Discovering Dairy Phospholipids: Nature's Functional Ingredients

Ameenabenazir P[1]*, Monika Sharma[2] and Chaithra B A[3]

[1]Ph D Research Scholar, [2]Senior Scientist, [3]PG Research Scholar, Dairy Processing Section, ICAR- National Dairy Research Institute, SRS, Bengaluru-560030, Karnataka, India

Corresponding Author
Ameenabenazir Peerbal
Email: ameenarizaneb@gmail.com

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ABSTRACT

Phospholipids are fascinating natural compounds that occur in many foods, including milk, dairy products, eggs, meat, seafood, and plant-based foods. Although they are present in relatively small amounts, their importance extends far beyond their quantity. Dairy phospholipids, particularly those associated with the milk fat globule membrane, possess unique nutritional and functional properties and are attracting increasing attention for their potential roles in brain health, gut health, lipid metabolism, and overall well-being. They also act as natural emulsifiers, making them valuable ingredients for developing innovative and functional foods. This article explores the major dietary sources of phospholipids, with special emphasis on dairy sources, their key health benefits, and their growing applications in the food and health sectors. Understanding these naturally occurring “hidden treasures” of milk can open new avenues for their sustainable utilization and value addition. Dairy phospholipids represent a promising link between nature, nutrition, and the future of functional foods.

INTRODUCTION:

Naturally occurring bioactive lipids called dairy phospholipids are present in milk and dairy products, where they play a crucial role in the membrane of the milk fat globule. Despite being found in trace amounts, these special substances are important for human health, food functionality, and nutrition. They have outstanding emulsifying qualities and are becoming more and more appreciated for their possible advantages in gut health, brain development, and general wellbeing. Dairy phospholipids are becoming recognized as one of nature's most promising functional ingredients as customers look for natural and healthier food ingredients.

The milk fat globule membrane (MFGM) contains phospholipids, which have both hydrophilic and lipophilic characteristics that help them emulsify. These traits affect phospholipids' roles, uses, and functions. Because phospholipids belong to the polar lipid group, Contarini and Povolo (2013) refer to them as "phosphorus lipids." Glycerol, two fatty acids, a phosphate group, and a polar headgroup make up the structural elements of phospholipids, which are crucial parts of cell membranes. The central carbon backbone of phospholipids, glycerol, is made up of three carbon atoms. Furthermore, small amounts of phosphatidylcholines (PC), phosphatidylethanolamines (PE), phosphatidylserines (PS), phosphatidylinositols (PI), or phosphatidic acid (PA) can be formed by further esterification of the phosphate group with polar headgroups like choline, serine, ethanolamine, or inositol (Chojnacka *et al*., 2012). Roughly 1% of the total lipids in cow's milk are phospholipids, of which roughly 60% are linked to the milk fat globule membrane. The skim milk phase contains residual MFGM material, which was probably released either during or after the lipid droplet was secreted. Some phospholipids are lost from the MFGM during processing, and serum proteins often attach to the MFGM around the lipid core.

Classification of phospholipids

There are various methods for categorizing PLs. Based on the kind of alcohol backbone, the majority of these classifications split PLs into two major classes or types. First, glycerol serves as the structural backbone of PLs (glycerophospholipids), while sphingosine forms the structural backbone of sphingolipids (sphingophospholipids) (Sikorski and Kolakowska, 2010). Based on their technological composition, PLs are classified as either hydratable or non-hydratable. Phosphatidic acid (PA) is classified as a non-hydratable species, whereas PE is moderately hydratable and the classes PC, PI, and lyso-PLs are only hydratable (Subramanian *et al*., 1999; Zufarov and Serkayev, 2024).

Structure and composition

The membrane of the fat globules contains the majority of the choline head-group-containing PLs, such as PC, SM, and the glycolipids gangliosides and cerebrosides. On the other hand, PE, PS, and PI are mostly present on the membranes' interior surface (Deeth, 1997). Lactosyl-cerebroside (3.4%), phosphatidylcholine (31%), phosphatidylethanolamine (30.5%), sphingomyelin (19.9%), phosphatidylinositol (7.1%), phosphatidylserine (5%), and glucosyl-cerebroside (0.3%) are the main ones, along with their approximate percentages (Fong and Norris, 2013).

Source of phospholipids

Human milk

According to Pita *et al*. (1985) and Smit *et al*. (2002), human breast milk is a dynamic material whose lipid composition is impacted by a variety of circumstances, including the mother's diet, the length of her pregnancy, the stage of lactation, her location, cultural customs, and her financial condition. The usual range of total PLs in human milk is 9.8–47.4 mg/100g. Regardless of the lactation stage, the two most common polar lipid species are sphingomyelin (SM) (28.9-43.3%) and phosphatidylcholine (PC) (19.0-38.4%), followed by Phosphatidylethanolamine (PE) (5.9-36.1%), phosphatidylserine (PS) (3.7-16.7%), and phosphatidylinositol (PI) (1.1-10.1%). Since these polar lipids provide around 17% of the total choline required for fast organ growth and membrane production, large amounts of SM and PC are thought to be essential for baby development (Sala-Vila *et al*., 2005; Zou *et al*., 2012).

Egg yolk

According to Yamashitha *et al*. (2023), the phospholipid (PL) content of egg yolks varies from 20% to 80%, and the glucose to PL ratio is 0.10% by weight or less. Eggs contain about 10% of the moist weight of the egg yolk, or roughly 22% of the total solids in the yolk, making them an important dietary source of PLs. Because egg PLs are economically valuable and readily available as premium lipid products, their extraction and purification must be done efficiently (Wang *et al*., 2017). The egg is composed of 11.0–11.1% shell, 59.7–60.6% albumen, and 28.4–29.3% yolk (Li-Chan and Kim, 2008). 62.4–65.2% lipids and 34.8–37.8% proteins make up the yolk solids, which comprise 59.0–64.4% of the total solids. About 33% of the lipid fraction in eggs is made up of phospholipids, which include 70% phosphatidylcholine (PC), 15.5% phosphatidylethanolamine (PE), 5.8% lysophosphatidylcholine (LPC), and 2% each of sphingomyelin (SM) and lysophosphatidylcholine (LPC) (Ternes and Jaekel, 2010).

Vegetable oils

According to Ohshima *et al*. (1993), Aluyor *et al*. (2009), and Carelli *et al*. (1997), phospholipids (PLs) contribute to the antioxidative qualities and improve the smoothness, consistency, and mouthfeel of fats, edible oils, and fatty meals. PLs also cooperate with tocopherols to prevent lipid oxidation and rancidity (Carelli *et al*., 1997; Ali *et al*., 2019; Amézaga *et al*., 2018). Additionally, they take part in the Maillard reaction, which helps create flavors and colors and increases the stability of oils at high temperatures (Cui and Decker, 2016; Anjum *et al*., 2006).

Crude oils usually have PL concentrations between 0.1% and 1.8%. By removing metals like iron and copper, PLs, or gums, improve the oxidative and flavor stability of vegetable oils (Flider and Orthoefer, 1981; Chua, 2009). In order to comprehend how phosphatides affect the qualities of oil, oil producers must keep an eye on the concentration of phosphatides during processing. Additionally, PLs cause the discolouration of oils during steam distillation and deodorization; hence, PL analysis is essential to assessing the degumming process's effectiveness (Panagiotopoulou and Tsimidou, 2002). Significant levels of PLs, usually between 1% and 2%, are found in oils like peanut and sunflower oil. Phosphatidylethanolamine (PE), phosphatidylinositol (PI), phosphatidylserine (PS), and phosphatidylcholine (PC) are the main PL compounds present in edible oils.

Milk and milk products

PLs are found in different amounts in different dairy products, such as whole milk (0.2-0.3g/100g DM), cream (0.2-0.4g/100g DM), butter (0.3g/100g DM), skim milk yogurt (0.2g/100g DM), and buttermilk (1.1-2.0g/100g DM) (Anto *et al*., 2020).

Buttermilk

The main dairy by-product whose phospholipid content has been investigated is buttermilk, a by-product of butter manufacture. Buttermilk is a possible source of phospholipids since the membrane is separated from the milk fat during the butter-making process. According to Costa-Junior *et al*. (2011), buttermilk has about 12% phospholipids, of which more than 84% are phosphatidylcholine (PC), sphingomyelin (SM), and phosphatidylethanolamine (PE). By combining membrane filtration and supercritical fluid technology, they were also able to concentrate the phospholipid fraction to 61% (based on fat). In a similar vein, Konrad *et al*. (2013) achieved a dried fraction with a phospholipid concentration of up to 14% (w/w) by using ultrafiltration to extract phospholipid-enriched fractions from whey buttermilk.

Ghee residue

The largest phospholipid content, roughly 17.39% of the total fat, was found in ghee residue made from creamery butter, which contributed to its superior emulsifying ability. According to Santha and Narayanan (1978) and Sangama *et al*. (2023), the phospholipid concentration of ghee residue from desi butter and the direct creamer method was 4.95% and 1.575%, respectively, much higher than that of ghee itself, which ranged from 0.004% to 0.080%.

Health Benefits of Phospholipids

Since the 2000s, researchers have examined the health benefits of phospholipids (PLs), especially in relation to a number of ailments and diseases such as cancer, coronary heart disease, inflammation, and cholesterol absorption (Cohn *et al*., 2008; Postle, 2009; Tang *et al*., 2013). In Western societies, the average daily intake of dietary phospholipids (PLs) is estimated to be between 2 and 8 grams, mainly because of increased consumption of animal and marine items. Cereal grains, dairy products, eggs, meat, fish, and oilseeds are only a few of the many foods that contain these substances (Cohn *et al*., 2010).

The advantageous biological effects of phosphorus and sphingolipids on the human body have attracted increasing attention in recent years. Sphingolipids' potential to lower blood cholesterol (Eckhardt *et al*., 2002), improve brain function (Pepeu *et al*., 1996), have antioxidative qualities (Saito and Ishihara, 1997), have bacteriostatic effects (Sprong *et al*., 2002), and prevent colon cancer (Conway *et al*., 2014) has been the subject of extensive research. Additionally, polar lipids (PL) are commonly used because of their usefulness and emulsifying qualities in many food systems (Gunstone, 2001; Schneider and Feller, 2001).

According to studies, phospholipids in MFGM have anti-carcinogenic qualities, can lower cholesterol, and are useful in avoiding depression, stress, Alzheimer's, gastritis, and multiple sclerosis (Dewettinck *et al*., 2008). To assist in closing the performance gap between formula-fed and breastfed babies, MFGM can be added to infant formulae as a dietary supply of phospholipids. Additionally, this supplementation has no serious adverse effects and is safe for babies starting in the first week of life (Hernell *et al*., 2016). Sphingomyelin has been identified as an active substance that controls the absorption of cholesterol and lessens the rise in blood triacylglycerol levels following a meal (Eckhardt *et al*., 2002).

Nutraceutical aspects of phospholipids

There are few reports on the amount of glycerophospholipids consumed throughout the diet; nevertheless, it has been claimed that US citizens typically consume 2–8 g of PC. Milk fat is responsible for one-third of human lipid intake (USDA, 2017). The significance of milk phospholipids (PLs) in nutrition has attracted a lot of scholarly attention since they were first used to make liposomes for encapsulating bioactive substances. Since then, milk PLs have been linked to a number of health benefits in several research trials. Below is a summary of the nutraceutical effects of PLs that have been reported in the literature.

Inhibition of intestinal cholesterol absorption

According to Zierenberg and Grundy (1982), half of the cholesterol that humans consume is absorbed in the gut lumen, with the remaining portion being eliminated through faeces. Individual differences exist in the precise ratios, tho. Compared to egg SM, milk SM is said to be better at preventing the absorption of cholesterol because it includes fatty acids with longer chains and higher degrees of saturation. According to a study, the intestine absorbed over 90% of dietary PC, which then showed up in red blood cells and lipoproteins (plasma) (Phan and Tso, 2001).

Neurological and neurocognitive diseases

By serving as efficient carriers of vital fatty acids, the components of PLs, particularly SM, are thot to have a structural function in the formation of brain cells (Noh and Koo, 2004). A commercially accessible fraction of MFGM-PLs was shown to reduce endoplasmic reticulum-stress-induced cell mortality (in vitro) (Küllenberg *et al*., 2012). The protective effect of dietary PLs was attributed to autophagocytosis modelling and cell signalling modification. Tanaka *et al*. (2013) found that bovine SM improved neurobehavioral development in preterm infants. The MFGM-sphingomyelin therapy was found to have a favorable correlation with every neurodevelopment parameter that was examined.

Phospholipids as anticancer agent

PLs are said to be beneficial in the fight against colon cancer. Fischer-344 rats were given MFGM, which was high in PLs and bioactive proteins, in a study (Snow *et al*., 2011). The therapy has been shown to lower colon cancer. It was warned, tho, that MFGM is extremely vulnerable to heat treatment. Therefore, careful consideration should be given when creating the formulation.

Because PLs easily incorporate omega-3 fatty acids, which are known to be a lipogenesis inhibitor, they are also known to play a significant role in the prevention of liver cancer (Lamaziere *et al*., 2013). The growth modulatory effect on SW480 colon cancer cells was investigated using PLs and buttermilk sphingolipid fractions obtained from membrane filtration (Kuchta-Noctor *et al*., 2016). The findings supported buttermilk's anti-proliferative properties, especially those caused by SM and glycosphingolipids. Castro-Gómez *et al*. (2017) used food-grade and non-food-grade solvents to isolate lipid fractions in accordance with this study. The findings demonstrated that food-grade solvents have a high phosphorus and sphingolipid content and could exhibit anti-proliferative effect against human colon and ovarian cancer. Sphingolipids' anti-cancer properties were attributed to their slow digestion, which allowed them to be retained throughout the colon and small intestine.

Effect against hepathopathies

PLs have been shown to have hepatoprotective qualities. Research on the effects of giving PC to rats showed that it inhibited mitochondrial uncoupling and reduced the increases in TAG and cholesterol esters induced by alcohol (Navder *et al*., 1997). In human studies, Gundermann *et al*. (2017) demonstrated the hepatoprotective effects of soy PC. PLs produced from milk and its byproducts had a greater hepatoprotective impact. Additionally, complex PL treatment was thot to have a more potent protective effect than isolated PC.

Effect against infections

Rats given PC and PI were protected against bacterial translocation and intestinal mucosal degeneration (Wang *et al*., 1974). Furthermore, by preventing Listeria monocytogenes from adhering to the intestinal mucosa, rats given buttermilk rich in PLs showed improved resistance to the pathogen (Sprong *et al*., 2001).

CONCLUSION

Although phospholipids may be found in trace amounts, their significance is far higher than their quantity would indicate. These special lipids, which are present naturally in milk, eggs, meat, seafood, and several plant foods, are becoming more well-known for their functional, nutritional, and health-promoting qualities. Dairy phospholipids, in particular, present intriguing opportunities for promoting gut and brain health while acting as natural emulsifiers in a variety of dietary applications. Sustainable phospholipid recovery from dairy streams and underutilized resources can open up new avenues for innovation and value addition as research continues to reveal their advantages. Once thot of as a minor component of milk, it is now becoming a useful functional ingredient, serving as a reminder that often nature's greatest riches are concealed in the smallest things.

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