Review Article

Recent Advances and Future Trends in Clean-Label Technology

ABSTRACT

Foodborne illness outbreaks, food scandals, and concerns about artificial ingredients have led to the rise of the clean label concept, which emphasizes natural, organic, non-GMO, minimally processed, and domestically sourced ingredients. ~~In response, f~~Food manufacturers are adopting various clean-labeltechnologies to enhance food safety and quality. This review examines the evolution and current status of clean labeling, its attributes, and its role in ensuring food quality and safety. It discusses different clean-label ingredients, particularly in dairy products, their market potential, and the challenges of implementing clean-label strategies, including maintaining shelf-life stability and finding cost-effective natural alternatives that preserve food quality.

***Keywords**: Clean label; Clean label ingredients; Antimicrobials; Dairy, Food label, synthetic additives*

INTRODUCTION

Foodborne illness outbreaks, food scandals, and growing awareness of the harmful effects of artificial ingredients have increased consumer concerns about food safety and quality. As a result, there has been a rising preference for and natural foods, leading to a demand for "clean label" products—foods with simple, recognizable ingredie minimal processing (Peng & Yao, 2017[23]; Do Nascimento, Paes, & Augusta, 2018[9]). The clean label trend first eme the UK in the 1980s when consumers grew aware of the negative health impacts ~~associated with~~ofE-numbers labels, resulting in their exclusion. Over the last two decades, the movement has gained traction globally, particu Europe and the US (Asioli et al., 2017[6]).Clean label interpretations vary by region and demographic. For ex Western Europe focuses on fewer ingredients and no artificial additives, while in Russia, it is closely associated w GMO foods. A 2017 survey found generational differences in understanding clean labels: Boomers prioritize r artificial sweeteners and trans fats, Millennials focus on sugar, protein, and preservatives, and Gen X is less concerned, primarily interested in product availability and absence of certain additives (C&R Research, 2017).This chapter will explore the definitions, attributes, and ingredients of clean labels and their role in promoting food quality and safety.

Definitions of clean label and Food label

There is no official regulatory definition for "clean labels," but the term generally refers to foods made with minimally processed, and easily recognizable ingredients, without artificial additives, preservatives, or synthetic ch (Maruyama, Lim, &Streletskaya, 2021; Asioli et al., 2017). Clean labels aim for transparency, with ingredients that consumers can easily understand and find acceptable.Definitions of clean labels can vary, but they typically focus on removing artificial additives like colors, flavors, and preservatives and using natural or organic alternatives. The clean label trend is driven by consumer demand for natural, non-GMO ingredients and transparency about what is in their food ("Innovations in Clean Label," 2013).Different regions have varying standards for clean labels. For example, in the U.S., artificial colors like Blue 1 and Red 40 are more accepted, while in Canada, natural colorants such as fruit and vegetable juice concentrates are preferred, resulting in higher costs and shorter shelf life for clean-label products.

Comment [T1]: How many studies were used (focusing on...)?
Main findings?
Contribution to the field?

Comment [T2]: This statement sets the stage for your investigation. You need **statistics** here on what, say for example the WHO says or other scholars on the numbers being affected by foodborne illnesses. Also, focus on recent scandals. Relying on data younger than 5 years is more ideal. Events that occurred in the year 2017 are too old to cause us significant worry.
Contexualise, is it a global issue, where is this issue loudest?

Comment [T3]: Revise to read:
This chapter explored clean labels' definitions, attributes, and ingredients and their role in promoting food quality and safety.

Comment [T4]: You also need to define Food label

Clean label attributes

- Simplicity and Familiarity- Fewer or a minimum number of recognizable ingredients that are easy to read should be there on the label.
- Only natural ingredients- No synthetic flavors, colors, chemical preservatives, or artificial food additives should be added in a clean-label food.
- Transparency- It is one of the core attributes of clean labeling. Information on sources of ingredients, methods of sourcing, and manufacturing methods on the label gives consumers ~~the~~ confidence that the food will be safe in all aspects.
- Less/ Minimal processing- Clean labeled foods should be minimally processed using conventional techniques ~~("https://insights.figlobal.com/report-downloads/clean-label-2020-guide-evolving-trend-report ," 2023~~; Wang, &Adhikara, 2017).

Comment [T5]: Use scholarly sources. Alternatively you can say: (Clean-label guide, 2023) of (Anonymous, 2023), and be consistent

Difference between natural, organic, and clean-labelfood

While "natural" and "organic" labels are often associated with clean labels, they have distinct meanings. The U.S. Food and Drug Administration (FDA) does not have a formal rule for "natural" labeling, but it does not object to the term if the food contains no artificial flavors, added colors, or synthetic substances. However, the FDA's "natural" policy does not address production methods, such as using pesticides or GMOs. The U.S. Department of Agriculture (USDA) defines "natural" foods as minimally processed, with no artificial additives or preservatives."Organic," on the other hand, is strictly regulated by the USDA's National Organic Program, covering both pre- and post-harvest processes and prohibiting GMOs and synthetic pesticides. Certain ingredients allowed in organic foods, like xanthan gum, are not permitted in clean-label products.While "clean label" is often confused with "natural," it focuses on simpler, minimally processed ingredients familiar to consumers, akin to "grandma's pantry." Unlike "natural," clean label is not a regulated term but has gained popularity due to its emphasis on transparency and simplicity in ingredient lists.

Comment [T6]: Cite source

Clean label methodology

The process of developing clean-label foods is complex, requiring careful consideration of ingredients and additives to meet consumer demands while preserving the product's taste, texture, freshness, and appearance (Inguglia et al., 2023). Strategies include "Replace," which involves directly swapping one ingredient for another; "Retool," which involves cleaning up redundant ingredients and adjusting processing steps; and "Rebuild," the most challenging strategy, which reconstructs the product with different raw materials, potentially requiring new equipment and investments

Clean label ingredients

To meet clean-label requirements, many food companies are reformulating products to replace artificial ingredients with natural alternatives, maintaining quality and sensory characteristics while controlling costs. For instance, natural preservatives like green tea, citrus, rosemary, acerola cherry, chamomile, and tocopherols (Vitamin E) can replace artificial ones like TBHQ and EDTA. Natural starches, proteins, and fibers can substitute synthetic texturizers, while apple juice concentrate can replace malic acid. Emulsifiers like egg yolk, lentil bean powder, and pea protein can replace synthetic ones, and cold-pressed vegetable oils can replace solvent-extracted oils

Antimicrobials and preservatives

Consumers today prefer foods free from artificial preservatives, pushing the industry, particularly themeat and fish sectors, to find clean-label alternatives that maintain quality and safety without synthetic chemicals like BHA, BHT, and sodium nitrites. Clean-label options for antimicrobials and preservatives include lactic acid, vinegar, ascorbic acid, rosemary, and other recognizable natural ingredients. Treatments like chlorine, ozone, hydrogen peroxide, and bacteriophages are also considered safe enough not to require labelling ~~("https://phageguard.com/antimicrobials-for-clean-labels/," 2023~~).Clean label development is a balancing act between ingredient effectiveness and consumer preferences, demanding constant innovation and research.

1. **Potassium and sodium chloride**

These simple salts are potential clean label ingredients that have antimicrobial, texture improving, flavor enhancing and shelf life extending functions. They are extensively used in meat and poultry industry. In processed meat both salts are used either alone or in combination to preserve and prevent microbial growth in meat and poultry. It also helps to keep the level of sodium content of the meat down. The antimicrobial activity of the salts is attributed by their ability to decrease water activity thereby increasing osmotic pressure that results in cell death via plasmolysis. Potassium and Sodium chloride also helps in improving texture of meat as the salts can solubilize meat proteins offering emulsifying effect that result in a juicier and more tender product. As the solubilized proteins can hold more water this will ultimately leads to increase in product yield. (“https://www.foodbusinessnews.net/articles/15741-seven-clean-label-technologies-to-extend-shelf-life -,” 2023).

2. **Salts of organic acid**

Lactic acid, acetic acid, and propionic acid are common organic acids used as antimicrobials in food. These acids are produced by fermenting carbohydrates and inhibit microbial growth by entering the bacterial cell wall in their undissociated form. Inside the cell, they dissociate, lowering the pH and disrupting essential metabolic functions, which prevents the growth of pH-sensitive pathogens. The effectiveness of these acids depends on their pKa value; at a given pH, acids with a higher pKa, like propionic acid (pKa 4.87), exhibit stronger antimicrobial activity. Acetic acid (pKa 4.75) is more inhibitory than lactic acid (pKa 3.83) at pH 4.0-4.6. Lactic and acetic acids are considered clean-label ingredients due to their natural occurrence and familiarity to consumers. While propionic acid is an effective antimicrobial, it is less frequently regarded as clean-label. Clean-label alternatives like cultured wheat flour or fermented starch can replace traditional preservatives like calcium propionate in baked goods, extending shelf life and preserving quality. (“https://phageguard.com/antimicrobials-for-clean-labels/ -,”2023;https://www.foodbusinessnews.net/articles/15741-seven-clean-label-technologies-to-extend-shelf-life -,” 2023).

3. **Plant and animal sources of clean-labelantimicrobials**

Secondary metabolites possessing antimicrobial activity are called the natural antimicrobials and could be extracted from different sources like plants (herbs and spices), animals (eggs, milk, and tissues), and microorganisms (bacteria and fungi). Utilizing plant-based ingredients and additives is a common component of the clean-labeltrend in food production (Karwowska, Munekata, Lorenzo, & Tomasevic, 2022). Many plant and animal sources possess antimicrobial properties when used either directly in food matrix or when their juice, oil, or extracts are processed from these natural sources. Research carried out to evaluate the antimicrobial effect of fruit peel extracts of apples, bananas, pomegranate, mango, sweet lime, oranges, papaya, etc. showed mild inhibitory activity against pathogenic bacteria. Secondary metabolites of common spices and herbs such as cloves, cinnamon, basil, oregano, rosemary, and garlic contain many antimicrobial agents with inhibitory effects against Gram (+) and Gram (-) bacteria. Green tea and rosemary extract are widely used to improve the taste, appearance, and quality of poultry and meat products. Most source plant extracts are rich sources of polyphenols and phytochemicals having antimicrobial and antioxidant properties. The phenolic compounds in tea and rosemary extracts prevent oxidative hydrolysis of meat pigments by their antioxidant activity (“https://phageguard.com/antimicrobials-for-clean-labels/,” 2019).

Antimicrobial activities of essential oils extracted from 14 natural sources like oregano, clove, rosemary, pepper, licorice, nutmeg, turmeric, cassia bark, aniseed, fennel, prickly ash, round cardamom, angelica, and *dahurianangelipca* root were studied against four common meat spoilage and pathogenic bacteria such as *E. coli, Pseudomonas fluorescens, Lactobacillus sake,* and *L. monocytogenes*. The results indicated that rosemary, clove, and cassia bark, have strong antimicrobial activity against these pathogens. A combination of licorice and rosemary extracts exhibited much more inhibition against all four bacteria.

Similarly, another study found that the main difference between the two plant extracts of green tea and rosemary is that green tea extract contributes less undesirable flavor to the final product compared to rosemary extract. Thus, a combination of extract blend with a lower level of rosemary extract and a higher level of green tea extract allows the manufacturer to increase the natural plant extract usage rate, often resulting in an extract blend that works better in the meat product than rosemary alone. The antimicrobial compound, thymol extracted from oregano and thyme, has an inhibitory effect on Pseudomonas, one of the common spoilage bacteria of meat sausages. Many studies reported the inhibitory effects of extracts of mustard, marjoram, cinnamon, rosemary, and lemon grass against *Listeria, S. typhi, E. coli* O157:H7. The oregano essential oils containing ~ 80.5% carvacrol have an antibacterial effect on bacteria like *B. subtilis, S. aureus, E. coli,* and yeast *Saccharomyces cerevisiae.* These antimicrobials from spices and herbs have a safe status approved by government agencies to be used by food industries (Arshad, &Batool, 2017).

Comment [T7]: Another study by???? Cite

Eggs and milk are potential animal sources of enzymes such as lysozyme and lactoferrin, having antibacterial effect effects (Sawale et al., 2022). Chitosan, a naturally occurring biopolymer derived from shrimp, is reported to have antimicrobial activity along with properties of emulsifier, thickener, or stabilizer that can be used in meat and poultry products.

Microbial sources of clean-labelantimicrobials

Bacteriocins are widely studied antimicrobial compounds from microbial sources used in food preservation. Other bio-preservatives produced by fermentation include organic acids (lactic, propionic, acetic, citric, and sorbic acids) and low molecular weight compounds like reuterin, diacetyl, hydrogen peroxide, fatty acids, cyclic dipeptides, and phenyl lactic acids. Their effectiveness makes them ideal for food preservation.

- They are generally recognized as safe substances
- They are not active and nontoxic to eukaryotic cells
- They become inactivated by digestive proteases, having little influence on the gut microbiota
- They are usually pH and heat-tolerant
- They have a relatively broad antimicrobial spectrum against many food-borne pathogenic and spoilage bacteria
- They show a bactericidal mode of action, usually acting on the bacterial cytoplasmic membrane: no cross-resistance with antibiotics
- Do not alter acceptance quality of food and are safe for human consumption

Currently, the only commercially produced bacteriocins are Nisin, from *Lactococcus lactis* ssp. *lactis*, and Pediocin PA-1, from *Pediococcusacidilactici*. Purified bacteriocins must be labeled as additives and require regulatory approval. Nisin, marketed as Nisaplin by Danisco, is the only bacteriocin approved for antimicrobial use by the Joint FAO/WHO Expert Committee on Food Additives. It is effective against Gram-positive bacteria like *S. aureus*, *L. monocytogenes*, *Bacillus*, and *Clostridium*. Bacteriocins are used to extend the shelf life of products such as yogurt, cheese, mayonnaise, and canned vegetables, with Nisin and Pediocin PA-1/AcH being the most widely utilized.GUARDIAN™ is another bacteriocin-based solution combining nisin and rosemary extract, which can kill Gram-positive bacteria and delay the oxidative rancidity of fats. Pediocins, another family of bacteriocins like Pediocin AcH, are effective against spoilage and pathogens such as *L. monocytogenes*, *E. faecalis*, *S. aureus*, and *C. perfringens*. Pediocin PA-1 inhibits *Listeria* in dairy products like cottage cheese, ice cream, and dry milk. Natamax®, based on natamycin (a polyene macrolide produced by *Streptomyces natalensis*), is effective against yeasts and molds, commonly used in cheese, dried meats, yogurt, sour cream, wines, and bakery products. However, bacteriocins like nisin, natamycin, *pediocin*, and *chitosan* are not considered clean-label ingredients since they may not align with consumer perceptions of natural and clean-label products, despite their effectiveness in preserving fresh and cooked meats. Even when made from organic-certified materials, these ingredients are not regarded as natural, organic, or clean-label.(~~"https://phageguard.com/antimicrobials-for-clean-labels/ ," 202~~3; Liong, 2015).

Milk as a source of clean-label ingredients

Milk is considered ~~as~~ an excellent source of clean-label ingredients. For centuries, milk has been used as a key ingredient in a wide range of foods such as ice cream, curd, yogurt, cheese, breads, cookies, cakes, puddings, soups, sauces, and confections bread. It provides carbohydrates, fats, proteins, and minerals that contribute nutrition, flavor, and functionality to all foods. Milk contains 3.4% protein, 4.8% lactose, 3.9% fat, 0.8% ash, and 87.5% water. The processing of dairy ingredients is very clean and simple. Typical processes include pasteurization, separation, fermentation, evaporation, and drying. Membrane filtration utilizes specific pore sizes to separate protein from lactose and creates concentrated, whey and milk protein ingredients. In milk, the casein-to-whey protein ratio is 80:20, and protein-concentrated ingredients can be classified as casein-rich or whey-protein-rich. Lactose-rich ingredients are created as a by-product, as are ingredients that are rich in important dairy minerals~~("https://www.thinkusadairy.org/resources-and-insights/resources-and-insights/application-and-technical-materials/technical-report-dairy-solutions-for-clean-label-applications ," 2023; "https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/ ," 2023~~).

Dairy ingredients have a clean image and are well-positioned to deliver various functional properties and versatility, leveraging their unique composition and inherent functionality. Dairy ingredients are an ideal choice for a clean label because they provide excellent functionality, cleaner flavor, and higher protein quality than many other ingredients. They allow food manufacturers to use fewer starches, hydrocolloids, and flavor maskers. They also don't require protein blending for protein claims, as do many vegetable protein ingredients. With their fairly neutral, clean flavor, dairy ingredients also deliver a superior sensory profile in final products. Dairy proteins provide excellent nutritional quality. The PDCAAS (Protein Digestibility Corrected Amino Acid Score) of milk protein and whey protein is 1.0, whereas soy protein is 0.98; pea protein is 0.89, and rice protein is 0.42. Using plant proteins often requires the blending of several proteins to achieve the desired protein quality, thus increasing the length of the ingredient legend.

Chelating out some of the calcium yields milk protein ingredients (e.g., MPCs) with significantly greater solubility and heat stability in RTD beverages. These tailored MPCs can replace phosphates in RTD beverage applications. In other examples from emerging research, a tailored ingredient that combines whey protein isolate and pectin has been shown to enhance emulsification in salad dressings and replace less label-friendly components, such as monoglycerides and polysorbate 80. Skim milk powder can be produced by treating milk with a high-pressure jet to increase its foaming properties. This ingredient will be useful in ice cream and lattés, where foaming is desired and can be declared as "skim milk" on the product label.

Cultured milk or cultured whey ingredients function as label-friendly, unique bio-preservatives that can replace potassium sorbate, or sorbic acid ~~("https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/," 2023~~). Fermented skim milk, acid whey, and buttermilk help to reduce staling in bread. Natural cheese can be used as a perfect clean-label ingredient for its flavor and functionality in cheesecake, cheese bread, cheese pastry, and cheese crackers. In cheesecake and cheese fillings, cream cheese provides a creamy, soft texture and an ideal tart flavor (“https://www.thinkusadairy.org/resources-and-insights/resources-and-insights/application-and-technical-materials/technical-report-dairy-solutions-for-clean-label-applications,” 2023).

Milk sugar and lactose show the same melting and recrystallization properties as the sucrose. However, lactose is 60% less sweet compared to sucrose. Lactose takes part in the Maillard browning reaction along with protein. Properties such as solubility, emulsification, whipping, gelation, browning, water binding, etc. can be provided by dairy proteins-casein and whey proteins in various food products. Milk fat has the ability to contribute functional properties like flavor, creaming, layering, whipping, and shortening. Minerals (Ca, Mg, P, K) in dairy ingredients play an important role in acid gels formation with casein in dairy products like yogurt and cheese. All these unique properties of milk and its ingredients have made them one of the healthiest, clean-label ingredients to use in food products. Skim milk powder (SMP) is the most popular and practical milk ingredient to use on an industrial scale. Whey protein concentrates (WPC) can be considered as a lower-cost substitute for SMP as both have the same level of proteins (34%).

Dairy ingredients like milk protein concentrates (MPC), milk protein isolates (MPI), high proteinWPC, whey protein isolates (WPI), etc. that are made by simple filtration techniques followed by spray drying are gaining popularity as clean-label dairy ingredients as the consumers consider manufacturing processes of these ingredients as clean label category. These dairy ingredients have clean-label scope in beverages, bakery products, dairy products, soups, sauces, and desserts as good substitutes for chemical emulsifiers, hydrogenated fats, or non-cleanlabel carbohydrates (“https://www.thinkusadairy.org/resources-and-insights/resources-and-insights/application-and-technical-materials/technical-report-dairy-solutions-for-clean-label-applications,” 2023).

Comment [T8]: Bracket WPC, and does C represents???

Clean label starches and lipids in beverages and food as a fat replacer

Starches are isolated from plant parts such as the root, tuber, leaf, and seeds. Starch granules can disperse individually in a form similar to emulsion droplets, bringing characteristic textural and sensory properties. Researchers attempted to use cross-linked starches in fat replacement applications.

Fat replacers provide fewer calories to food products than traditional fat sources, either by reducing the required weight in the mix or by calorie reductions per unit weight of some ingredient. Fat replacers can be carbohydrates, lipids, or proteins. Fat replacers can be used as an additional ingredient in meat products, meal replacers, soups, and sauces. Thus less-fat meat products are available, having a creamy and juicy mouthfeel and with enhanced firmness (Cho& Samuel, 2009). Different carbohydrates and fibers, such as inulin, β-glucan, oat bran and flaxseed flour, cocoa fiber, polydextrose, maltodextrin, and citrus pectin had, been applied to reduce the fat content of muffins and cakes and muffins. The general functions of different fat replacers in other food systems are given in **Table 1.**

Inulin is a water-solublestorage polysaccharide under fructan, a group of non-digestible carbohydrates. The richest source of inulin is Chicory roots, even though they can be harvested from more than 36,000 species of plants. Inulin attained GRAS status in the USA and is used as a fat replacer, prebiotic, sugar replacer, texture modifier, and in the development of functional foods. Adding inulin in reduced-fat sausages improved texture and sensory quality. Fermented chicken sausages were also made with inulin as a partial oil replacement. Inulin was added to biscuits to a level of 15% to attain a fat substitute. These findings are promising for the use of inulin as a clean-label ingredient.

β-glucan is a water-soluble dietary fiber, cereal beta-glucan is typically found in the endosperm cell wall in oats, barley, and wheat. Cereal beta-glucan can be used as a fat replacer and add body and texture to low-fat products. Beta-glucan from oats actively lowers total cholesterol and blood LDL. β-glucan is applied in non-fat yogurt as a fat replacer. A Fibre composite made from rice bran and barley flour, called race trim, was found to have similar rheological properties to coconut cream. Ricetrim was used to substitute coconut cream in low saturated fat-Thai foods, i.e., cookies, pumpkin pudding, layer cake, dip for pot crust, taro custard, etc.

Maltodextrin is aPartial hydrolysis product of starch with less than 20 dextrose equivalents. Maltodextrin used as a fat replacer has a dextrose equivalent of less than 10—wheat starch in low-fat hamburger formulation (ShahiriTabarestani, &MazaheriTehrani, 2014). Pumpkin seed kernel flour in beef meatballs (Öztürk&Turhan, 2020) acts as fat replacer. For cakes, canola or soy lecithin has been known to replace emulsifiers. Mechanically pre-gelatinized starch is used to replace chemically modified starch and dextrin. The various modifications also provide viscosity and, therefore, increase the stability of networks previously supported by emulsifiers. Fibers and gums also have a wide range of functional roles and can be clean label ingredients.

Fat-rich dairy ingredients provide a unique mouthfeel, superior flavor release and sensory experience. Using high-fat dairy ingredients in coffee creamers is a growing clean-label trend(“https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/,” 2023). Butter is used in the bakery industry to replace vegetable oils and benefit from butter's functionality, flavor and clean label. MPC and WPC have been applied for fat replacement in ice cream, and the application of WPC worked better for fat replacement than MPC.

TABLE 1. Food Systems showing functions of fat replacers

Replaced fat forms	Food Category	Physical state	General functions of fat replacers
Fat globules and fat emulsions; Diluted and dispersed	Milk, sauces, soups, gravies	Liquids	• Lipid-based; Providing mouthfeel and lubricity • Carbohydrate based; thickening, providing mouthfeel, texturizing • Protein based; texturizing
Fat globules and fat emulsions; Concentrated dispersed	Salad dressings, dairy products, frozen desserts, processed meat products, and confectioneries	High viscous liquids or Viscoelastic solids	• Lipid-based; Emulsifying, providing mouth feel, texturizing, holding flavorants, increasing overrun and stabilizing • Carbohydrate based; increasing viscosity, thickening, providing mouthfeel, texturizing, water holding, gelling, and stabilizing • Protein based; texturizing, providing mouthfeel, emulsifying, stabilizing, and water holding
Fat globules and fat emulsions; Incorporated in solid matrix			
Incorporating free oil, continuous oil phase,fat emulsions	Baked and fried products, snacks	Solids	• Lipid-based; Emulsifying, providing cohesiveness, replacing shortening, tenderizing, carrying flavor, preventing staling, conditioning dough, preventing starch retrogradation, providing flavor and crispiness, texturizing, conducting heat • Carbohydrate based; retaining moisture, retarding staling, texturizing, aiding formulation • Protein based; texturizing
Fat; semi- crystalline or crystalline	Margarines, shortenings, butters, spreads	Solids	• Lipid based; Providing spreadability, providing flavor, emulsifying, plasticizing • Carbohydrate based; Providing mouthfeel

Comment [T9]: You can reduce table contents line spacing to 1.0 or 1.15

			• Protein based; texturizing

Source:

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Proteins as a clean-label ingredient

Proteins are widely used food ingredients for their technological and physiological functionality and nutritional value. Proteins are obtained by minimal processing of various vegetable and animal sources. They are regarded as safe and do not require E numbers for identification. Based on the intrinsic molecular properties of proteins, they can be categorized into hydrocolloid-like proteins, unstructured, random proteins, globular, monomeric proteins, complex globular proteins, and gluten (Alting& Van De Velde, 2012).

1. Hydrocolloids

There are many sources for clean-label substances. However, the food sector uses hydrocolloids most frequently (Inguglia, Song, Kerry, O'Sullivan,& Hamill, 2023). Hydrocolloids are important components of many food products. Hydrocolloids in plant-based beverages include carrageenan, high-acyl gellan gum, and locust bean gum. Alternative ingredients gaining momentum in this area include tara, gum acacia, oat fiber, and citrus fiber. Carrageenan is utilised~~all~~ throughout the world as a low-cost means of supplying suspension and emulsion stability, though less so in the United States. Carrageenan is very heat stable so ~~that~~ it can be used in high temperature/short time (HTST) and UHT products, but it is unsuitable for retorted beverages. Because it is processed from an underutilized resource (seaweed), carrageenan may be attractive to consumers who appreciate a high employment factor. That is, carrageenan supports the financial well-being of industry workers—many in emerging economies. It's also of interest to note, said Zalesny, that "female entrepreneurs run many seaweed farms."Gellan gum, especially the high-acyl form, is a polysaccharide in nearly all plant-based beverages. The steric hindrance of this polymer's side chains results in a more fluid gel, providing a clean mouth feel and a good suspension of proteins. The low levels are needed to compensate for its high cost. However, gellan gum cannot be retorted and because it may be perceived as "non-natural," some consumers view it negatively. Gelatin is the hydrolyzed form of collagen from animalanimal skin and bones, bovine, fish, and pigs. Acid-treated and alkali-treatedcollagen are distinguished as type-A and type-B, respectively. When most of the other proteins form turbid particle gels, gelatin forms transparent polymer gels**.** Galactomannans are usually added with gellan gum when formulating plant-based beverages. Galactomannans are polymers with a mannose backbone and galactose side chains positioned along the spine. Galactomannans with an increased galactose: mannose ratio have a more crystalline structure and lower solubility in cold water. Locust bean gum works particularly well in plant-based dairy beverages but is relatively expensive. Tara gum is a good alternative as it has a similar chemical structure to LBG but at less than half the price. For plant-based beverages with added fat, gum acacia can also stabilize emulsions. This is because it has both hydrophilic and hydrophobic characteristics.

Comment [T11]: Remove coma, after O'Sullivan.

As an alternative to gellan gum, oat or citrus fibers are options for plant-based beverages, said Zalesny. Oat fiber especially "can do both," meaning no additional stabilizers are needed because manufacturers have "perfected Stoke's Law: the particle size and density are balanced by the viscosity of the beverage." Consumers are increasingly embracing clean-labelfoods, and plant-based foods score high in the "emotional" clean-label area (cruelty-free, sustainable, etc.). The use of hydrocolloids is important in plant-based products, just as it is in traditional products ~~("https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/," 2023~~).

Application of hydrocolloid-like proteins

In bakery products,, hydrocolloid gums enhance the properties of natural starches. Gums act as stabilizers or viscosifiers in food products. A functional ingredient with hydrocolloid capacity derived from flax seeds was used as a fat substitute. OptiSol™5300, derived from flax seeds, is a natural active ingredient rich in fiber and alpha-linolenic acid. This provides a natural substitute for guar and xanthan gums in baked products, hence avoiding E-numbers on their labels. A replacement level of up to 30% of the fat with OptiSol™5300 gives a product with a clean title and additional health benefits that bear semblance to the full-fat sponge cake (Eslava-Zomeño, Quiles, & Hernando, 2016).

2. Unstructured, random proteins

Caseins and Caseinates: Casein,is the major protein fraction in most mammalian lacteal secretion, milk, and exists as micelles. Casein can be separated by isoelectric precipitation (pH 4.6) or proteolytic coagulation. The proteolytic enzymes such as chymosin (rennet) can split off casein, destabilize the micellar structure, and thus achieve proteolytic coagulation; the product is called rennet casein. Acidification and selective precipitation at the isoelectric point of casein also lead to a disintegration of the micelle structure. To improve the solubility properties of this acid, casein neutralization is preceded by the product obtained is caseinate. Application of rennet and acid caseins are limited because they are water-insoluble; caseinates are hence found in a wide variety of applications. Micellar casein can result in a coffee creamer with superior whitening and emulsification properties and can replace sodium caseinate in this application. Lactose-rich ingredients can be modified by catalytic treatment or enzymatic conversion to create sweetening syrup that can be used as an alternative to artificial sweeteners.

3. Globular monomeric proteins

Globular proteins can be derived from a variety of animal and vegetable sources. Whey proteins from milk, patatin from tuber (potato), ovalbumin from egg, and serum albumin from blood are all examples. The functionality of globular protein is influenced by the physical, chemical, and conformational properties, which in turn depend upon the denaturation degree. In simple terms, the denaturation of globular protein is a prerequisite in most cases to activate the desired functionality.

4. Complex globular proteins

Seed storage proteins are categorized as complex globular proteins. Legume proteins, such as soy and pulses, belong to the globulin family of seed storage proteins called legumins (11S globulin fraction) and vicilins (7S globulin). Globulins (90% of protein fraction) are defined as protein extractable in dilute salt solutions. Grains contain a third type of storage protein called gluten or 'prolamines.' Legumes also contain biologically active or metabolic proteins such as enzymes, trypsin inhibitors, hemagglutinins, and cysteine proteases very similar to papain (Alting & Van De Velde, 2012).

The most well-known legume protein is soy protein. Soybeans are processed into three protein preparations: soy flour concentrates (70% protein) and isolates (90% protein). Soy protein concentrates are generally prepared from defatted soy flakes by aqueous-alcoholic extraction in which the soluble carbohydrate fraction is removed. Soy protein isolates are generally prepared by a two-step aqueous protein extraction from de-hulled, defatted soybean meal (a by-product of oil production).

5. Gluten

Gluten or prolamines are water-insoluble, composite storage proteins in grains, composed of 45%gliadin and 55% glutenin. Gliadins are monomeric, and glutenins are a mixture of polymers and comprise 80% of the protein present in wheat seed.

For artificial fruit flavors, concentrated fruit powders work well. When using natural coloring products, gel versions work best to avoid diluting your system and affecting viscosity and taste ~~("https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/," 2023). Tamarind gum works as a replacer for propylene glycol alginate ("https://www.naturalproductsinsider.com/regulatory/how-industry-engineering-clean-label-foods-and-beverages," 2023~~).

Application of clean label substitutes and ingredients in dairy products

1. Yoghurt

Some of the first products to get a clean-label makeover have been those with a healthy halo, such as yogurt ~~("https://www.naturalproductsinsider.com/regulatory/how-industry-engineering-clean-label-foods-and-beverages," 2023~~). Fat-free yogurt was made using modified food starch and hydrocolloids for a smooth mouthfeel and creamy texture. Combinations of heat-modified whey protein and buttermilk protein concentrates have replaced fat in yogurt (Saffon et al., 2013). To increase viscosity and reduce syneresis, whey proteins were used, reducing the dependence on starches and hydrocolloids (Hugunin, Lucey, & Verdes, 2009). Modified whey proteins positively impact water-holding capacity and viscosity when compared to the use of starch (Firebaugh, 2004; Matumoto-Pintro, Rabiey, Robitaille, & Britten, 2011). Whey proteins also provided a smoother texture of compared to caseinates(Akalın, Unal, Dinkci, &Hayaloglu, 2012). Greek-style yogurts are traditionally strained yogurts that utilize Quark cheese-type separators or ultrafiltration membranes to concentrate the dairy proteins while removing water, lactose, and minerals. The high protein level (10%) in Greek yoghurt can be achieved by addingyogurt dairy proteins, such as MPC, MPI, micellar casein, WPC, or WPI. Micellar casein will have a higher level of casein than the roughly 80% casein in an MPC or MPI. Micellar casein concentrates with 58% protein producesa yogurt with similar physical properties(Bong &Moraru, 2014).

2. Butter

Artificial butter flavors are replaced by concentrated dairy products, buttermilk, and yeast-based extracts ~~("https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/," 2023~~).

Comment [T12]: Spelling

3. Ice Cream

Milk and whey proteins traditionally have been used in ice cream to contribute to nonfat-milk-solids content and to replace fat, provide stabilization, and enhance protein. Ice creams have increased their dependence on fewer clean-label ingredients to give some of these same benefits at a lower cost. Ice cream has a standard of identity in the United States that defines its composition as not less than 10% milkfat and not less than 10% nonfat milk solids.

Any whey or modified whey products can contribute up to 25% by weight of the total nonfat milk solids of the finished ice cream. If the product is called a frozen dessert, there is no need to limit whey ingredient use. The current U.S. standards allow for adding other optional dairy ingredients such as "skim milk, that may be concentrated, and from which part or all of the lactose has been removed by a safe and suitable procedure" in a concentrated or dried form. This description would include ingredients such as UF milk, MPC, and MPI. The use of UF milk at varying replacement levels of nonfat milk solids improves body, texture, and heat-shock stability compared with ice creams made with WPC. Reduced-calcium milk protein concentrate (RCMPC) and milk protein concentrate (MPC) can function as natural emulsifiers and enhance the amount of protein in ice cream products. RCMPC may be more acceptable for inclusion in the ~~cold~~ ice cream mix because it was demonstrated to have higher cold solubility compared to MPC (Paglia, Fung, &Yeung, 2023).

Comment [T13]: Mind the space between

Whey ingredients have been evaluated and used extensively in ice cream and frozen desserts. MPC and WPC have been applied for fat replacement. In ice cream, the application of WPC worked better for fat replacement than MPC. The protease-peptone whey fractions and combined WPC have been used as an emulsifier in ice cream. Whey protein phospholipid concentrate and lactose permeate blends in ice creams retained mean ice crystal size, reduced the fat fatmilk destabilization, and had a higher melt rate. Other WPC coproducts, such as whey permeates, have been used to serve soft-serve ice cream and other frozen desserts. MPC and WPC have been utilizedutilizedto increase protein content from 4.9% to 7.2% in ice cream for application in low-carbohydrate diets.

Replacement to nitrites, nitrates, and synthetic antioxidants

Raw and cooked meat, including RTE products, are highly perishable due to microbial growth, active enzymes, and oxidation-prone compounds, which can affect sensory attributes like color and flavor. Sodium nitrates and nitrites, common preservatives, are linked to health issues and are increasingly rejected by consumers, especially older adults. While these additives help maintain color and flavor, they don't meet the demand for clean-label alternatives.The growth rate of meat products with natural or "no preservatives" claims is 5.2% annually, compared to stagnant growth for chemically preserved products. Emerging clean-label claims include "No added nitrites/nitrates except those naturally occurring in celery." Consumer-friendly alternatives are becoming crucial in the $84 billion global meat market to combat spoilage and reduce waste.Recent studies highlight the use of plant-based additives with antibacterial properties as clean-label substitutes for nitrites in fermented meats. Chia seeds and high-nitrate vegetables (e.g., celery) are often used in these formulations (Karwowska et al., 2022). Transitioning to clean-label alternatives requires careful consideration of reformulation impacts on product attributes and collaboration with ingredient suppliers to meet consumer demands ~~(“https://www.food-safety.com/articles/6736-clean-label-advances-in-meat-food-protection ,” 2023~~)

Bacteriophage therapy: an effective tool to produce clean-label food and dairy products

ListShield, EcoShield, Listex P100, and other bacteriophage preparations are certified for clean-label processing across the EU, Australia, Israel, the US, Canada, Switzerland, and New Zealand. In the US, bacteriophages have GRAS certification from the FDA and are often certified organic. ListShield (Intralytix) targets L. monocytogenes and was approved by the FDA and FSIS in 2006 and re-approved as GRAS in 2014 for use in chicken and RTE meats, showing effectiveness against 170 strains of L. monocytogenes. EcoShield (Intralytix), a cocktail of three phages targeting E. coli O157

, was FDA-approved in 2011. SalmoFresh (Intralytix), a mix of six Salmonella-targeting phages, received GRAS status in 2013. Listex P100 (Micreos) targets L. monocytogenes and was granted GRAS certification by the FDA in 2006. Stafal is effective against biofilms from methicillin-resistant S. aureus, and ShigaShield (Intralytix) received FDA GRAS approval for controlling Shigella, benefiting food safety for the military and travelers(“https://phageguard.com/antimicrobials-for-clean-labels/,” 2023).

Clean-label foods in the market

Even though many breakfast bowls of cereal have a clean label, children's cereals may contain artificial colors and flavours to achieve the flavor and colour intensity that appeals to children. Major morning cereal manufacturers are increasingly removing artificial colors and flavours to meet the demands of consumers concerned about them. ~~(“https://www.thinkusadairy.org/resources-and-insights/resources-and-insights/application-and-technical-materials/technical-report-dairy-solutions-for-clean-label-applications,” 2023~~).

Foodservice brands are also embracing clean eating. Panera Bread was an early adopter, unveiling 2016 its no-no list and Food Promise, which called for only 'clean' ingredients. Clif Bar & Company, GoMacroLLC, and Manitoba Harvest Hemp Foods are three notable clean-label bar brands. Clean-label chemicals like the FortiumRVC, a rosemary and ascorbic acid blend that improves the shelf life of snack goods, have been created by companies like Kemin. Consumers have been drawn to kettle chips, such as Herr's kettle chips, since the ingredients are simpler, demonstrating that a clean label is not just about health but also about simpler labeling.

Challenges and limitations hindering the implementation of clean label technologies

The clean-label movement faces challenges, including the functionality of natural alternatives to preservatives and their impact on food safety and sensory qualities. For example, essential oils may replace conventional preservatives, but their effects need thorough testing. Removing certain ingredients, like emulsifiers in beverages, can alter the product's appearance and taste. Costs are also higher due to testing, certification, and ingredient prices, though this can be justified for premium products. The food industry is responding to consumer demand for "cleaner" products (Asioli et al., 2017).

Commercial and regulatory requirements of clean label

While food safety plans have always focused on microbial contaminants, the Food Safety Modernization Act identifies chemical hazards, including heavy metals and pesticides, as factors that food producers must now consider. As explained in her presentation, "Chemical Risk Assessment: A Tool for Determining Customized Contaminant Programs," prepared for the 2020 Clean Label Conference, speaker Grace Bandong, MSc, Global Scientific Strategy Leader, Contaminants, Eurofins Food Integrity, and Innovations, explained that chemicals in foods are a problem ~~("https://cleanlabel.globalfoodforums.com/download/2020-clean-label-post-conference-magazine/," 2023~~).

Clean label certificates are provided by some non-governmental and private organizations, that have their clean label certification marks. These certification marks demonstrate a systematic approach for evaluating clean label claims, which keeps the product developer on their toes regarding the product label. In the industry, several trademarks are already in use. (Figure: Certificate logos for the clean label). International Center for Integrated Systems (ICIS), Clean Label Project Certification, Brisan Ingredients, Inc.

Several requirements for goods to be certified C.L.E.A.N. were identified by the International Center for Integrated Systems (ICIS).

- They should be "Aware." The conscious aspect was represented by the need that the product be completely safe (for a score of 0 or 25)
- To receive a score between 0 and 20, they must be "Live," meaning that most components must be organic.
- They should be "Ethical" in the sense that the ingredients must be 100% non-GMO (for a score of 0 or 25)
- They should be "Active." The level of bioavailability of the product's mix of chemicals was established using a bioinformatics technique now available by the CytoSolve® technology, and the name "Active" was coined. This aspect's score can range from 0 to 20.
- They should be "Nourishing." The Aggregate Nutrient Density Index (ANDI) nutritional score of the combination of ingredients, normalized between 0 and 10, was used to determine this.

The Steps to get C.L.E.A.N. Certification by ICIS are as follows:

The certification process involves three steps-

1. Manufacturer providing details on products, ingredients, processing steps, and supporting paperwork.
2. key analyses are performed:
    a. Determine bioavailability scores of ingredients in your products
    b. Check for safety and minimally processed criteria in the paperwork
    c. Calculate ANDI and Organic Score

Documentation for Safety Criteria comprises HACCP Plan/Audit Report/GMP Report, registration of the food processing facility with the Food and Drug Administration (FDA), Certificate of Analysis for each of the products, Post-Packaging Product Shelf-Life testing report (OR) and Expected Shelf Life of each product as an affidavit in the letterhead, however, documentation for Minimally Processed Criteria comprises Organic Certification, Non-GMO Certification and confirmation on if any of the ingredients were flash-pasteurized above 212° F.

3. Add up the results and ensure that the products are eligible for certification if they score 80 or more.

The clean label project is a non-profit structure dedicated to consumer product labeling that promotes health and transparency. Its goal is to educate customers so that they may make informed purchasing decisions every time they go shopping. This is performed by identifying toxins in consumer products using scientific data and sharing that knowledge with consumers. The Clean Label Project uses a similar certification technique. They buy products at the store, test them for purity (pesticide residues, heavy metals, and plasticizers, for example), and compare the results to high-risk substances on the Proposition 65 list of the California Environmental Health Hazard Assessment Office. If the product is found to adhere to this, it is competent for Clean Label Project Certification—validation of food safety certifications such as HACCP, GFSI, etc. The Go Clean Label certification consists of 4 steps submitting the required paperwork, signing the licence agreement, getting a Go Clean label official evaluation, and using the brand.

Marketing and commercial strategies to increase clean label awareness

According to shopper research company Nailbiter, 1 out of 6 customers mention that the ingredients are a reason to buy a product. Consumers are much more vigilant about the content of the products they buy; they look at ingredient lists from different angles: simplicity, transparency, clarity, and familiarity (“https://insights.figlobal.com/report-downloads/clean-label-2020-guide-evolving-trend-report ,” 2023).
Consumers are more interested in what is in the food they purchase. Survey data from Euromonitor has found that a quarter of consumers in France closely read the label of food and drink before consuming - in the UK, the figure is 19%. As a consequence, major food brands are looking to reduce the number of ingredients they use or to substitute unfamiliar-sounding ingredients with easy to recognize ones (“https://insights.figlobal.com/report-downloads/clean-label-2020-guide-evolving-trend-report ,” 2023).
Organic food items are widely acknowledged as one of the fastest-growing categories of the food business in several nations worldwide (Arbenz, Willer, Lernoud, Huber, &Amarjit, 2015; Willer &Lernoud, 2017). Organic agriculture is a type of farming that promotes soil, ecological, and human health. Instead of using harmful inputs, it relies on biological processes, biodiversity, and cycles tailored to local conditions. Organic agriculture is built on health, ecological, fairness, and care ideals (Arbenz, Willer, Lernoud, Huber, &Amarjit, 2015; Asioli, 2017).

Factors influencing buying behavior of consumers towards clean label

1. Socio-cultural factors
   - Consumer views and purchasing behavior are heavily influenced by personal conventions, ideological convictions, and ethical principles
   - Knowledge of natural product legal definition - Providing additional data about the functional meaning of the natural label improves consumer attitudes.
   - Egocentric attributes, such as health and taste
   - Life stability - in terms of a more sensible and caring attitude towards one’s own life, has a strong, positive outcome on perceived fundamental organic food quality elements.
   - Participation in cultural events influences buying organic products in a beneficial way.
   - The level of consumer uncertainty and distrust in organic certification, which has a detrimental impact on consumer purchasing behavior.
2. Intrinsic product characteristics
   - Nutritional properties - Organic foods were thought to have greater nutritive value and fewer calories by consumers than those without the organic label.
   - Health-promoting effects - Organic food products are seen as healthier and safer by consumers and an investment in their health.
   - Sensory characteristics.
   - Presence of fresh or raw components.
   - Degree to which a product has been processed – highly processed foods and manipulation hurt consumer perception.
   - Absence of negative characteristics such as food additives, human manipulation, etc promoted consumer buying tendency.
3. Extrinsic product characteristics
   - Product sustainability - Conservation of biodiversity and natural resources, as well as reduced energy usage.
   - Packaging – functional signals such as tags, emblems, or assertions and emotional impacts such as colors, shapes, and graphics affect customer behavior.
   - Labels and certification - for recognition of organic products and to instill faith in its credibility features.
   - Health claims – Occasional organic customers tend to consider items carrying health claims.
   - Higher price – Higher prices considered as quality indicator, and premium prices for such products are accepted.
4. Biological and physiological factors
   - Gender – Women are more likely than men to purchase organic food since they are the primary food shoppers, and they are more knowledgeable and sensible about food safety and health issues than men
   - Age – Younger customers are more likely to buy organic food.
5. Psychological factors

- Modern health worries – - The widespread use of pesticides, hormones, and antibiotics in food processing causes health concerns, leading to a desire for organic food.
- Risk perceptions – Risk perceptions of chemicals in food are positively associated with a preference for clean-label foods.

6. Situational Factors
   - Product availability – deficiency of product demotes consumers
   - High cost – higher prices denote a main deterrent for purchasing organic foods
   - Retail outlets (Expected taste and brand trust) - farmers' markets and self-production items are seen as customers' primary sources/locations for acquiring uncertified organic food.

In 2017, 62% of U.S. consumers believed that fewer ingredients indicate a healthier food, up from 55% in 2016 (Mintel). Clean and simple claims are perceived as healthier, and food manufacturers are increasingly moving towards clean-label products. Ingredient suppliers are developing clean-label ingredients to replace artificial additives, balancing sensory quality, cost, and shelf life (Rousset). The global clean-label ingredients market is projected to reach $51.14 billion by 2024, growing at a CAGR of 6.75% (Global Clean Label Ingredients Market Trends and Forecasts). Clean-label food sales were $165 billion in 2015, with $62 billion from North America, potentially reaching $180 billion by 2020 (Wang & Adhikari, 2017). By 2013, 27% of new packaged food products in Europe featured clean labels (Asioli, 2017; Nutraceutical Business Review, 2023). Consumers now demand more natural ingredients, transparency in manufacturing, and sustainable sourcing. Creating clean-label products involves maintaining sensory profiles, price, functionality, and shelf life while ensuring ingredient transparency. Nestlé's strategy for portfolio renovation includes: 1) Gaining consumer insights on valued and rejected ingredients, 2) Assessing product reformulation needs, 3) Identifying replacement solutions, and 4) Implementing these solutions (Rousset).

Conclusion

Clean-label has become mainstream, with a growing demand for simple ingredient lists and recognizable components. Consumers increasingly seek clean-label alternatives to chemical preservatives to extend shelf life without artificial additives, while also focusing on reducing food waste. Spoiled meat remains a significant public health issue, driving the need for cost-effective clean-label solutions to enhance safety and longevity. Effective clean-label products must feature clear, simple packaging communication about their "clean" attributes. Beyond being "clean," these products should also offer additional benefits such as convenience, unique flavors, or enhanced functionality. Many new clean-by-design products are emerging, particularly in the premium range, but renovating core products to meet clean-label expectations remains challenging.

Comment [T14]: Highlight any market growth projections for the clean-label foods

Comment [T15]: Ok fine, and what do governments think and say about that?

Comment [T16]: Call for action, by policymakers and manufacturers

Comment [T17]: Also, focus on practical recommendations. And what are the future research directions? Connect to broader implications

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