Review Article

Optimising Breastfeeding with Functional Foods: A Mini Review

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ABSTRACT

Breastfeeding is crucial for infant growth, development, and protection against infections, while also reducing the risk of chronic diseases. However, many infants still do not receive adequate breastfeeding. Lactating mothers also face increased energy and nutrient needs, requiring minerals like calcium, iron, zinc, iodine, and vitamins A, D, B9, B12, and C to maintain their health and support infant nutrition, on top of the required macronutrients. Functional foods, which provide essential nutrients and health benefits, can enhance breast milk production and maternal health. This article explores the role of plant-based foods, whole grains, omega-3 fatty acids, and prebiotics and probiotics as complementary dietary strategies for lactating mothers. Furthermore, the gut-mammary axis highlighting the link between maternal diet, gut health, and breast milk composition are also discussed.

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1. Introduction

As endorsed by WHO and UNICEF, breastfeeding initiated within the first hour of birth, exclusive breastfeeding for the first six months of life, and introduction of adequate and safe complementary foods at 6 months with continuation of breastfeeding up to 2 years old and beyond (Selim, 2018). Statistically, many infants and children do not receive optimal feeding, for instance, only 44% of infants aged zero to six months old worldwide were exclusively breastfed over the period of 2015-2020 (World Health Organization, 2023). Exclusive breastfeeding, defined as feeding practices of infant from birth to 6 months old with breast milk only was proven to provide a balanced supply of nutrients, such as bioactive proteins, indigestible oligosaccharides, bifidogenic bacteria which are protective against infection (Victora et al., 2021). Breast milk is essential for children's healthy growth and development, reducing the risks of developing chronic diseases such as obesity, Crohn's disease, irritable bowel syndrome, obesity, diabetes, allergies, and asthma as well as reducing risks of morbidity and mortality (Lyons et al., 2020; Mphasha et al., 2023).

During pregnancy and lactation, the mothers' nutrients requirements, particularly micronutrients increase tremendously compared to their usual dietary requirements (Marangoni et al., 2016). To provide foetus and newborn with enough nutrients for optimal development and long-term health, macro- and micronutrients are essential in maternal diet (Rees, 2019). Micronutrient deficiencies could result from inadequate intake of fruits, vegetables, meat and dairy products among pregnant and lactating mothers (World Health Organization, 2020). Lactating mothers in Bogor, Indonesia, reportedly doubled their vegetable intake across all investigated income quintiles, with 71% believing that this dietary strategy improved lactation performance (Madanijah et al., 2016). Despite the increased requirements, exclusively breastfeeding women did not receive adequate amounts of total calories, protein, total fat, dietary fibre, and water (Basir et al., 2019). The low intakes indicate that traditional postpartum eating patterns may have an impact on mothers' ability to meet their nutritional needs during lactation (National Coordinating Committee on Food and Nutrition (NCCFN), 2023).

The maternal diet determines the composition and quality of breast milk, which has a direct impact on infant health and development. According to research, the nutrients in a mother's diet, especially the Omega-3 polyunsaturated fatty acids (PUFAs) such as Docosahexaenoic Acid (DHA) and Eicosapentaenoic Acid (EPA from fish), can enhance breast milk composition, promoting newborn brain and visual development (Petersohn et al., 2023). Vitamins A, E, and K, and minerals like iodine and selenium, improve breast milk depending on maternal diet, affecting child growth and immunological health (Falize et al., 2024). Furthermore, practicing a Mediterranean diet has been linked to greater antioxidant levels in breast milk, which may provide preventive benefits for newborns (Karbasi et al., 2023). While nutritional needs during lactation are unique, others contend that individual differences in food choices and health can result in varying health outcomes.

Functional foods are deemed as foods that possess potential beneficial health benefits beyond their basic nutritional value where they can enhance health and lower risk of diseases (Essa et al., 2023). The concept of functional food started in Japan around 1980s and progressed to North America and other markets (Heasman & Mellentin, 2001). Indeed, the consumption of certain foods packed with nutrients, minerals and phytochemicals can reduce the risk of various metabolic and mutagenic disorders (Sorrenti et al., 2023). For example, the consumption of resveratrol, a compound found in grapes and pomegranates improves vascular function, immunity and the gut microbiota composition (Chaplin et al., 2018). Anthocyanin, a class of pigments found mostly in purple foods have been shown to reduce cognitive declines, protect cardiovascular system, protect organs such as liver, gastrointestinal tract and kidney and have improves bone health, as well as protecting against obesity and regulates glucose and lipid metabolism (Panchal et al., 2022). Several foods have been shown to improve breastmilk in lactating mothers. Hence, this mini review aims to revisit several functional foods that are beneficial for lactating mothers and explain the effects of gut-mammary axis in the production of breast milk.

2. Nutritional Requirements during Breastfeeding

The requirement for most nutrients during lactation is higher than during pregnancy because of the need to replace the copious nutrients secreted in breast milk (Allen, 2005). Breastfeeding mothers need about 500 extra kcal per day in addition to what is suggested for women who are not pregnant (National Coordinating Committee on Food and Nutrition (NCCFN), 2017). The estimate is based on the caloric content of milk (67 kcal/100 mL) (Institute of Medicine (US) Committee on Nutritional Status During Pregnancy and Lactation, 1991). The average amount of breast milk produced daily is 780 mL, and ranges between 450-1200 mL (Kominiarek & Rajan, 2016). In physiologic preparation for lactation, most pregnant women store an additional 2 to 5 kg (19,000 to 48,000 kcal) of tissue, mostly as fat. Body reserves are used to sustain lactation if women do not ingest the additional calories. It is common for breastfeeding women to lose about 0.5 to 1.0 kg per month after the first month postpartum (Weekly, 1992).

During lactation, an additional 25 g of protein should be consumed every day (Kominiarek & Rajan, 2016). Human breast milk protein consists mostly of casein and whey protein, as well as enzymes, endogenous peptides, and mucus derived from the membranes of the milk fat globules. Breast milk protein during lactation functions to fulfil nutrition and has an immunomodulatory effect against pathogens in infants (Donovan, 2019). There was a significant correlation between the total protein content of breast milk and the intake of animal protein, which was higher than that of plant protein (Wati et al., 2023). Following its amino acid composition, digestibility, and ability to help transport essential elements like calcium and iron, animal protein is known for containing a higher nutritional value than plant protein (Day et al., 2022). In contrast, compared to animal protein, vegetable protein typically contains fewer essential amino acids, especially methionine, lysine, and leucine (Gorissen et al., 2018). Suggesting that a more diverse plant-based diet should be consumed to provide similar amino acids composition provided by animal protein.

There is no evidence that dietary fat recommendations, as a percentage of energy intake, need to

be changed for pregnant and lactating women compared to non-pregnant, non-lactating women (Koletzko et al., 2007). Although the recommended fat intake remains at 25-30% of total energy during pregnancy, the increased need for dietary fat is instead addressed through higher daily energy requirements.
Hydration is vital during lactating, since the body needs for water increases. According to research, exclusive breastfeeding mothers had a decreased water balance, indicating increased risk for dehydration that could impair milk supply (Malisova et al., 2024). Breast milks are believed to contain roughly 87% water, with foremilk having the highest water percentage (Martin et al., 2016). During the first six months of exclusive breastfeeding milk output averages 750mL per day (Kent et al., 2016). If mothers are dehydrated, the content of breast milk changes and the amount of milk produced may be insufficient to feed their babies (Lusambili & Nakstad, 2023). Consequently, the infant's health could be in danger. Although extreme dehydration, such as that brought on by vomiting or diarrhoea resulting in a loss of more than 10% of bodily fluids, can seriously reduce milk volume, breast milk production is typically resistant to changes in the nutritional status of the mother (National Coordinating Committee on Food and Nutrition (NCCFN), 2023).

During lactation period, mothers require increased micronutrients to support healthy recovery and production of breast milk. Micronutrients are essential vitamins and minerals required in small amounts but are important for various physiological and biochemical functions including immune system, bone health and optimal metabolic processes. Adequate levels of micronutrients in a breastfeeding mother's diet are essential for both the quality of her breast milk and her own health during lactation. Deficiencies or imbalances in these nutrients can lead to various complications in both the mother and infant (Carretero-Krug et al., 2024). During the breastfeeding period, lactating mothers are at risk of vitamin deficiencies as their infants rely on the mother's nutrient stores through breast milk. Vitamin A is one of the most essential micronutrients during this time, as it plays a crucial role in lung function, maturation, and immune defence, thereby influencing the infant's vulnerability to infections (Cabezuelo et al., 2019). Vitamin D is another essential vitamin during lactation, as it is required for bone health, immune function and the absorption of calcium and phosphorus, the deficiency of this vitamin can lead to impairment in immune function and increased risk of bone conditions such as rickets in infants. It is important for mothers to continue getting adequate sunlight for enough vitamin D synthesis apart from the usual food sources for vitamin D (Heo et al., 2021). Folate or vitamin B9 is required for DNA synthesis, cell division and tissue growth, this vitamin is important for the optimal development of the infants' nervous system and cognitive functions (Naninck et al., 2019). There is an increased risk of folate deficiency in lactating mothers due to the increased demands to meet milk folate levels (Stamm & Houghton, 2013). Vitamin B12 is also vital for nerve function, red blood cell production and DNA synthesis, this vitamin helps promote healthy infants' development, enhance breast milk production and prevent neurological impairments for both infants and mothers (Leal et al., 2022). Early supplementation of vitamin B12 can be beneficial in pregnant mothers as a study reported that it vitamin B12 status of mothers and infants are retained throughout pregnancy and early lactation (Duggan et al., 2014). As an important antioxidant, vitamin C helps to reduce oxidative damages in infant tissues and maintain healthy collagen formation and immune health in both babies and mothers, though a study has reported that vitamin c from food is better absorbed than from supplementation (Martysiak-Żurowska et al., 2017).

Equally important are the intakes of minerals to support optimal health in mothers and infants. To maintain bone health, muscle function, blood clotting and nerve transmission, adequate calcium intake is required. Calcium deficiency can lead to maternal bone loss and a reduction in milk supply and can also impact the infant's growth and bone health (Ettinger et al., 2014). As a component for haemoglobin, iron is involved in proper oxygen transport in the blood and plays a role in energy metabolism and immune function. The deficiency of iron can lead to fatigue and reduced milk supply which if not corrected can lead to iron-deficiency anaemia, supplementation is required particularly if anaemia is diagnosed after delivery (Butte & Stuebe, 2024). As a mineral required for DNA synthesis and cell division, zinc also plays a vital role in immune function, protein synthesis and wound healing. Zinc deficiency in mothers may lead to a weakened immune system and zinc deficiency can develop in infants who are given mostly plant-based complementary diet (Krebs et al., 2014). Studies have shown that zinc levels in milk may decrease considerably after the first few months and there is a need to further assess zinc levels in both lactating mothers and infants (Aumeistere et al., 2018; Rios-Leyvraz & Yao, 2023). Another essential micronutrient is iodine, which is required to produce thyroid hormones that regulate metabolism, growth and development. As the nutrient is also transferred in breast milk, the deficiency of iodine may reduce developmental delay and cognitive impairments in infant (Andersson & Braegger, 2021; Bath, 2019). It is crucial for lactating mothers to have an adequate intake of micronutrients, as studies have shown that even in countries with a high standard of living, many breastfeeding mothers often have insufficient intakes of essential nutrients (Schaefer et al., 2020).

3. Functional Foods to Improve Maternal Lactation and Health

Functional foods can act both to improve mother's health and to increase breast milk production. Functional foods, especially those derived from plants, have analgesic, antioxidant, anti-inflammatory, anti-microbial and gastroprotective properties aids in enhancing recovery, lowering inflammation and promoting general health during puerperium phase by helping mother to recover from childbirth (Mulyanto et al., 2024). Several plant-based foods are recommended for breast milk production, for instance, Moringa and Katuk leaves are recognised for their galactagogue characteristics, which boost breast milk production, while mung beans and soybeans also help lactation by increasing milk secretion (Puspitasari et al., 2022). In this section, several examples of functional foods that are beneficial for breast milk production will be discussed.

3.1 Plant-based Galactagogues

Galactagogues are substances, both naturally occurring and synthetically prepared, that are known to enhance milk production or flow. These include various foods, herbal remedies, and pharmaceutical drugs. Galactagogues play a crucial role in addressing milk supply challenges by not only boosting milk production but also helping to restore a nursing mother's confidence. They are beneficial in supporting the initiation, maintenance, and augmentation of maternal milk production.

Herbal medicine is widely utilized by breastfeeding mothers, as it offers essential benefits for both maternal and infant health (Ibrahim et al., 2016). For mothers, herbal remedies have been shown to alleviate various postpartum conditions, including heartburn, abdominal discomfort, birth canal pain, wrinkled skin, fear, and anxiety. For infants, these natural interventions may help reduce breastfeeding challenges and promote smoother milk flow (Paryono & Kurniarum, 2014). For example, in Indonesia, the commonly used ingredients include *Sauropus* leaves mixed with turmeric, *Zingiber*, and tamarind (Sayuti & Atikah, 2023). Additionally, other herbal preparations often incorporate ingredients such as banana blossoms, turmeric, ginger, aromatic ginger, papaya leaves, tamarind, betel leaves, cubeb, soybeans, moringa leaves, and almonds, all of which are believed to enhance lactation and overall postpartum recovery, as reviewed by previously (Sayuti & Atikah, 2023).

Sauropus androgynus leaves also known as katuk leaves (Indonesia), sayur manis (Borneo) or star gooseberry has been shown to have carotenoids, flavonoids and various other phytochemicals (Purba & Paengkoum, 2022). Recent studies have revealed that the plant is effective for increasing breastmilk production (Suryawan & Lazarosony, 2021). For instance, 12 days supplementation of katuk leaves to mice increased prolactin gene expression compared to control group (Suryawan & Lazarosony, 2021). It was suggested that the alkaloid Papaverine found in the plant is responsible for the increased prolactin production due to the dilatating effects on smooth muscles and blood vessels which increase oxygenation of mammary cells and thus increasing circulating oxytocin and prolactin levels (Soka et al., 2010). A caution should be exercised to properly cook the katuk leaves as they may contain harmful compounds when eaten raw, which seems to disappear when cooked (Teo, 2023).

In Thailand, lactating mothers are encouraged to consume vegetables as functional foods and herbs to improve lactation (Luecha & Umehara, 2013). Several fruits and vegetables have been suggested as galactagogues and this include Chinese chives leaves (*Allium tuberosum*), jackfruit seeds (*Artocarpus heterophyllus*), papaya fruits, ivy gourds fruits (*Coccinia indica*), pumpkin fruits, horseradish tree leaves and flowers (*Moringa oleifera*), holy basil and lemon basil leaves, pepper seeds, cloves flowers, ginger roots and (*Zizyphus mauritiana*) jujube fruits (Luecha & Umehara, 2013). Several medicinal plants are also identified as galactagogues for instance the white caper bush leaves (*Capparis flavicans*), asthma weeds (*Euphorbia hirta*), golden fig roots (*Ficus benjamina*), licorice weed (*Scoparia dulcis*), *Glycosmis cochinchinensis* roots, tamarinds, and *Xantolis cambodiana* root and bark (Luecha & Umehara, 2013).

Based on a RCT study, the results showed that the use of natural galactagogues, such as fenugreek and fennel, has been shown to support increased lactation in mothers. Research indicates that consuming fennel and fenugreek tea for seven consecutive days leads to a significant boost in maternal milk production (Mahsa et al., 2024). According to reports, fenugreek seeds stimulate the formation of the mammary gland by having a mastogenic effect (Gbadamosi & Okolosi, 2013). Because of its high quantities of phytoestrogens, this plant is utilised as a galactagogue in women all over the world (Sreeja et al., 2010). By using in vitro assay, one study discovered that fenugreek seeds contain compounds resemble estrogen and increase the expression of pS2 (estrogen-induced protein) in the Michigan Cancer Foundation-7 (MCF-7) breast cancer cell line, where pS2 is commonly used as a marker to determine a compound's estrogenicity (Sreeja et al., 2010). The observed increase in milk flow may be explained by phytoestrogens such as diosgenin, a form of steroidal sapogenin (Mortel & Mehta, 2013).

A recent review reported that the effects of several key plant-based galactagogues which has been selected in the literature for its robust studies (Thakur et al., 2023). The leaf extract of *Amaranthus spinosus* administered on lactating mothers for 14 days increase prolactin levels and milk secretions and can be added as a good addition to lactating mothers' diet (Kuswaningrum et al., 2017). Fennel seed (*Foeniculum vulgare*) consumption increased prolactin secretion as it also acts as dopamine antagonist (Rifqiyati & Wahyuni, 2019). In rabbits, the administration of milk thistle (*Silybum marianum*) increases milk production through increasing prolactin level (Refaie et al., 2019). Borage (*Borago officinalis*) also increases milk production through increasing the release of prolactin (Wasan et al., 2006). The garden-cress seeds (*Lepidium sativum*) also treatment in rats have been shown to increase the levels of prolactin, estrogen and progesterone (Obeid et al., 2020). The black cumin (*Nigella sativa*) extract given to lactating rodents was able to increase milk production and pup weight (Hosseinzadeh et al., 2013). Alfalfa (*Medicago sativa*) also known as 'lucerne' is viewed as functional foods due to its low fat and sodium content but high in nutrients. Alfalfa leaf has been shown to have phytoestrogens which could stimulate prolactin secretion, mammary tissue maintenance and imparting essential nutrients for milk production (Foong et al., 2020). Star anise (*Illicium verum*) is also another herb that are considered galactagogues as the star anise extract increased the concentration of insulin-like growth factor 1 (IGF-1) in milk and serum prolactin in sows (Wang et al., 2015).

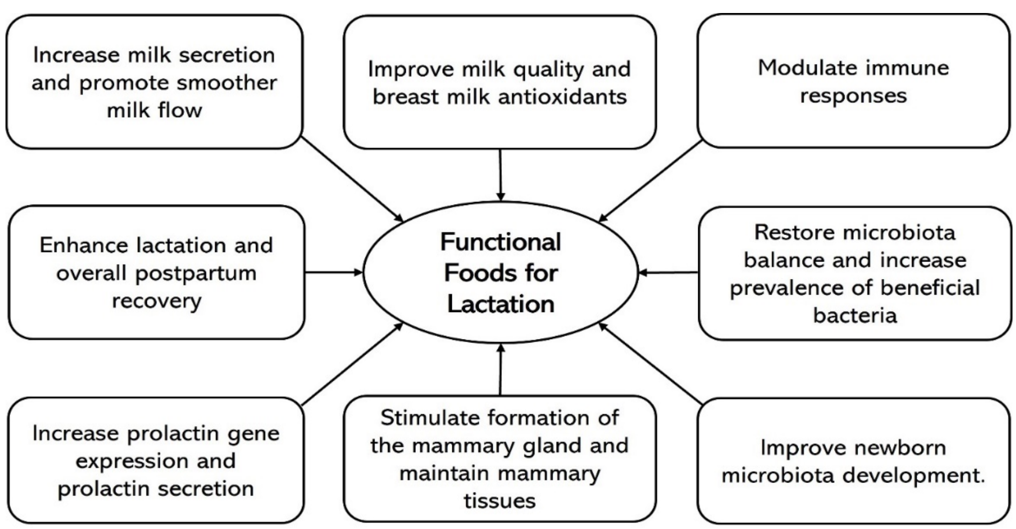

Figure 1. The potential mechanisms on how functional foods affect lactation process

The potential of Shavatari (*Asparagus racemosus*) as galactagogue agent has been discussed where the supplementation of bar containing Shavatari in lactating mothers showed increased milk expression compared to control (Birla et al., 2022). However, this herb should not be given to pregnant women as it may induce adverse effects on foetus (Hamed, 2016). The administration of sesame seeds (*Sesamum indicum*) in female albino rats have shown galactopoietic properties by increasing growth and development in mammary glands (Al-Bazii et al., 2019). These results showed that plant-based galactagogues are increasingly studied as functional foods to increase breast milk production and to improve lactating mothers' health as reported by related reviews (Ali et al., 2020; Budzynska et al., 2013; Millinga et al., 2022; Ryan et al., 2023; Sibeko et al., 2021). The potential mechanisms by which functional foods affect lactation is depicted in Figure 1.

3.2 Wholegrain-based Galactagogues

Lactogenesis is dependent on prolactin levels, which rise after delivery; however, milk production is affected by breastfeeding frequency and period. Preterm births frequently result in decreased in prolactin and insufficient milk production (Wesolowska et al., 2021). β-glucan concentration in barley boosts prolactin and milk production. Barley malt-based products can increase milk supply by 30%, especially among mothers with preterm infants as it provides beneficial components during the malting process. Moreover, barley has been traditionally used to promote breastfeeding, are also found in non-alcoholic beer, which increases blood prolactin and enriches breast milk antioxidants such as coenzyme Q10 (Javan et al., 2017). Wholegrains are rapidly being recognized for their health advantages, including their lactogenic properties. The nutritional makeup and bioactive components help in lactation and directly improves milk production and quality. Whole grains are rich in essential nutrients, including fibre, vitamins and minerals which are vital for pregnant women to support foetal development and mother's health (Mir et al., 2022). The addition of dietary fibre from whole grains may affect the composition of breastfeeding, which is critical for infant health. Breastfeeding mothers should include dietary fibre in their meals to improve milk quality and newborn microbiota development (Çavdar et al., 2019).

3.3 Omega-3 fatty acids

Omega-3 fatty acids, such as docosahexaenoic acid (DHA) and alpha-linolenic acid (ALA), are vital for breast milk production, providing significant nutritional benefits for both mothers and infants. These fatty acids play an essential role in the development of the infant's brain and retina, contributing to optimal neurodevelopment. Low levels of omega-3 fatty acids have been linked to poor neurodevelopmental outcomes in infants (Khandelwal et al., 2023). Research has demonstrated that omega-3 supplementation can substantially increase the levels of these fatty acids in breast milk. For example, one study found that mothers who took 400 mg of DHA daily while breastfeeding had higher DHA concentrations in their milk compared to those who did not take supplements (Khandelwal et al., 2023; Mazurier et al., 2017). Additionally, omega-3 fatty acids have been shown to positively influence infant cognitive development, enhancing communication and problem-solving skills (Nazeri & Ghavamzadeh, 2017). Moreover, omega-3 fatty acids help regulate inflammatory cytokines, fostering a healthier environment for infant growth and overall development (Rodriguez-Santana et al., 2017). Functional foods incorporating these elements represent a valuable dietary approach to improving maternal and infant health during lactation.

3.4 Prebiotics and Probiotics

Functional foods are innovative food products designed to include bioactive ingredients or beneficial microorganisms that improve health or prevent disease when consumed at safe, effective concentrations (Temple, 2022). Functional foods tailored for lactation, particularly those enriched with probiotics, prebiotics, and bioactive compounds, provide significant benefits for both maternal and infant health. These foods can deliver essential nutrients, strengthen immunity, and support a balanced gut microbiota.

Probiotics have shown promise in managing lactational mastitis by modulating immune responses and restoring microbiota balance, with specific strains demonstrating potential to reduce the incidence and severity of this condition (Barker et al., 2020). Similarly, prebiotic consumption during lactation has been linked to an increased prevalence of beneficial bacteria, such as Bifidobacteria, in the microbiomes of both mothers and infants. This enhancement in gut microbiota composition not only supports metabolic health but also reduces the risk of inflammatory diseases associated with microbial imbalances (Van Hul et al., 2024).

3.5 Gut-mammary axis

The gut-mammary pathway represents a vital connection between maternal diet, gut health, and breast milk composition (Ford et al., 2020). This microbial community generates a vast array of bioactive compounds, including short-chain fatty acids (SCFAs), immune-modulating molecules, and other metabolites, which can have far-reaching effects on the mother's overall health and the composition of her breast milk. This gut-mammary axis can be leveraged through functional foods, such as probiotics, which play a crucial role in enhancing the maternal gut microbiome and, in turn, enriching breast milk with a greater diversity of protective nutrients, immunoglobulins, and other bioactive compounds. This creates an environment that favours the proliferation of beneficial commensal bacteria, leading to increased production of metabolites that can be transported to the mammary gland and positively influence breast milk composition (Davis et al., 2022; Lyons et al., 2020; Nolan et al., 2019; Rodríguez et al., 2021; Taylor et al., 2023). Moreover, prebiotics, enhance the growth and activity of probiotic microbes and further improve the production of gut-derived metabolites that can be transferred to the mammary gland, finally optimizing the gut-mammary pathway (Moossavi et al., 2018; Oh et al., 2019; Yin et al., 2023). By optimizing this gut-mammary pathway through the strategic use of probiotics and prebiotics, we can support the health and development of the infant, providing long-term benefits that extend beyond the lactation period.

One critical mechanism involves the circulatory pathways, where gut-derived metabolites, including SCFAs cross the intestinal barrier and enter the bloodstream. Specifically, SCFAs can influence the activity and regulation of immune cells, altering the production of cytokines and other signalling molecules that play a crucial role in the immune response (Frolova et al., 2022; Li et al., 2023; Liu et al., 2023; Parkar et al., 2021). SCFAs, such as butyrate and acetate, have been shown to modulate the differentiation and function of T cells, B cells, and other immune cells, leading to changes in the production of pro-inflammatory and anti-inflammatory cytokines. This circulatory pathway allows the maternal gut microbiota to effectively shape the composition of breast milk, providing critical nutrients and immune factors that benefit the developing infant (Chen et al., 2021; Rodrigues et al., 2022). Probiotics can help maintain a diverse and balanced gut ecosystem through several mechanisms. Firstly, probiotic strains can competitively exclude pathogenic bacteria, preventing their overgrowth and promoting a healthier microbial balance. Secondly, probiotics can interact with the host's intestinal epithelial cells and immune cells, stimulating the production of antimicrobial compounds and anti-inflammatory cytokines (Mazziotta et al., 2023). The more diverse and balanced the maternal gut microbiome, the greater the array of metabolites it can produce, including SCFAs, vitamins, and other bioactive compounds. These gut-derived metabolites can then be absorbed into the bloodstream and transported to the mammary gland, where they can influence the synthesis and secretion of key components of breast milk, such as oligosaccharides, immunoglobulins, and antimicrobial proteins (Duale et al., 2021). Prebiotics, on the other hand, selectively promote the growth and activity of beneficial gut bacteria, such as Bifidobacterium and Lactobacillus species. By providing a favourable substrate for these probiotic microbes, prebiotics support the maintenance of a diverse and balanced gut microbiome (Hiraku et al., 2023; Miqdady et al., 2020).Together, probiotics and prebiotics optimize the maternal gut microbiome, and this circulatory pathway can be leveraged to enrich breast milk with an even greater diversity of protective nutrients, immunoglobulins, and other bioactive compounds, ultimately benefiting the health and development of the infant (Duale et al., 2021; Manoppo et al., 2022; Sánchez et al., 2021).

Another critical pathway is immune modulation, which highlights the intricate communication between the gut-associated lymphoid tissue and the immune cells within the mammary gland. This bidirectional crosstalk enhances the secretion of protective immune factors, such as secretory immunoglobulin A (SIgA), into the breast milk. SIgA is a key antibody that provides passive immunity to the developing infant, helping to protect against pathogenic microorganisms and regulate the infant's immune system development. This immune modulation pathway is crucial for strengthening neonatal immunity and establishing a balanced immune response (Bennike et al., 2020; Bhat & Kingsley, 2018; Kemp & Campbell, 1996). Furthermore, emerging research on microbial transfer reveals that specific bacterial species from the maternal gut microbiome may migrate to the mammary gland, a phenomenon known as the entero-mammary pathway. This direct seeding of the infant's gut with beneficial microbes from the mother's gut can have a profound impact on the composition and diversity of the infant's gut microbiota (Jost et al., 2014; Kordy et al., 2020; Mady et al., 2023). By promoting the establishment of a balanced and diverse gut microbial community, this microbial transfer helps to create a favourable environment for optimal infant gastrointestinal and immune system development. This connection between the maternal gut and the infant's gut microbiome, facilitated by the gut-mammary axis, is a critical aspect of the holistic maternal-infant dyad, with long-lasting implications for the infant's growth, health, and well-being. Probiotics and prebiotics can have a significant impact on this gut-mammary axis and the associated immune modulation pathway. Probiotics can help maintain a diverse and balanced gut ecosystem, which in turn enhances the production of immunomodulatory metabolites. For example, probiotic strains like *Lactobacillus* and *Bifidobacterium* can stimulate gut-associated lymphoid tissue to produce higher levels of secretory IgA (Bhat & Kingsley, 2018). This SIgA can then be transported to the mammary gland, where it is secreted into breast milk, providing passive immunity and pathogen protection for the developing infant (Kemp & Campbell, 1996). It is well known that prebiotics promote the growth and activity of beneficial gut bacteria and the maintenance of a well-balanced and diverse gut microbiome. This, in turn, enhances the production of immunomodulatory metabolites, such as short-chain fatty acids, that can directly influence the mammary gland and the composition of breast milk (Mady et al., 2023). For example, SCFAs like butyrate and propionate have been shown to stimulate the production of antimicrobial proteins and immunoglobulins in mammary epithelial cells, further strengthening the immune protection provided by breast milk (Bennike et al., 2020; Bilotta & Cong, 2019; Schulthess et al., 2019).

The gut-mammary pathway represents a critical axis that integrates maternal nutrition, gut microbiome health, and the composition of breast milk. This pathway not only optimises maternal well-being but also provides lasting benefits for the developing infant by strengthening immune function, supporting gut microbiome establishment, and promoting overall health and development. Despite the growing understanding of this gut-mammary axis, gaps remain in fully elucidating the mechanistic pathways and identifying the specific microbial species, metabolites, and signalling molecules that mediate these effects. Further research is needed to unravel the complexities of this bidirectional communication system and to develop targeted nutritional interventions, such as probiotics and prebiotics, that can harness the power of the gut-mammary pathway to improve maternal and infant health outcomes. Addressing these research challenges will enable the design of more personalised, evidence-based strategies to optimise lactation and ensure the optimal transfer of protective and nourishing components from mother to child through the miraculous process of breastfeeding.

4. Conclusion

Adequate nutrition during lactation is crucial for both infants and mothers' health. The prevalence of breastfeeding in newborns is still below the optimal level and needs continuous promotion and maintenance. The health of lactating mothers also needs to be attended to as providing breast milk to developing infants can be mentally and physically draining. The addition of functional foods to mothers' diet can help support the required essential nutrients for continuous breastfeeding, producing optimal quality breastmilk and maintaining maternal health. Simultaneously, understanding the gut-mammary axis can provide essential information and evidence to better plan maternal and infants' breastfeeding practice through targeted and personalised nutritional interventions. Further research should aim to conduct robust clinical trials using functional foods to help provide evidence-based recommendations for lactating mothers

Authors contribution

All authors agreed to the final draft. Wanessa Wanda William and Nuha Husna Binti Mohd Bukhari both contributed equally as first authors

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