At the canteen entrance, a large sustainability poster introduced the theme by depicting three “footprints” (including greenhouse-gas emissions, water use, and land use) and showing, proportionally within each, the environmental impact of major food groups (meat, fish, legumes, eggs, dairy, vegetables, grains), (**Figure S5**, page 94) [29,188].

As students approached the service line, two “healthy plate” posters, inspired by the optimum meal composition of the Harvard Healthy Eating [184], presented the components of a balanced, nutrient-dense meal and were displayed next to the weekly menu to support planning before selection (**Figure S6**, page 95). Closer to specific choice points, concise flyers reinforced targeted behaviors. Next to the bread baskets, messages encouraged choosing whole grain over white bread for combined health and sustainability benefits (**Figure S7**, page 96) [143,189].

At the fruit counter, a flyer promoted fresh, seasonal fruit as an appropriate way to conclude the meal (**Figure S8**, page 97) [190]. Near both the vegetable counter and the main-course station, paired flyers emphasized the nutritional value of legumes and framed them as a

primary protein source rather than a side dish, normalizing plant-based choices (**Figure S9**, page 98) [191]. At the condiments station, guidance on using herbs and spices highlighted flavor enhancement while reducing salt use (**Figure S10**, page 99) [192,193]. By the two water-refill points and next to the beverages counter, prompts advocated water as the default mealtime beverage and encouraged reusable bottles to minimize plastic waste (**Figure S11**, page 100) [194]. Finally, a tray placemat echoed the healthy-plate concept with practical tips for composing a balanced and sustainable meal, ensuring message reinforcement during consumption (**Figure S12**, page 101) [184].

Overall, the intervention embedded sustainability and health into everyday cafeteria decisions, advancing campus-level implementation of multiple goals of the 2030 Agenda, in particular SDG 3 (Good Health and Well-being), SDG 2 (Zero Hunger, targets on safe and nutritious food), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 4 (Quality Education) [195].

Figure 5 provides a schematic representation of the cafeteria layout, indicating the strategic placement of nudging materials and the typical path taken by students from food selection to payment.

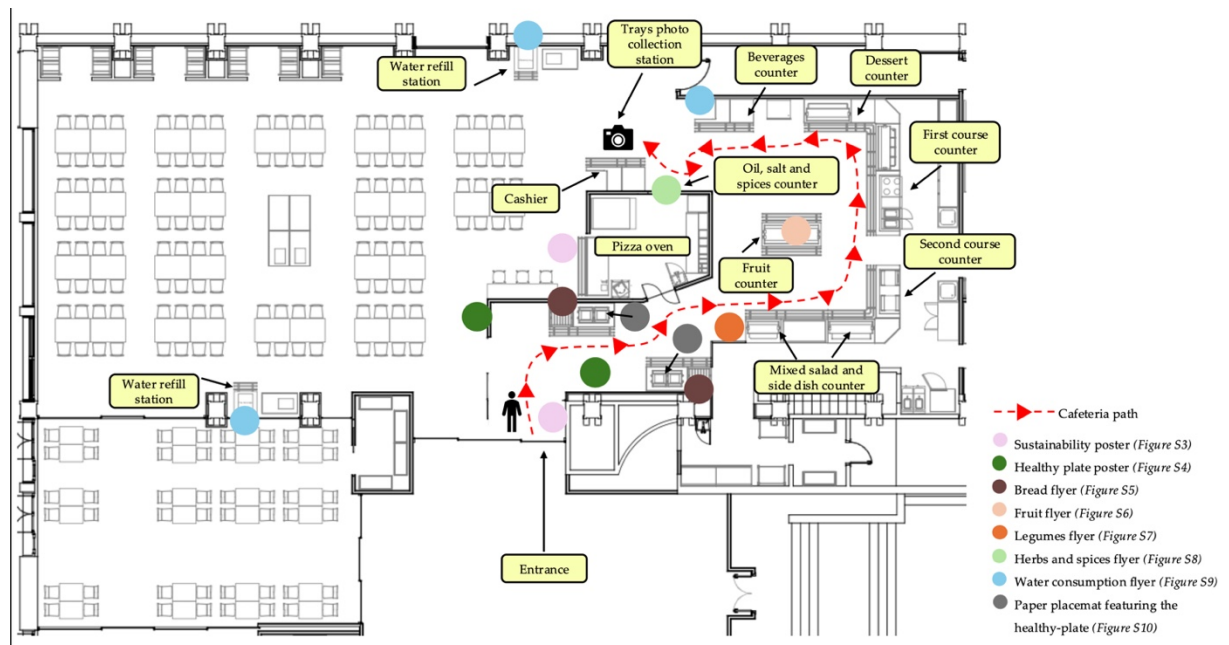


Figure 5. Map of the cafeteria indicating the placement of nudging materials.

2.5. Ethical considerations

During the study period, notices were posted at the cafeteria entrance (adjacent to the menu) and at each cash register. They informed customers that two researchers would photograph

the food on trays for research purposes, described the privacy safeguards (no faces or personal identifiers recorded) and emphasized that participation was voluntary. No customer who objected was photographed; if an image had already been taken, it was deleted immediately. The notices did not disclose the specific hypotheses, stating only that the study examined aggregate consumption patterns.

Cafeteria staff were also briefed about the procedures and trained to provide further clarification upon request. All procedures were conducted in accordance with the ethical standards of the institutional and/or national research committees, as well as the 1964 Helsinki Declaration and its subsequent amendments or comparable ethical principles. Formal approval by an Ethics Committee was not required, as no sensitive or personally identifiable data were collected.

2.6. Statistical analysis

All analyses were prespecified to compare tray selections between the pre-intervention phase (T0) and the post-intervention phase (T1). The analytic dataset comprised 4,800 photographed meals (200 trays/day over 12 collection days at each time point). Descriptive statistics were reported as absolute numbers and frequencies, expressed as percentages.

Between-phase differences in categorical variables, overall tray composition, dietary pattern classification (e.g omnivorous, vegetarian, vegan), composition of first and second courses, side dishes, bread types and accompaniments, fruit/dessert choices, and beverages, were evaluated using Pearson's chi-square tests with two-sided p-values and a nominal α of 0.05. Where cell counts were sparse, Fisher's exact test was used. Pizza trays were excluded from the analyses that classified dietary patterns and from the assessment of the compliance to the Harvard Healthy Eating Plate [184] and Planetary Diet by EAT Lancet Commission [23], as described above. To appraise the global impact of the nudging intervention on meal quality, trays were classified as compliant or non-compliant with the Harvard Healthy Eating Plate reference [184]; the proportion of compliant trays at T0 vs. T1 was compared using chi-square tests. Negative dietary quality indicators were also operationalized *a priori* and analyzed as binary outcomes: presence of two animal-protein sources in the same meal, absence of any protein source, absence of vegetables, presence of three carbohydrate sources (pasta/rice *plus* bread *plus* potatoes), absence of fruit, and absence of water (tap or bottled); phase differences in the prevalence of each indicator were tested analogously.

For first-course analyses, subcomponents were coded mutually exclusively as meat, fish, cheese, legumes, vegetables, or plain, and trays were additionally categorized as omnivorous, vegetarian, or vegan (the latter defined as plant-only without added grated cheese). The second course categories included meat, fish, cheese, legumes, and eggs. Side dishes were coded as vegetables, legumes, or potatoes for first and second servings. Bread and accompaniments were classified as white bread, whole bread, breadsticks, or crackers. Fruit/dessert categories included fresh fruit, fruit mousse, yoghurt, pudding, fruit juice, and cake; beverages were coded as tap water, bottled water, soft drinks, or beer. All comparisons were conducted on complete cases, and results are presented as p-values without multiplicity adjustment, given the primarily confirmatory/monitoring objective of the intervention evaluation. Statistical computations were performed using R (version 2025.05.0+496) statistical software.

2.3. Results of the nudging intervention

Two hundred trays per day were photographed across 12 days of data collection, both at T0 and at T1, yielding a total of 4,800 meals analyzed.

2.3.1. Overall meal composition

As shown in **Table 7** (page 82), most trays (>50%) contained only one item for each of the three main components of the meal (first course, second course, side dish). Nevertheless, a proportion of students or customers either omitted at least one component (14.9, 19.7%) or selected more than one item from the same category (0.2, 19.3%). At T1, a significant increase was observed in the selection of a second serving of second courses ($p < 0.001$) and fruit/dessert ($p < 0.004$), whereas the consumption of bread and accompaniments declined ($p < 0.001$).

Overall, the dietary patterns remained relatively stable between T0 and T1, with most trays reflecting an omnivorous profile (**Table 8**, page 82).

2.3.2. Trays' components

FIRST COURSE

Differences emerged in the composition of first courses, with an increased prevalence of dishes prepared with vegetables, cheese, and legumes at T1 (**Table 9**, page 83). The overall distribution of first-course dietary patterns showed a significant shift toward plant-based options (<0.001).

SECOND COURSE

By contrast, no significant differences were observed in second-course choices, where meat consistently remained the most frequent option, followed by fish and cheese (**Table 10**, page 83). Also, the overall distribution of first-course dietary patterns showed a high prevalence of animal-based products.

SIDE DISH

More notable changes were recorded for side dishes (**Table 11**, page 84). Vegetables became the predominant choice in the first serving (53.9%), while potato consumption markedly declined. Legumes also showed a modest increase, although the change was not substantial. Overall, a shift toward greater vegetable consumption in place of potatoes was observed in the post-intervention phase.

BREAD AND ACCOMPANIMENTS

No substantial modifications were detected in bread and related accompaniments after the intervention (**Table 12**, page 84). White bread remained the dominant choice (75.9%), while whole bread accounted for 24.1%. Crackers and breadsticks were rarely selected at either time point.

FRUIT OR DESSERT

As shown in **Table 13** (page 85), fruit selection increased after the intervention. Fresh fruit was more frequently chosen as both a first option (44.6% at T0 vs. 50.0% at T1) and as an additional option (2.2% vs. 26.9%).

WATER AND BEVERAGES

Beverage choices are shown in **Table 14** (page 85). Water consistently remained the predominant beverage choice. At T1, an increase in tap water consumption was observed, accompanied by a corresponding decline in bottled water purchases.

2.3.3. Effect of the nudging intervention on the overall quality of the meal

After the nudging intervention (T1) the proportion of trays aligning with the Harvard Healthy Eating Plate [184] and EAT-Lancet Planetary Diet [23] models composition significantly increased (<0.001), **Table 15** (page 85).

Based on the dietary quality indicators identified through the Harvard Healthy Eating Plate and EAT-Lancet Planetary Diet frameworks [23,184], the intervention led to clear improvements in several key meal components (**Table 16**, page 86). On one side, a significant

reduction was observed in trays containing two different animal protein sources ($p=0.037$). In addition, trays without a portion of vegetables as a side dish decreased significantly, from 59.2% at T0 to 54.1% at T1 ($p < 0.001$). Likewise, the absence of fruit fell from 65.6% to 10.3% ($p < 0.001$). A significant reduction was also recorded in trays containing multiple carbohydrate sources (37.2% vs. 14.6%, $p < 0.001$). Water consumption remained stable throughout the study period.

2.4. Discussion

Within the aim of this thesis, the FOOD-HACK project represents a case example of a multidimensional, environment-based intervention targeting young adulthood. Specifically, the study explored the use of nudging strategies within a university cafeteria to promote healthier and more sustainable food choices, addressing a population group undergoing profound lifestyle transitions and increased autonomy over dietary decisions.

Overall, the findings indicate that nudging strategies can effectively influence food selection patterns in a real-life university cafeteria setting. Consistent with previous evidence, interventions acting on food presentation, availability, and informational cues emerged as particularly promising approaches to promote both nutritional quality and environmental sustainability [196]. By modifying the choice architecture rather than restricting options, FOOD-HACK demonstrated that healthier and more sustainable choices can be encouraged while preserving individual freedom, a key principle in behavioral economics-based interventions.

Among the strategies implemented, changes in food placement and visibility proved especially effective. The repositioning of fruit as the default dessert option and the use of salient labels to promote vegetable side dishes led to clear improvements in selection patterns. These findings are particularly relevant given the low consumption of fruits and vegetables among Italian university students [197] and reinforce evidence from both school and university settings showing that simple environmental cues can substantially increase the uptake of plant-based foods [198,199]. In this sense, FOOD-HACK confirms that nudging can act as a low-threshold tool to support healthier behaviors in populations that may not actively seek nutritional guidance.

In contrast, nudges aimed at increasing the selection of legume-based dishes produced limited effects. This finding highlights the context-dependent nature of nudging strategies and the

importance of food culture and culinary practices. In the Italian context, legumes are often perceived as side dishes rather than main courses, and their limited culinary variety within the cafeteria setting may have reduced their attractiveness [200,201]. These results align with literature suggesting that nudges are most effective when supported by adequate food availability, appealing preparation, and cultural acceptability [202–204]. They also suggest that nudging alone may be insufficient to shift choices toward less familiar foods without accompanying structural adjustments to menu design. Similarly, the modest impact observed on whole-meal bread selection underscores the limits of nudging when healthier options are not clearly differentiated or sufficiently prominent [106,205]. Together, these findings emphasize that nudging strategies should be understood not as standalone solutions, but as components of broader, context-sensitive interventions that consider food culture, menu composition, and sensory appeal.

A distinctive strength of the FOOD-HACK project lies in its explicit integration of health and sustainability objectives. By promoting fruits, vegetables, and legumes, the intervention simultaneously addressed nutritional quality and environmental impact, aligning with contemporary dietary frameworks and the SDGs [195]. This dual focus represents an important step beyond traditional nutrition interventions and reflects the growing recognition of the interdependence between human and planetary health.

Several limitations should be acknowledged. The analysis was conducted at the tray level rather than the individual level, and actual consumption could not be verified. The pre–post design without a control group limits causal inference, and the short duration of the intervention raises questions about the persistence of observed changes. Moreover, the study was conducted in a single cafeteria, limiting generalizability. These constraints are common in real-world food environment research and should be interpreted within the context of feasibility and implementation studies. Despite these limitations, FOOD-HACK provides proof-of-concept evidence supporting the use of nudging strategies as effective tools for promoting healthier and more sustainable eating behaviors in university settings. By acting on the food environment rather than individual motivation, the project contributes to the broader framework of multidimensional interventions across the life course developed in this thesis and informs future efforts to redesign institutional food environments in support of public health and sustainability.

3. Study 3 - Project Specialized and Clinical Settings: The AUT-MENU Project

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3.1. Introduction: food selectivity and access to healthy diets in autism spectrum disorder

Feeding difficulties are highly prevalent among individuals with ASD, and caregivers frequently report mealtime challenges such as food refusal, restricted food intake, and rigid eating routines. These behaviors are commonly described under the umbrella term FS, a condition characterized by limited dietary variety and strong preferences or aversions to specific foods [206].

Although FS lacks a universally accepted definition and is assessed using heterogeneous methodologies, its prevalence is consistently higher among individuals with ASD than in neurotypical populations, with reported rates ranging from 23% to 69% in children with ASD compared to 1%–37% in neurotypical peers [108,109,207,208].

FS in ASD is shaped by a complex interaction of sensory, behavioral, and environmental factors. Sensory sensitivities related to texture, color, taste, temperature, shape, and even food presentation or packaging strongly influence food acceptance [107,110,206]. As a result, individuals with ASD often prefer foods that are soft or semi-liquid, pale in color, mild in taste, and homogeneous in appearance, while rejecting foods with strong odors, intense flavors, bright colors, or complex textures [111]. These preferences frequently lead to the exclusion of entire food groups, particularly vegetables and fish [111,113], with important implications for diet quality.

The nutritional consequences of FS are well documented: increased risk of inadequate intake of key micronutrients, including vitamins A, C, and D, zinc, iron, and omega-3 fatty acids, and higher risk of overweight and obesity due to a high reliance on energy-dense, ultra-processed foods [107]. Beyond nutritional status, FS also affects psychosocial well-being. Mealtimes are often experienced as stressful by caregivers, and non-functional coping strategies, although typically unintentional, may further reinforce maladaptive eating behaviors [108,115,206]. These dynamics highlight the importance of involving caregivers in interventions aimed at improving food access and eating behaviors among individuals with ASD.

In addition, FS represents a critical vulnerability that may persist into adolescence and adulthood. While some studies suggest that eating difficulties may attenuate with age, evidence remains inconsistent, and rigid food-related behaviors can become entrenched over time in the absence of targeted support [206]. This underscores the need for early and sustained interventions that address not only individual sensory sensitivities, but also the food environments in which individuals with ASD consume meals.

Despite growing awareness of these challenges, structured interventions targeting collective catering settings remain limited, particularly in countries such as Italy, where specific guidelines for adapting menus to the sensory and nutritional needs of individuals with ASD are lacking. This gap is especially relevant given that many children with ASD regularly consume meals in school or health care settings and many adults reside in care facilities where food choices are largely environment-driven [114]. To address this unmet need, a pilot study (FOOD-AUT) previously explored the adaptation of canteen meals for adults with ASD by modifying sensory characteristics such as texture, color, and shape, reporting improvements in food acceptance and dietary variety [113]. Building on these preliminary findings, the AUT-MENU project was developed to extend this approach to a broader and more diverse context, including three care facilities and one school accommodating both children and young adults with ASD [114]. In addition to menu adaptation, AUT-MENU aimed to evaluate the feasibility of a structured nutrition and behavioral education program for caregivers, recognizing their central role in shaping food access and mealtime dynamics across settings. Within the framework of this thesis, AUT-MENU represents a third example of a multidimensional intervention addressing healthy and sustainable eating behaviors in a population characterized by clinical and functional vulnerability.

3.2. Study Design and Methodology

3.2.1. Study design and setting

The AUT-MENU study is a single arm pre -post bicentric intervention study (without control) conducted by a multidisciplinary team consisting of researchers from the LDNC of the University of Pavia and the Research Centre for Food and Nutrition (CREA) of Rome [114]. The study was carried out in two different regions of Italy. In the northern region, three care centers have been involved: Tiglio Fondazione Onlus in Pavia (TP), Dosso Verde in Milan (DVM), and Dosso Verde in Pavia (DVP). In the central region, the study is currently taking

place in one high school in Rome: the “Giuseppe Garibaldi” Agricultural Technical Institute. This thesis reports data from the three centers in the Northern region. The study was approved by the Ethics Committee of the Department of the Nervous System and Behavioral Sciences, on 15 January 2024 (project number 155/23). The study lasted 36 months (November 2022-2025), including a 12-month experimental phase, from September 2024 until September 2025. The timeline of the timeline is shown in **Figure 6**.

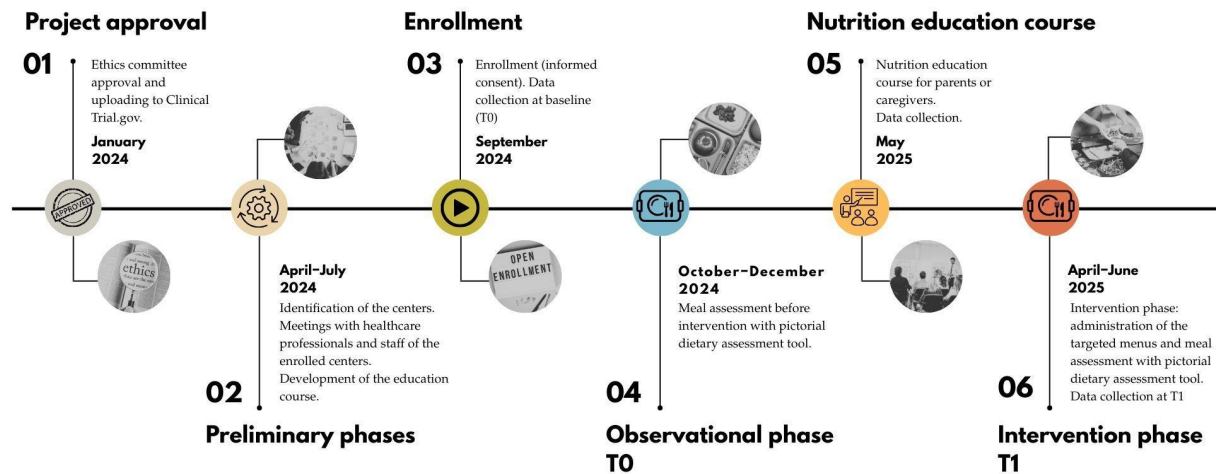


Figure 6. Timeline of AUT-MENU project

3.2.2. Study objectives

The primary objective of the AUT-MENU project was to assess meal consumption among individuals with ASD in collective catering settings, both quantitatively (e.g., portion intake) and qualitatively (e.g., sensory characteristics influencing food acceptance, such as texture, color, smell, and shape). Based on these findings and existing dietary guidelines for individuals with ASD [111,113], the project aimed to improve meal acceptance by adapting the proposed meals accordingly.

The secondary objective was to evaluate the feasibility of a structured nutrition and behavioral education program for parents and caregivers of enrolled participants. This intervention aimed to improve parents' knowledge on FS and meal experience at home, complementing the modifications implemented in the collective catering settings.

3.2.3. Selection criteria and enrollment

The study population included children, adolescents, and young adults with a diagnosis of ASD, defined according to the Diagnostic and statistical manual of mental disorders (DSM-5) [209] diagnostic criteria and encompassing all three severity levels. Participants were recruited from three centers listed above. The eligible age range varied depending on the recruitment

site: children and adolescents aged 3 to 17 years were enrolled from the Dosso Verde centers in Milan and Pavia; young adults aged 18 to 35 years were included from Tiglio Fondazione Onlus in Pavia.

Written informed consent was provided by parents or legal guardians of the participants. Exclusion criteria comprised individuals who could not eat independently due to physical or cognitive impairments, those presenting food-related comorbidities such as allergies, intolerances, or medical conditions requiring a specialized diet or artificial nutrition, and participants with other neurological or medical conditions unrelated to ASD (e.g., diabetes, epilepsy) that could influence food consumption or require specific medical management.

In June 2024, the researchers took contact with care centers for individuals with ASD to present the project. Centers that expressed interest were subsequently involved in multi-level presentation sessions addressed both to healthcare professionals (including child neuropsychiatrists, therapists, and educators) and to staff. In September 2024, dedicated meetings were also organized with parents and legal guardians. These sessions had a dual purpose: to inform and train professionals who would act as project facilitators, and to provide parents with detailed information while addressing their questions. During the parental meetings, written informed consent and privacy authorization were collected from parents or legal guardians. Participation in the project was entirely voluntary, and only children, adolescents, or young adults whose parents or legal guardians provided signed consent were enrolled in the study and included in data collection.

3.2.4. Experimental phase

MEAL ASSESSMENT AND MENU ADAPTATION

The study was structured into two main phases: an observation phase conducted across all three care-centers (T0), followed by an intervention phase carried out in a single center (T1). The observation phase (T0) aimed to assess food consumption from standard menus during lunchtime, focusing on both quantity and sensory characteristics such as shape, color, smell/taste, texture, and temperature. To systematically evaluate these aspects, the pictorial dietary assessment tool (PDAT) was employed [210]. To adequately capture individual variability in dish consumption, a total of 12 PDATs were collected per participant, distributed across three non-consecutive days within a four-week period to ensure robustness and reliability of the dietary assessment. Additional sessions were carried out for those absent to ensure complete data collection. To minimize observer influence and reduce bias, researchers

passively observed the participants during lunch without direct interaction. They were responsible for completing the PDATs based on observed consumption patterns. To enhance the accuracy of qualitative data, researchers also tasted and photographed each dish to capture its sensory characteristics comprehensively. At the end of each survey day, the research team convened to align on the organoleptic properties of the meals, ensuring consistency in data interpretation. Data entry was performed daily by two researchers, who decoded the PDATs using a predefined classification system and entered the information into an Excel spreadsheet for further analysis. Based on observed consumption patterns at T0, individual sensory preferences and aversions were inferred (e.g., avoidance of specific colors, temperatures, or textures). These insights were used to inform the adaptation of menus in collaboration with the collective catering service. During the intervention phase (T1) the modified menus were introduced and the same assessment process used during T0 was repeated.

The objective of this adaptation was to design nutritionally balanced meals that aligned with participants' sensory preferences, thereby increasing the likelihood of consumption in a real-world catering setting.

NUTRITION EDUCATION COURSE FOR PARENTS AND CAREGIVERS

Between the T0 and T1 phases, an online nutrition education course was offered to subgroups of parents and caregivers of enrolled subjects in the Milan and Pavia centers. The course aimed to support caregivers in managing FS during meals consumed at home. Participation was voluntary. Designed based on healthy eating guidelines and scientific literature on ASD and nutrition [115], the course was led by a multidisciplinary team, including a dietitian, nutrition biologists, speech therapists, and a psychologist. It consisted of seven modules delivered through weekly 1-hour sessions, integrating theoretical explanations with practical demonstrations using videos, images, and interactive activities. The topics covered in the modules were as follows:

- Module 1: The role of nutrition on health and macro- and micronutrients.
- Module 2: Food selectivity: associated factors and consequences.
- Module 3: Healthy plate tailored to the needs of individuals with ASD.
- Module 4: Behavioral strategies for the consumption of non-preferred foods.
- Module 5: Sensory strategies for the consumption of non-preferred foods.
- Module 6: Environment and meal presentation.
- Module 7: Mother-child relationship during mealtime.

The course was delivered separately for each participating center. To assess the course's impact and feasibility, specific evaluation tools (detailed in the following section) were used, along with the recording of attrition rates throughout the program.

3.2.5. Study Data collection

Data regarding meal consumption were collected by trained researchers and staff working in the participating centers, while mealtime. Training consisted of multiple on-site sessions led by the research team, including detailed explanation of study objectives, standardized tools, and data collection procedures. Prior to study initiation, pilot data collection exercises were conducted at each center. During data collection, at least one researcher from the University team was present in each dining area to supervise procedures, address uncertainties, and ensure protocol adherence. Data regarding both participants and their families were collected through structured phone interviews and then the data were collected into an electronic, web-based CRF (eCRF). Each participant was assigned a unique code to link their data securely while protecting their identity. Details of data collected throughout the study period are presented in the following sections and summarized in **Table 17** (page 87). All the questionnaires used are presented in the study protocol [114].

3.2.6. Primary outcome

MEAL ASSESSMENT

The quantity and quality assessment of meals consumed during lunchtime was conducted using the PDAT [210] at both T0 and T1. Rather than relying on the gold standard weighing method, the PDAT offers a less invasive alternative, allowing for uninterrupted mealtime evaluation. Additionally, when compared to the gold standard, it has demonstrated high accuracy and strong correlations with macronutrient and micronutrient intake [210]. The PDAT consists of two sections: a quantitative (**Figure S13**, page 102) and a qualitative component (**Figure S14**, page 103), with the latter developed by researchers based on findings from the FOOD-AUT project [113].

The quantitative section enables the monitoring of each meal component (first course, second course, side dish, accompaniment—bread, breadsticks, crackers—dessert, fruit or yogurt, and beverages) by recording the amount consumed. To facilitate data collection, intake was recorded both numerically (empty plate, 1/4, 1/2, 3/4, and fully consumed) and graphically. The graphic representation employs four circular sectors (representing a plate divided into four sections), which range from white (not consumed) to blue (completely consumed). For

beverages, a stylized glass was used, with a gradually increasing water fill indicating empty, one-quarter full, half full, three-quarters full, and full consumption.

The qualitative section evaluated the sensory characteristics of each meal component, detailing its shape, color, smell/taste, texture, and temperature. The development of the qualitative part of the PDAT was finalized with the collaboration of a sensory expert, who helped define the possible alternatives for completing each of the main organoleptic characteristics.

SOCIO-DEMOGRAPHIC INFORMATION

At T0, a structured telephone interview was conducted to collect sociodemographic and socioeconomic information. The first section focused on participants with ASD, gathering data on gender, age, ethnicity, clinical characteristics (including pharmacological treatments, therapeutic pathways, anthropometric measurements, weight and height). The second section addressed family-related variables, with particular attention to the primary caregiver, and included information on marital status, age, ethnicity, educational level, as well as strategies adopted for managing FS.

FOOD HABITS AND FEEDING-BEHAVIORS DURING MEALTIME

At T0, during the same telephone interview were also collected data regarding food habits and meal behaviors of the enrolled participants. The KIDMED questionnaire (Mediterranean Diet Quality Index for children and adolescents) [211] and the MedQ-Sus questionnaire (New Validated Short Questionnaire for the Evaluation of the Adherence of Mediterranean Diet and Nutrition Sustainability in all adult population groups) [212] were used to assess adherence to the MD and to get an overview of the consumption of the main food groups (fruits, vegetables, pasta and cereals, legumes, fish, meat, and dairy products). Adherence to MD diet was rated as low (score ≤ 4), medium (score between 5 and 7), and high (score ≥ 8) for KIDMED questionnaire and as low (score ≤ 9), medium (score between 9 and 11), and high (score > 11) for the MedQ-Sus questionnaire. While, BAMBI questionnaire (Brief Autism Mealtime Behavior Inventory) [207,213], validated for a population of 3-11 years old, and STEP questionnaire (Screening Tool for Feeding Problems) [214], validated for a population ≥ 12 years old were used to evaluate meal-related behavior of subjects with ASD, both at T0 and T1. The presence of feeding difficulties was recorded if BAMBI questionnaire score was > 34 . While using STEP three grades of difficulties were identified: absence or minimal feeding difficulties (score ≤ 7), moderate feeding difficulties (score between 8-11) and severe feeding difficulties (score ≥ 12).

3.2.7. Secondary outcome

NUTRITION KNOWLEDGE AND SATISFACTION QUESTIONNAIRE

Nutrition knowledge was assessed in parents and caregivers participating in the nutrition education course. A questionnaire, designed based on the course topics, consisted of 21 questions (three per module). Researchers administered the questionnaire via telephone interviews before and after the course to evaluate knowledge acquisition. Dichotomous scores were attributed if the answer was right (score=1) or wrong (score=0). The maximum score was 21. Satisfaction was evaluated in parents and caregivers attending the course through a 13-question questionnaire. Administered at the end of the program via telephone interviews, it aimed to assess the course's usefulness, organization, and areas for improvement. The score was based on a Likert scale ranging from 1 (not at all) to 4 (very much) to each question.

3.2.8. Statistical analysis

In 2024, a total of 78,826 individuals with a diagnosis of ASD were registered within the Italian healthcare system (Osservatorio Nazionale Autismo:

<https://osservatorionazionaleautismo.iss.it/aggiornamento-delle-attivit%C3%A0-2024>).

As part of this broader context, we were able to engage and enroll 72 cases at baseline (T0) from three care centers located in the Lombardy region: two in Pavia (n=23 and n=20) and one in Milan (n=23). Notably, the cases attending one center in Pavia continued the study into T1, with a follow-up sample of 27 participants.

Although the centers differed in their scheduled meal offerings and were attended by individuals with varying age distributions, autism severity levels, and degree of FS, this diversity allowed for a more nuanced analysis. To account for these differences, the data was analyzed across three distinct subgroups, enabling a more tailored interpretation of food-related behaviors. Given the exploratory nature of the subgroup analyses, no adjustment for multiple testing was applied. These analyses were intended to identify potential patterns rather than to support confirmatory statistical inference. At baseline (T0), a selection of dishes was tested with participants, and at follow-up (T1), the acceptance of newly introduced dishes was assessed. Food consumption for each menu was calculated as the average across 12 meals, approximating the original discrete variable—defined on a five-point scale—to a continuous variable. The distribution of the mean values of the dishes was found to be non-normal. Therefore, the differences in average consumption among the dishes, as well as within groups defined by demographic and nutritional variables, were assessed using the Kruskal-Wallis

test. Unlike ANOVA, this test does not assume normality of the data, making it suitable for ordinal data or continuous data that violate normal distribution assumptions.

3.3. Results of the menu adaptation intervention

3.3.1. Socio-demographic characteristics of the sample

Subgroup analyses were conducted to explore potential differences across age groups, care settings, and food categories. Given the exploratory nature of these analyses and the number of comparisons performed, the results should be interpreted descriptively rather than inferentially. **Table 18** (page 87) shows the main socio-demographic characteristics of the sample. The overall sample was predominantly male (77.8%), with females representing 22.2% of the total population. This imbalance was consistent across all care centers. While the DVM and DVP centers included participants with a mean age of 8 (SD, 3.5) and 10.3 (SD, 1.9) years respectively, the TP center had a higher mean age (25.4 years, SD 4.6), as it hosts adults aged 18 years and older. Overall, 18.1% of participants presented overweight and 6.8% were affected by obesity, with the highest prevalence observed in the TP center. Conversely, a high prevalence of underweight was recorded in the two centers for minors, DVM and DVP (60.9% and 44.8%, respectively). Regarding ASD severity, no participants presented with level 1 severity; most were classified as level 3 (80.3%).

Concerning food-related behaviors, 40.5% of participants under 12 years of age exhibited feeding difficulties. Among participants aged 12 years and older, 80% showed moderate to severe feeding difficulties (**Table 19**, page 88). As for adherence to MD, KIDMED scores indicated good overall adherence: among participants under 25 years of age, 51.6% showed medium adherence and 46.8% high adherence. In adults (aged 25 years and older), full adherence to MD was observed (**Table 20**, page 88).

3.3.2 Baseline results (T0): overall consumption patterns

At baseline (T0), food consumption patterns across the three settings highlighted marked differences in acceptance between meal components, settings, and participant characteristics, reflecting the heterogeneity of FS in individuals with ASD. Overall, first and second courses showed higher average consumption percentages (ACP) compared to side dishes and fruit, with consistently lower acceptance observed in the DVM setting and progressively higher consumption in the DVP and TP settings. Across all contexts, foods characterized by warm temperature, soft or homogeneous texture, mild smell, and simple sensory profiles were more

frequently consumed, whereas mono-colored dishes, raw preparations, and vegetable-based side dishes showed lower acceptance, particularly among younger participants and those with more severe feeding difficulties.

Plant-based foods, especially legumes and vegetables, were generally less consumed at baseline, particularly when offered as side dishes or in preparations perceived as unappealing or culturally incongruent. Fruit intake also varied substantially by type and presentation, with higher consumption of fruits that were easy to handle and consume (e.g., bananas or peeled fruit), suggesting a strong influence of texture and ease of consumption. Sociodemographic and clinical factors—including age, severity of ASD, feeding difficulties, dietary quality, and weight status—were frequently associated with consumption patterns, indicating that food acceptance at baseline was shaped by a complex interaction of sensory, developmental, and contextual determinants.

Taken together, baseline findings revealed a clear pattern of selective food acceptance, with limited dietary variety and low intake of vegetables, legumes, and some fruits, particularly in more restrictive settings. These results confirmed the presence of significant barriers to adequate food access and dietary diversity at T0 and provided a robust rationale for the subsequent menu adaptation and educational intervention implemented in the AUT-MENU project. Detailed results by food category, sensory characteristics, and subgroup analyses are reported in the published article and supplementary tables (doi: <https://doi.org/10.3390/nu18010165>).

3.3.3 Menu adaptation

The intervention phase, involving menu adaptation, was conducted in a single care center (DVP). Menu modifications were designed to tailor meal offerings to the specific needs and sensory profiles of participants with ASD, while maintaining nutritional adequacy and complying with the operational constraints of the collective catering service. The adaptation process was guided by three primary sources of information: (i) individual sensory preferences collected at baseline (T0) and findings from the FOOD AUT pilot study [113]; (ii) the Italian dietary guidelines [143]; and (iii) technical and logistical requirements of the collective catering service responsible for meal production. Based on these criteria, menus were modified to enhance both acceptability and nutritional quality. Legumes were incorporated into dry first courses (e.g., pasta with smooth chickpeas and carrot sauce) to

increase protein and fiber content while leveraging textures generally well tolerated according to sensory preference data. Cooked vegetables were also introduced into dry first courses, providing a gentle exposure to vegetables while minimizing sensory overload associated with raw textures. Vegetables were further added to omelets to create familiar, cohesive textures aligned with participants' sensory profiles. Given the tendency of many participants to prefer softer and warmer textures, cooked vegetables were systematically favored over raw preparations. Legumes were additionally offered as second-course options in the form of farinata, a chickpea-based dish with uniform texture and mild flavor, consistent with participants' sensory tolerance. To improve nutritional quality, ultra-processed and pre-fried items were replaced with freshly prepared fish and meat products, either plain or lightly breaded, in line with health guidelines and catering feasibility.

Overall, the menu adaptation process reflected a careful balance between sensory suitability, evidence-based nutritional principles, and real-world constraints of large-scale meal preparation, aiming to optimize both acceptability and healthfulness of meals provided to individuals with ASD.

3.3.4 Intervention results (T1): Average consumption of each course after the menu adaptation

Tables S11-14 (pages 112-114) report the ranking of the average consumption (%) of dishes and their main sensory characteristics by course (first course, second course, side dish, and fruit) during the intervention phase in a single care-center (DVP) (T1).

After menu adaptation, food consumption patterns confirmed the strong influence of sensory characteristics, dietary quality, and individual factors on food acceptance among individuals with ASD. Overall, first and second courses showed moderate-to-high average consumption, whereas side dishes and fruit remained the least consumed meal components. Across all food categories, dishes characterized by warm temperature, soft or homogeneous texture, mild aroma, and simple sensory profiles were consistently more accepted, while raw, crisp, or visually simple preparations, such as plain vegetables or salads, were less frequently consumed.

First courses were generally well accepted, particularly multicolored pasta and rice-based dishes, while vegetable-based preparations showed lower consumption. Second courses followed a similar pattern, with meat- and fish-based dishes being preferred over plant-based options, which continued to show lower acceptance. Side dishes remained the most critical

component of the meal, with cooked vegetables being more frequently consumed than raw salads. Fruit intake showed moderate acceptance overall, with higher consumption of fruits that were easy to handle and consume, such as apples and bananas.

Across all meal components, adherence to the MD emerged as a key determinant of consumption. Participants with higher adherence consistently showed greater acceptance of vegetables, legumes, and fruit, suggesting that baseline dietary quality strongly influenced responsiveness to menu adaptations. Feeding difficulties were also associated with consumption patterns, with some dishes, particularly cooked vegetables and fruit, being more accepted among participants with reported feeding challenges, highlighting the role of texture and ease of consumption. Age, BMI, and nationality further contributed to variability in intake, with younger age, foreign nationality, and underweight status often associated with lower consumption. Taken together, results at T1 indicate partial improvements in food acceptance, particularly for first and second courses, while persistent challenges remained for vegetables, legumes, and raw preparations.

3.3.5. Consumption comparison between T0 and T1 for each course at DVP care center

Table S15 (page 114) presents the comparison of average food consumption between two time points (T0 and T1) in the DVP setting. Overall, consumption patterns remained relatively stable, considering that different menu sets were provided in two distinct seasons. Mean consumption of first courses showed a minimal decrease, from 76.97 to 76.81 units, with the number of meals remaining constant (n = 304). Second-course consumption declined slightly more, from 70.92 to 68.65 units. Side dish intake decreased from 50.77 to 45.08 units (324 vs. 325 meals), while fruit consumption fell from 51.95 to 48.19 units. These results indicate a modest downward trend in average consumption across meal components over time, particularly for side dishes and fruit.

3.3.6. Parents' and caregivers' nutritional knowledge before and after the nutrition education course

Among all parents and caregivers of the enrolled subject of the three care centers the average initial attendance to the nutrition education course was 51.4% (n=38), while the total dropout rate after the course was 34.2% (n=13).

DOSSO VERDE PAVIA

The average score at T0 was 14 out of 21, rising to 17 at T1, corresponding to a +24.6% increase. Out of 7 lectures, the average attendance was 5, making this the center with the highest

participation rate. The dropout rate at this center was approximately 68.97%, with 14 of 29 enrolled parents and caregivers not participating in the course and an additional 6 not completing it.

DOSSO VERDE MILANO

The average score at T0 was 16 out of 21, increasing to 18 at T1, with a +6.3% improvement. Average attendance was 3 lectures. The dropout rate at this center was 39.13%. Specifically, of the 23 parents and caregivers enrolled, 5 did not participate in the course, and a further 4 did not complete it.

TIGLIO FONDAZIONE ONLUS

The average score at T0 was 17 out of 21, increasing to 18 at T1, corresponding to an +8.4% increase. Average attendance was 4 lectures. The dropout rate at this center was the highest (90%), as 15 out of 20 enrolled parents and caregivers did not participate in the course, and an additional 3 did not complete it.

3.3.7. Feasibility of the nutrition education course

Table 21 (page 89) reports the answers to the satisfaction questionnaire for caregivers. Among the parents who participated in the nutrition education course (n=38), n=21 parents responded to the questionnaire related to satisfaction and the majority were the mothers (90.5%). For the questions addressing course organization; perceived engagement during the sessions; satisfaction with the online format; usefulness for improving knowledge about healthy nutrition; and usefulness for increasing understanding of FS and its management, the most frequent response was the maximum score (4). The item regarding the reduction of parental/caregiver stress during mealtimes received an average score of 3, while the item addressing the reduction of stress in children/adolescents with ASD during mealtimes received an average score of 2. Finally, all participating parents and caregivers indicated that they would recommend the course and that they would not prefer in-person teaching.

3.4. Discussion

FS represents a common and persistent challenge in individuals with autism spectrum disorder (ASD), often leading to limited dietary variety and an increased risk of macro- and micronutrient inadequacy. To date, most interventions targeting FS have focused on psychotherapeutic and behavioral approaches, with relatively limited attention to nutritional strategies implemented directly within real-world food environments [215,216]. Although

early intervention has been shown to improve food acceptance and reduce selective eating behaviors, structured interventions in collective catering settings remain scarce, particularly across different developmental stages [217,218]. Within this context, the AUT-MENU project aimed to explore the feasibility and acceptability of sensory-informed, nutritionally optimized menu adaptations in children, adolescents, and young adults with ASD. Unlike previous studies that primarily targeted adults with consolidated eating habits [113], AUT-MENU was designed to reflect the organization of institutional food services in Italy, where standardized menus are commonly provided to heterogeneous groups across school and adult care settings. Although this heterogeneity complicates the interpretation of aggregated outcomes, it enhances ecological validity and allows the intervention to be evaluated across different developmental stages and living contexts.

Despite the implementation of menu adaptations informed by baseline sensory profiles, previous evidence, and national dietary guidelines [113,143], no statistically significant increases in overall food consumption were observed. However, this finding should be interpreted within the multifactorial framework of eating behaviors in ASD. Food acceptance is shaped not only by sensory characteristics, but also by familiarity, routine, predictability, and prior exposure. In this light, the stability of consumption observed between baseline and follow-up may reflect an early adaptation phase rather than lack of acceptability. Importantly, nutritionally relevant foods, such as cooked vegetables, legumes incorporated into familiar preparations, and breaded fish products, were introduced without reducing overall intake, suggesting that dietary quality can be improved without compromising acceptability.

From a life-course perspective, this result is particularly relevant. During childhood and adolescence, adequate nutrition supports physical growth and neurodevelopment, yet individuals with ASD often rely on ultra-processed foods [219,220] and avoid vegetables, legumes, and fish, increasing the risk of micronutrient deficiencies [221–224]. The ability to integrate these foods into institutional menus while maintaining stable consumption represents a meaningful outcome, even in the absence of short-term quantitative changes.

Variability in responses across age groups and care settings further highlights the importance of context-sensitive interventions. Younger individuals may exhibit greater sensory sensitivity and food neophobia, whereas adults often show more entrenched eating routines. Differences between school environments and adult care facilities, such as caregiver involvement, meal

structure, and social dynamics, are also likely to influence food acceptance. These factors reinforce the need to interpret results as context-dependent rather than uniform effects.

Several limitations should be acknowledged. Even if the study was conducted across three care centers, providing valuable insights into the dietary patterns of children, adolescents, and young adults with ASD, the sample may not fully reflect the heterogeneity of the broader Italian ASD population. Recruitment within care centers may have led to the overrepresentation of individuals with higher support needs, potentially underrepresenting those with Level 1 ASD who require minimal assistance. The sample size was inherently constrained by the number of individuals enrolled in collective catering services and was further reduced during the intervention phase due to structural and organizational factors. One centre was excluded because baseline meal acceptance was already high and menus were nutritionally balanced, limiting the potential for measurable change. A second center was excluded due to a change in catering provider during the adaptation phase, which prevented menu modifications. Consequently, full implementation occurred in a single center, reducing the effective sample size and limiting the scope of quantitative analyses. The absence of a control group represents an additional limitation. Although this design was shaped by ethical and organizational constraints typical of real-world collective catering settings, it limits internal validity and precludes causal inference. Therefore, findings should be interpreted as descriptive and exploratory, primarily reflecting feasibility and acceptability rather than intervention effectiveness. Multiple subgroup comparisons were conducted without formal correction for multiple testing, increasing the risk of type I error. Accordingly, statistically significant subgroup findings should be interpreted with caution. The relatively short duration of the project (one year) precluded the evaluation of medium- and long-term outcomes, such as anthropometric or metabolic changes. Furthermore, the translation of sensory-informed menu adaptations into the home environment remains uncertain, particularly among families who did not participate in the nutritional education program. Digital literacy barriers, especially among older caregivers, may have further limited parental engagement. The wide age range and contextual diversity of the sample enhance ecological validity but limit comparability across subgroups and complicate the interpretation of aggregated outcomes. Future studies employing age-stratified designs or context-specific interventions are warranted to better characterize developmental differences in response to menu adaptations.

Despite these limitations, the study presents several strengths. To our knowledge, it represents one of the first structured nutritional interventions specifically targeting individuals with ASD within collective catering contexts. Menus were adapted according to sensory preferences while maintaining nutritional adequacy, providing a replicable framework for institutional settings. The use of non-invasive consumption assessment methods minimized participant burden and enhanced feasibility. Moreover, the inclusion of a nutritional education program for caregivers extended the intervention beyond the institutional environment, promoting continuity between care settings and home contexts. Overall, while methodological constraints limit generalizability and causal inference, this study provides a pioneering, real-world model for sensory-informed and nutritionally optimized interventions in ASD populations, highlighting both feasibility and avenues for future refinement and scaling.

Within the scope of this thesis, AUT-MENU complements the other case studies by illustrating the potential of environment-based, multidimensional strategies to promote healthier and more inclusive eating practices in populations with complex needs.

Chapter 4.

Discussion and Policy Recommendations

1. The Critical Role of Food Policy

1.1. Bridging the Gap: How research informs policy to guarantee safe and healthy food access in different contexts

Individual food choices are strongly shaped by the environments in which people live, study, and work. Dietary behaviors emerge from the interaction of individual factors with social, physical, and macro-level determinants, including food availability, pricing, institutional rules, and broader policy frameworks [22]. As highlighted by ecological models of health behavior, individual-level interventions alone are insufficient to generate sustained and equitable improvements in diet quality without parallel changes in food environments and policies [122].

Despite robust scientific evidence on what constitutes a healthy diet [225], the persistent gap between what people know about health and what they do in real-world setting remains one of the greatest challenges in public health promotion [226,227].

Policies targeting food environments are more effective than those relying solely on individual behavior change [122,123,136]. Institutional settings such as schools, universities, and collective catering services represent strategic entry points for policy action, as they allow structural modifications to food availability, quality, and presentation while reaching large and diverse populations [92,106,113,124]. Evidence from applied interventions demonstrates that changes in food provision, combined with educational and environmental strategies, can support healthier and more sustainable dietary behaviors across the life course [92,106,113,124].

From a policy perspective, translating research into action requires moving upstream, addressing the structural determinants that shape food environments. This includes integrating nutritional criteria into public procurement, aligning agricultural and food policies with health objectives, and embedding equity considerations into policy design [228]. As emphasized in the public health literature, policies that modify food environments can achieve population-wide benefits while also reducing social inequalities in diet-related health outcomes [122].

Studies such as LIVELY, FOOD-HACK and AUT-MENU, illustrate how context-specific strategies can address diverse barriers to healthy eating across the life course. Although implemented in different settings and populations, the evidence generated by these interventions provides a common empirical foundation on which broader policy frameworks can be built. In this sense, research outcomes do not represent an endpoint, but rather a basis for informing scalable, adaptable policies capable of extending effective principles to wider institutional and population contexts.

1.2. Policy Recommendations: Based on LIVELY, AUT-MENU, and FOOD-HACK results

In light of the evidence discussed, policymakers play a central role in bridging the gap between scientific knowledge and everyday food practices. Ensuring effective access to healthy and sustainable diets cannot rely just on isolated educational projects or sporadic initiatives. Rather, it requires coherent and integrated policy frameworks capable of operating across multiple sectors of society and adapting to the specific contexts in which food choices are made.

A first policy priority concerns the strengthening of nutrition education within school systems, starting from early childhood. This requires the development of clear national guidelines, dedicated funding, and continuous training for teachers and educators, enabling them to deliver not only theoretical knowledge but also practical and experiential learning. In parallel, policies should promote active family involvement by providing accessible tools and educational pathways that foster continuity between school and home food environments. Evidence from school-based interventions, such as LIVELY, underscores the importance of inserting nutrition education within institutional curricula and reinforcing it through family engagement.

Beyond education, food environments themselves must be reframed as a core public health concern. Policies should support the increased availability, visibility, and affordability of healthy and sustainable foods in everyday settings, including school and university canteens, workplaces, and other public institutions. Interventions such as those tested in FOOD-HACK demonstrate how relatively simple environmental modifications can support healthier defaults without restricting individual freedom. At the same time, stronger regulatory actions are needed to limit the marketing and promotion of ultra-processed foods, particularly

advertising targeted at children. This includes restricting the promotion of products commonly marketed as “children’s foods”, such as sweet snacks and sugary drinks, during television and digital media time slots with high child exposure.

Policy action should also facilitate healthy and sustainable choices. Economic incentives and public procurement policies can play a crucial role in promoting local, seasonal, and environmentally sustainable food production, thereby improving access to fruits, vegetables, and legumes across institutional settings. Such measures not only support dietary quality but also align nutrition policy with broader sustainability and climate objectives.

Finally, digital technologies represent both a challenge and an opportunity for public health nutrition. When appropriately regulated and integrated into public health strategies, digital tools can expand the reach of educational interventions, support behavior monitoring, and counteract the widespread nutrition misinformation circulating on social media. Online platforms, applications, and interactive tools can serve as effective channels for disseminating evidence-based information and fostering participatory learning processes, particularly among younger populations.

2. Strengths and Limitations

This thesis presents a set of context-specific, multidimensional interventions aimed at improving access to healthy and sustainable diets across different life stages and settings. While the three studies differ in design, target population, and intervention tools, they share common strengths and limitations that should be interpreted collectively, in light of the real-world contexts in which the interventions were implemented.

A key strength across all studies lies in their implementation in real-life settings, schools, university cafeterias, and collective catering services, where food choices are made in everyday routines and institutional constraints. This approach allows the findings to reflect actual behaviors rather than hypothetical preferences, enhancing their relevance for public health practice and policy. Moreover, the interventions adopted a multidimensional perspective, combining educational, environmental, and behavioral components, and addressing both nutritional quality and sustainability. This integrated approach aligns with current calls for food system-oriented strategies and represents an important advancement beyond single-component interventions.

Another shared strength is the high level of acceptability observed among key stakeholders. In school and care settings, children, families, educators, and caregivers reported positive experiences, while teachers and institutional staff highlighted the feasibility and relevance of the interventions within routine activities. In the university setting, the use of nudging strategies allowed behavioral change without restricting choice, supporting autonomy while promoting healthier and more sustainable options. Across contexts, the adaptability of the interventions to existing institutional structures represents a critical element for potential scalability.

At the same time, several limitations must be acknowledged. From a methodological perspective, all studies were constrained by design features inherent to real-world intervention research. The absence of control groups and the reliance on pre-post or descriptive designs limit causal inference and prevent definitive attribution of observed changes solely to the interventions. Furthermore, the pre-post structure permits the assessment of level changes (i.e., shifts between baseline and post-intervention measurements) but does not allow robust evaluation of changes in temporal trends (slope change). Consequently, findings should be interpreted as observed shifts rather than sustained modifications in outcome trajectories. Follow-up duration was relatively short across studies, limiting the ability to assess long-term sustainability of behavioral or nutritional changes. In the LIVELY project, substantial attrition at 12 months prevented reliable long-term analysis, further restricting conclusions regarding maintenance of effects over time. External validity also warrants careful consideration. Sample sizes were relatively small, and recruitment occurred within specific institutional settings (e.g., a single primary school, selected care centres, or a university canteen), limiting generalizability beyond the populations studied. In particular, findings from the LIVELY and AUT-MENU projects should not be interpreted as nationally representative but rather as context-specific evidence derived from defined local settings. Additional methodological limitations include reliance in some cases on indirect measures of food consumption, such as tray photography or proxy reporting, which may not fully capture actual intake. In AUT-MENU, multiple subgroup comparisons were conducted without formal correction for multiple testing, increasing the risk of type I error; therefore, subgroup findings should be considered exploratory.

Contextual and population-specific challenges also emerged. Linguistic and cultural barriers limited participation and data completeness in multicultural school settings. Engagement with

vulnerable populations, such as individuals with autism spectrum disorder, required time to build trust and overcome parental concerns. In institutional catering contexts, collaboration with food service providers posed practical constraints, as menu modifications were not always feasible due to organizational, economic, or regulatory limitations. These structural barriers reduced sample sizes in intervention phases and limited the scope of quantitative analyses. The wide age range and contextual diversity of participants enhanced ecological validity but reduced comparability across subgroups and further complicated generalization of results. Moreover, the translation of institutional menu adaptations into home environments remains uncertain, particularly when caregiver engagement was limited by digital literacy or logistical barriers. Taken together, these limitations underscore that the findings should be interpreted with caution regarding effectiveness, generalizability, and long-term sustainability. However, they also reflect the inherent complexity of implementing nutrition interventions within real-world systems that are not primarily designed around health objectives.

Taken together, the findings of this thesis, together with their limitations and strength, should be interpreted within the methodological and contextual constraints described. The studies do not provide definitive evidence of effectiveness or causal impact, nor do they support population-level generalizations. Rather, they offer context-specific evidence on feasibility, acceptability, and implementation processes in diverse real-world settings. Across childhood, university, and institutional care environments, the interventions highlight both the potential and the complexity of modifying food environments to promote healthier and more sustainable dietary behaviors. The observed changes reflect shifts within defined contexts rather than sustained modifications in long-term trajectories. Importantly, the structural barriers encountered—organizational constraints, limited parental engagement, institutional rigidity, and attrition—are not incidental challenges but intrinsic features of applied public health nutrition research. In this sense, the contribution of this work lies not in demonstrating controlled efficacy, but in advancing practical knowledge on how nutrition interventions can be adapted, negotiated, and operationalized within existing systems. By integrating feasibility evidence with policy-oriented reflection, this thesis provides a grounded foundation for the development of scalable and context-sensitive strategies aimed at promoting healthy and sustainable eating behaviors across the life course.

3. Conclusions and Future Perspectives

Taken together, the findings from LIVELY, FOOD-HACK and AUT-MENU, indicate that improving access to healthy and sustainable diets requires moving beyond isolated actions toward continuous, multidimensional processes.

In particular, it is evident the importance of integrated approaches that involve not only the target population and the scientific community, but also the broader social networks in which individuals are embedded. For children, these include families, schools, healthcare professionals, and local communities; for young adults, universities and food service environments; and for individuals with clinical or functional vulnerabilities, both institutional and home settings. Ensuring coherence between educational messages and daily practices across these contexts is essential to support meaningful and lasting change.

Future studies should prioritize the long-term sustainability of interventions, shifting the focus from short-term behavioral changes to the consolidation of healthy eating patterns over time. This requires longer follow-up periods and the development of multidisciplinary evaluation frameworks capable of integrating nutritional indicators, alongside psychological and social dimensions, to better capture the complexity of eating behaviors. Particular attention should be devoted to assessing the adaptability of interventions across diverse contexts and among vulnerable population groups.

Beyond scientific and methodological considerations, the results of this thesis underscore the need to strengthen a broader culture of prevention. Food should be recognized not merely as a technical or individual matter, but as a central determinant of individual and collective well-being. This perspective calls for sustained awareness-raising initiatives, inclusive communication strategies, and the active involvement of territorial actors, in the co-construction of food environments that facilitate healthy and sustainable choices.

In conclusion, this thesis supports a shift toward flexible, context-sensitive, and integrated food policies that build on real-world evidence. Rather than prescribing uniform solutions, effective strategies should scale up principles that have demonstrated feasibility and acceptability across settings, aligning health, sustainability, and equity objectives. By addressing food access as a systemic issue across the life course, it is possible to promote healthier, more inclusive, and more sustainable food environments, contributing to both human and planetary well-being.

Appendix

Tables

Tables from study 1: The LIVELY Project

Table 1. Summary of the lectures and activities proposed during the LIVELY intervention

Lectures title	Covered topics	Games/activities	Lectures aim
Macronutrients	Carbohydrates; proteins; lipids; water	True or false; crossword puzzle; game of sets; rhyming riddles	Learn what macronutrients are, their functions, importance to our bodies and what foods they are present in. Know the importance of water, main functions and daily intake.
Micronutrients	Vitamins and minerals	Rhyming riddles; the hangman's game; memory game	Learn what micronutrients are, their functions, importance to our bodies and what foods they are present in.
Digestive system	The pathway of food from the mouth to the esophagus, to the stomach, to the intestines; the enzymes involved; where major macronutrients are absorbed.	World search; true or false; rhyming riddles; vision of a short cartoon on the digestive system; human anatomy labeling game	Learn what happens to food when we eat, what path it takes inside our bodies, how food is digested and how nutrients are absorbed.
Food pyramid	Composition of the food pyramid; frequency of food consumption; ultra-processed foods; food labels	Rebus; food pyramid sorting game; riddles	Learn the frequency of food consumption; know the foods to consume every day and those to consume only occasionally. Learn what ultra-processed foods are and learn how to read food labels.
Healthy eating plate	Plate composition; How to compose a healthy dish; importance of breakfast; seasonality of fruits and vegetables	Create your own healthy dish game; Find the Odd One Out game; Find the Missing Part game	Learn how to compose a balanced, healthy dish; learn about alternatives for each part of the dish (fiber, carbohydrates, and protein); learn how to compose a healthy dish on your own by choosing seasonal foods.
Lifestyle	Sleep habits; screen time; physical activity	True or false; riddles; Complete your healthy day activity	Know what the good habits are to stay healthy and lead an active lifestyle; know the difference between moderate and intense physical activity and related examples; learn how much time should be devoted to these activities; know how many hours of sleep a child needs and what are good habits before sleeping; know what the limit of screen time is and what are alternative activities.
Multimedia lab	Drawing and storytelling	Drawing a humanized food and proposing a dramaturgy	To work on the content learned in previous lessons, activate motivation and discussion among students, work on character design and the creation of shared dramaturgies.

Table 2. Distribution of demographic and anthropometric characteristics of 227 children enrolled in the LIVELY study at baseline (T0)

	Males n=110	Female n=117	Total n=227
Age (years); mean (SD)	8.9 (1.2)	8.9 (1.1)	8.9 (1.2)
Place of birth			
Italy	83 (75.5%)	97 (82.9%)	180 (79.3%)
Africa	10 (9.1%)	13 (11.1%)	23 (10.1%)
South America	6 (5.5%)	5 (4.3%)	11 (4.8%)
Europe	9 (8.2%)	1 (0.9%)	10 (4.4%)
Asia	2 (1.8%)	1 (0.9%)	3 (1.3%)
Attended class			
Second grade (6-7 years old)	8 (7.3%)	4 (3.4%)	12 (5.3%)
Third grade (7-9 years old)	36 (32.7%)	41 (35.0%)	77 (33.9%)
Fourth grade (8-10 years old)	17 (15.5%)	19 (16.2%)	36 (15.9%)
Fifth grade (9-12 years old)	49 (44.5%)	53 (45.3%)	102 (4.9%)
Ethnicity			
Caucasian	44 (40.0%)	38 (32.5%)	82 (36.1%)
African	36 (32.7%)	50 (42.7%)	86 (37.8%)
Hispanic	16 (14.5%)	15 (12.8%)	31 (13.7%)
Asian	9 (8.2%)	11 (9.4%)	20 (8.8%)
Mixed	5 (4.6%)	3 (2.6%)	8 (3.5%)
Anthropometric measurements			
Weight, kg; mean (SD)	35.27 (10.5)	36.41 (10.57)	35.86 (10.53)
Height, cm; mean (SD)	135.85 (8.38)	136.75 (9.09)	136.33 (8.74)
Waist circumference, cm; mean (SD)	65.22 (10.95)	65.15 (11.79)	65.19 (11.37)
BMI z-score classes			
Underweight	4 (3.6%)	1 (0.9%)	5 (2.2%)
Normal weight	80 (72.7%)	89 (76.1%)	169 (74.4%)
Overweight	16 (14.5%)	24 (21.4%)	41 (18.1%)
Obesity	10 (9.1%)	3 (1.7%)	12 (5.3%)
WHtR			
WHtR<0.5	76 (69.1%)	74 (63.2%)	150 (66.1%)
WHtR≥0.5	34 (30.9%)	43 (36.8%)	77 (33.9%)

Data are expressed as counts (%) unless otherwise specified; Body Mass Index (BMI); Waist to Height ratio (WHtR); Standard deviation (SD).

Table 3. Children's eating behaviors and lifestyle habits at baseline (T0)

	Total sample N=205	
	N (%)	Missing
Adherence to Mediterranean Diet		
Low	29 (14.4%)	
Medium	111 (55.2%)	4
High	61 (30.4%)	
Breakfast consumption	160 (78.4%)	1
Consumption of whole foods (<i>pasta, cereals, bread, breakfast cereals%</i>)	130 (64.4%)	3
Use of sweeteners (<i>sugar, honey, sweetened cocoa etc.%</i>)	143 (70.1%)	1
Hydration		
< 1L a day	69 (33.8%)	
1L – 1.5L a day	108 (52.9%)	1
> 1.5 L a day	27 (13.3%)	
Physical activity		
No physical activity	18 (9.0%)	
Only non-programmed physical activity	50 (24.9%)	4
1-2 times a week of programmed physical activity	93 (46.3%)	
3 or more times a week of programmed physical activity	40 (19.9%)	
Screen time		
~ 2 h or less	175 (89.3%)	9
~ 3 h or more	21 (10.7%)	
Sleep hygiene		
Less than 9 hours of sleep	66 (33.3%)	7
9 or more hours of sleep	132 (66.7%)	

Categorical variables are expressed as counts (percentages).

Table 4. Children's anthropometric measures at baseline (T0) and at 6 months follow-up (T1)

	Total sample n=194	
	Baseline (T0)	Six months (T1)
Anthropometric measurements		
Weight, kg; mean (SD)	35.91 (10.06)	37.53 (10.86)
Height, cm; mean (SD)	136.49 (8.40)	139.91 (8.73)
Waist circumference, cm; mean (SD)	65.24 (11.07)	65.47 (11.44)
BMI z-score classes		
Underweight	4 (2.1%)	6 (3.1%)
Normal weight	144 (74.2%)	149 (76.8%)
Overweight	36 (18.6%)	30 (15.5%)
Obesity	10 (5.1%)	9 (4.6%)
WHtR		
WHtR<0.5	130 (67.0%)	143 (73.7%)
WHtR≥0.5	64 (33.0%)	51 (26.3%)

Data are expressed as counts (%) unless otherwise specified; Body Mass Index (BMI); Waist to Height ratio (WHtR); Standard deviation (SD).

Table 5. Children's eating behaviors and lifestyle habits (T0) and at 6 months follow-up (T1)

Table 5A. Eating behaviors		
	Total sample n=186	
	Baseline (T0)	Six months (T1)
Adherence to Mediterranean Diet		
Low	27 (14.5%)	30 (16.1%)
Medium	103 (55.4%)	98 (52.7%)
High	56 (30.1%)	58 (31.2%)
Breakfast consumption	145 (79.0%)	125 (67.2%)
Consumption of whole foods (pasta, cereals, bread, breakfast cereals)	116 (62.4%)	109 (58.6%)
Use of sweeteners (sugar, honey, sweetened cocoa etc.)	128 (68.8%)	127 (68.3%)
Hydration		
< 1L a day	61 (32.8%)	60 (32.3%)
1L – 1.5L a day	100 (53.8%)	94 (50.5%)
> 1.5 L a day	25 (13.4%)	32 (17.2%)

Table 5B. Lifestyle habits		
	Total sample n=178	
	Baseline (T0)	Six months (T1)
Physical activity		
No physical activity	15 (8.4%)	10 (5.6%)
Only non-programmed physical activity	41 (23.0%)	36 (20.2%)
1-2 times a week of programmed physical activity	86 (48.3%)	89 (50.0%)
3 or more times a week of programmed physical activity	36 (20.2%)	43 (24.2%)
Screen time		
~ 2 h or less	161 (90.4%)	163 (86.5%)
~ 3 h or more	17 (9.6%)	25 (13.5%)
Sleep hygiene		
Less than 9 hours of sleep	57 (32.0%)	48 (27.0%)
9 or more hours of sleep	121 (68.0%)	130 (73.0%)

Categorical variables are expressed as counts (percentages).

Table 6. Average scores (SD) obtained in the knowledge questionnaire

Topic	Average score
Macronutrients	4.07 (2.60)
Micronutrients	3.92 (2.54)
Digestion	6.71 (1.72)
Food pyramid	7.09 (2.26)
Healthy plate	7.24 (3.31)
Lifestyle	7.22 (2.99)
Total	6.04 (1.50)

Data are expressed as mean (SD); Standard deviation (SD).

Tables from study 2: The FOOD-HACK Project

Table 7. Tray composition at pre- and post-intervention phase.

Course	Pre-intervention (T0) N=2400			Post-intervention (T1) N=2400			p-value
	0 dish	1 dish	2 dishes	0 dish	1 dish	2 dishes	
First course (pasta, rice or other cereals)	467 (19.5%)	1907 (79.5%)	26 (1.1%)	473 (19.7%)	1902 (79.3%)	25 (1.0%)	0.9
Pizza	2117 (90.7%)	283 (11.8%)	0 (0.0%)	2142 (89.2%)	258 (10.8%)	0 (0.0%)	0.3
Second course (meat, fish, cheese, legumes or mixed salads)	362 (15.1%)	2033 (84.7%)	5 (0.2%)	357 (14.9%)	2005 (83.5%)	38 (1.6%)	<0.001
Side dish (vegetables raw or cooked, potatoes)	372 (15.5%)	1566 (65.3%)	462 (19.3%)	358 (14.9%)	1533 (63.9%)	509 (21.2%)	0.2
Bread and accompaniments (bread, breadsticks or crackers)	1083 (45.1%)	1304 (54.3%)	13 (0.5%)	1258 (52.4%)	1138 (47.4%)	4 (0.2%)	<0.001
Fruit or dessert (fresh fruit, yoghurt, pudding, fruit mousse or pie)	551 (23.0%)	1803 (75.1%)	46 (1.9%)	496 (20.7%)	1826 (76.1%)	78 (3.3%)	0.004

Data are presented as absolute numbers and frequency, expressed as a percentage. One serving = refers to those who have ordered only one course; two servings = refers to those who have ordered two courses of the same plate (e.g. two first courses or two second courses, etc.).

Table 8. Tray composition at pre- and post-intervention phase.

Type of meal	Pre-intervention (T0) N=2117	Post-intervention (T1) N = 2142	p-value
Omnivorous	1845 (87.2%)	1848 (86.3%)	0.3
Vegetarian	217 (10.3%)	220 (10.3%)	
Vegan	55 (2.6%)	74 (3.5%)	

Data are presented as absolute numbers and frequency, expressed as a percentage. Omnivorous = trays containing meat or fish; Vegetarian = trays containing eggs or cheese (no meat or fish); Vegan = trays containing only plant-based foods (no animal products). Pizza was excluded from this analysis.

Table 9. First course.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=1933	Servings N=1927	
Added grated cheese			
Yes	1,050 (54.3%)	1,004 (52.1%)	0.2
First course with			<0.001
Meat	226 (11.7%)	293 (15.2%)	
Fish	637 (33.0%)	481 (25.0%)	
Cheese	361 (18.7%)	373 (19.4%)	
Legumes	42 (2.2%)	48 (2.5%)	
Vegetables	610 (31.6%)	683 (35.4%)	
Plain	57 (2.9%)	49 (2.5%)	
Type of meal			<0.001
Omnivorous	863 (44.6%)	774 (40.1%)	
Vegetarian	969 (50.2%)	853 (44.3%)	
Vegan	101 (5.2%)	300 (15.6%)	

Data are presented as absolute numbers and frequency, expressed as a percentage. Omnivorous = trays containing meat or fish; Vegetarian = trays containing eggs or cheese (no meat or fish); Vegan = trays containing only plant-based foods (no animal products, no added grated cheese).

Table 10. Second course.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=2038	Servings N=2043	
Second course with			0.12
Meat	1286 (63.1%)	1337 (65.4%)	
Fish	386 (18.9%)	372 (18.2%)	
Cheese	162 (7.9%)	168 (8.2%)	
Legumes	162 (7.9%)	121 (5.9%)	
Eggs	42 (2.1%)	45 (2.2%)	
Type of meal			0.026
Omnivorous	1672 (82.2%)	1709 (84.0%)	
Vegetarian	204 (9.9%)	213 (10.3%)	
Vegan	162 (7.9%)	121 (5.7%)	

Data are presented as absolute numbers and frequency, expressed as percentage. Omnivorous = trays containing meat or fish; Vegetarian = trays containing eggs or cheese (no meat or fish); Vegan = trays containing only plant-based foods (no animal products, no added grated cheese).

Table 11. Side dish preferences.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=2028	Servings N=2042	
First serving			<0.001
Vegetables	979 (48.3%)	1100 (53.9%)	
Legumes	2 (0.1%)	10 (0.4%)	
Potatoes	1047 (51.6%)	932 (45.7%)	
	Servings N=462	Servings N=509	
Second serving			<0.001
Vegetables	4 (0.9%)	33 (6.5%)	
Legumes	0 (0.0%)	16 (3.1%)	
Potatoes	458 (99.1%)	460 (90.4%)	

Data are presented as absolute numbers and frequency, expressed as a percentage.

Table 12. Bread and accompaniments.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=1304	Servings N=1138	
Bread			0.7
White bread	982 (75.3%)	864 (75.9%)	
Whole bread	322 (24.7%)	274 (24.1%)	
	Servings N=13	Servings N=4	
Other			0.5
Breadsticks	7 (53.8%)	3 (90.0%)	
Crackers	6 (46.2%)	1 (10.0%)	

Data are presented as absolute numbers and frequency, expressed as a percentage.

Table 13. Fruit or dessert choices.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=1849	Servings N=1904	
First serving			0.001
Fruit	825 (44.6%)	953 (50.0%)	
Fruit mousse	242 (13.1%)	187 (9.8%)	
Yoghurt	196 (10.6%)	181 (9.5%)	
Pudding	238 (12.9%)	239 (12.6%)	
Fruit juice	213 (11.5%)	186 (9.8%)	
Cake	135 (7.3%)	158 (8.3%)	
	Servings N=46	Servings N=78	
Second serving			0.001
Fruit	1 (2.2%)	21 (26.9%)	
Fruit mousse	7 (15.2%)	9 (11.5%)	
Yoghurt	16 (34.8%)	11 (14.1%)	
Pudding	8 (17.4%)	16 (20.5%)	
Fruit juice	7 (15.2%)	15 (19.2%)	
Cake	7 (15.2%)	6 (7.7%)	

Data are presented as absolute number and frequency, expressed as percentage.

Table 14. Water and beverages.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=2400	Servings N=2400	
Beverages			0.87
Tap water	2151 (89.6%)	2198 (91.6%)	
Water Plastic bottle	235 (9.8%)	189 (7.9%)	
Coke or soft drinks	13 (0.5%)	11 (0.5%)	
Beer	1 (0.0%)	2 (0.1%)	

Data are presented as absolute number and frequency, expressed as percentage.

Table 15. Trays following the Harvard Healthy Eating Plate and EAT-Lancet Planetary Diet models composition.

	Pre-intervention (T0)	Post-intervention (T1)	p-value
	Servings N=2117	Servings N=2142	
Adherent	239 (11.3%)	347 (16.2%)	<0.001
Not adherent	1878 (88.7%)	1795 (83.8%)	

Data are presented as absolute numbers and frequency, expressed as percentage. Pizza was excluded from this analysis.

Table 16. Negative dietary quality indicators.

	Pre- intervention (T0)	Post- intervention (T1)	P- value
	Servings N=2117	Servings N=2142	
Presence of two sources of animal protein <i>trays containing both meat and fish, or two portions of either</i>	705 (33.3%)	640 (29.9%)	0.037
Absence of protein sources <i>Trays with no sources of protein such as meat, fish, legumes, eggs or cheese</i>	36 (1.7%)	40 (1.9%)	0.6
Absence of vegetables <i>trays with no vegetable side dishes</i>	1421 (67.1%)	1300 (60.7%)	<0.001
Presence of three carbohydrate sources <i>trays including a combination of pasta or rice, bread, and potatoes</i>	893 (42.2%)	351 (16.4%)	<0.001
Absence of fruit <i>trays with no fruit at the end of the meal</i>	1575 (74.4%)	1448 (67.7%)	0.001
Absence of water <i>trays where no water was chosen, either from a refillable bottle or purchased, and only other beverages were selected</i>	14 (0.7%)	13 (0.6%)	0.8

Data are presented as absolute number and frequency, expressed as percentage. Pizza was excluded from this analysis.

Tables from study 3: The AUT-MENU Project

Table 17. Summary of data collection tools

Evaluated aspects and tools	Data regarding	T0	T1
Meal assessment			
PDATs	Participants	X	X
Socio-demographic information			
CRF	Participants, Parents and Caregivers	X	
Food habits and MD adherence			
KIDMED (3-24 years old)	Participants	X	
MedQ-Sus (≥25 years old)			
Food behaviors			
BAMBI (3-11 years old)	Participants	X	X
STEP (≥12 years old)			
Nutrition course			
Nutrition knowledge questionnaire	Parents and Caregivers	Before and after the course	
Satisfaction Questionnaire		Before and after the course	

Case Report Form (CRF); pictorial dietary assessment tool (PDAT); Mediterranean Diet (MD); Mediterranean Diet Quality Index for children and adolescents' questionnaire (KIDMED); New Validated Short Questionnaire for the Evaluation of the Adherence of Mediterranean Diet and Nutrition Sustainability in all adult population groups questionnaire (MedQ-Sus); Brief Autism Mealtime Behavior Inventory questionnaire (BAMBI); Screening Tool for Feeding Problems questionnaire (STEP).

Table 18. Sociodemographic at baseline (T0)

	DVM n=23	DVP n=29	TP n=20	Total n=72
Age (years); mean (SD)	8 (3.5)	10.3 (1.9)	25.4 (4.6)	13.8 (6.7)
Sex				
Female	3 (13.0%)	8 (27.6%)	5 (25.0%)	16 (22.2%)
Male	20 (87%)	21 (72.4%)	15 (75%)	56 (77.8%)
Nationality				
Italy	18 (78.3%)	24 (82.8%)	20 (100.0%)	62 (86.1%)
Other	5 (21.7%)	5 (17.2%)	0	10 (13.9%)
BMI classes				
Underweight	14 (60.9%)	13 (44.8%)	1 (5.0%)	28 (38.9%)
Normal weight	5 (21.7%)	14 (48.3%)	7 (35.0%)	26 (36.1%)
Overweight	3 (13.0%)	2 (6.9%)	8 (40.0%)	13 (18.1%)
Obesity	1 (4.3%)	0 (0.0%)	4 (20.0%)	5 (6.9%)
ASD severity				
Grade 2	10 (43.5%)	3 (7.1%)	2 (10.0%)	15 (19.7%)
Grade 3	13 (56.5%)	26 (92.9%)	18 (90.0%)	57 (80.3%)

Categorical variables presented as absolute frequencies (n) and percentage (%). Body Mass Index (BMI); autism spectrum disorder (ASD). Dosso Verde Milano (DVM); Dosso Verde Pavia (DVP); Fondazione Tiglio Onlus (TP).

Table 19. Feeding difficulties at baseline (T0)

Age: 3-11 years n= 37	
BAMBI	
Absence of feeding difficulties	22 (59.5%)
Presence of feeding difficulties	15 (40.5%)
Age: ≥ 12 years n= 35	
STEP	
Absent or minimal feeding difficulties	7 (20.0%)
Moderate feeding difficulties	8 (22.9%)
Severe feeding difficulties	20 (57.1%)

Categorical variables presented as absolute frequencies (n) and percentage (%). Bambi questionnaire (Presence of feeding difficulties if score >34); STEP questionnaire: absent or minimal feeding difficulties (score ≤7), Moderate feeding difficulties (score between 8-11), Severe feeding difficulties (score ≥12).

Table 20. Adherence to the Mediterranean diet at baseline (T0)

Age: 3-24 n= 62	
KIDMED	
Low	1 (1.6%)
Medium	32 (51.6%)
High	29 (46.8%)
Age: 25-35 N= 10	
MedQ-Sus	
Low	0 (0.0%)
Medium	0 (0.0%)
High	10 (100.0%)

Categorical variables presented as absolute frequencies (n) and percentage (%). KIDMED questionnaire (adherence is rated as low (score ≤4), medium (score between 5 and 7), and high (score ≥8); MedQ-Sus questionnaire (adherence is rated as low (score ≤9), medium (score between 9-11), and high (score >11)).

Table 21. Satisfaction Questionnaire (T1)

	Not at al	Slightly	Quite	A lot
COURSE ORGANIZATION				
1. Do you think the course was well organized?	0 (0%)	1 (4.8%)	8 (38.1%)	12 (57.1%)
2. Did you feel involved during the course lectures?	0 (0%)	3 (14.3%)	8 (38.1%)	10 (47.6%)
3. Did you find the online mode to your liking?	0 (0%)	2 (9.5%)	5 (23.8%)	14 (66.7%)
	Not at al	Slightly	Quite	A lot
COURSE CONTENTS				
1. In your opinion, was the course content helpful in reducing your stress during mealtime?	2 (9.5%)	7 (33.3%)	8 (38.1%)	4 (19.0%)
2. In your opinion, was the course content helpful in reducing your son/daughter's stress during mealtime?	3 (14.3%)	8 (38.1%)	7 (33.3%)	3 (14.3%)
3. In your opinion, was the course helpful in improving your knowledge of proper nutrition?	2 (9.5%)	2 (9.5%)	7 (33.3%)	10 (47.6%)
4. In your opinion, was the course helpful in increasing/improving your knowledge about food selectivity and its management?	0 (0%)	3 (14.3%)	7 (33.3%)	11 (52.4%)
5. In your opinion, was the course helpful in expanding your son/daughter's dietary diversity?	2 (9.5%)	4 (19.0%)	9 (42.9%)	6 (28.6%)
	No		Yes	
OTHER ASPECTS				
1.Would you prefer the in-person mode?	17 (81.0%)		4 (19.0%)	
2.Would you suggest this course to other parents of children with ASD?	0 (0%)		21 (100%)	

Categorical variables presented as absolute frequencies (n) and percentage (%).

Supplementary material

Supplementary figures

S. figures from study 1: The LIVELY Project

Figure S1. Summary of the topics covered during Lecture n°2 “Micronutrients”

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LECTURE 2 . MICRONUTRIENTS

Mineral are divided into major elements (whose requirements are on the order of a gram or a little less) and trace elements, whose requirements are much less (milligrams or micrograms). Each element performs specific functions in our bodies: plastic functions, such as calcium and phosphorus, constituents of bones and teeth, iron a component of the hemoglobin of red blood cells; regulatory functions for example calcium, which regulates muscle contraction and blood clotting, or sodium and potassium, which are involved in the transmission of nerve impulses and the regulation of heart rhythm.

MINERALS	MAIN FUNCTIONS	FOOD SOURCES
Calcium (Ca)	Along with phosphorus, it is the major mineral in bones and teeth. It is involved in muscle contraction and relaxation, nerve impulse transmission, blood clotting, blood pressure, and immune defense.	
Phosphorus (P)	Along with calcium, it is the main mineral in bones and teeth and plays a key role in converting food into energy.	
Sodium (Na)	It is the main electrolyte of extracellular fluids and is important in nerve impulse transmission.	
Potassium (K)	Electrolyte important for maintaining water balance, nerve impulse transmission, and muscle contraction.	
Iron (Fe)	A component of hemoglobin and myoglobin, it serves for the transport of oxygen in the blood and muscles.	
Iodine (I)	Constituent of thyroid hormones.	

Figure S2. Laminated placemat



Figure S2A



Figure S2B

S. figures from study 2: The FOOD-HACK Project

Figure S3. Plant-based option tags.



Figure S4. Dishes with legumes tags.

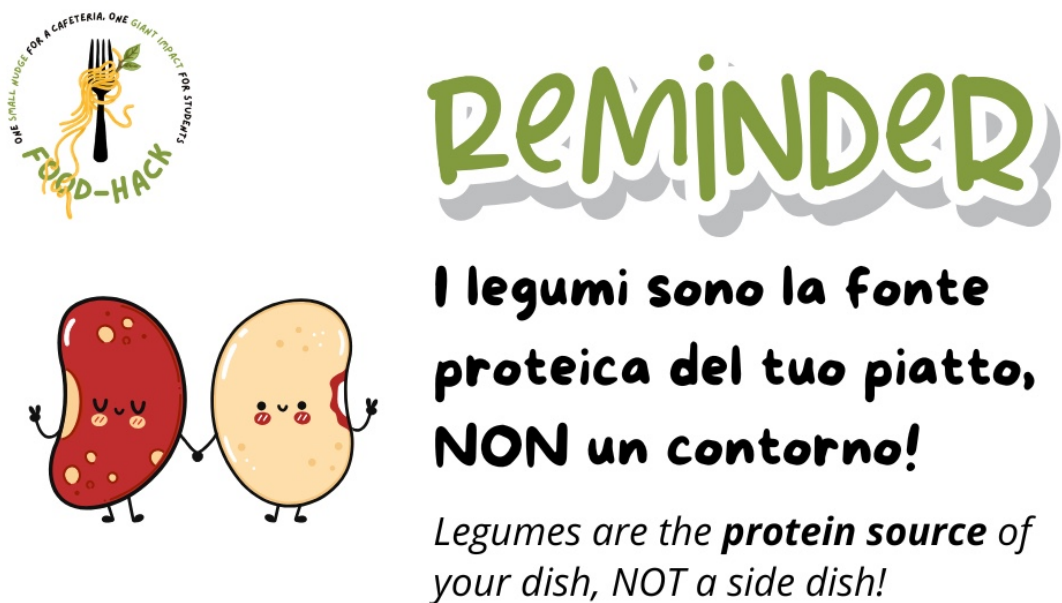


Figure S5. Sustainability poster

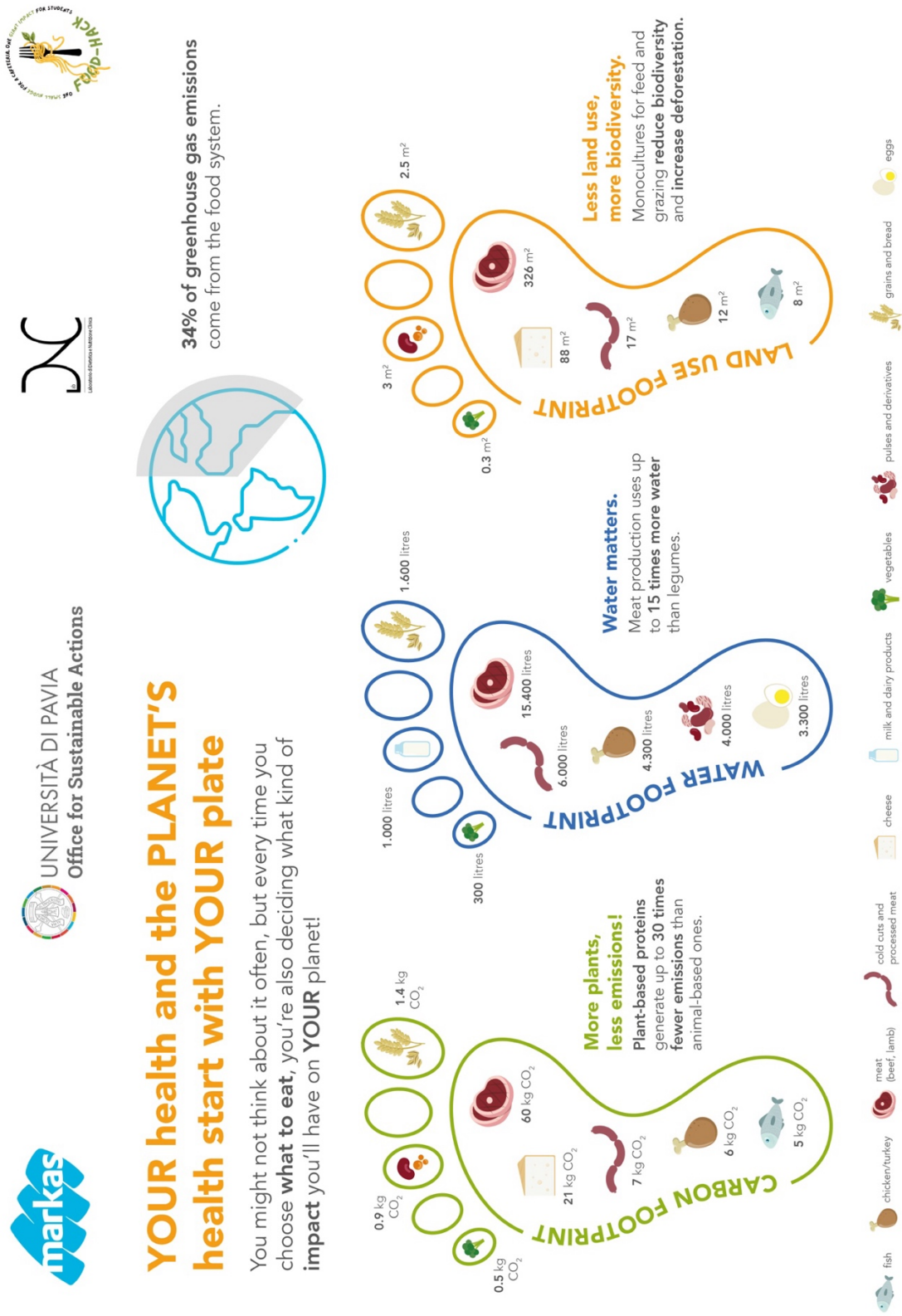


Figure S6. Healthy plate poster



Figure S7. Bread flyer



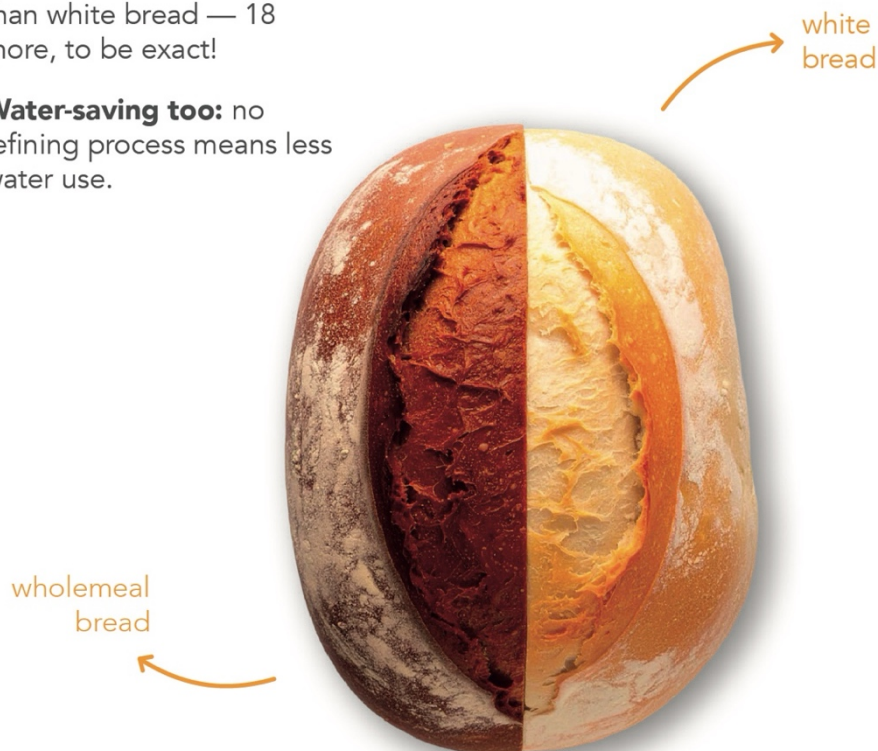
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Wholemeal bread? Whole-grain, whole-gain!

Less waste: the same amount of wheat produces more wholemeal loaves than white bread — 18 more, to be exact!

Water-saving too: no refining process means less water use.



More fiber and more proteins to support digestion and help you feel fuller!

Figure S8. Fruit flyer

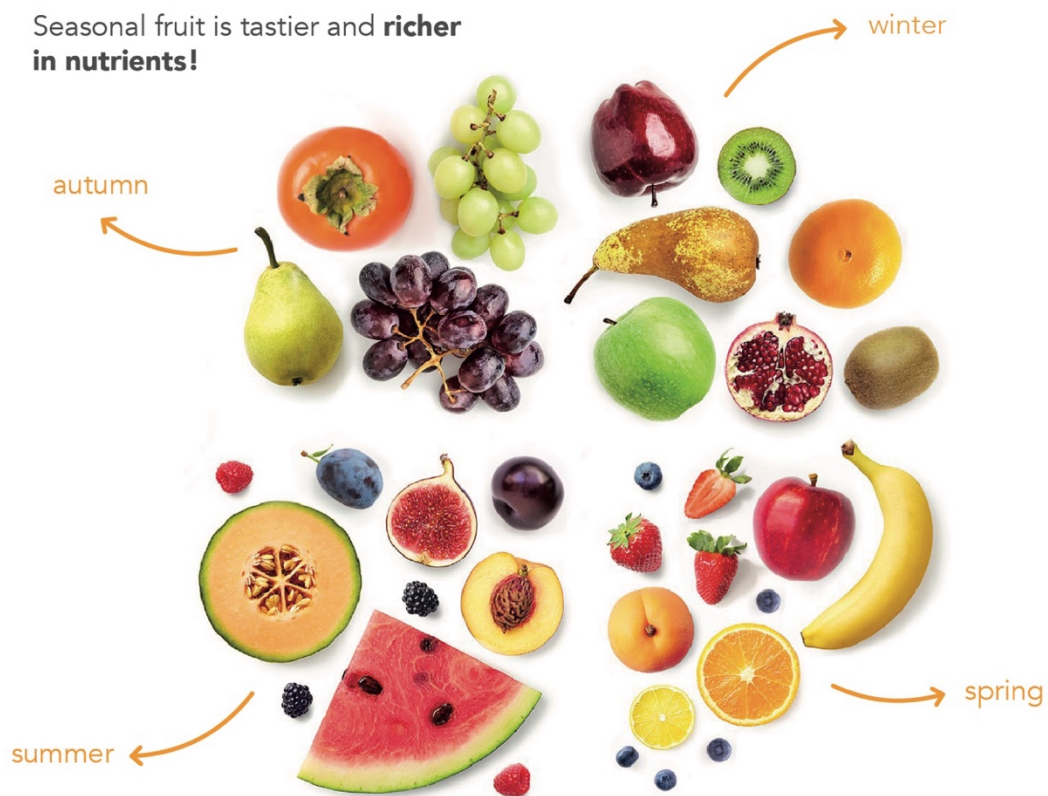


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Where are you rushing to? Grab some fruit... and eat it all up!

Eat it in season: imported and greenhouse-grown fruit can generate up to 10 times more CO₂?
Seasonal fruit is tastier and **richer in nutrients!**



Follow the **seasonality wheel** to make more mindful choices and add variety with color!

Yep... you can enjoy it any time of the day!

Figure S9. Legumes flyer



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Don't call them vegetables... Legumes are on a whole different mission!

They're good for the planet:

- 90% less CO₂ emissions
compared to meat.

They support **biodiversity**, use
less water, and cost less.



A **booster for your health:**
rich in protein and fiber,
low in saturated fats!

Figure S10. Herbs and spices flyer



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Shake the salt habit

GOAL

Less than 5g of salt per day
(most people consume nearly
twice as much!)

How?

Choose fresh, low-salt
foods like wholemeal
bread.

Use **herbs and spices**
to add flavor without
the salt.



Did you know that the
Mediterranean Diet
is great for reaching
these goals?

How much salt is in your food?

HIGH > 1–1.2 g per 100 g

MEDIUM 0.3–1.2 g per 100 g

LOW < 0.3 g per 100 g

Figure S11. Water consumption flyer.



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Refill, Reduce, Repeat

With a reusable bottle, you can avoid using up to **150 plastic bottles** a year – and only 13 of them would actually be recycled!

Your **wallet will thank you** too: refilling your bottle is free!



The University encourages the use of reusable bottles to reduce waste — and water is drinkable everywhere on campus!

Drinking more water and fewer sugary drinks is good for your health.

Figure S12: Paper placemat for trays with the Healthy plate.



S. figures from study 3: The AUT-MENU Project

Figure S13. Dietary Assessment Tool (PDAT), quantitative section



PICTORIAL DIETARY ASSESSMENT TOOL - AUTMENU PROJECT

DATE: _____ ☐ T0 ☐ T1 OPERATOR: _____

SURNAME: _____ NAME: _____

PLACE:

- ☐ Dosso Verde Milano
- ☐ Dosso Verde Pavia
- ☐ Tiglio Fondazione Onlus

QUANTITATIVE SECTION

LUNCH	NULL	¼	½	¾	ALL
FIRST COURSE					
MAIN COURSE					
SIDE DISH					
BREAD GRISSINI CRACKERS					
FRUIT YOGURT ICECREAM					
BEVERAGES					

Figure S14. Dietary Assessment Tool (PDAT), qualitative section

QUALITATIVE SECTION

LUNCH	GENERAL INFOS	COLOUR	TASTE/SMELL	TEXTURE	TEMPERATURE
FIRST COURSE	Name: _____ Pasta type: _____ ☐ Short (e.g. penne, fusilli, rice, barley) ☐ Long (e.g. spaghetti, fettuccine) Grated cheese? ☐ Yes ☐ No Spices/herbs: ☐ Yes ☐ No If yes, please specify: _____	☐ White ☐ Beige ☐ Brown ☐ Green ☐ Yellow ☐ Orange ☐ Red ☐ Monochrome ☐ Bicolor ☐ Multicolor	☐ Faint ☐ Intense	☐ Dry ☐ Firm/Al dente ☐ Soft ☐ Sticky/Too dry ☐ Untied ☐ Broth ☐ Dense/creamy ☐ Liquid ☐ Firm/Al dente ☐ Soft	☐ Hot ☐ Cold ☐ Room temperature
MAIN COURSE	Name: _____ Spices/herbs: ☐ Yes ☐ No If yes, please specify: _____ Breadcrumbs/grating: ☐ Yes ☐ No	☐ White ☐ Beige ☐ Brown ☐ Green ☐ Yellow ☐ Orange ☐ Red/Pink ☐ Monochrome ☐ Bicolor ☐ Multicolor	☐ Faint ☐ Intense	☐ Crunchy ☐ Firm/Hard ☐ Soft ☐ Too dry/chewy	☐ Hot ☐ Cold ☐ Room temperature
SIDE DISH	Name: _____ ☐ Raw ☐ Cooked Spices/herbs: ☐ Yes ☐ No If yes, please specify: _____ Breadcrumbs/grating: ☐ Yes ☐ No	☐ White ☐ Beige ☐ Brown ☐ Green ☐ Yellow ☐ Orange ☐ Red/Pink ☐ Monochrome ☐ Bicolor ☐ Multicolor	☐ Faint ☐ Intense	☐ Crunchy ☐ Soft ☐ Stringy	☐ Hot ☐ Cold ☐ Room temperature
BREAD GRISSINI CRACKERS	☐ Bread ☐ Focaccia ☐ Crackers ☐ Grissini Whole grains? ☐ Yes ☐ No	☐ White/Beige ☐ Brown	☐ Faint ☐ Intense	☐ Crunchy ☐ Soft	☐ Hot ☐ Cold ☐ Room temperature
FRUIT YOGURT ICECREAM	☐ Fruit Kind: _____ ☐ Whole ☐ Cutted ☐ Fruit puree ☐ Raw ☐ Cooked ☐ With peel ☐ Whitout peel ☐ Yogurt ☐ Icecream ☐ Pudding Flavour: _____ (Yogurt: fruits, plain, flavored; Pudding: cream/chocolate; Icecream: creams/fruits)	☐ White ☐ Beige ☐ Brown ☐ Green ☐ Yellow ☐ Orange ☐ Red/Pink ☐ Purple ☐ Monochrome ☐ Bicolor ☐ Multicolor	☐ Faint ☐ Intense	☐ Crunchy ☐ Soft ☐ Creamy ☐ Gelatinous	☐ Hot ☐ Cold ☐ Room temperature
BEVERAGES	☐ Water ☐ Fruit juice How many glasses? _____	If juice, please specify the flavour: _____	☐ Faint ☐ Intense	☐ Liquid	☐ Cold ☐ Room temperature

Supplementary tables

S. tables from study 1: The LIVELY Project

Table S1. Children's anthropometric measures distributed by ethnicity at baseline (T0)

	Total sample n=227				
	Caucasic N=82	African N=86	Hispanic N=31	Asian N=20	Mixed N=8
BMI z-score classes					
Underweight	1 (1.2%)	1 (1.2%)	0 (0.0%)	3 (15.0%)	0 (0.0%)
Normal weight	70 (85.4%)	57 (66.3%)	21 (67.8%)	14 (70.0%)	7 (87.5%)
Overweight	6 (7.3%)	21 (24.4%)	9 (29.0%)	3 (15.0%)	1 (12.5%)
Obesity	5 (6.1%)	7 (8.1%)	1 (3.2%)	0 (0.0%)	0 (0.0%)
WHtR					
WHtR<0.5	62 (75.6%)	55 (64.0%)	13 (41.9)	13 (65.0%)	7 (87.5%)
WHtR≥0.5	20 (24.4%)	31 (36.0%)	18 (58.1%)	7 (35.0%)	1 (12.5%)

Data are expressed as counts (%) unless otherwise specified. Body Mass Index (BMI); Waist to Height ratio (WHtR).

Table S2. Mothers' and fathers' characteristics at baseline (T0)

	Mothers n=205	Fathers n=190
Study title		
No one	11 (5.5%)	10 (5.6%)
Elementary school license	9 (4.5%)	9 (5.0%)
Middle school license	37 (18.4%)	33 (18.4%)
High school license	74 (36.8%)	70 (39.1%)
University degree or above	70 (34.8%)	57 (31.8%)
Missing	4	11
Occupation		
Yes	125 (70.2%)	162 (98.8%)
No	53 (29.8%)	2 (1.2%)
Missing	27	26
BMI class		
Underweight	5 (2.6%)	3 (1.8%)
Normal weight	83 (43.0%)	64 (37.9%)
Overweight	71 (37.8%)	85 (50.3%)
Obesity	34 (17.6%)	17 (10.0%)
Missing	12	11
Physical activity		
Yes	134 (70.2%)	117 (64.6%)
No	57 (29.8%)	64 (35.4%)
Missing	14	9

Categorical variables are expressed as counts (percentages).

Table S3. Distribution of answers at each KIDMED questions at baseline (T0)

	Total sample N=205		
	Yes	No	Missing
KIDMED questions			
Does the child consume a fruit or a juice every day?	168 (82.4%)	36 (17.6%)	1
Does the child consume a second fruit every day?	113 (56.2%)	88 (43.8%)	4
Does the child consume vegetables, cooked or raw, regularly, once a day?	146 (71.9%)	57 (28.1%)	2
Does the child consume vegetables, cooked or raw, more than once a day?	78 (39.0%)	122 (61.0%)	5
Does the child regularly consume fish (at least 2-3 times a week)?	93 (46.0%)	109 (54.0%)	3
Does the child go to fast food restaurants (hamburgers) more than once a week?	37 (18.1%)	167 (81.9%)	1
Does the child like legumes and consume them more than once a week?	122 (59.8%)	82 (40.2%)	1
Does the child consume pasta and rice every day (5 or more times a week)?	158 (77.5%)	46 (22.5%)	1
Does the child consume whole grains or bread for breakfast?	108 (54.3%)	91 (45.7%)	6
Does the child regularly consume nuts (at least 2-3 times a week)?	64 (31.7%)	138 (68.3%)	3
Is olive oil used at home for preparing the child's meals?	180 (90.0%)	20 (10.0%)	5
Does the child skip breakfast?	51 (25.1%)	152 (74.9%)	2
Does the child consume dairy products for breakfast (yogurt, milk, etc.)?	165 (81.3%)	38 (18.7%)	2
Does the child consume baked products or pastries for breakfast?	89 (44.1%)	113 (55.9%)	3
Does the child consume two yogurts and/or 40g of cheese daily?	61 (30.4%)	140 (69.6%)	4
Does the child consume candies or sweets multiple times a day?	54 (26.7%)	148 (73.3%)	3

Categorical variables are expressed as counts (percentages).

Table S4. Frequency of children who often (≥ 4 time a week) eat ultra-processed foods at baseline (T0)

	Total sample N=205	
	N (%)	Missing
Ultra-processed food		
Biscuits	90 (44.3%)	2
Fruits juices	75 (37.5%)	4
Milk-based beverages	71 (35.9%)	7
Industrial bread	42 (21.4%)	9
Salty snack	39 (19.5%)	5
Breakfast cereals	34 (17.2%)	7
Sweets and cake	32 (15.9%)	4
Gravy, condiments and ready-to-eat sauce	25 (12.4%)	4
Chips	20 (9.9%)	3
Sausages and other meat products	19 (9.6%)	6
Industrial dessert	17 (8.5%)	4
Margarine and other creams	9 (4.7%)	6
Confetti	9 (4.5%)	6
Soy and other beverages substituted of milk	7 (3.6%)	9
Confectioned ready-to-eat meal	4 (2.0%)	2
Industrial pizza	3 (1.5%)	4

Categorical variables are expressed as counts (percentages).

Table S5. Odds Ratios (OR) and 95% Confidence Interval (95% CI) from logistic regression model of association of overweight/obesity with nutritional factors (Model 1) and lifestyle (Model 2)

	Model 1*	Model 2**
Sex		
Female	1.00	1.00
Males	1.03 (0.51-2.06)	1.06 (0.53-2.14)
Ethnic group		
Caucasian	1.00	1.00
African	3.08 (1.29-7.34)	3.24 (1.31-8.02)
Others §	2.56 (0.97-6.75)	2.20 (0.80-6.04)
Mediterranean Diet Adherence		
Low	1.00	-
Medium	0.44 (0.17-1.14)	-
High	0.83 (0.31-2.26)	-
Hydration level		
< 1 L	1.00	-
1-1.5 L	0.94 (0.44-2.02)	-
>1.5 L	1.46 (0.51-4.15)	-
Physical Activity		
None	-	1.00
Not programmed	-	2.69 (0.30-23.75)
Programmed (1-2 times/week)	-	5.46 (0.67-44.24)
Programmed (≥ 3 times/week)	-	5.82 (0.67-50.39)
Screen time (~ 3 h or more)	-	1.37 (0.68-2.78)
Sleep hygiene (≥ 9 hours)	-	0.97 (0.45-2.09)

* Model 1 was fitted using 200 observation (46 with overweight/obesity) ; ** Model 2 was fitted using 194 observations (43 with overweight/obesity); § Others categories included Asiatic, Hispanic and Mixed ethnic groups.

Table S6. Frequency of children who often (≥ 4 time a week) eat ultra-processed foods at baseline (T0) and at 6 months follow-up (T1).

	Total sample N=186			
	Baseline (T0)		Six months (T1)	
	N (%)	Missing	N (%)	Missing
Ultra-processed food				
Biscuits	88 (45.6%)	1	83 (43.2%)	2
Fruits juices	71 (37.2%)	3	58 (30.2%)	2
Milk-based beverages	67 (35.5%)	5	76 (39.4%)	1
Industrial bread	40 (21.4%)	7	35 (18.3%)	3
Salty snack	37 (19.5%)	4	29 (15.1%)	2
Breakfast cereals	32 (16.8%)	4	41 (21.6%)	4
Sweets and cake	31 (16.2%)	3	36 (18.9%)	3
Gravy, condiments and ready-to-eat sauce	22 (11.5%)	2	20 (10.4%)	1
Sausages and other meat products	19 (10.0%)	4	38 (19.9%)	3
Chips	18 (9.4%)	2	15 (7.8%)	2
Industrial dessert	15 (7.8%)	2	18 (9.3%)	1
Margarine and other creams	9 (4.7%)	4	12 (6.3%)	2
Confetti	8 (4.2%)	4	18 (9.4%)	3
Soy and other beverages substituted of milk	7 (3.7%)	7	5 (2.6%)	7
Confectioned ready-to-eat meal	4 (2.1%)	1	2 (1.0%)	0
Industrial pizza	2 (1.1%)	3	4 (2.1%)	1

Categorical variables are expressed as counts (percentages).

Table S7. Responses to the satisfaction questionnaire addressed to children

Questions	Very	Enough	A little	Not at all	Missing data
1. Did you enjoy participating in this project?	144 (59.3%)	84 (34.6%)	13 (5.4%)	2 (0.8%)	1
2. Do you think participating in this project was useful?	136 (57.1%)	75 (31.5%)	22 (9.2%)	5 (2.1%)	6
3. Do you think the proposed activities helped you understand the importance of a healthy diet?	142 (58.7%)	85 (35.1%)	12 (5.0%)	3 (1.2%)	2
4. Do you think the proposed activities helped you understand the importance of a healthy lifestyle?	133 (55.0%)	89 (36.8%)	14 (5.8%)	6 (2.5%)	2
5. Do you think the number of meetings we had was sufficient?	93 (38.9%)	87 (36.4%)	41 (14.2%)	18 (7.5%)	5
6. Did you feel engaged in the proposed activities?	114 (47.7%)	83 (34.7%)	38 (15.9%)	4 (1.7%)	5
7. Did you have any difficulties working with your classmates in the group?	27 (11.4%)	44 (18.6%)	67 (28.4%)	98 (41.5%)	8
8. Do you think the proposed activities were interesting/fun?	146 (60.8%)	75 (31.3%)	13 (5.4%)	6 (2.5%)	4
9. Did you understand the topics covered?	73 (30.5%)	135 (56.5%)	31 (13.0%)	-	5
10. Was the language used simple?	118 (49.4%)	89 (37.2%)	27 (11.3%)	5 (2.1%)	5
11. Was the material used easy to understand?	144 (61.0%)	69 (29.2%)	16 (6.8%)	7 (3.0%)	8
12. While doing the activities, did you experience positive emotions (interest, surprise, joy, happiness, fun...%)?	135 (57.9%)	60 (25.8%)	26 (11.2%)	12 (5.2%)	11
13. Did you learn new things?	155 (65.4%)	60 (25.3%)	19 (8.0%)	3 (1.3%)	7
	Yes		No		Missing
14. Would you like the project to be repeated?	209 (89%)		26 (11.0%)		9

Data are expressed as counts (percentages).

Table S8. Responses to the satisfaction questionnaire addressed to parents or caregivers.

Questions	Very	Enough	A little	Not at all	Missing data
1. Are you satisfied that your son/daughter participated in this project?	122 (75.3%)	35 (21.6%)	2 (1.2%)	3 (1.9%)	2
2. Do you think your son/daughter is satisfied that he/she participated in this project?	115 (72.9%)	42 (26.3%)	2 (1.3%)	2 (1.2%)	3
3. In your opinion, was the project helpful in improving your son/daughter's knowledge of proper nutrition and lifestyle?	121 (75.6%)	31 (19.4%)	6 (3.8%)	2 (1.3%)	4

Data are expressed as counts (percentages).

Table S9. Responses to the satisfaction questionnaire addressed to teachers.

Questions	Very	Enough	A little	Not at all
1. In your opinion, were the project objectives well defined?	9 (50%)	9 (50%)	-	-
2. Do you believe that projects like this can have a positive impact on public health, beyond benefiting the individual child?	15 (83.3%)	2 (11.1%)	1 (5.6%)	-
3. Were the content of the sessions and the proposed activities aligned with the project objectives?	13 (72.2%)	4 (22.2%)	1 (5.6%)	-
4. To what extent did the various aspects of the project meet your expectations?	13 (72.2%)	4 (22.2%)	1 (5.6%)	-
5. In your opinion, were the proposed activities presented and conducted in a way that encouraged the engagement and participation of all students?	10 (55.6%)	7 (38.9%)	1 (5.6%)	-
6. Was the overall duration of the project appropriate to achieve its objectives?	12 (66.7%)	5 (27.8%)	1 (5.6%)	-
7. Do you think the project was well-organized and balanced in terms of the educational activities proposed for the class?	6 (33.3%)	9 (50%)	3 (16.7%)	-
8. In your opinion, were the project objectives achieved?	11 (61.1%)	5 (27.8%)	2 (11.1%)	-
9. Do you think the language used by the research team was clear and effective (keeping students engaged%) in relation to their age?	13 (72.2%)	3 (16.7%)	2 (11.1%)	-
10. In your opinion, did the students participate in the proposed activities with enthusiasm?	12 (66.7%)	5 (27.8%)	1 (5.6%)	-
11. Do you think the students actively and constructively collaborated with each other and with the researchers to achieve the project objectives?	6 (33.3%)	11 (61.1%)	1 (5.6%)	-
12. Do you believe the project contributed to students' learning or improved their knowledge about adopting a healthy diet?	9 (50%)	7 (38.9%)	2 (11.1%)	-
13. In your opinion, were the proposed activities effective in raising children's awareness of the importance of a healthy diet?	8 (44.4%)	10 (55.6%)	-	-
14. Do you think the proposed activities could be integrated into students' daily school routines?	5 (27.8%)	11 (61.1%)	2 (11.1%)	-
15. In your opinion, did the proposed activities increase students' awareness of the importance of a healthy diet and an appropriate lifestyle?	10 (55.6%)	7 (38.9%)	1 (5.6%)	-
	Yes		No	Missing
16. Would you like the project to be repeated?	14 (77.8%)		1 (5.6%)	3 (16.7%)

Data are expressed as counts (percentages)

S. tables from study 2: The FOOD-HACK Project

Table S10. Summer menu adopted during the study period.

Day	First courses	Second courses	Side dishes	Fixed alternatives
Monday	- Risotto with scamorza cheese and zucchini[†] - Cold pasta with raw tomato and mozzarella cheese[†] - Curry risotto with vegetables[†] - Mushroom risotto[†] - Pasta with <i>arrabbiata</i> sauce (<i>hot tomato sauce</i>)[‡] - Pasta salad with vegetables[‡] - Pasta with vegetable ragù[‡] - Pasta with tomato sauce and clams[*] - Salmon risotto[*]	- Cheesy puff pastries[†] - Potato, ricotta cheese, and spinach pie[†] - Breaded mozzarella cheese balls[†] - Chicken escalope with curry[*] - Mediterranean-style cod fillet[*] - Rabbit roll[*] - Chicken escalope with cherry tomatoes and pine nuts[*] - Beef slice with tomato sauce[*] - Chicken escalope with artichokes[*] - Sliced beef[*]	- Steamed zucchini - Potato croquettes	<u>First courses:</u> - Pasta/rice with oil/tomato sauce[‡] <u>Second courses:</u> - Legumes of the day[‡] - Cold cuts[*] - Grilled meat of the day[*] - Mixed salads with eggs[‡] - Mixed salads with legumes[‡] - Mixed salads with tuna[*] - Fresh/aged cheeses[†]
	- Mushroom risotto[†] - Spelt and barley salad with pesto, cherry tomatoes, and mozzarella cheese[†] - Pasta with <i>norma</i> (eggplant and tomato) sauce[‡] - Pasta with <i>Amatriciana</i> sauce (tomato sauce and <i>guanciale</i>)[*] - Spelt salad with tuna and mozzarella cheese[*] - Risotto with shrimp, zucchini, and saffron[*] - Pasta with ragù[*] - Salmon risotto[*] - Pasta with tomato, cream, and speck[*] - Risotto with speck, provola cheese, and chicory[*]	- Fresh baked ricotta cheese[†] - Artichoke terrine[†] - Pizzaiola cheese puffs[†] - Spicy borlotti bean salad[‡] - Roast turkey[*] - Perch fillet with lemon[*] - Trio of ribs, Prague ham, and pork sausage[*] - Roast turkey with herbs[*] - Pork chop with herbs[*] - Chicken and vegetable salad[*] - Perch fillet with zucchini and paprika[*] - Chicken bites with curry[*]	- Steamed green beans - French fries	<u>Side dishes</u> - Raw vegetables <u>Fruit/dessert:</u> - Fresh seasonal fruit - Yogurt - Fruit mousse - Pie - Pudding

		• Breaded mozzarella cheese balls[†] • Ricotta cheese and spinach pie[†] • Vegetable quiche[†] • Pepper stew with potatoes and peas[‡] • Meat skewer and chicken sausage[*] • Mackerel fillet with fresh tomatoes[*] • Pangasius fillet au gratin[*] • Roast veal[*] • Salmon trout with fresh tomatoes[*] • Roast pork[*] • Perch fillet au gratin[*] • Pork escalope with herbs[*]	
Friday	• Pasta with tomato and pesto sauce[†] • Risotto with cheese[†] • Asparagus risotto[†] • Vegetable risotto[†] • Risotto with peas[†] • Barley salad with tuna and tomato[*] • Pasta with tuna and tomato[*] • Seafood pasta[*]		• Steamed broccoli • French fries

* Omnivorous; † Vegetarian; ‡ Vegan

S. tables from study 3: The AUT-MENU Project

Table S11. T1 DVP Ranking of average consumption and characteristic of first course dishes

	Number of meals	Average consumption of the dish (%)	SD	Dish	Kind of pasta	Cheese	Color	Texture	Temperature	Smell	Aromas
First course	49	85.71 ^a	29.32	Saffron <i>risotto</i>	Rice, barley, <i>ditalini</i>	Yes	Bicolored	Dry	Warm	Mild	No
	28	82.14 ^a	33.92	Pasta with pesto sauce	<i>Penne, mezze maniche, sedanini</i>	Yes	Bicolored	Dry	Warm	Mild	No
	75	78.00 ^a	36.75	Pasta with smooth chickpeas and carrots sauce	<i>Penne, mezze maniche, sedanini</i>	Yes	Multicolored	Dry	Warm	Mild	No
	125	76.60 ^a	39.24	Pasta with pesto sauce	<i>Fusilli, caserecce</i>	Yes	Multicolored	Dry	Warm	Mild	No
	27	52.78 ^b	45.11	Rice with vegetables	Rice, barley, <i>ditalini</i>	Yes	Multicolored	Dry	Warm	Mild	No
	Total 304	76.81	37.96								

Superscript letters following the mean values of dish consumption indicate significant differences based on Kruskal–Wallis post-hoc pairwise comparisons with $\alpha \leq 0.05$. Dosso Verde Pavia (DVP)

Table S12. T1 DVP Ranking of average consumption and characteristic of second course dishes

	Number of meals	Average consumption of the dish (%)	SD	Dish	Kind of food	Breadcrumbs	Color	Texture	Temperature	Smell	Aromas
Second course	52	86.06 ^a	33.73	Chicken cutlet	<i>Cotoletta</i>	Yes	Mono colored	Soft	Warm	Mild	No
	54	77.78 ^a	40.24	Tuna	Tuna	No	Mono colored	Soft	Ambient	Intense	No
	58	74.14 ^a	42.40	Chicken scallopini	Chicken, turkey	No	Mono colored	Soft	Warm	Mild	No
	26	67.31 ^a	46.78	Baked fishballs	Fish	No	Mono colored	Soft	Warm	Intense	No
	73	58.90 ^{bc}	47.39	Chickpeas <i>farinata</i>	Plant-based balls	No	Mono colored	Soft	Warm	Mild	No
	56	51.34 ^b	47.05	Zucchini omelet	Eggs	No	Bicolored	Soft	Warm	nd	No
Total 319		68.65	44.52								

Superscript letters following the mean values of dish consumption indicate significant differences based on Kruskal–Wallis post-hoc pairwise comparisons with $\alpha \leq 0.05$. Dosso Verde Pavia (DVP)

Table S13. T1 DVP Ranking of average consumption and characteristic of side dishes

	Number of meals	Average consumption of the dish (%)	SD	Dish	Kind of food	Cooked	Color	Texture	Temperature	Smell	-
Side dish	32	55.47	46.11	Mixed vegetable trio	Boiled vegetables	Cooked	Multi-colored	Soft	Warm	Mild	-
	55	46.82	49.31	Tomato salad with extra-virgin olive oil	Carrots, fennels	Raw	Mono colored	Soft	Ambient	Mild	-
	131	44.85	48.21	Boiled green beans	Cooked vegetables	Cooked	Mono colored	Soft	Warm	Mild	-
	72	43.75	45.34	Oven-baked diced carrots and zucchini	Cooked vegetables	Cooked	Bicolored	Soft	Warm	Mild	-
	35	36.43	47.49	Green salad	Raw vegetables, mixed salad	Raw	Mono colored	Crunchy	Ambient	Mild	-
Total 325		45.08	47.41								

Superscript letters following the mean values of dish consumption indicate significant differences based on Kruskal–Wallis post-hoc pairwise comparisons with $\alpha \leq 0.05$. Dosso Verde Pavia (DVP)

Table S14. T1 DVP Ranking of average consumption and characteristic of fruit

	Number of meals	Average consumption of the dish (%)	SD	Fruit	Cut fruit	Peeled	Cooked	Color	Texture	Temperature	Smell	-
Fruit	15	66.67	48.80	Apple	Cut	No	Raw	Bicolored	Crunchy	Ambient	Mild	-
	26	65.38	48.52	Banana	Cut	Yes	Raw	Mono colored	Soft	Ambient	Mild	-
	26	57.69	50.38	Apricot	Cut	No	Raw	Mono colored	Soft	Ambient	Mild	-
	61	49.18	49.36	Plum	Cut	No	Raw	Bicolored	Soft	Ambient	Mild	-
	27	42.59	46.93	Melon	Cut	Yes	Raw	Mono colored	nd	Cold	Intense	-
	89	42.25	47.67	Apple	Cut	Yes	Raw	Mono colored	Crunchy	Ambient	Mild	-
	27	41.67	49.52	Watermelon	Cut	Yes	Raw	Mono colored	Crunchy	Ambient	Mild	-
	27	41.67	47.54	Peach	Cut	No	Raw	Bicolored	Crunchy	Ambient	Mild	-
	Total 298	48.19	48.65									

Superscript letters following the mean values of dish consumption indicate significant differences based on Kruskal–Wallis post-hoc pairwise comparisons with $\alpha \leq 0.05$. Dosso Verde Pavia (DVP)

Table S15. Setting DVP - Comparison of the average consumption between the two measurements by course

T0			T1	
	Number of meals	Average consumption of the dish (%)	Number of meals	Average consumption of the dish (%)
First course	304	76.97	304	76.81
Second course	300	70.92	319	68.65
Side dish	324	50.77	325	45.08
Fruit	321	51.95	298	48.19

Superscript letters following the mean values of dish consumption indicate significant differences based on Kruskal–Wallis post-hoc pairwise comparisons with $\alpha \leq 0.05$. Dosso Verde Pavia (DVP)

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