

Article

Assessment of Rapeseed Soapstock as a Potential Source of Lecithin for Food Industry Applications

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Abstract

The present research assesses the potential of rapeseed oil soapstock for producing lecithin and its application in the food industry in the context of the circular economy and bio-economy. The theoretical part summarizes information on the types of lecithin and its production technologies and functional properties, while the empirical part combines semi-structured interviews with 30 experts and company representatives (in Latvia and abroad) and a laboratory experiment with rapeseed soapstock samples. The data provided by the experts were analyzed using descriptive statistics and thematic analysis, while the soapstock samples were tested for dry matter, lipid content, and lecithin and acid oil yield using the techniques of *n*-hexane Soxhlet extraction and fractionation with cold acetone. The experts' ratings showed that rapeseed lecithin is technologically competitive with soybean and sunflower lecithin, especially to produce bread, flour confectionery, as well as oil and fat, thereby providing good emulsification capability, texture improvement, and stabilization. The highest potential for the introduction of rapeseed lecithin has been identified in the oil and fat, bread and flour confectionery segments, but wider use is currently hampered by high production costs and lower market visibility. This research demonstrated the practical possibility of isolating lecithin from rapeseed oil soapstock. The laboratory experiment revealed that it is possible to obtain lecithin from rapeseed soapstock in amounts of 1.4–5.2% of the total weight of soapstock (6.2–23.5% of dry matter), which confirmed the usability of rapeseed soapstock as a raw material for lecithin production. The results confirm that the use of rapeseed oil soapstock to produce lecithin can reduce the amount of industrial waste and increase resource efficiency, thus reducing dependence on imported soybean lecithin. Rapeseed lecithin can be found as a sustainable alternative to soybean and sunflower lecithin with potential for oil and fat and bread production.

Keywords: rapeseed oil soapstock; lecithin; circular economy; food production; sustainability; emulsifier



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1. Introduction

Over the last ten years, rapeseed oil output has increased significantly, reaching more than 32 million tons in 2022 (Figure 1). According to some researchers [1], rapeseed is the most productive oil crop in the world. This confirms the stable availability of raw

materials and creates prerequisites for the expansion of the rapeseed lecithin market, and it increases the availability of raw materials for the production of rapeseed lecithin from waste of rapeseed oil production, e.g., rapeseed soapstock.

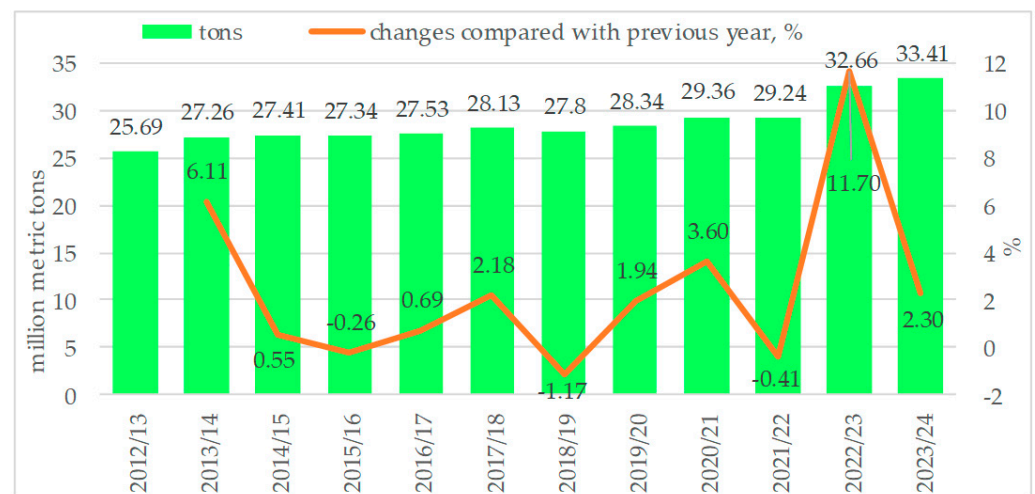


Figure 1. Output of rapeseed oil worldwide from 2012/13 to 2023/24 (in million metric tons and percentage change). Source: authors' construction based on statistical data provided by Statista [2].

The production of rapeseed (Figure 1) generally shows a steady upward trend, increasing from approximately 26 million tons in 2012/2013 to nearly 34 million tons in 2022/2023. In 2023/2024, production levels stabilized. Year-to-year changes throughout most of the analyzed period remained moderate (2–6%), with larger fluctuations only in isolated cases. The largest increase, both in total production volume and in percentage growth, was observed in 2022/2023, when rapeseed output rose by approximately 12%.

Given increasing environmental sustainability requirements and circular economy principles, it is important to assess the potential for reusing food-industry by-products, including their valorization as sources for food emulsifiers [3].

Food emulsifiers stabilize mixtures of immiscible liquids (e.g., oil and water) by reducing interfacial tension and are widely applied to improve the texture, stability, and sensory quality of products such as margarine, mayonnaise, sauces, dairy foods, and flour confectionery [4,5]. Among these, natural emulsifiers—particularly phospholipids (lecithins) with amphiphilic structure—are especially relevant due to their broad functionality in food formulations, including roles as emulsifiers, stabilizers, wetting agents, and dispersants [6].

Lecithin is a by-product of the vegetable oil-refining process and can be defined as a mixture of acetone-insoluble polar lipids and vegetable oil, alongside other minor components. Commercial lecithin is mostly produced from soybean oil, typically containing between 0.5 and 3% of phospholipids [7]. The functional properties of lecithin are mainly caused by the surface-active character of its phospholipids. They consist of a glycerol backbone esterified with two fatty acids and a phosphate group, which might be esterified with monovalent alcohols (for example, choline or ethanolamine) or polyvalent alcohols (such as glycerol or inositol) [8].

One of the components of lecithin is phosphatidylcholine (true lecithin), and its emulsifying, separating, lubricating, and surface-active properties help to optimize, improve, and enhance many technical processes in the food manufacturing cycle. Phosphatidylcholine content in rapeseed lecithin is higher than that in soybeans [9]. Commercially available lecithin is mainly extracted from soybeans using organic solvents and separated from other lipids using the techniques of hydration and precipitation with cold acetone [10].

Rapeseed oil soapstock is an aqueous emulsion of lipids, containing water, salts of fatty acids, acylglycerols, phospholipids, pigments, and minor inorganic components. Soapstock has a low commercial value, and it is mostly used for acid oil production via acidulation and water phase separation. Acid oil is oily material containing fatty acids, acylglycerols, phospholipids, and other oil-soluble minor components.

The present research aims to assess the possibilities of using rapeseed oil soapstock for the isolation of lecithin as well as to analyze the technological properties of rapeseed lecithin and its application in food production based on the expert ratings and the results of laboratory experiments. Utilizing local resources—rapeseed soapstock—reduces the need for importing soybean lecithin, providing independence from imports and supporting the local economy.

2. Lecithin: Production Technologies, Types, Functional Properties, and Sources

2.1. Producing Lecithin in the Refining of Vegetable Oils and the Types of Lecithin

Most food manufacturers and food chemists understand the term ‘lecithin’ to mean a natural, complex mixture of phospholipids, while chemists, biochemists, and pharmacists understand ‘lecithin’ to mean a chemically pure phospholipid—phosphatidylcholine [11]. Lecithin has several alternative names, including vitellin, lecitina, vitelline, ovolecthin, vegilecithin, soybean lecithin, egg lecithin, and soybean phospholipid [12]. The commercial term ‘lecithin’ generally means a composition of lipid constituents and surface-active compounds rather than a single chemical entity called phosphatidylcholine [13] that is obtained during the degumming process of crude vegetable oils—a crucial step in edible oil refining that removes phospholipids and other impurities. Three principal methods are commonly used to refine vegetable oils: enzymatic refining, physical refining, and chemical refining, with the latter being the most widely practiced at an industrial scale [14]. Within refining routes, three main degumming stage techniques are typically employed: water degumming, acid degumming, and enzymatic degumming. Among these, water degumming remains the most common and economically favorable method for producing commercial lecithin [15,16]. This process not only facilitates the recovery of phospholipids for lecithin production but also contributes to the purification and improved quality of the refined oil.

Water degumming is the first step in refining vegetable oils and aims to remove impurities—mostly phospholipids, commonly known as gums in the oil refining industry. The gums are formed when the oil absorbs water, causing certain phospholipids to hydrate and become insoluble in oil. They consist primarily of phospholipids, entrained oil, and small meal particles. The efficiency of water degumming depends largely on the hydrophilicity of the phospholipids. When non-hydratable phospholipids are present, acid degumming is applied by adding phosphoric, sulfuric, or citric acid to adjust the pH and dissociate metal–phospholipid complexes. The treated oil is then cooled, promoting the formation of a precipitate that can be separated centrifugally [17]. The separated precipitate or gums can subsequently be processed to recover phospholipids or lecithin.

In the next step, known as neutralization, a sodium hydroxide solution is added to the oil to convert free fatty acids into sodium salts (soaps). A slight excess of sodium hydroxide ensures the complete removal of free fatty acids. The resulting mixture is then separated in a centrifugal separator into neutralized oil and soapstock. After separation, the oil is washed with hot water to remove any residual soaps, then dried under a vacuum. The resulting soapstock is a complex mixture containing soaps, other removed impurities, excess sodium hydroxide, and some remaining oil, as complete phase separation is rarely achieved [18].

Lecithin is most easily obtained from water-degummed oil, but in some refining systems, water and acid degumming and neutralization are performed consecutively, without intermediate gum separation. This produces a mixed soapstock composed mainly of alkaline water (32–67%), fatty acids as soaps (10–28%), phospholipids (5–9%), and acylglycerols (12–13%) [19]. Such soapstock could be applied for lecithin isolation; this approach was carried out for soybean oil soapstock with the main objective to produce biodiesel from separated acid oil [20]. It is also well established that phosphatides could be separated from other lipids by dissolving the lipid material in an approximately six-fold volume of cold acetone, followed by filtration to remove the precipitated phosphatides [20,21].

Depending on the extraction technology, lecithin can be classified into four main types (see Table 1). Chemically modified lecithin is also available, where purified lecithin undergoes chemical reactions, thereby producing products with altered structure and applications [22–24].

Table 1. Types of lecithin depending on the production technology and use in food production.

Type of Lecithin	Production Technology	Changes in Composition and Properties	Technological Effects and Consequences	Sources
Standard (fluid/regular) lecithin	Lecithin is produced by hydrating vegetable oils; the separated gums are dried and homogenized with oil to produce a standardized liquid product	Natural mixture of phospholipids with triglycerides; high lipophilicity and solubility in the fat phase	Universal emulsifier and humidifier; it stabilizes dispersions, modulates viscosity and crystallization	[22–30]
Hydrolyzed lecithin (lysolecithin)	Industrially, enzymatic hydrolysis of phospholipids (usually with phospholipase A2) is applied, controlling the degree of hydrolysis according to the required properties	The proportion of lysophospholipids increases; hydrophilicity and surfactants in the aquatic environment increase; dissolution and dispersion in the aqueous phase are improved	Improved oil–water emulsification and stability; faster humidification, less dustiness	[23,25,26,28–35]
De-oiled lecithin	Neutral lipids are selectively extracted from standard lecithin using an organic solvent such as acetone, resulting in a powder or granules with a high content of acetone-insoluble substances	The phospholipid content usually exceeds 95 percent; neutral taste and color; better dispersion in the aquatic environment; more accurate dosing	Suitable as an emulsifier and moisturizing/dispersing agent for dry form; it promotes the formation of instantly soluble products and reduces particle aggregation	[23,25,26,28–30,36,37]
Fractionated lecithin	Selective fractionation, e.g., in alcohols, extracting phosphatidylcholine or anionic phospholipid-enriched fractions; available as both fat-free and liquid. Enzyme, ultrafiltration, or supercritical CO ₂ technologies are also applied to purify and concentrate phosphatidylcholine	Altered phospholipid profile; improved emulsibility and stability of suspensions. A high content of bioactive phospholipids is obtained while maintaining naturalness	Increased functional activity according to the fraction; more pronounced inhibition of crystallization and the formation of a finer texture. Suitable for functional foods and nutraceutical products	[23–26,30,35,38–40]

Source: authors' compilation based on the relevant literature.

A comparison of the types of lecithin reveals that the production technique determines changes in composition and properties, as well as how lecithin behaves in food systems. Standard (liquid) lecithin produced in the hydration/reflux process performs well in the fat phase and helps to retain emulsions. Enzymatically hydrolyzed lecithin, having more lysophospholipids, more easily “performs” in the aqueous phase and more efficiently forms oil and water emulsions. Fat-free lecithin with a higher proportion of phospholipids is usually more neutral in taste and color; therefore, it is convenient for dry form and instantly soluble products. Fractionated lecithin, in contrast, with individual fractions

being purposefully enriched, allows for precise regulation of emulsifiability, inhibition of crystallization, and the formation of a finer texture.

In practical terms, this means that when moving from standard to hydrolyzed, de-oiled, and fractionated variants of lecithin, its adaptability to water-phase systems and overall “accuracy” in technological operations increases. Accordingly, the information in Table 1 serves as a simple choice map: a type of lecithin could be selected for a particular formulation that is expected to improve emulsification, dispersion, and texture of the final product in the production of foods, where the process requires the use of one of the types of lecithin, e.g., in chocolate products, in which lecithin acts as an emulsifier, thereby improving texture and preventing separation of ingredients [41,42].

Lecithin improves the texture of the dough and also extends the shelf life, thus helping to retain moisture in flour confectionery [43,44]. In margarine and lubricants, in contrast, lecithin provides stability and prevents splashing by maintaining the dispersion of fine water droplets in the oil phase [45–48]. In soups and sauces, lecithin helps to maintain a homogeneous texture [45,48,49].

Understanding the types, extraction techniques, and applications of lecithin is crucial for its effective use in the food industry, thereby ensuring product quality and meeting consumer preferences.

2.2. Sources of Lecithin and a Comparison of Rapeseed, Soybean, and Sunflower Lecithins

A research study conducted by Topuz et al. (2021) revealed that lecithin can be produced from various oils (soybean, rapeseed, sunflower, corn, camelina, peanut), and it can be isolated from milk, egg yolk, and marine organisms [50]. The most widely used lecithin in the food industry is soybean lecithin, mainly due to its cost-effectiveness and excellent emulsifying properties [14,51,52]. According to the results of a research study conducted by Alhajj et al. (2020) [22], soybeans are also the most researched source of lecithin, followed by lecithin from sunflower seeds and egg yolk.

In the EU, GM-derived soybean lecithin is largely shaped by labeling rules that require disclosure for ingredients “produced from GMOs” [53,54]. Consequently, many producers either buy non-GMO soybeans or pivot to sunflower lecithin to avoid a GMO label on finished products [25,55–57]. Li and Guo (2016) [58] indicated that rapeseed, on the contrary, does not have GMO problem, thus making rapeseed oil one of the most promising feedstocks for lecithin production, and more phenolics exist in rapeseed than in the other oilseeds. Phenolics, on the one hand, are potent antioxidants, but on the other hand, they have a bitter taste, leading to an urgent need for investigation of the phenolic distribution in gums from different processes. This could benefit further commercialization of rapeseed lecithin production.

Canola and rapeseed belong to one of the most widespread and diverse cultivated plants known as the *Brassica* genus. Canola was created through traditional plant cross-breeding by removing two components found in the rapeseed plant: glucosinolates (less than 30 micromoles per gram) and erucic acid (less than 2%). Erucic acid was removed because it was believed to be inedible or toxic in high doses. The newly developed plant was renamed “canola,” a combination of “Canadian” and “oil” (or ola), to make this difference apparent [59]. Later, canola was genetically modified to withstand herbicides. Low-erucic-acid rapeseed (LEAR) varieties or 00-rapeseed varieties were developed in Europe later than canola and used in oil production. Rapeseed oil and canola may also be confused because they can be labeled incorrectly outside of Canada and the United States [60,61]. In the present research, the name “rapeseed” represents both canola and rapeseed, which is used for the production of food oil and lecithin.

A research study [62] showed that rapeseed lecithin liposomes not only have stable physicochemical properties but also help to boost antioxidant and anti-inflammatory effects. In practice, this means that rapeseed lecithin liposomes can protect and enhance the activity of valuable bioactive compounds, thus making them a useful tool for developing healthier functional foods and nutraceuticals.

Rapeseed lecithin is commonly used in the preparation of a wide range of food products, medications, and cosmetics. Rapeseed lecithin extends the shelf life of food, medication, and cosmetic products and also acts as an emulsifier. Rapeseed lecithin is used as a cholesterol reducer and to prevent digestive issues. Rapeseed lecithin is used to improve the immune system, particularly in people with diabetes [63]. Bende [64] indicated that lecithin can be used in the food industry as an emulsifier, stabilizer, texturizing agent, wetting agent, and food supplement. Food manufacturers can easily use rapeseed lecithin in their food products with very few adaptations. Rapeseed lecithin is used as an emulsification, stabilization, softening, wetting, blending, and flavoring agent and a neutral colorant in a wide range of food products due to its versatile functionality [63].

Sunflower lecithin is not produced in considerable amounts worldwide. This fact is mainly because of the low lecithin content (0.2–0.8%) of crude sunflower oil, compared with 2.9% for soybean, 1.9% for rapeseed, 2.4% for cottonseed, and 2.0–2.7% for corn oil (normalized at 70% of insolubles in acetone) [65]. Maxwell [51], Bende [64], and Guiotto et al. [66] indicated that sunflower lecithin has emerged as a popular alternative to soybean lecithin, particularly for consumers seeking non-GMO and allergen-free options. Lecithin modification under industrial conditions with adequate techniques of analysis could be useful for evaluating the potential applications of these sunflower byproducts to produce new emulsifiers. Guiotto et al. [66] presented a focused review of sunflower lecithin as a functionally equivalent—sometimes superior—alternative to soybean lecithin, examining its phospholipid profile, emulsifying performance, oxidative stability, and processing behavior in food emulsions. Guiotto highlights non-GMO and allergen advantages, “clean-label” alignment, and supply-chain considerations (cost and availability), outlining formulation adjustments stemming from its different phosphatidylcholine/inositol ratios compared with soybean.

3. Materials and Methods

Partially structured interviews were conducted as part of the research grant Evaluation of waste processing from rapeseed oil production (No. RTU-PA-2024/1-0038) during the period from January to June 2025. The interviews were developed and conducted in accordance with the approval of the RTU Research Ethics Committee (No. RTU-PEK-011/2024, Riga, 28/11/2024) following the principles of the Helsinki Declaration. The data were anonymized, and participation in the interviews was voluntary, with prior informed consent. The purpose of the interviews was to assess the potential for the use of rapeseed oil soapstock for lecithin production and the market prospects for such lecithin in the food industry. The results of the interviews made it possible to obtain both quantitative and qualitative assessments and insights into the experience, attitudes, and perspectives of the experts and companies. A total of 30 experts or entrepreneurs participated in the interviews, of which 8 were foreign experts—researchers or food technology professionals with international experience—and 22 were local representatives—Latvian food industry companies and experts. Of the foreign experts, eight were international specialists from Lithuania, representing research and professional experience within the regional Baltic food and oil processing sector.

The number of interview participants is consistent with methodological recommendations for qualitative and expert-based research. Previous studies indicate that in-depth

or semi-structured interviews with approximately 15–30 experts are sufficient to achieve data saturation, thematic completeness, and analytical robustness, particularly when participants are selected based on their professional expertise and relevance to the research topic [67–69].

The characteristics of the interview participants/experts are summarized in Table 2, which illustrates the diversity of competencies among the participants and the breadth of the professional environment represented. Such diversity is considered essential in expert studies addressing technological innovation and market potential, as it enhances the credibility and transferability of the findings [70].

Table 2. Characteristics of interview participants, %.

Role of the respondent:	
Food technologist	29.4
Food engineer	11.8
Food chemist	2.9
Food quality manager	8.8
Researcher/academic	23.5
Manager/management representative of a food manufacturing company	23.5
Work experience (practical/research) in the food production sector:	
Less than 1 year	20.0
1–3 years	13.3
4–7 years	23.3
More than 7 years	43.3
Current occupation:	
Research (food technology, functionality of ingredients, etc.)	34.4
Food production—additives (lecithin, emulsifiers, etc.)	3.1
Food production—baking and flour confectionery	40.6
Food production—beverages and juices	9.4
Research and food production at the same time	12.5

Source: authors' construction based on semi-structured expert interviews.

The experts/entrepreneurs were selected based on their expertise in the use of or research on lecithin in the food industry. The interviews were conducted in two languages: Latvian and English. The question groups were as follows:

- I. Technological efficiency;
- II. Economic viability;
- III. Environmental sustainability and technological benefits;
- IV. Market potential and competitiveness;
- V. Legal and quality aspects;
- VI. Investment potential and return prospects;
- VII. Product diversity and by-products;
- VIII. Professional profile.

Both descriptive (statistical) analysis and thematic (qualitative) analysis were performed. Quantitative data were analyzed with Microsoft Excel and the Statistical Package for the Social Sciences (SPSS version 23) (percentage distribution tables, cross-tabulation tables, etc.). Qualitative comments and open-ended responses were processed using Quali-

tative Data Analysis Software NVivo Version 14, performing a content analysis and coding by thematic category.

The response option “do not know/cannot evaluate” was excluded from the quantitative analysis because it did not reflect the respondents’ attitudes toward the phenomenon under assessment. Instead, this option indicates a lack of information or experience related to the specific issue. For example, 60% of the experts had not been involved in the lecithin production process, and 26.7% reported insufficient information regarding by-products.

The interpretation of such answers as neutral on the scale would not be methodologically justified, since they do not provide an assessment but instead indicate a lack of information or uncertainty. The high proportion of such responses confirmed that the use of rapeseed lecithin in food production was at an early stage of implementation, which was consistent with the diffusion process of innovation described by Dearing and Cox [71], i.e., a social process that occurs when innovation is disseminated in a particular societal system through communication channels over time.

The role of early adopters and science-driven innovation transfers is particularly important at this stage. Therefore, the inclusion of such answers for the calculation of average scores could artificially lower the results and reduce the comparability of data on lecithin types and industries.

Regarding the profiles of the experts as respondents, the largest share was made up of food technologists (29.4%) with more than 7 years of work experience (practical/research) in food production (43.3%). The current occupation of the respondents related to practical food processing—baking and flour confectionery products (40.6%). Therefore, the experts involved in the interviews provided both a practical and scientific view of the application of lecithin in the food industry. The expert profile was designed to obtain an interdisciplinary view of the potential for the use of rapeseed lecithin and to assess the early nature of the spread of technological innovations in the food industry.

Four batches of soapstock were used in a chemistry laboratory experiment, obtained from the chemical refining process of rapeseed oil production at BioVenta, Ltd., Ventspils, Latvia. Soapstock was stored at +4 °C and used within one week of receiving, or alternatively, soapstock was frozen and stored at −20 °C. Before use, soapstock was thawed if necessary and shaken to homogenize. Reagents were used as received: sulfuric acid (97%, Fluka, Buchs, Switzerland), *n*-hexane (95%, Chempur, Piekary Slaskie, Poland), and acetone (99%, Chempur). The dry residue of the soapstock samples was determined using a moisture analyzer, Precisa EM 120-HR (Precisa Gravimetrics AG, Dietikon, Switzerland).

The soapstock (100.00 g) was acidulated via drop-wise addition of concentrated sulfuric acid to obtain a pH of 3; the water was removed via centrifugation (10 min at 8000 rpm, Sigma 4K15 Sartorius (Sigma Laborzentrifugen GmbH, Osterode am Harz, Germany) centrifuge), and the residue was mixed with clean sand (mass 4 times exceeding the mass of the calculated dry residue of the soapstock sample) and dried at 103 °C. Soxhlet extraction [72] of soapstock with sand was performed for 25 cycles using *n*-hexane (200 mL) as a solvent. The evaporated Soxhlet extract was weighed and further separated by adding cooled acetone (5 °C) in a volume 5 times that of the extract mass. The sample was stirred and refrigerated for 1 h. Then, the sample was filtered. The acetone insoluble fraction (phospholipids) was dried in a Vaciotem-T (J.P.Selecta S.A, Barcelona, Spain) vacuum drying oven at 50 °C to a constant weight, but the mother liquor was evaporated to yield acid oil.

Thin layer chromatography (TLC) was performed using TLC Silica gel 60 F254 aluminum sheets, 20 × 20 cm (Merck KGaA, Darmstadt, Germany) and eluent composed of chloroform (99.8%, Merck), methanol (99.9%, Fisher Chemical, Loughborough, UK), acetic acid (99.8%, Lachner, Neratovice, Czech Republic), and distilled water in a volume

ratio of 25:4:4:1) [10]. Soy phosphatidylcholine (95%, Cayman Chemical Company, Ann Arbor, USA) and granulated de-oiled rapeseed lecithin (97%, My Lecithin, Neu Wulmstorf, Germany) were used as standards. TLC spots were visualized in iodine vapor.

4. Results

4.1. Assessment of the Technological Properties of Lecithin for Food Production

The experts rated the properties of the lecithin types (soybean, sunflower, rapeseed) (emulsification capacity, texture improvement, stabilization, and other significant technological impacts) for food production (flour confectionery, bread, oil and fat, and dairy products) on the following scale: “not effective”, “little effective”, “moderately effective”, “effective”, and “very effective”.

Figure 2 shows that the experts considered lecithins to be application-specific ingredients, with preferences shaped by the product matrix and processing demands rather than by emulsifying capacity alone [25,73]. Higher ratings for sunflower lecithin in flour confectionery and dairy likely reflect a pragmatic fit for “sensitive” products, where producers value sensory neutrality and market/label expectations while maintaining effective emulsification [16,74]. In bakery products, stronger evaluations for rapeseed and soy lecithin are consistent with evidence that lecithin-type emulsifiers can improve dough rheology and aeration and thereby support bread structure and texture under processing stresses [75,76]. In dairy systems, expert preferences also align with research highlighting phospholipid–protein and interfacial interactions that can enhance emulsion and heat stability [77]. Overall, because compositional and functional differences between soy, sunflower, and rapeseed lecithins are often modest, the “best” option is typically determined by application constraints (sensory impact, labeling, and process robustness) in addition to emulsification performance [25,78].

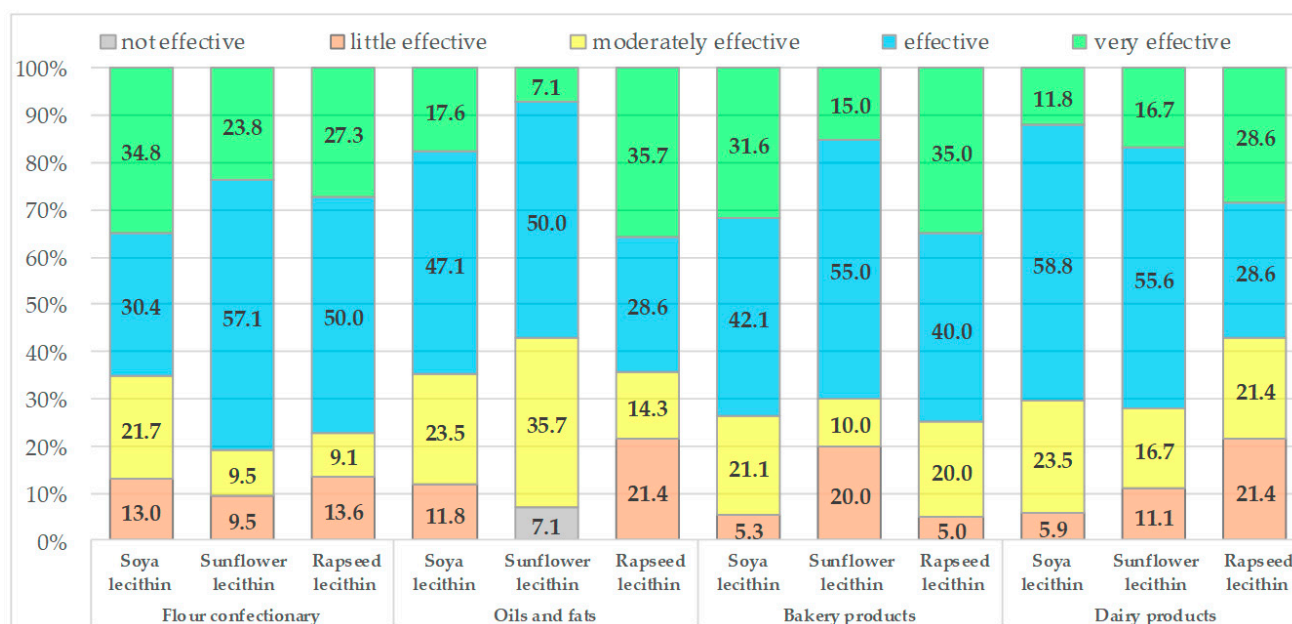


Figure 2. Ratings of the properties of lecithin for food production in terms of the suitability of the type of lecithin and the emulsification capacity. Source: authors’ construction based on the results of the expert interviews.

4.2. Texture Improvement, Stabilization, and Other Technological Impacts for Food Production

Figure 3 indicates that experts view texture improvement as matrix-dependent, not as a universal advantage of one lecithin type. Rapeseed lecithin’s stronger evaluation in flour confectionery is consistent with findings that lecithin origin/phospholipid

profile can alter viscosity and crystallization in fat-based systems, shaping perceived smoothness [9]. Preference for sunflower lecithin in oils and fats aligns with evidence that sunflower (especially PC-enriched) lecithins can enhance emulsion stability and droplet structuring [25,79,80]. Similar ratings in bakery products match research showing lecithins act mainly via dough/bread structure mechanisms, with effects often driven more by dosage and processing than botanical origin [75,76,81]. In dairy, soy lecithin's slight advantage is consistent with phospholipid–protein interfacial interactions that support emulsion/heat stability [77,78]. Overall, because differences among vegetable lecithins are often modest, selection typically depends on product requirements and processing constraints [16,73].

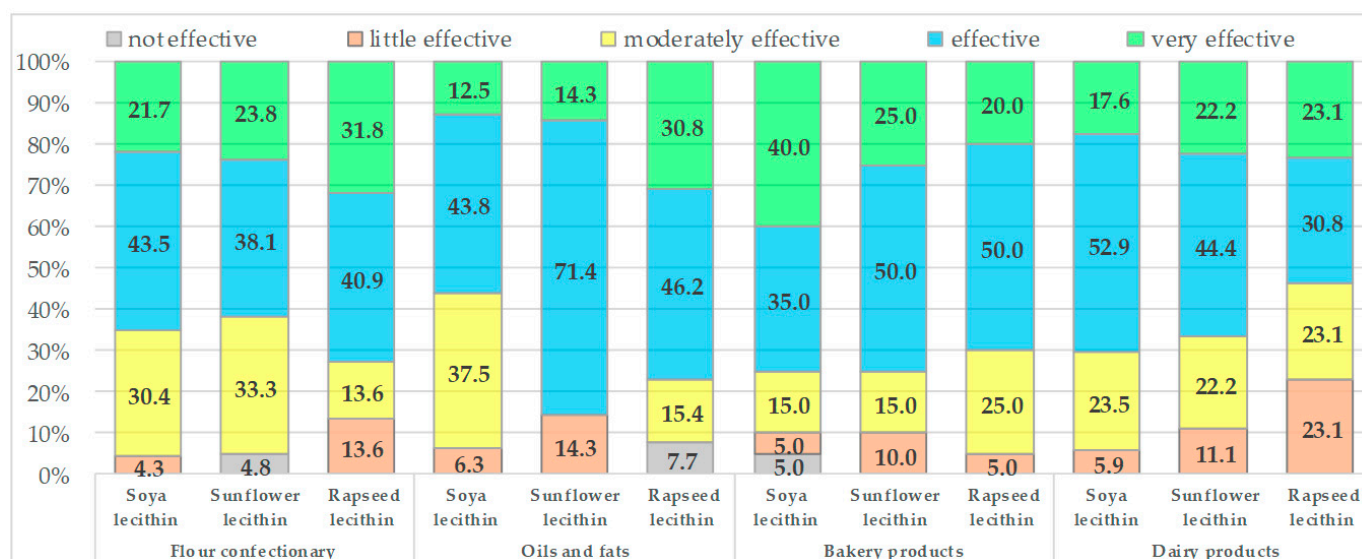


Figure 3. Ratings of the properties of lecithin required for food production in terms of the suitability of the type of lecithin and the capability to improve the texture. Source: authors' construction based on the results of expert interviews.

Figure 4 indicates that experts see stabilization as highly application- and matrix-dependent, rather than a fixed advantage of one lecithin source [16,25,73]. The preference for rapeseed lecithin in flour confectionery and in oils/fats is consistent with evidence from fat-rich systems showing that lecithin origin and phospholipid profile can influence interfacial film strength, viscosity/yield stress, and fat-crystallization behavior—all central to physical stability [9,16]. In bakery products, the higher assessment of soy lecithin aligns with studies showing that lecithin-type emulsifiers can stabilize structure mainly through dough/bread mechanisms (gluten/starch interactions and gas-cell stabilization), where performance often depends on processing tolerance and formulation tuning [75,76]. The stronger rating of sunflower lecithin for dairy is compatible with literature emphasizing the role of phospholipids at the milk/protein interface in improving emulsion and heat stability, which can be decisive in thermally processed dairy systems [77,78].

Figure 5 indicates that experts associate “other technological impacts” of lecithins mainly with process performance (e.g., flow/handling, dispersion, and robustness under processing); therefore, their preferences vary by product category [16,25,73]. In flour confectionery and oils/fats, the stronger preference for sunflower lecithin is consistent with its widespread use as a processing aid in fat-rich systems, where lecithin helps tune viscosity and yield stress and supports manufacturability; studies in chocolate-like matrices show that lecithin can substantially reduce viscosity via changes in particle–particle interactions, and sunflower lecithin can be substituted for soy in chocolate production with comparable functionality [82–84].

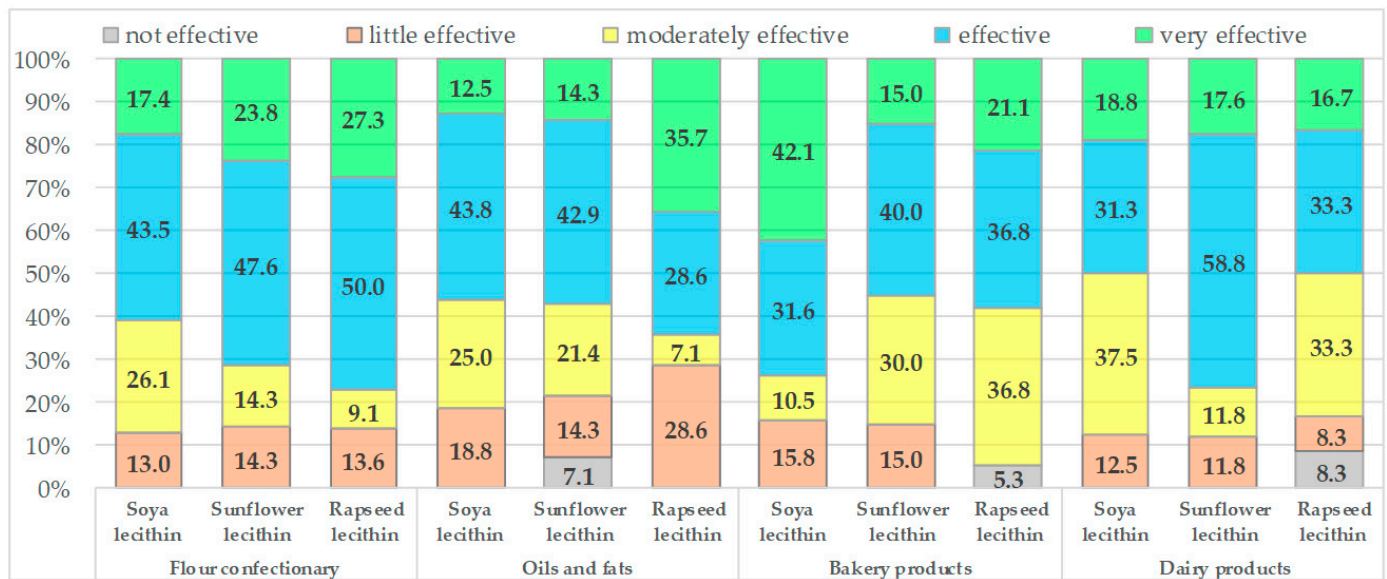


Figure 4. Ratings of lecithin properties for food production in terms of the suitability of the type of lecithin and the stabilization capacity. Source: authors' construction based on the results of expert interviews.

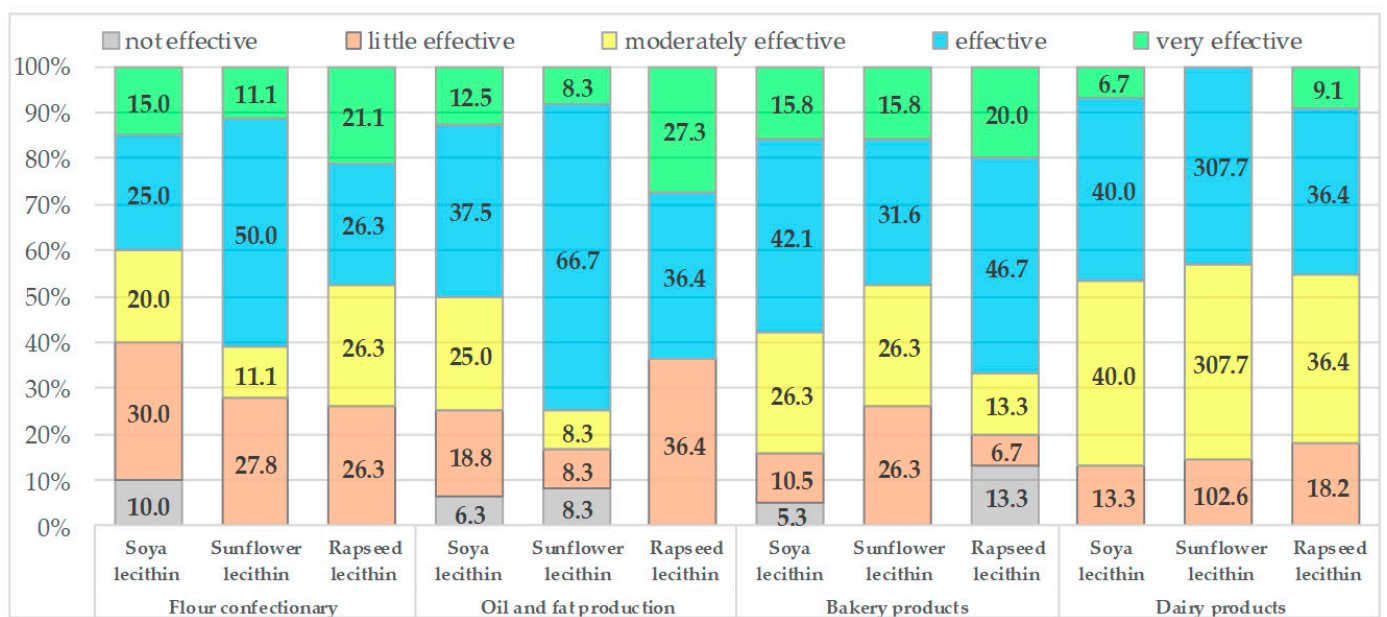


Figure 5. Ratings of lecithin properties for food production in terms of the suitability of the lecithin type and other relevant technological impacts. Source: authors' construction based on the results of expert interviews.

The higher rating for rapeseed lecithin in bakery products aligns with evidence that specific glycolipid fractions from different lecithin origins can improve crumb softness and grain via interfacial effects in the dough liquor [85], which can be perceived by practitioners as valuable “technological” benefits beyond emulsification. In dairy applications, the preference for sunflower lecithin is compatible with the general role of lecithins as wetting/instantizing aids and interfacial stabilizers—important for reconstitution and thermal processing—supported by work showing that lecithin addition can markedly improve the wettability of milk powders [78,86].

4.3. Overall Ratings of the Suitability of Lecithin for Food Production

The ratings of the properties of lecithin required for different food production segments in terms of the suitability of lecithin types, emulsification capacity, improvement of texture, stabilization, and other significant technological impacts on the food production process showed differences depending on the segment.

Table 3 highlights a clear “no single best lecithin” pattern: the highest expert ratings cluster by product matrix and technological goal, implying that lecithin choice is primarily driven by how its phospholipid profile performs under specific processing and formulation constraints [16,25,73]. In flour confectionery and dairy, the heatmap concentrates around sunflower lecithin for emulsification and broader processing effects, which is consistent with literature describing sunflower lecithin as a robust emulsifier/processing aid in fat-rich or sensory-sensitive systems where interfacial behavior and manufacturability (e.g., flow/handling) are critical [9,16]. Conversely, rapeseed lecithin stands out when texture and stabilization are prioritized—especially in confectionery and oils/fats—aligning with evidence that lecithin origin can alter rheology and crystallization-driven stability in fat-based matrices [9,25]. For bakery, the strongest cluster shifts toward soy lecithin (and, for some functions, sunflower), which matches studies showing that lecithin-type emulsifiers support crumb structure and softness mainly through dough/bread mechanisms (gluten/starch interactions and gas-cell stabilization), where practical performance is closely tied to processing tolerance [76,85]. Overall, Table 3 supports the broader scientific view that differences among vegetable lecithins are often subtle but technologically meaningful, so selection should be framed as “fit-for-purpose” rather than “best overall” [25,73].

Table 3. Heatmap of technological properties by product and by lecithin type.

	Emulsifying Power			Texture Improvement			Stabilization			Other Technological Properties		
	Soya lecithin	Sunflower lecithin	Rapeseed lecithin	Soya lecithin	Sunflower lecithin	Rapeseed lecithin	Soya lecithin	Sunflower lecithin	Rapeseed lecithin	Soya lecithin	Sunflower lecithin	Rapeseed lecithin
Flour confectionary	65.2	81.0	77.3	65.2	61.9	72.7	60.9	71.4	77.3	40.0	61.1	47.4
Oils and fats	64.7	57.1	64.3	56.3	85.7	76.9	56.3	57.1	64.3	50.0	75.0	63.6
Bakery products	73.7	70.0	70.0	75.0	75.0	70.0	73.7	55.0	57.9	57.9	47.4	66.7
Dairy products	70.6	72.2	57.1	70.6	66.7	53.8	50.0	76.5	50.0	46.7	61.5	45.5

Source: authors’ construction based on the results of expert interviews. , <50%, very low level, the property is insufficient for the specific application; , 50–59%, low level, possible quality or stability issues; , 60–69%, medium level, acceptable but not optimal; , 70–79%, high level, the property performs well and is technologically suitable; , ≥80%, very high level of technological properties, excellent performance for the specific product and lecithin type.

The heatmap indicates that sunflower and rapeseed lecithins generally perform better than soya lecithin, especially in texture improvement and stabilization. The best results appear in oils and fats, while bakery and confectionery products show mostly medium to high performance. Dairy products are more variable, highlighting the need for careful lecithin selection by application.

4.4. Rapeseed Lecithin Potential for Food Production

The experts rated the potential of using rapeseed lecithin for food production, considering its technological characteristics and compliance with a particular product category.

Figure 6 suggests that experts see the strongest near-term opportunity for rapeseed (canola) lecithin in oils/fats and bread/bakery, where functionality is closely tied to interfacial stabilization and process robustness. This aligns with research showing that canola lecithin’s polar-lipid composition can support stable oil-in-water emulsions, and that glycolipid fractions from rapeseed/sunflower/soy lecithins can deliver strong baking performance by improving crumb structure and softness [85,87].

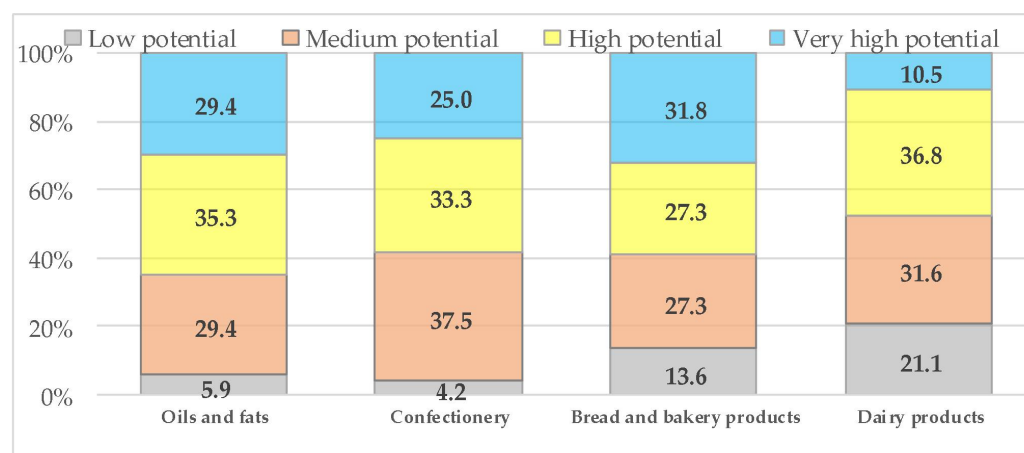


Figure 6. Potential for the use of rapeseed lecithin for food production, considering its technological characteristics and compliance with the specific product category. Source: authors’ construction based on the results of the expert interviews.

In contrast, the lower potential in dairy likely reflects the fact that successful use often depends on optimized phospholipid–protein interfacial interactions and thermal processing conditions—factors that can complicate direct substitution even when lecithins can improve wetting/instantization and emulsion stability [77,78,86]. Overall, this pattern matches broader reviews emphasizing that lecithin performance is application-driven and governed by composition–structure–function relationships rather than a single “best” botanical source [16,25,73].

Figure 7 illustrates that experts judge lecithin competitiveness as a trade-off across criteria, not a single performance ranking. Rapeseed lecithin is positioned as the strongest option regarding environmental sustainability, which fits the broader view that shifting to alternative vegetable lecithins and valorizing oil-refining side streams can strengthen sustainability narratives and circularity in lipid ingredients [25,73,88]. At the same time, experts view rapeseed as only mid-range regarding production-cost competitiveness, suggesting that scale, standardization, and supply-chain maturity still lag behind established soy-based solutions [16].

Sunflower lecithin appears as a balanced substitute, combining solid technological potential (quality/purity and emulsification) with a sustainability-friendly and “non-GMO” positioning that has helped sunflower lecithin expand in natural/organic markets where soy is sometimes avoided [16,83]. Soy lecithin, in contrast, benefits from incumbency advantages (cost familiarity and established use), which helps explain why experts continue to rate its technological usefulness well even when sustainability is not its primary differentiator [16,25].

A notable insight is the risk-perception mismatch around allergenicity. Experts attribute relatively high allergenic potential to rapeseed and sunflower lecithins, yet the literature more strongly documents allergy to the seeds (and, in rapeseed, allergenic proteins detectable in some oils), implying that any lecithin-related risk likely depends on residual protein carryover and needs targeted analytical/clinical confirmation [89,90]. This supports the practical conclusion from Figure 7 that wider adoption of rapeseed and sun-

flower lecithins may hinge as much on evidence-building and market confidence (e.g., compositional verification and risk communication) as on functionality itself.

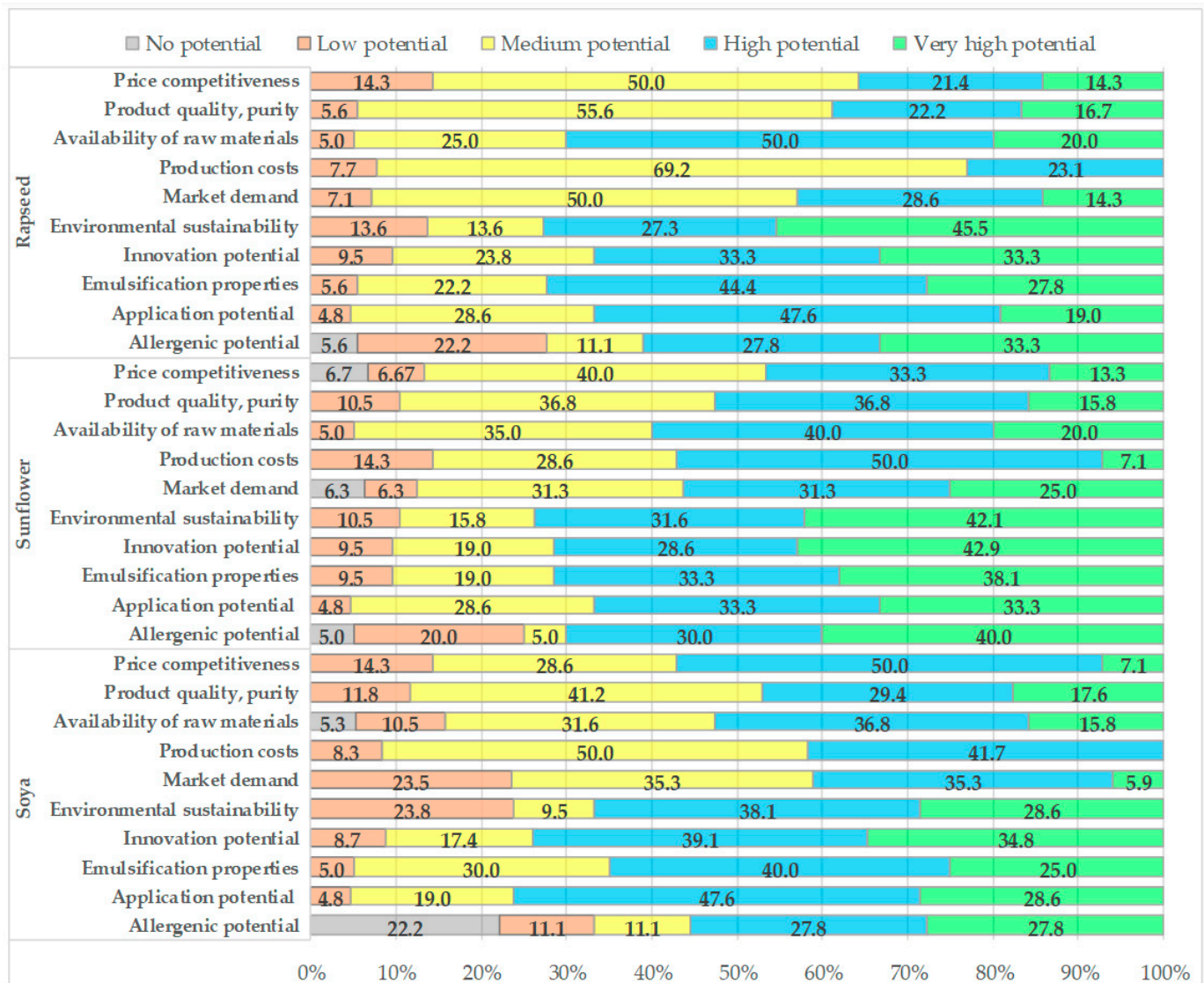


Figure 7. Experts' ratings of the competitiveness of lecithin produced from rapeseed oil soapstock compared with soybean and sunflower lecithins. Source: authors' construction based on the results of expert interviews.

4.5. Extraction of Phospholipids from Rapeseed Soapstock

Mixed water degumming and chemical refining rapeseed soapstock samples of four batches were analyzed in a chemistry laboratory to determine the dry residue and lipid contents (Table 4). The lipids were extracted using *n*-hexane in a Soxhlet apparatus to yield an extract composed of lecithin, free fatty acids, monoglycerides, diglycerides, triglycerides, and minor oil-soluble components. The extract was separated using cold acetone treatment in liquid acid oil and semi-solid de-oiled lecithin.

Table 4. Analysis of rapeseed soapstock used in the research: dry residue, Soxhlet extract using *n*-hexane, acid oil, and lecithin as yields from soapstock, % by mass. Calculated lecithin yield as a % of dry residue by mass.

Soapstock Batch No.	Dry Residue (%)	Soxhlet Extract (%)	Acid Oil (%)	Lecithin (%)	Lecithin Yield from Dry Residue (%)
1	22.1	13.5	8.2	5.2	23.5
2	20.7	15.2	11.9	3.2	15.5
3	43.6	39.9	36.3	2.7	6.2
4	15.5	13.1	11.2	1.4	9.0

Source: authors' calculations.

Rapeseed lecithin was recovered at a 1.4–5.2% yield from the mass of soapstock—a rapeseed oil refining waste. Other by-product acid oil was composed of free fatty acids, monoglycerides, diglycerides, triglycerides, and minor oil-soluble components in various proportions. The acid oil yield was 8.2–36.3% of the mass of soapstock.

Lecithin composition was analyzed using qualitative analysis based on a TLC plate comparing spots with two standards: pure phosphatidylcholine and commercial de-oiled rapeseed lecithin (Figure 8) using the method described by Haq and Chun [10].

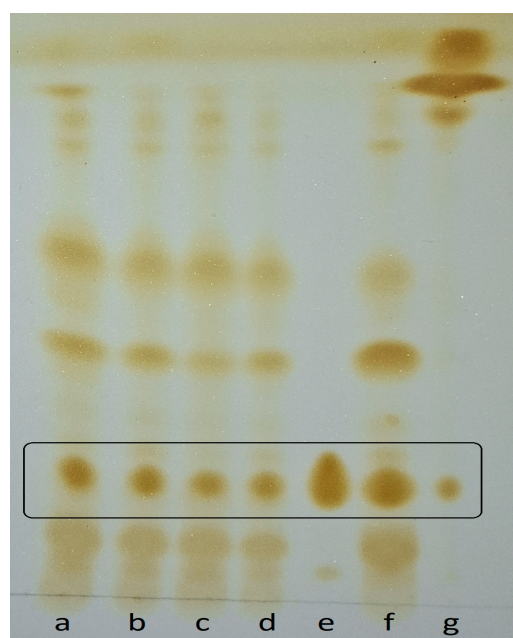


Figure 8. TLC analysis of lecithin quality on silica gel plates, eluent chloroform, methanol, acetic acid, and water in a volume ratio of 25:4:4:1. Samples are: a—lecithin from soapstock batch No 1; b—lecithin from soapstock batch No 2; c—lecithin from soapstock batch No 3; d—lecithin from soapstock batch No 4; e—phosphatidylcholine; f—commercial de-oiled rapeseed lecithin; g—acid oil. Source: created by the authors.

The purity of the obtained lecithin samples was confirmed by comparison with standards. Figure 8 shows that the lecithins from all four batches had the same spots on TLC as commercial rapeseed lecithin, with the strongest spot corresponding to phosphatidylcholine (squared in Figure 8). It is also clear that acid oil components (glycerides, fatty acids) were not present in the lecithin samples in significant quantities.

5. Discussion

5.1. Technological Advantages and Potential for the Introduction of Rapeseed Lecithin into the Food Production Industry

The experts' ratings of the three lecithins of plant origin overall confirmed that rapeseed lecithin is a full-fledged alternative to soybean and sunflower lecithins, yet its technological advantages are best manifested in certain food production segments. The results showed that the ratings of emulsification capacity, texture improvement, stabilization, and other significant technological impacts revealed no single "best" origin of lecithin across all product categories; rather, functional specialization emerged depending on the industry and technological purpose. The research results revealed that rapeseed lecithin has significant potential for food production, especially due to its functional properties, while the use of rapeseed oil soapstock for the production of lecithin demonstrates a practical possibility that could contribute to a more efficient use of resources. For several product groups, rapeseed lecithin received a high rating from the experts for its practical impact. For bakery products and flour confectionery, it showed a particularly good ability to stabilize the structure and create an even texture. The experts emphasized that rapeseed lecithin performed well both in water and fat systems and in dough products with low fat content. This means that rapeseed lecithin can also be suitable for recipes that require moisture retention and product uniformity. Such functionality could make rapeseed lecithin a valuable raw material for producers seeking locally sourced alternatives. The results of the interviews revealed that the use of rapeseed lecithin for food production is at an early stage of implementation. This is also indirectly evidenced by the significant proportion of "do not know/cannot evaluate" answers, which, as indicated in the methodology section, indicates not a neutral attitude, but a lack of information or uncertainty. Although this innovation is still in its early stages of implementation, its potential for strengthening local economies and resource efficiency is considerable. Educating food producers and improving access to information could become key factors in promoting the competitiveness of rapeseed lecithin both nationally and internationally. Compared to soybean and sunflower lecithins, rapeseed lecithin has a higher potential for sustainability and availability of raw materials, especially if it is obtained from oil production waste. This approach is in line with the principles of the circular economy, thereby reducing the amount of by-products, promoting the use of local resources, and strengthening national food security. The present research also had a number of limitations that must be taken into account when interpreting the results. First of all, the sample of experts included 30 respondents, a large segment of whom represented Latvian food production companies and specific segments (especially bakery products and flour confectionery). This means that the data obtained on the potential of rapeseed lecithin for other industries, e.g., milk or beverage production, might not be fully representative. Secondly, the laboratory experiment was conducted on four batches of soapstock from one manufacturer, which limited the generalization of the results to other technological lines. Additionally, there was variation in the quality of raw materials.

5.2. Functional Impacts of Lecithin on Food Production and Interpretation of the Results of Extracting Rapeseed Lecithin

The experts' ratings showed that the effectiveness of lecithin is specific to the food industry and depends on technological requirements:

- Rapeseed lecithin is highly rated for the production of bread (emulsifying ability, other technological impacts) and flour confectionery (texture improvement, stabilization);
- Soybean lecithin is especially effective for the production of oils and fats (emulsification) and dairy products (texture improvement);

- Sunflower lecithin was given the highest ratings for the production of dairy products and flour confectionery (emulsification, stabilization, other significant technological impacts).
- The research results confirmed that the structure, origin, and fatty acid composition of lecithin directly impact its functional properties and effectiveness in specific food matrices [24,64,91].

The experts gave high ratings to rapeseed lecithin for oil and fat production (64.7%) and bread production (59.1%), confirming its technological suitability and potential for these product groups. However, low market confidence and high production costs limit its wider use. This is in line with recent market research [52,87,91], which has found that rapeseed lecithin could become a competitive alternative if processing technologies are optimized and sustainability benefits are highlighted.

Compared to soybean and sunflower lecithins, rapeseed lecithin has higher potential for sustainability and availability of raw materials, especially if it is produced from oil production waste. This approach is in line with the principles of the circular economy, thereby reducing the amount of by-products, promoting the use of local resources, and strengthening national food security.

We have demonstrated with analytical methods that de-oiled lecithin can be obtained from rapeseed soapstock of complex composition, containing not only water, oil, and lecithin but also soaps, particles, and other impurities. Mixed water degumming and chemical refining of rapeseed soapstocks can vary significantly in composition, depending on rapeseed variety, growing conditions, and refining conditions. Additionally, soapstock can also be diluted with water to improve transportation within the production plant. The content of dry residue varied by almost three times across the tested samples; therefore, the yield of lecithin was expressed relative to both soapstock mass and dry residue mass, with the latter being more informative. Lecithin content in the dry residue of soapstock varied by almost four times, from 6.2% to 23.5%, and qualitative analysis of lecithin contents showed high similarity with commercial rapeseed lecithin. Lecithin recovery from rapeseed oil production waste is important to reduce waste amounts and diversify production.

6. Conclusions

The use of rapeseed lecithin in food production is at an early stage of implementation, which is characterized by limited practical experience and a high level of uncertainty among industry professionals. This is in line with the early stages of the innovation diffusion model, where cooperation between science and industry is important to promote innovation transfer.

The selected experts gave a cross-sectoral perspective, combining both academic and industrial expertise. Such a balance made it possible to assess the potential of rapeseed lecithin not only from a technological perspective but also from the perspective of economic and environmental sustainability.

Rapeseed lecithin involves wide, but industry-specific, technological suitability. It demonstrates high efficiency for flour confectionery and oils and fats in terms of stabilization and texture improvement, while for bread, it shows a pronounced emulsification capacity. This functional versatility confirms the potential of rapeseed lecithin as an alternative raw material for soybean and sunflower lecithins.

The market potential for rapeseed lecithin is high, especially in relation to oils, fats, and bakery products; however, its introduction is limited by higher production costs and lower market confidence compared to traditional sources of lecithin. Communicating the benefits of sustainability and improving technological efficiency can be important factors in developing this potential.

The utilization of by-products from rapeseed oil production for lecithin production contributes to the circular bioeconomy. This approach reduces industrial waste, enhances resource efficiency, and strengthens the sustainability of local food production by decreasing dependence on imported raw materials. Our results demonstrate that de-oiled lecithin can be recovered from rapeseed oil soapstock using *n*-hexane and acetone as solvents; however, further research is required to develop more sustainable extraction methods that fully align with circular bioeconomy principles for rapeseed oil processing. Rapeseed soapstock has great potential as a raw material for lecithin production in the food industry.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of Riga Technical University (protocol code was RTU-PEK-011/2024 and date of approval was 28 November 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: All datasets generated during the current study are available from the corresponding author upon reasonable request and in accordance with the Data Management Plan of the research grant.

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