

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(2): 281-294
www.biochemjournal.com
Received: 21-12-2025
Accepted: 25-01-2026

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Formulation, processing and storage stability of plant-based seed butter spreads: A comprehensive review

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i2Sd.7564>

Abstract

Growing consumer demand for plant-based, allergen-free, and clean-label foods has accelerated research on seed-based butter spreads as alternatives to dairy butter and peanut butter. Seed butters derived from sesame, pumpkin, sunflower, flaxseed, melon seed, walnut, soybean, and multi-seed blends offer favorable lipid profiles, high-quality plant proteins, dietary fiber, minerals, and bioactive compounds. However, these systems are colloidal suspensions prone to oil separation, oxidative deterioration, textural inconsistency, and limited shelf life. Drawing exclusively on recent experimental studies uploaded by the author, this review critically synthesizes advances in raw material selection, pretreatments (roasting, infrared roasting, sprouting), formulation strategies (sweeteners, stabilizers, emulsifiers), rheological behavior, and storage stability. Comparative result data are summarized to elucidate the influence of processing variables on texture, oxidative stability, and sensory acceptance. The review identifies knowledge gaps and outlines future research directions for scalable, consumer-acceptable, and sustainable plant-based seed butter spreads.

Keywords: Seed butter spreads, plant-based alternatives, rheological properties, oxidative stability, post-harvest processing

Introduction

Spreads are a broad category of food items that are vital to culinary creativity as well as staples in many diets. By utilizing cutting-edge components and processing techniques, they offer a useful means of promoting sustainability, lowering the risk of disease, and supporting health. They so occupy a promising position in the expanding market for wholesome, practical, and ecological goods (Županjac *et al.*, 2025) ^[59]. Butter spreads are semi-solid, food products with a wide application of spreads that are usually made as water-in-oil emulsions with fats as the continuous phase (Gojiya *et al.*, 2024) ^[19]. Although conventional butter and margarine have been used for a long time as essential parts of human diets, the whole scenario has changed due to reasons like dietary preferences, lactose intolerance, being vegan, and the awareness of heart problems which has led to the manufacture of substitutes for traditional butter spreads (Ghosh *et al.*, 2021) ^[17]. Both the terms "butter" and "spread" refer to somewhat different percentages of the primary ingredients. Nut butter must contain at least 90% nuts, according to the United States Department of Agriculture (USDA), whereas nut spread must contain at least 40% nuts scattered throughout the continuous oil phase. Similar plant-seed-based products might also be covered under the USDA regulation. For convenience, these plant-based butter/spread products are also referred to as "butter-like spreads," which is a loosely defined alternative term (He *et al.*, 2023). People who follow a vegan, vegetarian or even flexitarian diet are increasingly consuming plant-based foods as substitutes for meat and dairy products. Over the past five years, the number of people in Europe who identify with these eating habits has doubled (Alexi *et al.*, 2021) ^[4]. Consumers and the food business may view wild and plant edible foods like seeds, nuts, or roots as sustainable ingredients because of their beneficial micronutrients, bioactive compounds, and low toxicity. People from developing nations already include this in their subsistence diet (Chauhan *et al.*, 2018; Puşcaş *et al.*, 2024) ^[10, 40]. Over the past few decades, consumers' desire to incorporate nut and seed butters and spreads into healthy diets and lifestyles has grown significantly. This is because, unlike dairy butter products, these plant-based butter and

spread products are excellent sources of fiber, protein, vital fatty acids, and other nutrients without cholesterol. Usually, the nut/seed kernels are roasted before being ground (homogenized) with specific ingredients (such as sugar, salt, flavors, and/or emulsifiers) to create these plant-based butters or spreads. When comparing different options, plant-based spreads made from nuts and seeds like peanut butter, sesame paste, almond butter, and sunflower seed butter have gained more and more popularity throughout the years because they are rich in protein, contain unsaturated fatty acids and have a good amount of bioactive compounds (Chien & Pascall, 2021) ^[11]. On the other hand, the dilemma of having to switch from the more flavourful and less healthy butter to the healthier and less flavourful one is universal, and even nutritional butter spreads still faced technical problems like oil separation, oxidative rancidity, microorganism issues, and the development of undesirable texture during storage (Ibrahim *et al.*, 2025) ^[24]. These products are not just using agricultural by-products that have been little exploited but are also in line with sustainability and food waste valorisation goals (Sahin *et al.*, 2022) ^[44]. Besides formulation development, the applying of strict testing to butter spreads is needed to guarantee quality, stability, safety, and consumer acceptance.

2. Nutritional and compositional analysis of various seed materials: This section presents the nutritional and compositional characteristics of various seeds (as shown in fig.1) material, including peanut, sesame, sunflower, flaxseed, and others. Detailed descriptions highlight their protein, lipid, carbohydrate, and mineral content, providing a comparative understanding of their potential in the formulation of butters, spreads, and functional food products.

2.1 Peanut-based butter spread: Peanut butter is a perfect example of a superfood. The crop known as peanuts (*Arachis hypogaea* Linn) is a member of the Leguminosae sp. family of legumes (Janila *et al.*, 2016) ^[25]. It contains a variety of micronutrients, minerals, and numerous bioactive substances in addition to about 50% fats, 20% proteins, and 15% carbs. It provides high-quality proteins and fats at a reasonable price (Sithole *et al.*, 2022) ^[48]. Additionally, vitamin E, sterols, flavonoids, resveratrol, choline, and other compounds found in peanuts can improve cognition, slow down the process of ageing, and hydrate the skin. Additionally, they can lessen inflammation and cardiovascular illness (Wang *et al.*, 2005) ^[56]. It is a kind of nut spread that is frequently consumed in homes and widely used as an ingredient in the food industry is peanut butter, which is made from finely ground roasted peanuts. After being processed into peanut butter, peanuts maintain their high protein and unsaturated fatty acid (UFA) content, making them a great and reasonably priced source of lipids and protein. Peanut butter-based ready-to-use therapeutic food (RUTF) has been used in diet programs to address child malnutrition in developing nations because of its high nutritional value (Stephenson *et al.*, 2023) ^[50].

2.2 Sesame Seed-Based butter spread

The scientific name for sesame is *Sesamum indicum* L., and it is widely renowned for its flavor, rich oil content, and delicious nutty aroma (Myint *et al.*, 2020) ^[34]. Sesame seeds are used to make spreads, which have become much more

popular recently because of their remarkable shelf durability and high antioxidant content (Gojiya and Gohil, 2022; Koysuren *et al.*, 2021) ^[18, 29]. Sesame spread is an excellent energy source (651.43 k Cal/100 g) and a very healthy diet with approx 22.07% protein and 52.33% fat (Hou *et al.*, 2023; Ma *et al.*, 2022) ^[32]. Sesame paste has recently gained popularity among customers as a nutrient-dense condiment due to the rising desire for natural and healthful foods. However, consuming too much sesame paste can raise the risk of obesity and heart disease because it is a food heavy in fat and calories (Wang *et al.*, 2023) ^[55]. Sesame spread is a colloidal dispersion made from roasted and ground sesame seeds (Gorrepati *et al.*, 2015) ^[20]. For those looking to cut back on dairy while still getting a sufficient amount of micronutrients, including antioxidants, and trace elements, this plant-based spread is a wonderful substitute. Because of its proteins (rich in sulfur-containing amino acids like methionine and tryptophan), stable lipids (primarily oleic and linoleic acids), essential minerals, fibre, and vitamins, sesame paste has a significant nutritional value (Gojiya & Gohil, 2022; Jin *et al.*, 2022) ^[18, 27].

2.3 Sunflower Seed-based butter Spread

Sunflowers (*Helianthus annuus* L.) are becoming more and more prized for their functional and nutritive qualities in a variety of culinary uses and traditionally grown for their oil. Compared to conventional nut butter, sunflower seed butter is a healthy, allergy-free substitute (Vene *et al.*, 2025) ^[53]. Studies show that sunflower seeds have an average of 33.85% proteins, 65.42% lipids, and 2.73% ash, with the kernels containing the majority of these constituents (Petraru *et al.*, 2021) ^[38]. Sunflower seeds have drawn interest due to their use in plant-based spreads and butter. Nut and seed-based butter, known for its high nutritional content, including dietary fibre, protein, and vital fatty acids, was developed in response to market demand for plant-derived substitutes. These goods, which have practical and health-promoting advantages, are in line with the growing trend of vegetarian and vegan diets (Vene *et al.*, 2025) ^[53].

2.4 Flaxseed-based butter Spread: The flax plant (*Linum usitatissimum*) yields flaxseed, a plant-based substance that has grown in popularity because of its high nutritional profile such as Omega-3 fatty acids, lignans, dietary fiber, vitamins, and mineral materials. The flaxseed is 2.5 x 5.0 x 1.5 mm, in size, oval and flat, and has sharp extremities. Its colour varies from black to yellow (Freeman, 1995) ^[14]. Flaxseeds have a favourable n-6:n-3 fatty acid ratio of about 0.3:1 because they include 53% linolenic acid (ALA), 17% linoleic acid (LA), 19% oleic acid, 3% stearic acid, and 5% palmitic acid (Simopoulos, 2002; Basumatary *et al.*, 2024) ^[47]. Flaxseed's nutritional makeup includes 20.3% protein, 37.1% fat, 3s7.1% minerals, 4.8% crude fibre, 24.5% total dietary fibre, and 28.9% carbohydrate (Morris, 2007; Payne, 2000; Basumatary *et al.*, 2024) ^[33, 37]. The creation of a functional food product based on flaxseed butter is gaining traction on a global scale to promote healthier eating habits and meet the increasing demand for distinctive functional food options. Flaxseed intake is still low compared to other dietary sources, despite increased knowledge of its potential benefits. Creating a functional food product based on flaxseed butter is a creative and useful way to close this gap and optimise the use of flaxseed (Basumatary *et al.*, 2024) ^[8].

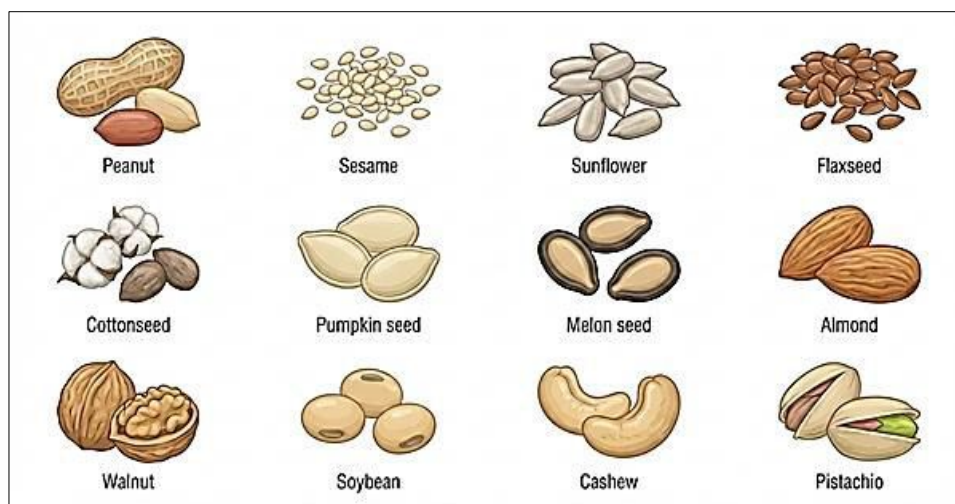


Fig 1: Various seed materials for butter spread production

2.5 Cottonseed-based butter spread

A whole cottonseed has roughly 27% hulls, 8% linters, 4% waste material, 45% meals, and 16% crude oil; its dehulled meat, or kernel, has roughly 37% crude oil, 41% protein, 10% acid detergent fibre, and other mineral and carbohydrate elements. Additionally, cottonseed has been revealed to have bioactive chemicals and peptides that have special health benefits (He *et al.*, 2023). Because gossypol, a toxic polyphenolic compound, is present in its pigment glands, traditional cottonseed and its meal derivatives are unsuitable for human eating; this variety of cottonseed is also known as glanded cottonseed (Kumar *et al.*, 2022; He *et al.*, 2023) [21, 30]. Complicated procedures are needed to reduce the gossypol content of glanded (Gd) cottonseed products below 450 ppm as required by the US Food and Drug Administration's food standard, or 600 ppm of the permissible limit as per the United Nations Food and Agriculture Organization and the World Health Organization, to encourage the use of cottonseed products in the food industry. As an alternative, attempts have been undertaken to create cotton types that are glandless and have a very low gossypol concentration. The use of cottonseed products in the food business is particularly promising because of their low gossypol concentrations (He *et al.*, 2023) [21].

2.6 Pumpkin seed-based butter spread

The edible kernels of the pumpkin fruit are called pumpkin seeds. The seeds have a typical oval shape with a conical apex and are semi-flat. Its kernels have a white outer shell, an olive green colour, a sweet, buttery texture, and a nutty flavour. Pepita is used as a snack and in savoury and dessert recipes. Additionally, the seeds are concentrated sources of numerous vitamins, minerals, and antioxidants that are good for your health. Numerous proteins and peptides are produced by the seeds of plants in the Cucurbitaceae family. In addition to being low in fat and calories, pumpkin seeds are high in antioxidants, vitamins such as carotenoids and tocopherols, and minerals (Amin and Thakur 2013) [5]. Pumpkin seeds are a good source of edible protein (320g/kg) and oil (450g/kg) for human consumption and animal feed. It is an excellent source for strengthening the immune system since it contains significant concentrations of minerals like magnesium, phosphorus, manganese, iron, copper, zinc, and vitamins E and K (Radočaj *et al.*, 2011;

Das *et al.*, 2021) [12, 41]. Spread made from pumpkin seeds is an excellent substitute for other recipes for nut/seed butter, often. It is a smooth mixture of pumpkin seeds. It is made by smoothly processing pumpkin seeds, just as any other nut or seed like peanut butter (Das *et al.*, 2021) [12].

2.7 Melon seed-based butter spread

Melon (*Cucumis melo* L.), a creamy, whitish oval fruit, is a member of the Cucurbitaceae family. Melon seeds include 41.6%-44.5% fat, 34.4%-39.8% proteins, 4.5%-8.5% crude fibre, 8.2%-12.7% carbs, 3.7%-4.2% soluble sugars, and 4.6%-5.1% minerals. Tocopherols, phospholipids, and sterols are among the lipid fractions. The two main fatty acids found in lipids were oleic acid (24.8%-25.6%) and linoleic acid (51.1%-58.5%). The three main triglycerides were palmitoyl dilinolein (PLL) (14.9%-22.3%), oleoyl dilinolein (OLL) (31.0%-34.0%), and trilinolein (LLL) (31.3%-32.2%) (Zeb 2016; Sahin *et al.*, 2022) [44]. Melon seeds' high fat content (51.46%) and high protein content (26.05%) make them a viable substitute raw material for spreadable butter. Therefore, melon seed butter, which was high in protein, may be utilized in baked goods, fruit dip sauce, confectionary filling, ice cream, desserts, and drinks to boost the nutritional value of a variety of dishes (Sahin *et al.*, 2022) [44].

2.8 Almond-based butter spread

Almond (*Prunus dulcis*) butter contains substantially more fibre, calcium, and potassium compared to peanut butter or sunflower seed butter (Gorrepati *et al.*, 2015) [20]. Fatty acids, dietary fibre, micronutrients, and phytochemicals are just a few of the many advantageous nutritional and functional substances found in almonds as a whole food. Almonds have been shown to have a cholesterol-lowering effect in an increasing number of human nutritional researches (Fulgoni *et al.*, 2002; Hyson *et al.*, 2002; Spiller *et al.*, 2003) [15, 23, 49]. Almonds' proteins include an arginine-rich amino acid profile that is believed to be cardioprotective, and they are high in nine fatty acids, which have been shown to have positive effects on lipoprotein profiles. They are also excellent providers of phytochemicals including plant sterols and dietary fibre, which have been demonstrated to lower the incidence of coronary heart disease (Spiller *et al.*, 2003) [49]. High-density lipoprotein cholesterol (HDL) increased modestly with

almond butter but did not significantly change with raw or roasted almonds. High levels of HDL cholesterol lower the risk of heart disease and are the beneficial cholesterol that elevates the bloodstream (Gorrepati *et al.*, 2015) ^[20].

2.9 Walnut-based butter spread

The walnut (*Juglans regia* L.) is valuable economically, nutritionally, and medicinally. All around the world, but especially in Asia, North America, South America, southern Europe, South Africa, Australia, and New Zealand, it is widely grown. The growth of walnut cultivars is significantly influenced by climate and altitude (Zhu *et al.*, 2024) ^[58]. Walnuts are rich in lipids (58.3-65.2%), proteins (15.1-17.4%), carbs (13.9-19.4%), cellulose (1.5-2%), and minerals (1.7-2%) (Jiao *et al.*, 2023) ^[26]. Walnut butter, which is made by grinding walnut kernels, is a type of highly processed walnut food that has a unique flavour profile and significant nutritional benefits. On the other hand, butter-type food products' durability has long been a major worry. Foods like butter are particularly vulnerable to autoxidation-related degradation. Additionally, other macromolecules, including proteins and carbohydrates, can be attacked by free radicals produced by lipid oxidation. As a result, the food's flavour, aroma, colour, and nutritional value deteriorate (Tang *et al.*, 2025) ^[52]. Medium-chain triglycerides (MCT), diacylglycerol (DG), and conjugated linoleic acid glycerides (CLA) are examples of functional lipids (FL) that can lower fat energy consumption without altering eating behaviours. As a result, they could serve as substitutes for high-fat foods, lower blood fat and visceral fat, and, to some extent, prevent obesity, heart disease, fatty liver, and other illnesses. The flavour, taste, and processing appropriateness of low-calorie functional fats and oils could also meet people's needs. Thus, substituting functional lipids for the oil in conventional walnut butter offers potential benefits for both human health and walnut butter quality (Xie *et al.*, 2025) ^[57].

2.10 Soybean butter spread

A great source of high-quality protein, soybeans (*Glycine max* L.) contains 40 g/100 g of high-quality protein that contains all the key amino acids required for growth (Gorrepati *et al.*, 2015) ^[20]. It has a lot of necessary amino acids that our bodies can't produce. Numerous health advantages, such as the prevention of cancer, cardiovascular disease, and menopause, are offered by soy beans and soy-based foods (Barret 2006) ^[7]. One serving tablespoon of soybean butter saved 5.5 g of fat and 85 calories compared to peanut butter, indicating that soybean butter has less total and saturated fat than peanut butter (Abd-Elsattar & Abdel-Haleem, 2016) ^[1]. Technological treatments have been used in an attempt to increase soy products' sensory and technological aspects as well as their nutritional worth. It has been suggested that sprouting before butter production will yield benefits related to the sprouting process. A series of metabolic changes brought on by sprouting boosts the nutritional value of legumes and reduces antinutritional elements like phytic acid and trypsin inhibitor (TI) by 60%. During sprouting, lipoxygenase I, II, and III are broken down, which stops volatile chemicals from developing and improves flavour and odour ratings. In comparison to other protein sources, soy butter delivers all the advantages of soybeans, including a well-balanced protein that may supply all the essential amino acids needed for adults and children,

as well as a comparatively high amount of lysine. Additionally, oleic, linoleic, and linolenic fatty acids, which account for 85% of the oil, are abundant. Additionally, it is a good source of minerals, B vitamins, folic acid, and isoflavones, all of which are thought to inhibit the onset of osteoporosis, heart disease, and cancer (Abd-Elsattar & Abdel-Haleem, 2016) ^[1].

2.11 Cashew-based butter spread

The cashew (*Anacardium occidentale*, L.) is a significant edible nut. The main industrialised product of the nut is its kernel, which makes it valuable. The kernels contain 575 kcal of calories per 100 g and are rich in lipids (42.6%), proteins (20.0%), and fibre (5.9%). 3.96 g of sugar, 2.82 mg of vitamin B, 37 mg of calcium, 292 mg of magnesium, 593 mg of phosphorus, and 660 mg of potassium are also found in 100 g of edible cashew (Chandrasekara & Shahidi 2011) ^[9]. An edible nut that is high in proteins and fats is the cashew nut kernel. It creates two cotyledons and is somewhat bent back on itself, making about 20-25% of the nut's weight (Gadani *et al.*, 2017) ^[16]. The cashew kernel is a valuable delicacy that enhances the flavour and look of confections, including cakes, pastries, candies, and chocolates. Additionally, the nut can be turned into cashew nut butter, nut milk, kuli-kuli snacks, powder, and paste. Dry roasted cashew nuts are ground into a paste to make cashew nut butter. When compared to groundnut slurry spread, cashew nut slurry butter produces a more spreadable product (Orisa *et al.*, 2023) ^[36].

2.12 Pistachio butter spread

A popular and nutritious tree nut is the pistachio nut (*Pistacia vera* L.). Split pistachios are eaten as salted or roasted nut snacks. Pistachio items like pistachio halva, pistachio milk, pistachio butter, and pistachio nut spread can be made using the unsplit form (Shakerardekani *et al.*, 2013) ^[46]. In addition to protein, carbs, dietary fibre, and vital micronutrients like calcium, potassium, phosphorus, iron, and copper, it is high in unsaturated fatty acids like oleic and linoleic acids, which are well-known for their health advantages. Pistachios also include phenolic chemicals and vitamins that strengthen their antioxidant qualities. Carotenoids, flavonoids, and phytoestrogens are examples of natural antioxidants that improve cardiovascular health and may lower the risk of chronic diseases by lowering oxidative stress and inflammation (Khadiji *et al.*, 2025). According to Taghizadeh & Razavi (2009) ^[28, 51], pistachio butter is a semi-solid paste that acts as a non-Newtonian pseudoplastic under yield stress. It is created from ground and roasted pistachio kernels with the addition of suitable flavorants and sweeteners.

3. Stabilisers, emulsifier and sweeteners

3.1 Stabilisers and emulsifiers

To illustrate the functional roles of different stabilising and Emulsifying agents used in formulations, Table 1 and Table 2 presents an overview of common stabilisers and emulsifiers and their effects on product properties. The major purposes of stabilizers and emulsifiers in butter and spread formulations made from seeds and nuts are to prevent oil separation, preserve textural consistency, and enhance spreadability while being stored. Chien and Pascall (2021) ^[11] assessed the effects of hydrogenated rapeseed oil (HRO) and palm kernel oil (PKO) as stabilizing agents in

multi-seed butter compositions with pumpkin, sesame, and sunflower seeds. In comparison to the control sample, the scientists found that adding 2-3% HRO greatly decreased oil separation, improved texture, and prevented excessive hardening during storage. Although PKO had an impact on hardness as well, it had a less noticeable stabilising effect

than HRO (Chien & Pascall, 2021) ^[11]. These results show that the kind of stabiliser has a major impact on the texture and physical stability of seed butter products. Additionally, it has been shown that emulsifiers affect the sensory qualities and structural

Table 1: Stabilisers and their effects

Butter/Spread type	Stabiliser used	Effect on butter/spread	References
Multi-seed butter	Hydrogenated rapeseed oil (2-3%)	Significantly reduced oil separation and prevented excessive hardening during storage	Chien & Pascall, 2021 ^[11]
Multi-seed butter	Palm kernel oil	Influenced hardness; stabilising effect weaker than hydrogenated rapeseed oil	Chien & Pascall, 2021 ^[11]
Pistachio spread	Red palm oil	Affected viscoelastic behavior and spreadability	Shakerardekani <i>et al.</i> , 2013 ^[46]
Peanut butter	Rice bran wax	Reduced oil separation and improved oxidative stability during storage	Praveen <i>et al.</i> , 2024 ^[39]
Cottonseed butter/spread	Stabiliser (general additive)	Texture and oil separation governed mainly by oil content rather than stabiliser	He <i>et al.</i> , 2023
Soybean butter	Carboxymethyl cellulose (CMC)	Contributed to acceptable texture and spreadability across treatments	Abd-Elsattar & Abdel-Haleem, 2016 ^[1]
Sesame spread	Hydrogenated vegetable oil (6.2%)	Limited initial oil separation; separation increased with storage time and temperature	Gojiya <i>et al.</i> , 2024 ^[19]
Flaxseed butter	Palm oil/groundnut oil	Oils incorporated as fat sources; no stabilising effect experimentally evaluated	Basumatary <i>et al.</i> , 2024 ^[9]

Table 2: Emulsifiers and their effects

Butter/Spread type	Emulsifier used	Effect on butter/spread	References
Pumpkin seed spread	Soy lecithin	Significantly affected work of shear and color; acceptable spreadability maintained	Saydam <i>et al.</i> , 2025 ^[44]
Pistachio spread	Soy protein isolate (SPI)	Influenced texture and sensory attributes; formulations without SPI showed higher acceptability	Shakerardekani <i>et al.</i> , 2013 ^[46]
Soybean butter	Soy proteins (inherent/added)	Affected hardness, adhesiveness, and sensory acceptability	Abd-Elsattar & Abdel-Haleem, 2016 ^[1]
Sunflower seed butter	Commercial emulsifiers (mono-/diglycerides, proprietary blends)	Different emulsifiers produced significant differences in hardness and spreadability	Vene <i>et al.</i> , 2025 ^[53]
Cashew nut butter	Soy lecithin (2%)	Enabled formation of stable butter with acceptable physicochemical, microbiological, and sensory quality	Lima <i>et al.</i> , 2012 ^[31]

Integrity of seed-based spreads. Saydam *et al.* (2025) ^[44] employed soy lecithin as an emulsifier in pumpkin seed spread formulations and discovered that its concentration had a substantial impact on colour and work of shear characteristics. According to the study, lecithin-containing formulations within the studied range retained adequate spreadability and structural consistency, which helped them gain favoured customer approval. In a similar vein, Rajput and Singh (2023) ^[42] showed satisfactory physicochemical stability and sensory quality throughout storage without excessive oil separation when they included emulsifying components in multi-seed functional spreads. These findings suggest that emulsifiers help composite seed spreads retain homogeneity and a texture that consumers find acceptable. However, some research found that processing parameters and oil content were more important than stabilisers or emulsifiers. He *et al.* (2023) found that total oil content was the primary determinant of texture, stiffness, and oil separation in cottonseed butter/spread products, with stabilising additives playing a minor role. Similarly, red palm oil affected spreadability and viscoelastic behaviour in pistachio spread, but no other emulsifier was shown to be a major factor in stability (Shakerardekani *et al.*, 2013) ^[46]. While their impact may be less pronounced in high-oil

systems where fat content determines structure, research studies generally confirm that stabilizers and emulsifiers are essential for lowering oil separation and enhancing texture in multi-seed and composite formulations.

3.2 Sweeteners: In seed- and nut-based butter and spread formulations, sweeteners play a crucial role in determining textural and storage qualities, as summarised in Table 3. Sahin *et al.* (2022) ^[44] showed that the choice of sweetener has a substantial impact on shear work and hardness in melon seed butter. Compared to samples containing glucose, formulations including 10% sucrose or 10% honey showed significantly lower hardness values and reduced work of shear, indicating greater spreadability. On the other hand, butter made with 20% glucose had the greatest work of shear and hardness values, making it tougher and less spreadable (Sahin *et al.*, 2022) ^[44]. These results demonstrate that the kind of sweetener has a direct impact on the rheological properties of melon seed butter. It has also been demonstrated that customer preferences and the textural quality of pumpkin seed spreads are impacted by natural sweeteners like honey. Formulations with 12.5% honey received the greatest consumer like scores while keeping acceptable instrumental texture values, according to

Saydam *et al.* (2025) ^[44]. The study found that moderate honey integration produced preferred product quality and that honey amount had a substantial impact on both sensory and instrumental responses.

Table 3: Sweeteners used in butter/spreads and their effects on butters/spreads

Butter/Spread type	Sweetener used	Effect on butter/spread	References
Melon seed butter	Sucrose (10-20%)	10% sucrose resulted in significantly lower hardness and work of shear, indicating improved spreadability compared with higher sugar levels	Sahin <i>et al.</i> , 2022 ^[44]
Melon seed butter	Honey (10-20%)	Honey-containing samples showed lower hardness values and smoother texture than glucose-based formulations	Sahin <i>et al.</i> , 2022 ^[44]
Melon seed butter	Glucose	20% glucose produced the highest hardness and work of shear values, leading to firmer and less spreadable butter	Sahin <i>et al.</i> , 2022 ^[44]
Pumpkin seed spread	Honey (10-15%)	Formulation containing 12.5% honey achieved the highest consumer preference and acceptable textural properties	Saydam <i>et al.</i> , 2025 ^[45]
Pistachio spread	Icing sugar	Improved overall sensory acceptability; excessive sugar increased work of shear and reduced spreadability	Shakerardekani <i>et al.</i> , 2013 ^[46]
Sesame seed spread	Jaggery	Increased viscosity and adhesiveness; oil separation and peroxide value increased during storage, especially at ambient temperature	Gojiya <i>et al.</i> , 2024 ^[19]
Peanut butter	Refined sugar	Sugar used as standard ingredient; study did not report significant textural changes attributable to sugar addition	Praveen <i>et al.</i> , 2024 ^[39]
Cottonseed butter/spread	Sugar	Sugar listed as formulation additive; texture and stability primarily governed by oil content rather than sweetener	He <i>et al.</i> , 2023
Multi-seed functional spread	Sugar	Sweetened spreads showed acceptable sensory quality; no adverse physicochemical effects attributed to sugar	Rajput & Singh, 2023 ^[42]
Flaxseed butter	Sugar	Sugar used to improve palatability; study focused on nutritional composition with no negative texture effects reported	Basumatary <i>et al.</i> , 2024 ^[9]

Similar to this, icing sugar was utilized as the main sweetener in pistachio spread formulations, which enhanced sensory appeal. However, excessive sugar levels increased work of shear, which adversely affected spreadability, according to Shakerardekani *et al.* (2013) ^[46]. These findings suggest that although sweeteners improve acceptance, their concentration needs to be carefully adjusted. Due to their nutritional significance, traditional sweeteners like jaggery have been studied for sesame-based spreads. According to Gojiya *et al.* (2024) ^[19], jaggery-based sesame spread showed increasing oil separation, peroxide value, acid value, and increased viscosity and adhesiveness after storage, especially in ambient settings. The authors linked variations in storage stability to the temperature and physicochemical properties of jaggery. Studies on peanut butter and cottonseed butter, on the other hand, mostly used sugar as a standard formulation ingredient without mentioning sugar as a significant factor affecting texture or structural stability; instead, oil content and storage conditions were found to be the main factors influencing product quality (He *et al.*, 2023; Praveen *et al.*, 2024) ^[39]. Overall, the reviewed research shows that sweeteners primarily affect the sensory quality of butter and spread products as well as their texture and storage behavior in some formulations.

4. Processing technologies and their effects

4.1 Pretreatments and Roasting: To demonstrate the impact of different processing methods on product quality, Table 5 presents an overview of key processing technologies and their effects on the physicochemical and sensory attributes of butters and spreads. Seed processing usually consists of a series of operations including cleaning, roasting, blanching, cooking, sprouting, and frying before the eventual production of butter. Among them, roasting is regarded as one of the most important and critical unit operations, as it not only decreases the amount of antinutritional factors and microbial load through Maillard reactions but also enhances flavour, colour, and aroma (Abd-Elstarr& Abdel-Haleem, 2016; Gojiya *et al.*, 2024) ^[11, 19]. Controlled roasting, for example, has been shown through studies on soybean and sesame butter to enhance sensory quality and textural properties while making products more acceptable to consumers (Abd-Elstarr& Abdel-Haleem, 2016) ^[11]. Sprouting and cooking have also been incorporated, especially in the case of spreads made from legumes and soybeans, to enhance protein digestibility and inhibit the action of the enzyme that produces off-flavors (Abd-Elstarr& Abdel-Haleem, 2016). Sahin *et al.* (2022) ^[1, 44] indicated that the roasting of melon seeds before grinding was a

Table 4: Processing technologies and their effects on the physicochemical and sensory attributes of butters and spreads

Seed/Nut	Key pre-treatments	Roasting method	Temperature (°C)	Time	Application in butter/spread	Reference
Cashew	Cleaning, shelling, peeling, drying, grading	Oil	140	3-4 min	Smooth cashew butter	Lima <i>et al.</i> , 2012 ^[31]
Peanut	Cleaning, shelling, blanching/peeling	Hot-air	160	30 min	Peanut butter	Sithole <i>et al.</i> , 2022; Ogunsanwo <i>et al.</i> , 2005 ^[35, 48]
Walnut	Cleaning, shelling, kernel sorting	Hot-air	180	15 min	Walnut butter	Tang <i>et al.</i> , 2025 ^[52]
Pistachio	Cleaning, shelling, peeling	Hot-air	134 ± 1	30 min	Pistachio spread	Shakerardekani <i>et al.</i> , 2013 ^[46]
Sunflower seed	Dehulling, drying, antioxidant	Hot-air	180	40 min	Sunflower seed butter	Vene <i>et al.</i> , 2025 ^[53]

	pre-treatment					
Sesame seed	Cleaning, dehulling, drying	Hot-air	147	27.30 min	Sesame paste/spread	Gojiya <i>et al.</i> , 2023
Pumpkin seed	Cleaning, dehulling, drying	Hot-air	160	2 min	Pumpkin seed spread	Saydam <i>et al.</i> , 2025; Rajput& Singh, 2023 [42, 45]
Melon seed	Cleaning, dehulling, drying	Hot-air	120	10 min	Melon seed butter	Sahin <i>et al.</i> , 2022 [44]
Soybean	Soaking, blanching/sprouting, drying	Hot-air	160	90 min	Soy butter	Agrahar-Murugkar <i>et al.</i> , 2013b [2]
Cottonseed	Dehulling, drying, particle size control	Hot-air	140	30 min	Cottonseed butter/spread	He <i>et al.</i> , 2023
Flaxseed	Cleaning, drying	Hot-air	180	8 min	Flexseed butter spread	Basumatary <i>et al.</i> , 2024 [9]

-determining factor in obtaining appropriate hardness and shear work values for melon seed butter, thus stressing the role of pre-treatment in ascertaining the quality of the final product. Cleaning and sorting were consistently reported as the first steps to remove foreign matter and defective kernels before butter or spread preparation in all of the uploaded studies on cashew, almond, peanut, walnut, sesame, sunflower, pumpkin, melon, soybean, cottonseed, and flaxseed (Lima *et al.*, 2012; Shakerardekani *et al.*, 2013; Das *et al.*, 2021; He *et al.*, 2023; Basumatary *et al.*, 2024) [9, 12, 31, 46]. To guarantee consistent grinding and repeatable product quality, several procedures were required.

For oilseeds (sunflower, sesame, pumpkin, melon, cottonseed, flaxseed) and nuts (cashew, walnut, pistachio, almond, peanut), shelling or dehulling has been specifically reported, providing access to edible kernels and increasing process efficiency during grinding (Shakerardekani *et al.*, 2013; Gojiya *et al.*, 2023; Sahin *et al.*, 2022; He *et al.*, 2023) [44, 46]. Kernel peeling was found to enhance color and sensory quality in cashew butter production (Lima *et al.*, 2012) [31]. Although exact moisture targets were not always stated, moisture reduction through drying before grinding or roasting was regularly used across numerous investigations (Lima *et al.*, 2012; Das *et al.*, 2021; Sahin *et al.*, 2022; Basumatary *et al.*, 2024) [12, 31, 44]. Soaking, blanching, sprouting, and heating were specifically examined as pre-treatments to alter texture, rheology, and sensory acceptance in studies on soybean butter (Agrahar-Murugkar *et al.*, 2013; AbdElsattar & Abdel-Haleem, 2016) [3]. Particle size management during grinding, as opposed to intricate pre-treatments, was highlighted as a critical factor influencing butter firmness, oil separation, and spreadability in research on cottonseed and flaxseed butter (He *et al.*, 2023; Basumatary *et al.*, 2024) [9].

4.2 Grinding and Milling

Grinding and milling are essential processing steps in the preparation of nut- and seed-based butters and spreads. These operations reduce particle size, enhance homogeneity, and influence the final texture and mouthfeel of the product. Lima *et al.* (2012) [31] ground roasted kernels in a food processor for five minutes with sugar, salt, and soy lecithin. The authors used kernel grades and sensory texture descriptors to indirectly evaluate the impact of particle size, but they did not describe particle size in numerical terms. After grinding, butter made from butts, splits, and pieces (B, S, and P) had a smoother texture, greater shine, and less

graininess, suggesting a finer and more consistent particle distribution. On the other hand, butter composed of granules, special small pieces, and small pieces (G, SP and SSP) showed increased thickness, consistency, and visual graininess, indicating the presence of coarser particles. These textural characteristics were deemed undesirable since creaminess and smoothness are essential nut butter quality criteria. The authors came to the conclusion that cashew nut butter of higher sensory quality is produced by kernel grades that yield finer effective particle sizes (Lima *et al.*, 2012). He *et al.* (2023) [31] used a high-speed blender to ground roasted glandless cottonseed kernels, which were then homogenized by hand. Using laser scattering analysis, particle size was quantitatively quantified and revealed a trimodal distribution between ~0.1 and 350 µm, with the majority of particles (~61-66%) in the medium size range of ~4.5-10 µm. SEM examination verified that increasing the total oil content (36-57%) improved smoother particle shape and marginally decreased average particle size. Higher oil concentrations, however, also led to more oil separation during storage, which suggests less structural stability. He *et al.* (2023) conclude that, although excessive oil caused instability despite smaller particle size, an intermediate oil concentration (47-50%) achieved a balance among fine particle size, smooth texture, and adequate stability. Sahin *et al.* (2022) [44] used a rigorous multi-stage grinding process to turn melon seeds into spreadable butter. To encourage oil release from the seed matrix, roasted melon seeds were first pulverized for about an hour using a double-knife blender running at 30,000 rpm. After that, the ground material was refined in a melanger for almost three hours while lecithin and sunflower oil were added, until the required smooth and spreadable consistency was reached. To guarantee even dispersion, the butter was reblended during the sweetening process once it had reached this consistency. The authors stressed that grinding is an essential process for melon seed butter's oil release, consistency development, and ultimate spreadability. Praveen *et al.* (2024) [39] ground roasted, dehulled peanuts while adding 5% sugar and 1% salt. The grinding process was then maintained for 30 minutes. Microstructural analysis (such as laser diffraction or microscopy) and particle size distribution are not reported in the study. As a result, no direct evaluation of the impact of grinding on particle size was conducted. Shakerardekani *et al.* (2013) [46] used a Supermass Colloider (Masuko, Japan) running at 1000 rpm with a stone clearance of 20 µm to grind roasted pistachio kernels. This grinding operation

produced a fine pistachio paste, reflecting a desired particle size in the micrometer range ($\sim 20 \mu\text{m}$ clearance). The increased spreadability and rheological behavior of the finished product were indicative of the fine grinding, even though the authors did not provide an analytical report on the particle size distribution. Higher work of shear values indicated coarser or poorly lubricated structures, while spreads with lower work of shear ($0\text{--}11 \text{ kg}\cdot\text{s}$), due to finer particle structure and greater oil dispersion after grinding, were assessed as sensory acceptable, according to instrumental measures. According to Shakerardekani *et al.* (2013) [46], obtaining a smooth texture, good spreadability, and customer acceptability in pistachio spreads required fine grinding with a tiny stone gap. Saydam *et al.* (2025) [45] prepared pumpkin seed spread by first coarsely grinding raw pumpkin seeds in a bar-style blender. During early trials, the study specifically changed the shape of pumpkin seeds (finely ground vs. coarsely ground). According to sensory evaluations, spreads made with finely ground, unroasted pumpkin seeds had better texture, spreadability, look, and overall appeal than spreads made with coarser grinding, which produced a less palatable texture. The authors also observed that the ground seed material's particle size affected oil separation and texture, which was consistent with variations in spreadability and work of shear as determined by instrumental measurements. Thus, finer grinding was associated with smoother texture, increased spreadability, and higher consumer approval, while coarse particles negatively affected product quality.

5. Rheological behaviour

The complex rheological behavior of butter and spread products made from nuts and oilseeds is greatly impacted by their multiphase structure, which is made up of finely ground solid particles scattered across a continuous lipid phase. The majority of plant-based spreads and butters exhibit non-Newtonian, shear-thinning (pseudoplastic) properties with a noticeable yield stress, suggesting that a little stress is needed to start flow. This behavior, which has been extensively documented for pistachio, sesame, cottonseed, melon, pumpkin, sunflower, and walnut butters, is technologically advantageous because it enables the product to spread easily under applied shear during consumption while remaining stable at rest (Shakerardekani *et al.*, 2013; Gojiya *et al.*, 2024; Sahin *et al.*, 2022) [19, 44, 46]. Dynamic oscillatory rheological studies further illustrate that nut and seed butters often show weak gel-like viscoelastic behavior, defined by larger storage modulus (G') than loss modulus (G'') throughout a broad frequency range. This suggests that the creation of a structured particle-oil network is reflected in the dominance of elastic components over viscous ones. These viscoelastic properties have been shown in systems such as walnut butter, pistachio spread, sesame seed spread, and pumpkin seed spread, where the network's strength is dependent on processing parameters, oil composition, and particle size (Shakerardekani *et al.*, 2013; Saydam *et al.*, 2025; Xie *et al.*, 2025) [45, 46, 57]. Rheological factors including apparent viscosity, hardness, yield stress, and work of shear are all significantly influenced by oil content. Due to the dilution of solid particle interactions, increasing oil content often lowers viscosity and textural strength; however, too much oil weakens the structural network and raises the possibility of oil separation during storage. This inverse link between

oil concentration and rheological strength has been well proven in cottonseed butter, where increasing oil levels led to exponential declines in firmness and spread resistance (He *et al.*, 2023). Similar patterns have been noted in spreads made from melon and pumpkin seeds, where formulations with a moderate fat content had better rheological and sensory qualities than those with a low or high fat content (Sahin *et al.*, 2022; Saydam *et al.*, 2025) [44, 45]. Thixotropy, which represents time-dependent structural breakdown under shear and partial recovery when shear is removed, is another crucial rheological characteristic of butter and spread systems. Sesame, pistachio, and walnut butters have been shown to exhibit pronounced thixotropic behavior, which indicates reversible disruption of the internal network after spreading. It has been demonstrated that adding functional lipids such as diacylglycerols or conjugated linoleic acid glycerides enhances thixotropic recovery and elasticity, producing rheological behavior that is remarkably similar to that of commercial walnut butter (Xie *et al.*, 2025) [57]. Overall, the interaction of oil concentration, particle size distribution, lipid type, and processing conditions determines the rheological behavior of butter and spread products. In order to attain suitable shear-thinning behavior, yield stress, viscoelasticity, and thixotropy all of which collectively impact spreadability, stability, and consumer acceptance of plant-based butter and spread products it is crucial to optimize these variables (He *et al.*, 2023; Shakerardekani *et al.*, 2013; Vene *et al.*, 2025) [46, 53].

6. Storage Stability: The storage stability of spread and butter products is primarily determined by temperature and time, as these factors have a significant impact on lipid oxidation, oil separation, textural integrity, and microbiological safety. Storage studies of jaggery-based sesame spread under room temperature conditions ($24 \pm 4^\circ\text{C}$, 40-50% RH) and refrigerated conditions (8°C , 17-20% RH) for 90 days showed a progressive increase in microbiological counts, peroxide value, acid value, and oil separation with storage time. While refrigerated storage successfully reduced oxidative and physicochemical changes, maintaining sensory and rheological qualities for a longer period of time, quality deterioration was much higher at ambient temperature (Gojiya *et al.*, 2024) [19]. A six-month storage study of peanut butter enhanced with curcuminoid-removed turmeric oleoresin (CROTO) was conducted at 27°C and 65% relative humidity (ambient storage) and 37°C and 95% relative humidity (accelerated storage). The findings showed that, in comparison to the control sample, CROTO oil and curcuminoids considerably slowed oxidative rancidity and decreased oil separation. Peanut butter samples were safe for six months at 27°C and roughly four months at 37°C , according to microbiological analysis, demonstrating how temperature affects shelf life. Additionally, by lowering oxygen-induced lipid oxidation, oxygen-scavenger film packing improved storage stability even more (Praveen *et al.*, 2024) [39].

Cottonseed butter and spread products were chilled at 4°C before oxidative stability was assessed in order to examine the impact of oil content on storage stability. According to the study, even in low-temperature storage, increasing oil content led to increased oil separation and decreased oxidative stability. This result highlights how formulation parameters, especially total oil content, have a significant

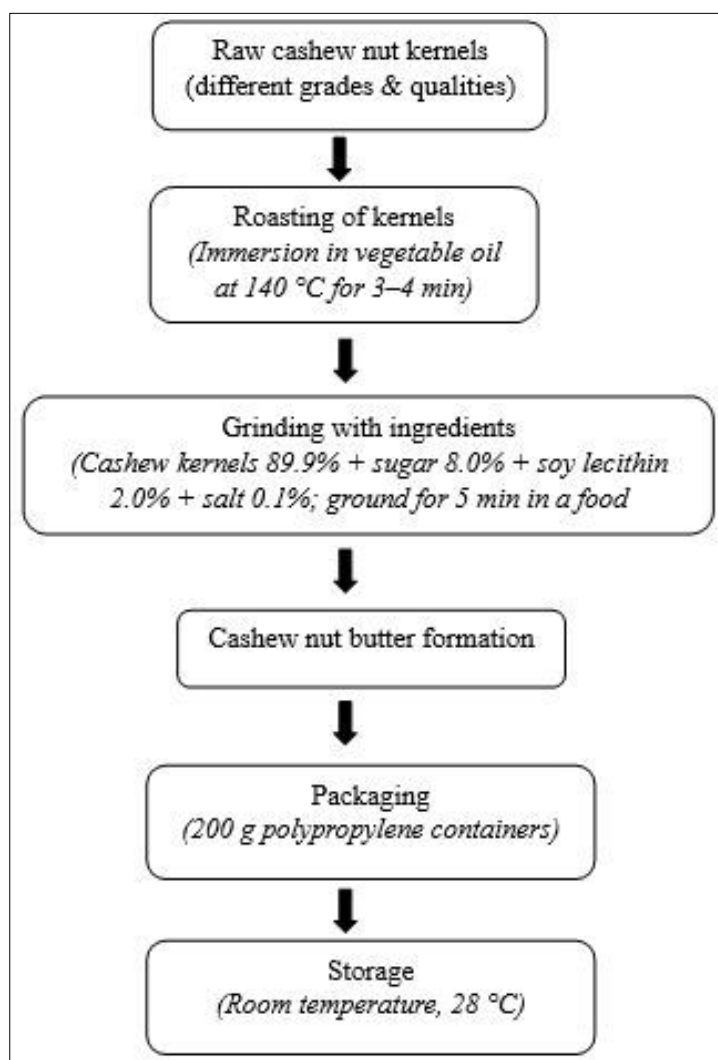
impact on storage behaviour in addition to temperature (He *et al.*, 2023). Peanut butter enhanced with date paste and lecithin was evaluated for storage stability over a 60-day period at 25 and 45 degrees Celsius. Emulsion stability, antioxidant activity, cohesiveness, and overall sensory acceptability all decreased as storage temperature and duration increased. However, adding date paste to the peanut butter matrix increased oil retention and reduced quality deterioration in comparison to the control, especially at 25 °C, suggesting better shelf stability at moderate storage temperatures (Safaei *et al.*, 2024) [43].

7. Processing steps in formulation of butter spread

As depicted in the prepared flow chart, the common processing steps for formulating butter spreads generally commence with seed preparation predominantly roasting to develop flavor and color in substrates like peanuts, cashews, and pistachios (Praveen *et al.*, 2024; Lima *et al.*, 2012; Shakerardekani *et al.*, 2013) [31, 39, 46], though specific

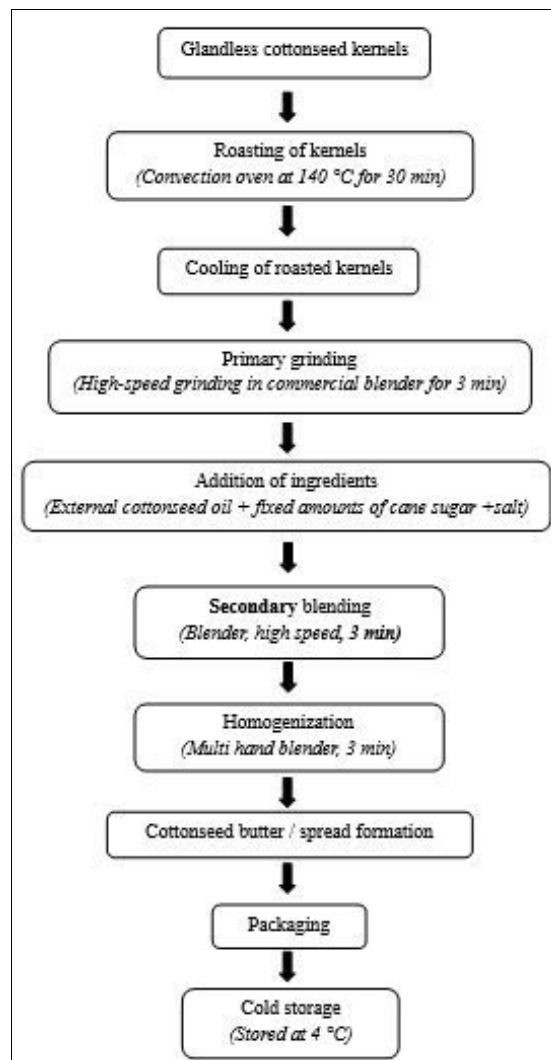
pretreatments like sprouting or cooking for soybeans (Abd-Elstattar and Abdel-Haleem, 2016) [11] or the use of raw seeds for pumpkin spreads (Saydam *et al.*, 2025) are also utilized. This phase is followed by grinding or homogenization, where the structural network is defined; studies indicate that sequential grinding or extended melanging is critical for particle size reduction in melon seed (Sahin *et al.*, 2022) [44, 45] and cottonseed butters (He *et al.*, 2023). The process culminates in the strategic blending of functional ingredients to optimize rheology and stability, such as adding oil for spreadability in cottonseed (He *et al.*, 2023), incorporating stabilizers like lecithin, guar gum, or protein isolates in cashew, sesame, and walnut formulations (Lima *et al.*, 2012; Gojiya *et al.*, 2023; Tang *et al.*, 2025) [31, 52], and balancing sweeteners ranging from sugar and honey to jaggery to achieve the desired sensory profile (Vene *et al.*, 2025; Basumatary *et al.*, 2024) [9, 53].

Processing Flow Chart for Cashew Nut Butter

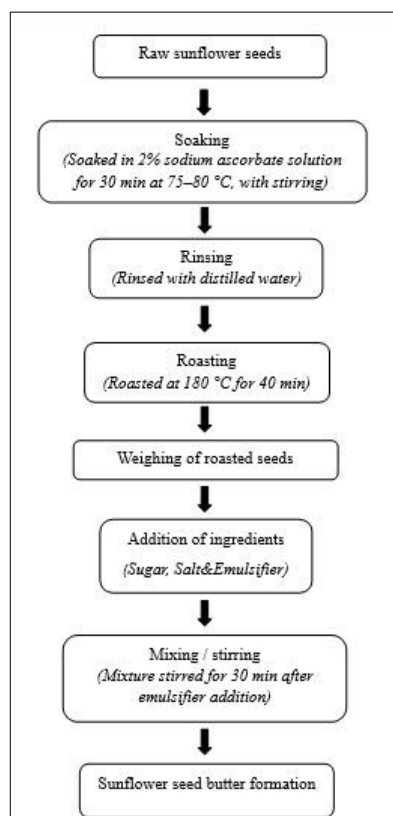
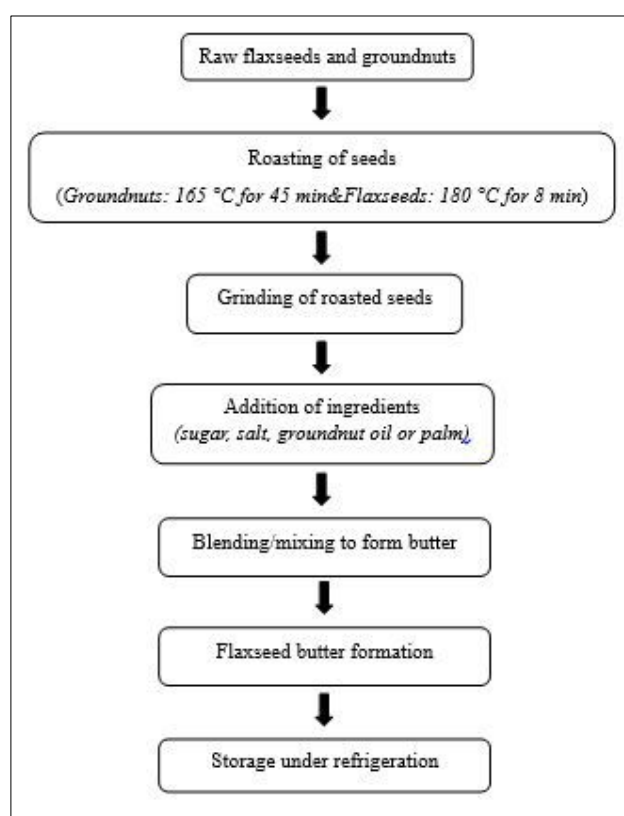
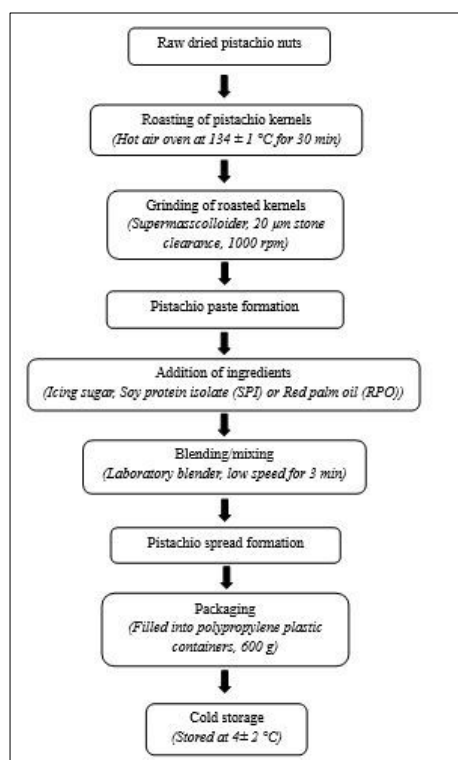
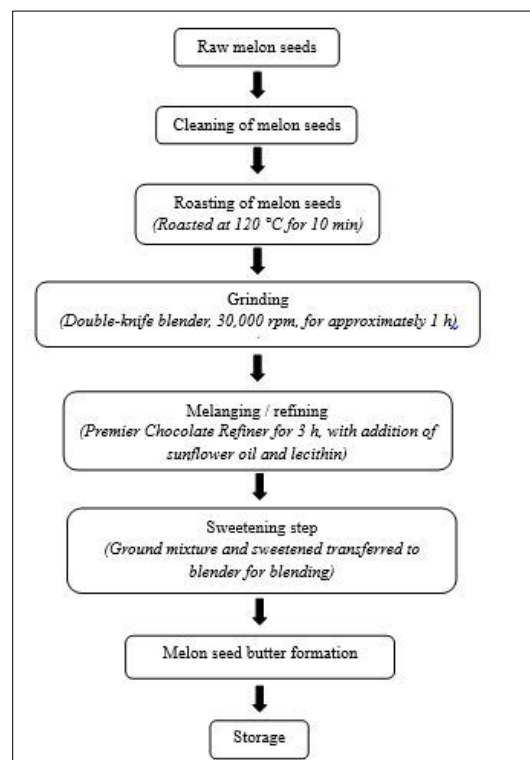


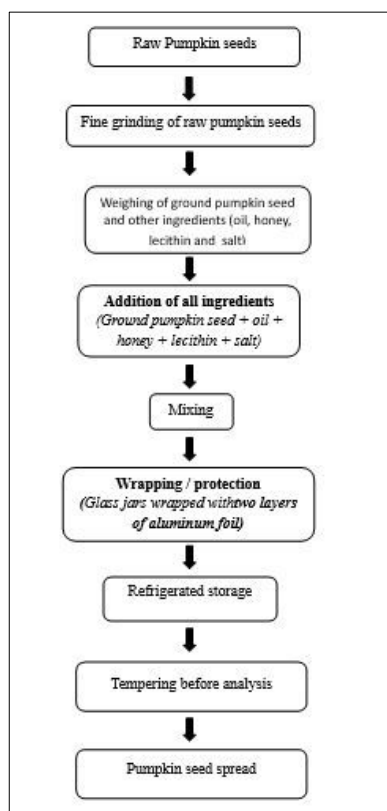
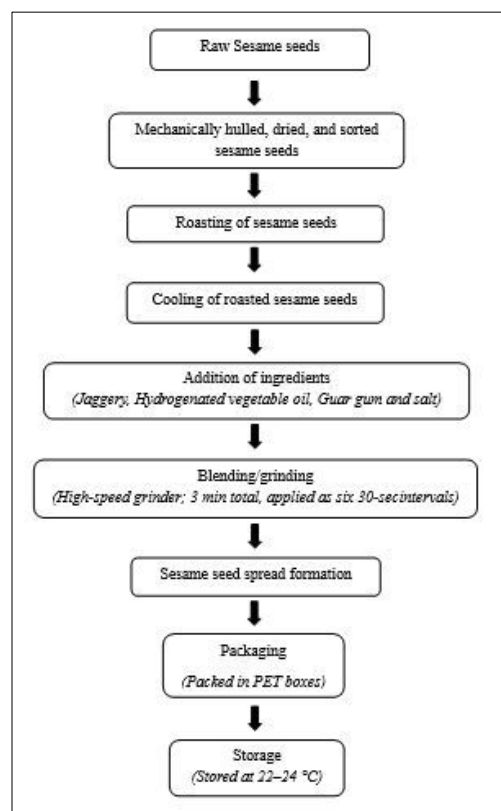
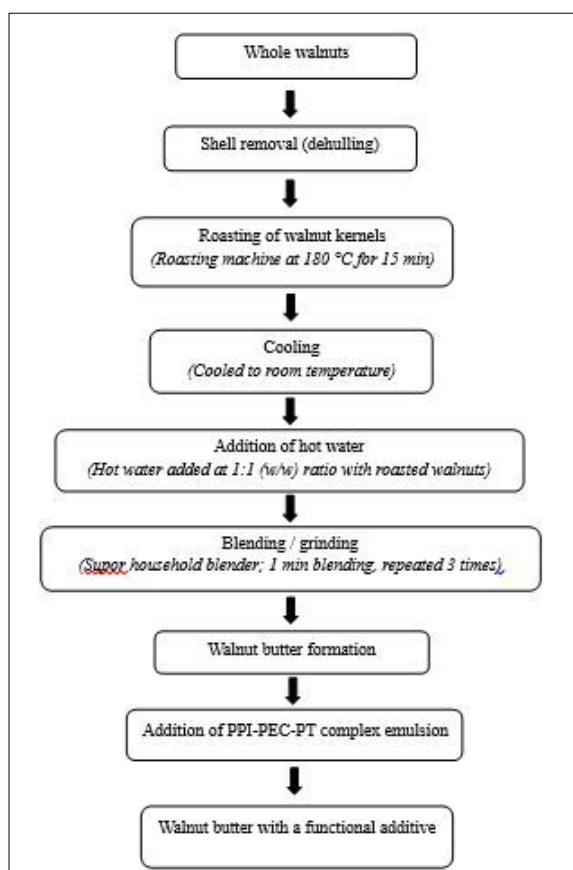
Source: Lima *et al.* (2012) [31]

Processing Flow Chart for Cottonseed Butter/Spread

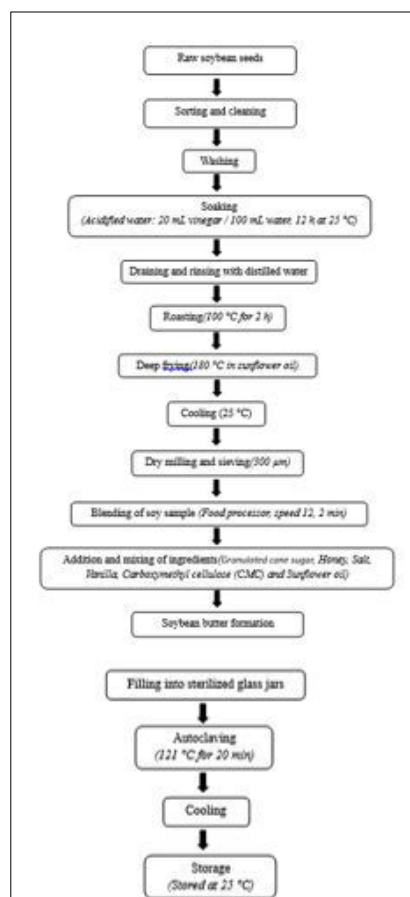


Source: He *et al.* (2023)

Processing Flow Chart for Sunflower Seed ButterSource: Vene *et al.* (2025) ^[53]**Processing Flow Chart for Flaxseed Butter**Source: Basumatary *et al.* (2024) ^[9]**Processing Flow Chart for Pistachio Spread**Source: Shakerardekani *et al.* (2013) ^[46]**Processing Flow Chart for Melon Seed Butter**Source: Sahin *et al.* (2022) ^[44]

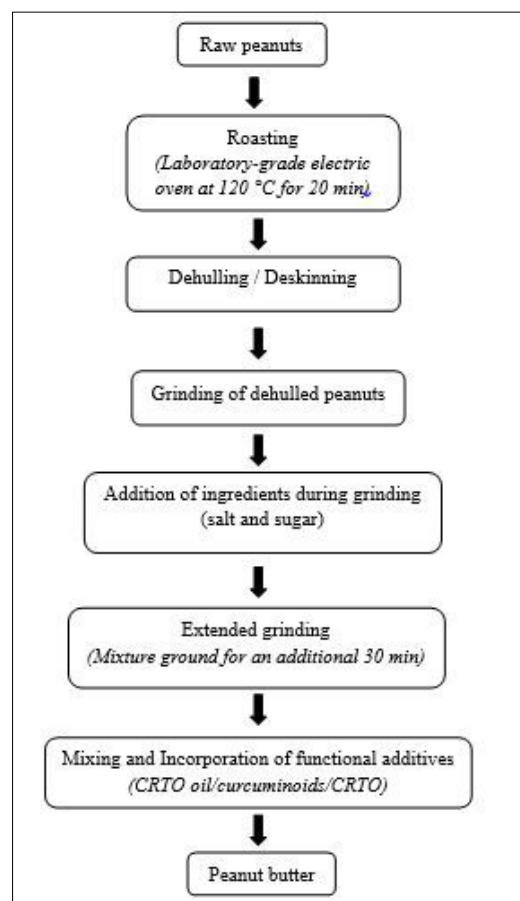
Processing Flow Chart for Pumpkin Seed SpreadSource: Dursun Saydam *et al.* (2025)**Processing Flow Chart for Jaggery-Based Sesame Seed Spread**Source: Gojiya *et al.* (2024) ^[19]**Processing Flow Chart for Walnut Butter**Source: Tang *et al.* (2025) ^[52]

Processing Flow Chart for Soybean Butter



Source: Abd-Elsattar and Abdel-Haleem (2016) [1]

Processing Flow Chart for Peanut Butter



Source: Praveen *et al.* (2024) [39].

Conclusions

Plant-based seed butters and spreads are emerging as nutritious, sustainable, and consumer friendly alternatives to conventional dairy and nut-based products. Their rich nutritional composition, including healthy fats, proteins, vitamins, and minerals, makes them excellent choices for health-conscious consumers. The type of seed used such as peanut, sesame, sunflower, flaxseed, pumpkin, or melon strongly influences the texture, flavour, and overall quality of the final product. Stabilisers, emulsifiers, and sweeteners not only improve texture and spreadability but also enhance flavour balance and product stability. Controlled processing steps such as roasting, grinding, and milling are crucial for achieving smooth, creamy textures and consistent sensory appeal. Storage stability, a key challenge, can be improved through balanced formulations, antioxidant incorporation, and temperature management. Overall, a deeper understanding of how ingredients and processing interact can help create plant-based butters and spreads that are both nutritious and enjoyable. Continued innovation using natural stabilisers, clean-label ingredients, and sustainable technologies will further strengthen the potential of these products in future food systems.

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