Revolutionizing Food Quality and Safety: Recent Advances in Clean-Label Technology

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ABSTRACT

The rising incidence of foodborne illnesses and scandals, coupled with heightened consumer awareness of the negative impacts of artificial ingredients, has driven a significant shift toward clean label products—foods defined by simple, recognizable ingredients and minimal processing. This review provides a comprehensive analysis of clean label technology, exploring its historical evolution, key definitions, applications, and current market trends. It also examines consumer behavior toward clean label products and the marketing strategies employed by brands to foster transparency. Drawing on 61 peer-reviewed references published between 2020 and 2024, this narrative review integrates findings from academic research and industry reports to offer a holistic perspective on clean label practices. Key challenges hindering the implementation of clean label technologies, such as the effectiveness of natural preservatives, the impact of ingredient removal on sensory qualities, and the financial implications of transitioning to clean label practices, are discussed. The findings underscore the necessity for the food industry to address these challenges to ensure the sustained growth of the clean label movement, aligning with consumer preferences for healthier and more transparent food options.

Keywords: Clean label; Clean label ingredients; Natural ingredients, Food safety, Consumer behavior, Ingredient labeling

1. INTRODUCTION

In recent years, heightened awareness of food safety and quality issues, driven by numerous foodborne illness outbreaks and scandals, has significantly influenced consumer preferences. Increasing concerns over the potential harmful effects of artificial ingredients have led to a marked shift toward organic and natural foods, fostering a burgeoning demand for "clean label" products. Clean label refers to foods that are characterized by simple, recognizable ingredients and minimal processing, aligning with consumers' desire for transparency and healthfulness(48). This review aims to provide a comprehensive analysis of clean label technology, exploring its historical development, key definitions, applications, challenges, and market trends. The purpose is to examine the current landscape of clean label products, highlight the innovations driving this trend, and address the limitations hindering its widespread implementation. The study also aims to assess consumer behavior toward clean label products and the marketing strategies used by brands to promote transparency.This narrative review incorporates **61** peer-reviewed references collected between 2020 and 2024, offering an up-to-date perspective on clean label technology. The sources were obtained from a range of academic databases, including PubMed, ScienceDirect, and Google Scholar, as well as **industry reports, blogs, news articles, and food-related publications**. This diverse selection ensures a comprehensive understanding of both academic research and current industry practices. By combining peer-reviewed research with reports and insights from non-academic sources, the review captures both the scientific developments and practical market trends shaping the clean label movement.

2. Evolution of Clean Label Technology

The clean label trend first emerged in the UK in the 1980s when consumers grew aware of the negative health impacts associated with E-numbers on food labels, resulting in their exclusion. Over the last two decades, the movement has gained traction globally, particularly in Europe and the US (22). Clean label interpretations vary by region and demographic. For example, Western Europe focuses on fewer ingredients and no artificial additives, while in Russia, it is closely associated with non-genetically engineered foods. A 2017 survey found generational differences in understanding clean labels: Boomers prioritize reducing 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).

There is no official regulatory definition for "clean labels," but the term generally refers to foods made with simple, minimally processed, and easily recognizable ingredients, without artificial additives, preservatives, or synthetic chemicals (41,22). 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-genetically engineeredingredients and transparency about what is in their food.Different regions have varying standards for clean labels.

3. Key Attributes of Clean Label Products

Clean label products are characterized by a set of attributes that prioritize transparency, simplicity, and the use of natural ingredients. Although there is no official regulatory definition for clean label foods, the following attributes are commonly associated with them:

- 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(14,15,25,57), These key attributes define what it means for a product to have a clean label, focusing on natural, simple, and recognizable ingredients while also emphasizing transparency and ethical practices.

4. Difference between natural, organic, and clean label foods

While "natural," "organic," and "clean label" are often used interchangeably by consumers, these terms have distinct meanings and regulatory implications. Understanding these differences is essential for both consumers and manufacturers aiming to navigate the growing demand for transparency and healthy eating.

4.1 Natural Foods

The term "natural" is widely used on food packaging, but its definition can be ambiguous. The **U.S. Food and Drug Administration (USFDA)** does not have a formal rule for "natural" labeling, but it permits the use of the term if the food does not contain artificial flavors, colors, or synthetic substances. However, the USFDA's policy does not cover production methods, meaning that foods labeled as "natural" may still be produced using**pesticides, Genetically modified organisms (GMOs), Irradiation etc.**In contrast, the **U.S. Department of Agriculture (USDA)** defines "natural" foods as those that are minimally processed and free from artificial additives and preservatives. Despite these guidelines, there is no strict regulatory framework governing "natural" labels, leading to varying interpretations across the industry.

4.2 Organic Foods

"Organic" foods are strictly regulated by the **USDA's National Organic Program (NOP)**, which oversees both pre- and post-harvest processes. To be labeled as organic, foods must meet the following criteria:

- No genetically engineered ingredients (GMOs)
- No synthetic pesticides or chemical fertilizers
- No irradiation or sewage sludge
- Adherence to strict animal welfare standards, if animal products are involved

Certified organic foods are verified through audits and inspections, ensuring compliance with USDA standards. However, some organic-approved ingredients, such as **xanthan gum**, might not meet clean label standards, as clean label products typically avoid even organic additives that are unfamiliar to consumers.

4.3 Clean Label Foods

Unlike "natural" and "organic," the term "clean label" is not officially regulated by any governmental agency. Instead, clean label products are guided by industry standards and consumer expectations for simplicity and transparency. Clean label foods emphasize:

- **Simple, recognizable ingredients** (akin to "grandma's pantry")
- Minimal processing
- Avoidance of artificial additives, synthetic preservatives, and complex chemicals

While many consumers associate clean label with "natural" and "organic," there are key differences. For example, some ingredients allowed in natural or organic foods may not be accepted under clean label standards. Compounds such as **potassium bicarbonate, ammonium bicarbonate, and calcium hydroxide**, which are permitted in organic foods, may not meet clean label expectations. Similarly, natural colorants like **carotenoids** and **anthocyanins** are allowed in clean label products but not in foods labeled as "natural."(23,27,55)

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 (34). 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. (51)

5. 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. Here's a breakdown of some commonly used clean-label ingredients and their applications:

6.1 Antimicrobials and preservatives

Consumers today prefer foods free from artificial preservatives, pushing the industry, particularly meat 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 (11,12).Clean label development is a balancing act between ingredient effectiveness and consumer preferences, demanding constant innovation and research.

6.1.1 Natural alternatives

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. (17).

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.(4,5).

5.1.2 Plant and animal basedsources

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 label trend in food production (14). 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 apple, banana, pomegranate, mango, sweet lime, orange, 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

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 allow 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 safe status approved by government agencies to be used by food industries (1).

Eggs and milk are potential animal sources of enzymes such as lysozyme and lactoferrin, having antibacterial effect effects (54). 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.

6.1.3Microbial sources

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.These substances are generally recognized as safe and are not active or toxic to eukaryotic cells. Once ingested, they are inactivated by digestive proteases, thus having minimal impact on the gut microbiota. They are typically pH and heat tolerant, offering a broad antimicrobial spectrum effective against a wide range of food-borne pathogens and spoilage bacteria. Their bactericidal action targets the bacterial cytoplasmic membrane without causing cross-resistance to antibiotics. Importantly, they do not affect the sensory qualities of food, ensuring they are safe and acceptable for human consumption.(38,61))

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.(40).

6.3Clean 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 (**26**). 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.

Inulin is a water soluble storage 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 had been added to biscuits to a level of 15% to attain fat substitute. These findings are promising for the use of inulin as a clean-label ingredient.(35)

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.(39)

Maltodextrin is a partial hydrolysis product of starch with less than 20 dextrose equivalent. Maltodextrin used as a fat replacer has a dextrose equivalent of less than 10—wheat starch in low-fat hamburger formulation (28,56)Pumpkin seed kernel flour in beef meatballs **(45)**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.

6.4 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 (3).

6.4.1 Hydrocolloids

There are many sources for clean-label substances. However, the food sector uses hydrocolloids most frequently (34). 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 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 animal skin and bones, bovine, fish and pigs. Acid-treated and alkali treated collagen are distinguished as type-A and type-B, respectively. When most 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 has 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.

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 label foods, 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 (13,15)

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 were 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 bears semblance to the full-fat sponge cake (30).

6.4.2. Unstructured, random proteins

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 disintegration of the micelle structure. To improve the solubility properties of this acid, casein neutralization is preceded 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.(52)

6.4.3 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 depends upon the denaturation degree. In simple terms, the denaturation of globular protein is a prerequisite in most cases to activate the desired functionality.(43)

6.4.4Complex 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 (3).
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).(44.)

6.4.5Gluten

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. Gluten, particularly wheat gluten, is sometimes considered a clean-label ingredient due to its natural origin and minimal processing. As a protein derived from wheat, gluten provides several functional benefits in food formulations. It helps with dough elasticity and structure in baked goods, making it essential for products like bread and pizza crusts. Gluten contributes to the texture, chewiness, and rise of the dough, which makes it an important ingredient for achieving desirable product quality without the need for artificial additives. In clean-label products, gluten is used as a natural alternative to chemically modified ingredients, particularly for its role in replacing synthetic stabilizers, thickeners, or emulsifiers. Its inclusion aligns with consumer demand for ingredients that are familiar, easy to recognize, and minimally processed. However, gluten's use is increasingly scrutinized due to rising consumer awareness around gluten intolerance and celiac disease, pushing manufacturers to offer gluten-free alternatives.(58,47)

6.5 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(4,5).

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 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 (4).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 (10,17).

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 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 protein WPC, 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- clean label carbohydrates(16,27).

6. Application of clean label substitutes and ingredients in dairy products

Clean label substitutes and ingredients have been increasingly applied to dairy products like yogurt, butter, and ice cream, offering healthier alternatives while maintaining desirable texture and functionality. In yogurt, clean-label trends have focused on replacing synthetic additives with natural ingredients. For example, fat-free yogurt, traditionally made with modified food starch and hydrocolloids for smoothness, now utilizes heat-modified whey protein and buttermilk protein concentrates to replace fat **(53)**. Whey proteins have been shown to increase viscosity and reduce syneresis, lessening the reliance on starches and hydrocolloids **(33)**. Additionally, whey proteins enhance water-holding capacity and provide a smoother texture compared to caseinates (**1**). In Greek-style yogurts, micellar casein, milk protein concentrate (MPC), milk protein isolates (MPI), whey protein concentrate (WPC), and whey protein isolates (WPI) are used to achieve high protein content. For instance, a micellar casein concentrate with 58% protein produced a yogurt with physical properties similar to those made with other casein-rich products like MPC or MPI (**24**).In butter, artificial flavors have been replaced by concentrated dairy products, such as buttermilk and yeast-based extracts, aligning with clean label principles. This change enhances flavor naturally while eliminating synthetic ingredients.In ice cream, clean-label ingredients like milk and whey proteins are used to replace fat, stabilize the product, and enhance protein content. U.S. ice cream standards require a minimum of 10% milk fat and 10% non-fat milk solids, and whey products can constitute up to 25% of nonfat milk solids. Optional dairy ingredients like UF milk, MPC, and MPI improve texture, body, and heat-shock stability (46). Reduced-calcium milk protein concentrate (RCMPC), which has better cold solubility than MPC, functions as a natural emulsifier. Whey protein concentrate (WPC) and milk protein concentrate (MPC) have been used extensively for fat replacement, with WPC showing superior performance in ice cream (46). Additionally, blends of whey protein phospholipid concentrate and lactose permeate have helped improve the texture of ice creams by reducing fat destabilization and maintaining ice crystal size. These clean-label innovations not only support healthier product formulations but also meet consumer demands for simple and recognizable ingredients (27).

7. Application of clean label substitutes and ingredients in meat products

Raw and cooked meat products, including ready-to-eat varieties, are highly perishable due to microbial growth, active enzymes, and compounds susceptible to oxidation, which can negatively impact sensory attributes such as color and flavor. Traditional preservatives like sodium nitrates and nitrites, though effective in preserving color and flavor, are increasingly rejected by consumers, particularly older adults, due to their association with potential health risks. This has led to a growing demand for clean-label alternatives. Meat products marketed with "no preservatives" or natural claims are seeing an annual growth rate of 5.2%, while those using chemical preservatives show stagnant growth. Emerging clean-label claims, such as "No added nitrites/nitrates except those naturally occurring in celery," are becoming increasingly popular. In the $84 billion global meat market, clean-label alternatives are essential to addressing spoilage and waste reduction. Recent research has identified plant-based additives with antibacterial properties, such as chia seeds and high-nitrate vegetables like celery, as effective substitutes for nitrites in fermented meats (37). However, transitioning to these clean-label alternatives requires careful reformulation and collaboration with ingredient suppliers to ensure that product quality and consumer demands are met **(34).**

8. Bacteriophage as a clean label preservative

Bacteriophages, or phages, are viruses that specifically target and kill bacteria, offering a promising clean-label alternative for preserving food. As natural, non-toxic agents, bacteriophages are highly selective, only attacking harmful bacterial species without disturbing the beneficial microbiota, making them suitable for clean-label applications. 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 (15,49)

9. Clean-label foods in the market

Many breakfast cereals now carry clean-label status, though children's cereals may still include artificial colors and flavors to achieve an appealing intensity. However, major cereal manufacturers are increasingly removing these artificial ingredients to satisfy consumers' growing concerns. Food service brands are also jumping on the clean-label trend. Panera Bread, for instance, launched its "No-No List" and Food Promise in 2016, pledging to use only clean ingredients. Other notable clean-label brands include Clif Bar & Company, GoMacro LLC, and Manitoba Harvest Hemp Foods, which focus on simple, natural ingredients in their products.

10. Moreover, clean-label preservatives are being developed for processed foods. For example, Kemin has introduced Fortium RVC, a blend of rosemary and ascorbic acid, which extends the shelf life of snacks. Clean-label snack items like Herr's kettle chips, with their simpler ingredients, show that the appeal of clean-label foods extends beyond health to a desire for transparency and minimalism in food labeling. The shift toward clean-label products reflects consumers' increasing desire for simplicity and healthier choices.(**25,22,50)Factors influencing buying behavior of consumers towards clean label products**

The growing consumer interest in clean label products has shifted the food industry towards transparency and natural ingredients. Various factors influence purchasing behavior, which can be categorized into socio-cultural, intrinsic, extrinsic, biological, psychological, and situational elements.

11.1 Socio-Cultural Factors

Consumer views and purchasing behavior are significantly shaped by personal beliefs, ethical principles, and cultural context. Knowledge about the legal definitions of "natural" products enhances consumer attitudes, while egocentric attributes such as health and taste play crucial roles. Life stability fosters a caring approach toward personal health, positively impacting perceptions of organic food quality. Moreover, cultural participation can favorably influence the purchasing of organic products, although uncertainty and distrust regarding organic certification may hinder buying behavior.

11.2 Intrinsic Product Characteristics

Intrinsic factors such as nutritional properties and perceived health benefits are pivotal in consumer preferences. Many consumers associate organic foods with greater nutritional value and fewer calories. Additionally, organic products are viewed as healthier and safer, constituting an investment in personal health. Sensory characteristics, the presence of fresh ingredients, and the degree of processing also affect consumer perceptions. The absence of negative traits—such as artificial additives—tends to promote purchasing tendencies.

11.3 Extrinsic Product Characteristics

Extrinsic factors also play a significant role in consumer choices. Sustainability practices, such as biodiversity conservation and reduced energy usage, resonate with environmentally conscious consumers. Packaging—encompassing functional signals and emotional cues—affects consumer behavior. Labels and certifications lend credibility and recognition to organic products, while health claims further attract occasional organic buyers. Interestingly, higher prices are often accepted as indicators of quality.

11.4 Biological and Physiological Factors

Demographic factors like gender and age influence the purchasing of organic foods. Women, often the primary food shoppers, show a higher likelihood of buying organic due to greater awareness of food safety issues. Additionally, younger consumers tend to favor organic options.

11.5 Psychological Factors

Modern health concerns about pesticide and antibiotic use in food processing contribute to the demand for organic products. Perceptions of risk associated with chemicals in food are positively correlated with preferences for clean label foods.

11.6 Situational Factors

Situational aspects, such as product availability and pricing, heavily influence consumer behavior. Limited product access can deter purchases, while high costs are a significant barrier to buying organic foods. Retail settings, including farmers' markets, are preferred locations for consumers seeking organic products.

11. Marketing and commercial strategies to increase clean label awareness

Research by Nailbiter indicates that one in six consumers cites ingredient transparency as a significant factor influencing their purchasing decisions. Shoppers are increasingly scrutinizing product labels for simplicity, transparency, clarity, and familiarity in the ingredients they choose. According to Euromonitor, approximately 25% of consumers in France and 19% in the UK carefully examine food and drink labels before consumption. This growing awareness has prompted major food brands to streamline their ingredient lists, opting for recognizable substitutes for complex or unfamiliar ingredients. (15)
To effectively market clean label products, companies must align their strategies with these consumer priorities, emphasizing the integrity of ingredients and the health benefits associated with organic and clean label offerings. By doing so, brands can not only increase awareness but also build trust and loyalty among increasingly conscientious consumers. **(20,22)**

13. Commercial and regulatory requirements of clean label

Clean label certifications are issued by various non-governmental and private organizations, offering certification marks that signify a thorough evaluation of clean label claims. These marks ensure product developers remain vigilant about their labeling practices. Several certification trademarks, such as those from the International Center for Integrated Systems (ICIS), Clean Label Project Certification, and Brisan Ingredients, Inc., are already widely used in the industry.

ICIS identified several requirements for goods to be certified as C.L.E.A.N. These include:

- Aware: The product must be completely safe, earning a score of either 0 or 25.
- Live: Most of the components must be organic, scoring between 0 and 20.
- Ethical: All ingredients must be 100% non-genetically engineered, with a score of either 0 or 25.
- Active: The product's bioavailability is evaluated using CytoSolve® technology, with scores ranging from 0 to 20.
- Nourishing: The nutritional quality is assessed using the Aggregate Nutrient Density Index (ANDI), with a normalized score between 0 and 10.

The process for obtaining C.L.E.A.N. Certification from the International Center for Integrated Systems (ICIS) involves three key steps:

1. Submission of Product Details: Manufacturers must provide information about their products, ingredients, processing methods, and relevant supporting documents.
2. Key Analyses:
    - Bioavailability Scores: The bioavailability of ingredients is evaluated.

- Safety and Minimal Processing Criteria: Documentation is checked for safety compliance, including HACCP Plan, FDA registration, Certificates of Analysis, shelf-life reports, and organic and non-GMO certifications. Additionally, it's confirmed whether any ingredients were flash-pasteurized above 212°F.
- ANDI and Organic Score Calculation: Nutritional and organic scores are calculated.

3. Scoring: The results are compiled, and products must score 80 or more to qualify for certification.

Additionally, the Clean Label Project, a non-profit focused on product transparency, follows a similar approach. It tests products for purity, checking for contaminants like pesticides and heavy metals. Products are compared against the California Proposition 65 high-risk substances list. If compliant, the product qualifies for Clean Label Project Certification, ensuring adherence to safety certifications such as HACCP and GFSI.

For ‘Go Clean Label Certification,, the process involves four steps: submitting required documentation, signing a license agreement, undergoing an official evaluation, and obtaining certification to use the brand.

14. Challenges and limitations hindering the implementation of clean label technologies

The clean label movement encounters several obstacles that hinder the widespread adoption of clean label technologies. One primary challenge is the functionality of natural alternatives to traditional preservatives, which often requires extensive testing to ensure they maintain food safety and sensory qualities. For instance, while essential oils can be employed as replacements for conventional preservatives, their effectiveness and potential interactions must be thoroughly assessed. Another significant limitation arises when removing certain ingredients, such as emulsifiers in beverages, which can lead to noticeable changes in the product's appearance and taste. This alteration can impact consumer acceptance and marketability. Additionally, the financial implications of transitioning to clean label practices cannot be overlooked. The costs associated with testing, certification, and sourcing higher-quality natural ingredients can be substantial. Although these expenses may be justifiable for premium products, they can present barriers for smaller producers or those operating on tighter margins. Despite these challenges, the food industry is actively responding to consumer demand for "cleaner" products, as highlighted by (22). Addressing these obstacles will be crucial for the continued growth and success of the clean label movement.

15. Conclusion

In conclusion, the clean label movement represents a transformative shift in the food industry, driven by consumer demand for transparency, safety, and natural ingredients. As awareness of foodborne illnesses and artificial additives grows, consumers increasingly prioritize products that are simple and recognizable. Despite the challenges posed by the functionality of natural alternatives, higher costs, and potential impacts on sensory qualities, the industry's response to these demands indicates a promising future for clean label products. Continued innovation in clean label technologies, combined with effective marketing strategies, will be crucial for meeting consumer expectations and overcoming existing limitations. By fostering collaboration between producers, researchers, and regulatory bodies, the clean label movement can not only enhance consumer trust but also contribute to a healthier food landscape. Future research should focus on developing cost-effective clean label alternatives and addressing the regulatory hurdles that currently impede widespread adoption, ensuring that the clean label promise is accessible to all consumers.

COMPETING INTERESTS

Thereisnoconflictofinterest.

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