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Immunonutrition in Early Life: The Role of Complementary Feeding, Dietary Patterns, and Nutritional Exposures on the Health of Young Children—An EAACI Scoping Review

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ABSTRACT

Background: Immunonutrition examines how diet influences immune development. Complementary feeding represents a critical window for long-term health. We aimed to map evidence linking complementary feeding to immune outcomes, allergy, infection, and growth in infants and toddlers (≤3 years). We conducted a scoping review and evidence-gap mapping, following PRISMA-ScR. MEDLINE and Epistemonikos were searched from inception to November 2024. Concepts included diet diversity/patterns, feeding practices/models, and timing of allergen introduction, timing of complementary feeding, macronutrients, micronutrients, foods, supplementation, and ultra-processed foods. We included systematic reviews and recent primary studies meeting criteria.

Results: From 13,512 records screened, 108 systematic reviews were included, comprising 99 randomized controlled trials, 41 cohorts, 22 case–control, and 14 cross-sectional studies. Most reviews addressed nutrient intake, supplementation, or timing of allergen introduction, while fewer reviews explored diet diversity, foods, or ultra-processed food intake. Responsive complementary feeding was consistently associated with healthier growth and lower obesity risk, whereas restrictive practices showed adverse effects. Greater diet diversity was linked to reduced asthma and food allergy risk, though eczema findings were inconsistent. Western-style diets high in processed foods, fat, sugar, and meat correlated with higher allergy risk, while home-prepared diets were protective. Micronutrient supplementation (iron, zinc, vitamin D) reduced infection and anemia risk but had mixed effects on allergy. Early allergen introduction reduced food allergy incidence.

Conclusions: Complementary feeding research now extends beyond calorie counting, macronutrients, and early allergen introduction to dietary patterns and early life nutrition that supports the microbiome. Evidence supports dietary diversity, timely food allergen introduction, and responsive feeding, while discouraging restrictive practices and ultra-processed foods. Future work should harmonize definitions and investigate plant-based diets, advanced glycation end products, and processed food exposures.

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1 | Introduction

Immunonutrition encompasses the study of how dietary patterns, food diversity, specific foods, and nutrients influence the development, regulation, and function of the immune system across the lifespan. These nutritional exposures may exert their effects through multiple interconnected biological pathways, including modulation of the microbiome, epigenetic regulation, metabolism, and the integrity and function of epithelial barriers [1]. While the relationship between diet and health has long been established, there is increasing interest in understanding how long-term dietary habits, particularly those in early life, shape the risk of disease. Within this framework, complementary feeding represents a critical and complex period for determining early immune outcomes and, ultimately, immune health.

Complementary feeding is essential for immune health because it provides nutrients required for the maturation of the immune system, supports infection resistance, and contributes to long-term well-being [2]. The neonatal immune system is highly dynamic and developmentally programmed to support tissue growth, epithelial barrier maturation, microbial colonization, and the establishment of immune tolerance. During infancy, epithelial tissues and the gut microbiota are still developing and are therefore particularly susceptible to dietary and environmental influences. Concurrently, the immune system must learn to appropriately distinguish between harmless food antigens, commensal microbes, and pathogens, with early-life exposures playing an important role in shaping immune regulation and tolerance pathways. Nutrition during this period may therefore influence immune development directly and indirectly through effects on epithelial integrity, microbial composition, metabolism, and immune signaling pathways. These concepts are increasingly recognized as central to immune ontogeny and disease susceptibility in early life. Appropriate nutrition ensures provision of key micronutrients to support these aspects of early life [3, 4].

Deficiencies or imbalances in these nutrients can compromise immune function, leaving young children more vulnerable to infections, allergies, and autoimmune diseases [5, 6]. In addition, adequate nutrition during early childhood contributes to immune resilience later in life, lowering the likelihood of allergy and autoimmune conditions [7]. Furthermore, an important indirect effect of dietary components on the immune system is mediated via the microbiota, as microbial fermentation generates metabolites with immune modulatory effects [8, 9]. It is thought that dietary patterns with reduced diversity, low-quality, highly processed, high-energy foods can alter the metacommunity, and its processes that underpin assembly and activity of the human microbiome [10, 11]. Consequently, there is an increased risk of inappropriate and uncontrolled immune responses that damage host tissues and function [12–14].

Beyond immunity, complementary feeding also plays a crucial role in growth by preventing both undernutrition and obesity [4]. Growth and immune development are tightly linked in early life [15, 16]. Rapid expansion of tissues and organs occurs alongside proliferation and maturation of immune cells, with the thymus reaching peak size relative to body weight in early infancy. Adequate nutrition is required to balance energy allocation between somatic growth and immune function; both under-nutrition and over-nutrition can impair immune development [17].

According to the developmental origins of health and disease hypothesis, early nutritional exposures can influence the risk of disease later in life [5]. Allergic diseases are a growing global public health challenge, contributing to significant morbidity and mortality. Although current food allergy guidelines support the early introduction of allergen containing foods to prevent food allergies, the broader influence of diet during the complementary feeding period on allergy and immune health outcomes remains insufficiently defined. This systematic review therefore aimed to map and synthesize empirical evidence on the effects of complementary feeding, dietary patterns, macronutrient composition, and targeted nutritional supplementation in infancy and early childhood on the health of infants and toddlers up to 3 years of age.

2 | Methods

This scoping review and evidence map was conducted in accordance with Joanna Briggs Institute (JBI) methodology and Campbell Collaboration guidance, and reported per Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [18–20]. A scoping review aims to systematically identify and summarize the breadth of available evidence on a given topic, clarify key concepts, and describe the characteristics of relevant research. Detailed methods are reported in the full report (Appendix S1). An apriori protocol was developed for this work and is published elsewhere [21]. Briefly, The European Academy of Allergy and Clinical Immunology (EAACI) Guideline Panel (GP) defined one overarching research question and 15 sub-questions to guide the evidence synthesis (see Box 1).

2.1 | Eligibility Criteria

Eligibility criteria followed the Population, Concept, Context (PCC) format (See Table 1; full criteria in Appendix S1) and included healthy infants (0–12 months or toddlers 1–3 years) during complementary feeding. Concepts included Complementary-feeding factors, including dietary diversity and patterns; diet quality indices; feeding models; timing/order of food introduction (allergenic and non-allergenic); specific foods/food groups; macronutrients; micronutrients and bioavailability; supplementation practices (including avoidance of unnecessary supplements); ultra-processed foods; and advanced glycation end-products (AGEs). As context, we considered everyday feeding settings with generalizable, real-world practices. Outcomes included immune system development (including type-2 inflammation), gut microbiome, immune-related health outcomes (allergy development; eczema, asthma/wheezing, food allergy; autoimmune disease; infection risk), and growth (patterns; risk of under nutrition/overweight/obesity). The full outcomes list

BOX 1 | Review questions and sub questions.

Review question
What is the available empirical evidence on complementary feeding on immune health in infants and toddlers (from birth to 3 years)?

Review sub-questions
What is the available empirical evidence and what are the knowledge gaps regarding the impact on immune health of:

1. Advanced glycation end products (AGEs) in the diet?
2. Complementary feeding practices or models?
3. Diet diversity and diet patterns?
4. Food quality?
5. The avoidance of unnecessary supplementation?
6. The consumption of ultra-processed foods?
7. The order in which foods are introduced?
8. Home-cooked foods?
9. Macronutrient intake, including carbohydrates/sugars, fats/oils, fiber, and protein sources?
10. Nutrient intake?
11. Proposed definitions and key features or factors related to complementary feeding concepts?
12. Specific foods or food groups?
13. Supplementation with probiotics, prebiotics, and synbiotics?
14. The timing of complementary feeding introduction?
15. The types and characteristics of evidence available on complementary feeding concepts?

and prioritization are in Appendix S1. Information sources included systematic reviews and primary studies.

2.2 | Search Strategy

An information specialist developed searches for MEDLINE (Ovid) and Epistemonikos using Medical Subject Headings (MeSH) and keywords, adapted per source. Searches covered database inception to 14 November 2024 (strategies in Appendix S1).

2.3 | Selection of Sources

One calibrated reviewer screened titles/abstracts against PCC criteria. Two calibrated reviewers independently assessed full texts; disagreements were resolved by consensus or third-reviewer adjudication. For primary studies, core data were extracted from the index systematic reviews (SRs).

2.4 | Data Extraction and Charting

Data were charted in a piloted REDCap form: one reviewer extracted study characteristics and findings; a second reviewer cross-checked. Data items are listed in Appendix S1.

2.5 | Risk of Bias and Certainty

Where available, we extracted risk-of-bias assessments (tool and judgments) and any certainty/quality ratings.

2.6 | Outcome Prioritization

We conducted a structured process (survey followed by a validation meeting) to rank outcomes as (a) limited importance, (b) important but not critical, or (c) critical, informing subsequent decision-making (Appendix S1).

2.7 | Synthesis

We undertook descriptive synthesis (tables, narrative summaries, figures) and developed evidence maps.

3 | Results

Our results provide a comprehensive synthesis of research examining complementary feeding, dietary patterns, macronutrient composition, and targeted nutritional supplementation in infancy and early childhood. A total of 108 papers [22–33, 35–130] were identified for inclusion in this review (Figure 1). The included studies were organized into key concepts and corresponding interventions related to complementary feeding in infants and toddlers (Table 1).

The included systematic reviews varied in scope, comprehensiveness, and methodological rigor. Most searched major bibliographic databases such as PubMed, EMBASE, and CENTRAL, though search strategies were inconsistently reported and coverage of gray literature was limited. Risk of bias was typically assessed using the Cochrane RoB tool or the Newcastle–Ottawa Scale; however, only a minority of reviews applied GRADE to rate the certainty of evidence. Publication years of the included studies ranged from 2002 to 2024, with a notable increase in the number of reviews published over the past decade. Full methodological details of each review, including search sources and appraisal tools, are provided in Appendix S1.

4 | Overview of Evidence Across Concepts

4.1 | Complementary Feeding Models and Practices

Three systematic reviews (SRs) published between 2018 and 2022 examined a range of complementary feeding practices (CFPs), including baby-led weaning (BLW), the Baby-Led Introduction to Solids approach (BLISS), responsive feeding (RF), non-responsive feeding (NRF), and traditional spoon-feeding models [22–24]. The populations studied comprised children aged 4–36 months, with follow-up extending up to 6 years. Across reviews, BLW/BLISS showed no consistent benefit for healthy weight gain, obesity prevention, nutritional adequacy, or infection/dental caries outcomes; evidence was generally low quality or sparse. RF was associated with healthier growth trajectories and reduced risk

TABLE 1 | Concepts, sub concepts, and exposure or interventions' definitions.

Concept and sub concepts	Exposure or intervention (as defined in reference)	References
Complementary feeding models and practices		
Baby-Led Introduction to Solids (BLISS)	A modified version of Baby-Led Weaning that follows the same self-feeding principles but emphasizes including three types of food at each meal: one rich in iron, one high in energy, and one high in fiber, such as fruits or vegetables	Bergamini et al. (2022) [22]
Baby-Led Weaning (BLW)	Complementary feeding practice encourages a child's autonomy by allowing them to self-feed family foods they can handle using their hands	Bergamini (2022) [22], D'Auria (2018) [23], Martinon-Torres (2021) [24]
Non-Responsive Complementary Feeding (NRCF)	Lacks a balanced interaction between caregiver and child during meals. Caregivers may be overly controlling, overly passive, use food mainly to soothe, or be disengaged, ignoring the child's hunger or fullness cues	Bergamini (2022) [22]
Responsive Complementary Feeding (RCF)	Focuses on the child's cues, offering food only when the child shows interest and stopping when they indicate they have had enough. Food is provided in ways that match the child's developmental stage, using suitable family foods	Bergamini (2022) [22]
Diet diversity and dietary patterns		
Diet diversity	High dietary diversity, defined as 5–7 food groups	Molani Gol (2022) [25]
	High dietary diversity, introduced before 4 months of age	Wang (2023a) [26]
	Low dietary diversity, defined as 0–2 food groups	Molani Gol (2022) [25]
	Minimum dietary diversity, defined as at least 4 food groups	Molani Gol (2022) [25]
	Total number of different foods or food groups introduced by a specific age (3, 4, 5, 6, 12 and 24 months), assessed as categorical threshold-based groupings (e.g., 0, 1–2, 3–4, ≥ 4 or ≥ 5, ≥ 8 food groups)	Lv (2024) [27], Obbagy (2019a) [28], Obbagy (2019c) [29]
	Total number of different foods or food groups introduced by specific ages (3, 4, 6, 12 and 24 months), assessed as continuous scores	Lv (2024) [27], Obbagy (2019a) [28], Obbagy (2019c) [29]
	Increased dietary diversity, assessed in the first year of life as food diversity (defined in terms of diversity of foods eaten); as fruit and vegetable diversity (FVD); as food allergen diet diversity (FAD), and as per World Health Organization (WHO) guidelines	Wang (2023a) [26]
Diet patterns	Adherence scores for healthy diet patterns	English (2019b) [30], Obbagy (2019c) [29]
	Adult food pattern (0 to 12 months)	Obbagy (2019c) [29]
	Easy to prepare food cereals, juices, cake, and biscuits dietary pattern (at 9 months of age)	Wang (2023a) [26]
	Finger food pattern	Obbagy (2019a) [28], Obbagy (2019c) [29]
	Healthy dietary patterns (higher intake of fruits, vegetables, etc.)	English (2019b) [30], Obbagy (2019a) [28], Wang (2023a) [26]
	Home-prepared foods	Wang (2023a) [26]
	Infant guideline-based pattern	English (2019b) [30], Obbagy (2019a) [28], Obbagy (2019c) [29]
	Low variety or inadequate patterns	English (2019b) [30]

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Concept and sub concepts	Exposure or intervention (as defined in reference)	References
	Macrobiotic diets (low in animal products and fat)	English (2019b) [30]
	Mixed feeding with high energy-dense foods (MXHED)	English (2019b) [30]
	Plant-based foods, vegetarian or vegan diet (with small quantities or without any animal product)	Simeone (2022) [31]
	Predominantly breastmilk dietary pattern (at 12 months of age)	Wang (2023a) [26]
	Rich in noodles and seafood	Wang (2023a) [26]
	Unhealthy or non-guideline patterns	English (2019b) [30]
	Western dietary pattern	Wang (2023a) [26]
Macronutrients		
Carbohydrates and sugar	Carbohydrates intake	Lampousi (2021) [32]
	Sugar intake	Lampousi (2021) [32]
Fats or oils	Complementary foods and beverages with different fats/fatty acid composition	English (2019b) [30]
	Fish oil	de Silva (2020) [33]
	Linoleic acid (LA)	Udell (2003) [34]
	Polyunsaturated fatty acid (PUFA)	Schindler (2016) [35], Yang (2013) [36]
Protein sources	Animal protein intake	Arnesen (2022) [37]
	Animal-source supplementation	Asare (2022) [38], Pimpin (2019) [39]
	Cereal protein	Arnesen (2022) [37]
	Dairy protein	Arnesen (2022) [37]
	Dairy products (cow's milk vs. formula)	Arnesen (2022) [37]
	High-protein milk	Arnesen (2022) [37]
	Lower protein diets	Arnesen (2022) [37]
	Meat protein	Arnesen (2022) [37]
	Plant protein intake	Arnesen (2022) [37]
	Total protein intake	Ferré (2021) [40], Pearce (2013a) [41]
Other	Energy intake	Pearce (2013a) [41]
Nutrient intake		
Lipid-based nutrient supplementation	Lipid-based nutrient supplements (LNSs)	Nikooyeh (2021) [42]
	Medium quantity LNS (MQ-LNS)	Das (2019a) [43], Dewey (2023) [44]
	Small quantity LNS (SQ-LNS)	Das (2019a) [43]
Fortified complementary food	Fortified complementary food	Csölle (2022) [45]
	Fortified milk or cereals with vitamins (other than vitamin A) and/or with a combination with iron, vitamin A, and zinc	Eichler (2012) [46]

(Continues)

TABLE 1 | (Continued)

Concept and sub concepts	Exposure or intervention (as defined in reference)	References
Micronutrients	Micronutrient powder combined with home-prepared semi-solid or solid foods	Nikooyeh (2021) [42]
	Micronutrient supplementation	Goudet (2019) [47], Matsuyama (2017) [48]
	Multiple-micronutrients (MMN)	Das (2013b) [49], Park (2019) [50]
	Multiple-micronutrient, foodLETS (food-like tablet)	Nikooyeh (2021) [42]
	Multiple-micronutrient powders (MNPs)	Suchdev (2020) [51]
	Multiple-micronutrient powders (MNPs) formulated with at least iron, zinc and vitamin A	De-Regil (2013) [52]
	Nucleotide supplementation	Wang (2019) [53]
Minerals and vitamins	Calcium supplementation	Park (2019) [50]
	Folic acid supplementation	Park (2019) [50]
	Fortified milk or cereals with iron	Eichler (2012) [46]
	Fortified milk or cereals with vitamin A	Eichler (2012) [46]
	Fortified milk or cereals with Zinc	Eichler (2012) [46]
	Fortified milk or cereals with iron, vitamin A, and zinc	Eichler (2012) [46]
	Iron and calcium	Park (2019) [50]
	Iron and folic acid	Park (2019) [50]
	Iron and zinc	Park (2019) [50]
	Iron supplementation	Cai (2017) [54], Dewey (2020) [55], Karamantziani (2024) [56], Park (2019) [50], Pasricha (2013) [57], Petry (2016) [58]
	Vitamin D supplementation	de Silva (2020) [33], Lampousi (2021) [32], Luo (2022) [59], Wang (2023a) [26], Yepes-Nuñez (2018) [60], Zeng (2023) [61]
	Zinc supplementation (general)	Aggarwal (2007) [62], Gulani (2014) [63], Das (2013a) [64], Das (2013b) [49], Imdad (2011) [65], Lassi (2020) [66], Mayo-Wilson (2014) [67], Patel (2011) [68], Park (2019) [50], Petry (2016) [58]
	Zinc supplementation in combination with other micronutrients (e.g., iron, vitamin A, etc.)	Imdad (2011) [65]
	Zinc supplementation in combination with riboflavin	Lassi (2020) [66]
	Zinc formulation (acetate, gluconate, or sulfate)	Liu (2018) [69]

(Continues)

Concept and sub concepts	Exposure or intervention (as defined in reference)	References
Specific foods and food groups		
Dairy products	Animal milk	Ehrlich (2022) [70]
	Cow's milk	Griebler (2016) [71], Obbagy (2019a) [28], Ram (2002) [72]
	Milk (unspecified)	Shapiro (2019) [73]
	Yogurt	Donovan (2019) [74]
Grains and gluten	Cereal	English (2019b) [30]
	Wheat	Obbagy (2019a) [28]
	Wheat or gluten-containing products of any type	Chmielewska (2017) [75]
	Gluten, amount of	Silano (2016) [76]
Protein-source foods	Animal-source foods (yogurt, meat, eggs, beef, pork, gravy)	Eaton (2019) [77]
	Beef	Shapiro (2019) [73]
	Egg	Al-Saud (2018) [78], Larson (2024) [79], Obbagy (2019a) [28], Shapiro (2019) [73]
	Fish	Byrd (2022) [80], Obbagy (2019a) [28], Shapiro (2019) [73], Wang (2023a) [26] Yang (2013) [36]
	Fish-based products	Byrd (2022) [80]
	Insects	Shapiro (2019) [73]
	Meat (general)	English (2019b) [30], Shapiro (2019) [73]
	Meat as complementary food	Arnesen (2022) [37]
	Peanut, nuts, seeds	Obbagy (2019a) [28]
	Pork	Shapiro (2019) [73]
	Soy	Obbagy (2019a) [28]
Other	Beverages, juice drinks or 100% juice	English (2019b) [30]
	Beverages, sugar-sweetened beverages	English (2019b) [30]
	Bovine colostrum (5.7 g) and dried whole egg powder (4.3 g) vs. isoenergetic amounts of unfortified corn/soy flour (15 g)	Larson (2023) [79]
	Complementary Foods and Beverages (CFBs), types and amounts	Obbagy (2019c) [29]
	Complementary Foods and Beverages (CFBs), other (e.g., vegetables, ready-made foods, confectionery foods)	English (2019b) [30]
	Food not common allergens	Obbagy (2019a) [28]
	Food type/groups (unspecified)	Pearce (2013a) [41]
	Meat vs. cereal as complementary foods	Arnesen (2022) [37]
	Meat vs. dairy as complementary foods	Arnesen (2022) [37]

(Continues)

TABLE 1 | (Continued)

Concept and sub concepts	Exposure or intervention (as defined in reference)	References
Supplementation with probiotics, prebiotics, and synbiotics		
Prebiotics	Prebiotics	Cuello-Garcia (2017) [81], de Moura (2013) [82], de Silva (2020) [33], Dror (2017) [83], Ferro (2023) [84], Osborn (2013) [85], Qin (2024) [86], Wawryk-Gawda (2021) [87]
	Prebiotics, fructans	Lohner (2014) [88]
	Prebiotics, fructo-oligosaccharides (FOS)	Lohner (2014) [88]
	Prebiotics, galacto-oligosaccharides (GOS)	Lohner (2014) [88]
	Prebiotics, inulin	Lohner (2014) [88]
	Prebiotics, oligofructose	Lohner (2014) [88]
	Prebiotics, oligosaccharides	Lohner (2014) [88]
Probiotics	Probiotics, supplementation of	Amalia (2019) [89], Azad (2013) [90], Chen (2020) [91], Chen (2022) [92], de Silva (2020) [33], Dror (2017) [83], Du (2019) [93], Elazab (2013) [94], Ferro (2023) [84], Indrio (2022) [95], Jiang (2020) [96], Jiang (2024) [97], Li (2019) [98], Mansfield (2014) [99], Panduru (2015) [100], Pelucchi (2012) [101], Qian (2024) [86], Qin (2024) [102], Skórka (2017) [103], Sun (2021b) [104], Wang (2024) [105], Wawryk-Gawda (2021) [87], Wei (2020) [106], Zhang (2016) [107]
	Probiotics, *L. acidophillus*; *L. johnsonii*; *L. reuteri*; *L. rhamnosus*	Osborn (2007) [108]
	Probiotics, *Lactobacillus rhamnosus* GG	Szajewska (2018) [109]
	Probiotics, mixture of	Osborn (2007) [108]
	Probiotics, mixture of Bifidobacterium and Lactobacillus	Sun (2021a) [110]
	Probiotics mixture of Bifidobacterium, Lactobacillus, and Streptococcus	Wang (2023a) [26]
Probiotics and prebiotics	Probiotics and prebiotics, mixture of	Osborn (2007) [108]
Synbiotics	Synbiotics, supplementation of	Chan (2020) [111], de Moura (2013) [82], de Silva (2020) [33], Dror (2017) [83], Ferro (2023) [84], Qian (2024) [86], Wawryk-Gawda (2021) [87]

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Concept and sub concepts	Exposure or intervention (as defined in reference)	References
Timely introduction of complementary feeding and allergenic foods		
Timely introduction of complementary solid food (non-allergenic)	Early introduction, < 4 months vs. 4–6 months	Wang (2016) [112]
	4–6 months	Verga (2022) [113]
	Early introduction, 4–6 months vs. > 6 months	Wang (2016) [112]
	Early age at introduction	Padhani (2023) [114]
	Late age at introduction	Padhani (2023) [114]
	Early weaning	Vail (2015) [115]
	Complementary feeding, early age at introduction of	Araújo (2019) [116], EFSA (2019) [117]
	Complementary foods and beverages (CFB), early introduction of (4–5 months)	English (2019a) [118]
	Complementary foods and beverages (CFB), timing of introduction	Obbagy (2019b) [119], Obbagy (2019c) [29]
	Complementary foods (CF), 4 months age at introduction of	Qasem (2015) [120]
	Complementary foods (CF), 6 months age at introduction of	Qasem (2015) [120]
	Complementary foods (CF), age at which were first introduced	Pearce (2013b) [121]
	Complementary foods, early introduction of	Wang (2023a) [26]
	Egg, age of introduction of	Burgess (2019) [122]
	Egg, early introduction (< 8–10 months) vs. late introduction (> 8–10 months) measured at 1 year	Waidyatillake (2018) [123]
	Solids, introduction of (< 4 months)	Tarini (2006) [124]
	Solids, introduction after 4 months of age and eczema (outcome measured at age 1–5 years)	Waidyatillake (2018) [123]
	Solids, introduction after 7 months of age and eczema (outcome measured at age 1.5–4 years)	Waidyatillake (2018) [123]
	Solids, introduction between 4 and 6 months of age vs. earlier introduction and eczema (outcome measured at 1.5–4 years)	Waidyatillake (2018) [123]
	Solids, timing or age at which were introduced	Moorcroft (2011) [125]
Timely introduction of complementary solid food supplementation	Lipid-based nutrient supplements, < 6 months at introduction of	Dewey (2023) [44]
	Lipid-based nutrient supplements, ≥ 6 months at introduction of	Dewey (2023) [44]
Timely introduction of specific allergenic foods	Allergenic food, early introduction of	Wang (2024) [26]
	Allergenic foods (6 types)	de Silva (2020) [33]
	Allergenic foods (multiple), earlier introduction of	Scarpone (2023) [126]
	Allergenic foods (specific), timely of introduction to	Burgess (2019) [122]
	Cereal, gluten, and fiber, early introduction to	Lampousi (2021) [32]
	Cereals, age of introduction	Burgess (2019) [122]
	Complementary foods (CF), age of introduction	Obbagy (2019a) [28]
	Cow's milk, introduction of	Yuan (2020) [127]

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TABLE 1 | (Continued)

Concept and sub concepts	Exposure or intervention (as defined in reference)	References
	Cow's milk formula (CMF), introduction	Yuan (2020) [127]
	Cow's milk, early introduction of	Lampousi (2021) [32], Scarpone (2023) [126]
	Egg (Hen's) to the infant diet	de Silva (2020) [33]
	Egg (raw/pasteurized)	de Silva (2020) [33]
	Egg, earlier introduction of	Scarpone (2023) [126]
	Fish and omega-3 fatty acids, early introduction to	Lampousi (2021) [32]
	Fish, age of introduction	Burgess (2019) [122]
	Fruit and vegetables, early introduction to	Lampousi (2021) [32]
	Gluten, early introduction of (< 4 months)	Pinto-Sánchez (2016) [128]
	Gluten, late introduction of (> 6 months)	Pinto-Sánchez (2016) [128]
	Gluten, time of introduction	Silano (2016) [76]
	Meat and egg, early introduction to	Lampousi (2021) [32]
	Other foods, early introduction of	Scarpone (2023) [126]
	Peanut	de Silva (2020) [33]
	Peanut, early introduction of	Scarpone (2023) [126]
	Peanuts, age of introduction	Burgess (2019) [123]
Ultra-processed foods		
Ultra-processed sugar	Beverages, sugar containing Beverages, sugar-sweetened Beverages, soda beverages, carbonated	Large (2024) [129]
	Beverages or snacks at night, sugary	Large (2024) [129]
	Sweets, candy	Large (2024) [129]

of overweight or obesity during the first 2 years of life, without measurable impact on dental caries infection. NRF (restrictive/controlling/coercive) was linked to adverse outcomes, including excessive weight gain or impaired growth. Overall, responsive feeding demonstrated the most favorable outcomes for early development. In conclusion, while self-feeding models such as BLW and BLISS show mixed or inconclusive results, caregiver responsiveness during feeding remains a key determinant of healthy growth and reduced obesity risk in early childhood.

4.2 | Dietary Diversity and Whole Dietary Patterns (Whole Diet Approach)

Seven SRs published between 2019 and 2024 examined the association between diet diversity or overall dietary patterns during infancy and a range of immune health outcomes [25–31]. Age at exposure ranged from birth to 36 months, with outcomes assessed from 6 months of age through 42 years in some cohorts. Health outcomes assessed included allergic diseases, growth, and obesity risk [25–28, 30, 31]. Increased diet diversity was generally associated with lower risk of asthma and food allergy [26–28], though findings for eczema and allergic rhinitis were inconsistent [26]. Introducing a diverse range of foods before 4 months may increase eczema risk [26]. Low dietary diversity was linked to undernutrition outcomes such as stunting and underweight [25, 34], whereas evidence for effects on obesity was inconclusive [26]. Western-style diets high in refined grains, soups and sauces, savory and snacks, other fats, sugar-containing beverages and meat were associated with increased asthma and eczema risk, while diverse, home-prepared diets were protective [26]. Vegetarian and vegan diets showed no clear benefits and potential risks to growth and neurodevelopment compared with omnivorous diets [31]. In summary, greater dietary diversity in infancy appears to protect against some allergic diseases and support healthy growth. Early diet diversity or western diets may be harmful.

4.3 | Macronutrients

Ten systematic reviews (SRs) published between 2003 and 2023 evaluated the influence of macronutrient intake on a range of health outcomes in infants and young children [30, 32, 33, 35–37, 39–41]. These reviews examined how protein, fat, and carbohydrate intake affect growth, obesity, food allergies, eczema, and autoimmune conditions such as type 1 diabetes (T1D).

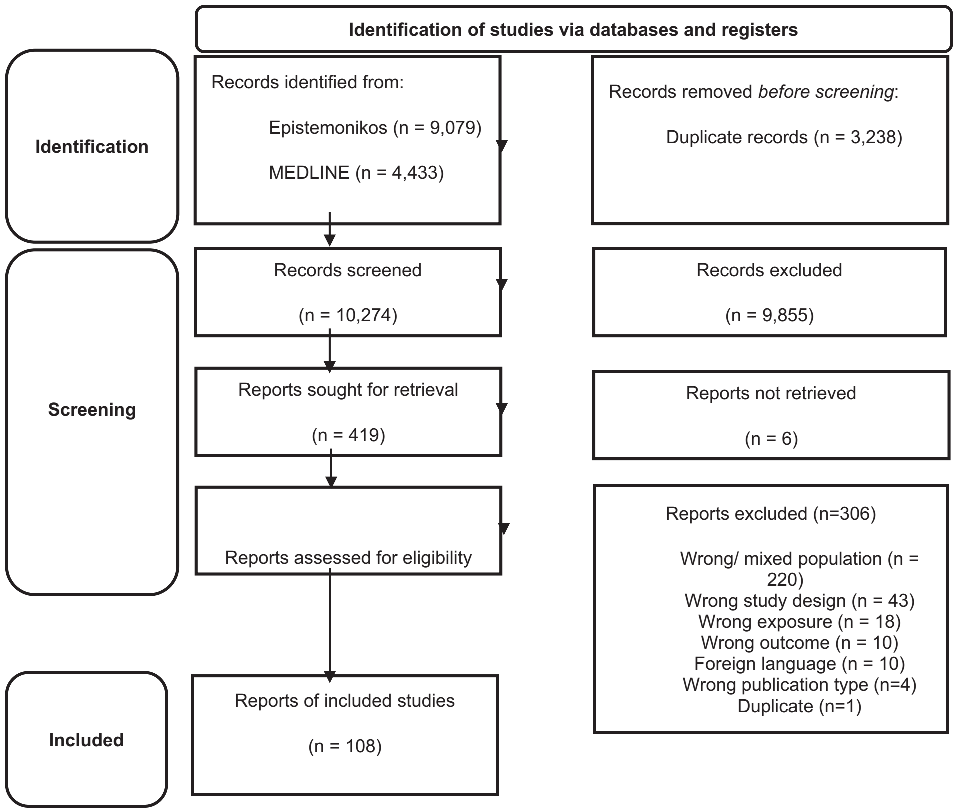

FIGURE 1 | PRISMA flowchart.

Exposures were reported from birth to 24 months, while outcomes were tracked from infancy into adolescence, with some studies extending follow-up to 42 years.

High consumption of sugar and sugar-sweetened beverages (SSBs) was consistently associated with increased risk of T1D and obesity [30]. In contrast, no clear effects of complementary foods high in fat were observed for growth or obesity [26, 30, 33], although linoleic acid showed a possible benefit for normal infant growth.

Udell observed some potentially positive effects of linoleic acid on infant growth at 12 months, though overall findings were inconsistent at 12 months [130]. PUFA supplementation had no significant impact on allergy-related outcomes such as eczema, asthma, or food allergy, though one review suggested a potential reduction in allergic rhinitis [35]. The effects of dietary supplements such as fish oil or multiallergen strategies remained uncertain or minimal [33].

In conclusion, macronutrient composition consistently shows improvement or increased growth and/or positive immune-related outcomes. While high intake of sugar and SSBs shows increased risk of T1D and obesity, evidence for protective effects of other macronutrient modifications remains weak and inconclusive.

4.4 | Nutrient Intake and Supplementation

Thirty-one systematic reviews (SRs) and meta-analyses published between 2007 and 2024 have investigated the effects of nutrient-based interventions in early childhood [26, 32, 33, 42–69]. These interventions include micronutrient supplementation, home fortification strategies, lipid-based nutrient supplements (LNS), micronutrient powders (MNPs), fortified complementary foods, and individual nutrients such as iron, vitamin D, folic acid, calcium, and zinc. The primary aim of these interventions has been to evaluate their influence on growth trajectories, infection risk, autoimmune and allergic diseases, and other health and developmental outcomes. Some reviews also considered changes in gut microbiota [56, 58], as well as broader developmental and health outcomes [43, 44].

Most studies included children from birth to 59 months of age, with exposures introduced from birth through 52 months and follow-up periods extending as long as 7 years. Zinc supplementation modestly improved linear growth in some studies but had limited impact on immune-related outcomes. Vitamin A supplementation was linked to reduced measles incidence and all-cause mortality in deficient populations, while vitamin D showed inconsistent associations with respiratory infections and allergy outcomes. Evidence for iodine, calcium, and multivitamin/mineral supplementation was sparse and largely inconclusive [49, 51, 52, 56, 58, 60, 61, 131, 132]. LNSs and MNPs emerged as the interventions with the most consistently positive outcomes, particularly for supporting child growth and reducing infection risk in low- and middle-income countries [43, 44].

In conclusion, while LNSs, MNPs, and fortified complementary foods consistently demonstrate benefits for growth and infection prevention, the evidence for single-nutrient strategies remains mixed, with some interventions associated with both potential benefits and risks including nutrient excess or imbalance (e.g., iron or zinc), potential adverse effects on the gut microbiota, increased infection risk in specific contexts, and possible displacement of diverse, nutrient-dense foods from the diet. This is in agreement with earlier findings in a Systematic Review and meta-analysis on the effect of nutrients on the prevention of respiratory tract infections (RTIs) [133]. In that paper it was found that supplementation of nutrients in the general population has either no or at most a very limited effect on prevention of rRTIs. Zinc supplementation appears protective for children in Asia, specifically in children with low zinc serum as compared to children with normal zinc serum levels.

4.5 | Specific Foods and Food Groups

Eighteen systematic reviews (SRs) and meta-analyses [26, 28–30, 36, 37, 41, 69–79, 130], published between 2002 and 2024, have investigated the effects of specific complementary foods and food groups introduced during infancy and early childhood on child health outcomes. These interventions focused on individual dietary components such as animal-source proteins (meat, eggs, fish, dairy), cereals, soy, gluten, and sugar-sweetened beverages, with particular emphasis on growth, obesity risk, allergy development, and immune-related conditions.

The SRs included children from birth to 5 years of age, with outcomes measured from infancy through adolescence and in some cases up to 42 years of age.

Primary outcomes included child growth (e.g., stunting, linear growth, weight gain, obesity risk), development of allergic and immune-related conditions (eczema, asthma, food allergy), and infection risk. Some reviews also assessed longer-term outcomes, including body composition and developmental markers. Animal-source foods such as eggs, meat, and fish generally supported healthy growth and may help reduce allergy and infection risk. Eggs showed consistent growth benefits, while fish intake was linked to both improved growth and potential protection against allergic disease. Consumption of sugar-sweetened beverages in young children were associated with increased obesity risk. Evidence for soy, cereals, and gluten introduction was mixed or neutral. Early introduction of allergenic foods showed promise for food allergy (egg, peanut) or asthma (fish) prevention, though results varied by timing, dose, and population risk. Overall, evidence supports early introduction of peanut and egg as well as including diverse, nutrient-rich complementary foods while limiting excessive dairy protein and sugary drinks.

4.5.1 | Supplementation With Prebiotics, Probiotics, and Synbiotics

Thirty-three systematic reviews (SRs) published between 2007 and 2024 have examined the effects of prebiotic, probiotic, and synbiotic supplementation on infant and child health [26, 33, 81–111]. The reviews focused mainly on infants and young children aged 0–24 months, with follow-up periods ranging from several weeks to over 13 years. Across reviews, probiotic supplementation showed inconsistent effects on growth, respiratory or gastrointestinal infections, and allergy outcomes; some studies suggested reduced incidence of diarrhea or atopic dermatitis, but findings were not consistent across strains or populations [91, 93, 94, 96]. Prebiotic supplementation was associated with modest reductions in gastrointestinal infections in a few studies but showed no clear effects on growth or allergy-related outcomes [81, 84, 86, 87]. Evidence on synbiotics was very limited and inconclusive [33, 95]. Overall, supplementation with probiotics, prebiotics, or synbiotics during complementary feeding has not demonstrated consistent benefits for growth, immune, or allergy outcomes, with effects appearing strain- and context-specific rather than generalizable.

4.6 | Timing of Complementary Feeding (CF)

Twenty-four systematic reviews and meta-analyses published between 2006 and 2024 have also assessed the impact of the timing of complementary feeding (CF) introduction during infancy on growth, obesity risk, allergic and autoimmune conditions (e.g., eczema, asthma, food allergy, type 1 diabetes), and infection outcomes [26, 28, 29, 32, 33, 44, 76, 112–128]. The evidence most consistently supported CF introduction between 4 and 6 months of age as safe and beneficial. Reviews such as Qasem [120] and Verga [113] found that timely introduction of solid food was associated with neutral or positive effects on growth without increasing obesity risk. By contrast, early solid food introduction, before 4 months [112, 116], was associated with increased risk of overweight and obesity in later childhood or adulthood, as well as higher rates of food allergy and eczema [26, 123]. Delayed solid food introduction after 6 months generally did not provide additional health benefits and, in some instances, was linked to nutritional deficiencies or undernutrition [44, 114]. Evidence linking CF timing with autoimmune diseases such as type 1 diabetes was sparse and of low certainty [32].

In summary, the evidence most consistently supports CF introduction between 4 and 6 months as the optimal window, balancing risks and benefits across multiple health domains. Earlier introduction (before 4 months) is linked to greater risk of obesity and allergic outcomes, while introduction after 6 months may not confer added benefit and could be associated with nutritional risks in some settings.

4.7 | Ultra-Processed Foods

One SR [129] specifically addresses the consumption of ultra-processed foods, with a focus on sugar-containing beverages and sugary snacks, highlighting concerns regarding their nutritional quality during complementary feeding (Figure 2).

5 | Discussion

Overall, the evidence suggests that how and when complementary foods are introduced is as important as what foods are offered. Consistent patterns emerged showing that responsive feeding supports healthier growth and lower obesity risk, timely introduction of complementary foods between 4 and 6 months is optimal, greater dietary diversity is associated with reduced asthma and food allergy risk, and early introduction of allergens such as peanut and egg reduces food allergy incidence. In

FIGURE 2 | Study overview.

contrast, restrictive feeding practices, western-style diets high in processed foods, and early or delayed introduction of solids were linked to less favorable outcomes. Despite these consistent findings, important gaps remain, particularly regarding the effects of ultra-processed foods, plant-based dietary patterns, and novel exposures such as advanced glycation end products, highlighting priorities for future research. Most reviews were based on data from high-income settings, with low- and middle-income countries underrepresented despite their higher burden of malnutrition and infection. Any future recommendations will need to be tailored for specific populations, including those from high-income settings and those from low- and middle-income countries. To our knowledge, this is the first scoping review to systematically map the breadth of systematic reviews on complementary feeding (CF) and its impact on growth, immune, and allergy-related outcomes. While individual reviews have previously focused on specific aspects, such as the timing of allergen introduction, dietary diversity, or supplementation, no prior overview has synthesized evidence across the full range of feeding practices, nutrient exposures, and dietary patterns.

The World Health Organization and UNICEF advocate initiation of complementary foods at 6 months [134], continuation of breastfeeding ideally until 2 years of age, avoidance of sugar-sweetened beverages and ultra-processed foods, and promotion of dietary diversity. EAACI [5] and several national guidelines [135, 136] recommend introducing CF between 4 and 6 months of age and not delaying allergenic foods during the complementary feeding period. Our review aligns with these positions on age of introduction and limiting early or delayed initiation of CF. There is overall alignment around the evidence for the benefits of responsive feeding and dietary diversity of home-made foods. Systematic reviews conducted by EAACI also indicated that responsive feeding is important to prevent feeding difficulties, which are common in food allergic infants [137].

At the same time, this review identifies gaps that remain insufficiently addressed in both research and policy. Evidence on ultra-processed foods, plant-based dietary patterns, lipid-based supplements, and microbiota-targeted interventions is sparse and inconsistently incorporated into current guidelines. Likewise, few recommendations explicitly integrate considerations of equity, cultural practices, and feasibility across diverse settings, despite their importance for implementation. By mapping the current evidence base, our review underscores the need for updated, context-sensitive guidelines that reflect emerging exposures and evolving dietary patterns.

6 | Strengths and Limitations

This scoping review provides the most comprehensive mapping to date of evidence syntheses on complementary feeding (CF) and its links to growth, immune, and allergy-related outcomes. By systematically identifying and summarizing systematic reviews and meta-analyses across diverse dietary exposures, it highlights both areas of consistency and key evidence gaps. A further strength is its broad scope, covering behavioral practices, dietary patterns, specific nutrients, supplements, and timing, thereby offering a panoramic view of how CF has been studied in relation to child health.

Several limitations should be acknowledged. The evidence base is constrained by heterogeneity in definitions of dietary diversity, timing categories, and outcome measures, limiting comparability across studies. Many included systematic reviews relied on observational studies prone to confounding and bias, often with short follow-up periods. Inconsistent use of appraisal tools limited meta-analyses, and reliance on narrative syntheses reduced the strength of conclusions. Most reviews were based on data from high-income settings, with low- and middle-income countries underrepresented despite their higher burden of malnutrition and infection. Any future recommendations will need to be tailored for specific populations, including those from high-income settings and those from low- and middle-income countries. Finally, as a scoping review, we summarized existing evidence without formally assessing the quality of individual studies or reviews.

7 | Implications for Practice and Research

This review underscores complementary feeding as a critical window for influencing growth, immune development, and long-term health. For practice, consistent priorities include supporting caregivers to adopt responsive feeding, promote dietary diversity with minimally processed foods, and avoid both early (<4 months) and delayed (>6 months) introduction of complementary foods. This is important as a recent EAACI survey amongst health care professionals indicated regional, professional, and educational differences regarding early life feeding advice, with Northern European health care professionals favoring earlier introduction of complementary feeding and food allergens, often without structured guidance. Southern European health care professionals preferred a structured sequence and later introduction of complementary foods [138]. A better understanding of different diet diversity measures and the interplay between maternal and infant diet is also required [139, 140]. Reducing sugar and sugar-sweetened beverage intake remains essential, while targeted micronutrient supplementation (iron, zinc, vitamin A) should be context-specific rather than universal. A good example is the potential interaction between vitamin A supplementation and vaccination in children from low to middle income countries [141]. These findings align with global guidance and emphasize tailoring recommendations to local dietary cultures, resources, and healthcare contexts.

For research, substantial gaps persist. Future studies should standardize definitions of dietary diversity, timing, and outcomes; prioritize longitudinal designs; and include biomarker-based immune assessments, such as microbiota composition and epigenetic profiling, to clarify mechanisms. Underexplored exposures, including ultra-processed foods, vegetarian and vegan diets, and culturally specific feeding practices, require greater attention. Evidence on probiotics, prebiotics, synbiotics, and early allergen introduction also need refinement to inform diverse populations. Increased representation of low- and middle-income countries and consistent application of transparent appraisal and meta-analytic methods are essential to strengthen future evidence.

In conclusion, complementary feeding, dietary patterns, macronutrient composition, and targeted nutritional supplementation in infancy and early childhood shape the immune system and affect the health of infants and young children. Interventions promoting dietary diversity of healthy foods, responsive feeding, and timely allergen introduction show the greatest promise. Microbiota-friendly strategies during complementary feeding have not demonstrated consistent benefits for growth, immune, or allergy outcomes. Conclusive guidance remains hindered by heterogeneous and low-certainty evidence. Advancing this field requires harmonized research methodologies and mechanistic studies that clarify causality and long-term impact.

Author Contributions

Conceptualization: C.V. and L.O. and all authors; methodology: P.A.-C., J.B., J.Br., F.K.F.-S.; writing – original draft preparation: C.V. and L.O.; writing – review and editing: all authors; review and editing: P.A.-C., J.B., J.Br., F.K.F.-S., I.S., P.R., R.B.C., F.R.-W., E.V. All authors read and reviewed the final version of the paper.

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** all70429-sup-0001-AppendixS1.doc.