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Sustainable Innovation in Food Sauce Formulation: A Scoping Review of Challenges, Trends, and Market Drivers

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***Abstract*— Food sauces constitute a diverse category of processed food products that significantly contribute to the sensory and nutritional qualities of meals. However, consumers are increasingly concerned not only with nutritional and sensory attributes but also with the environmental implications of food production and consumption. In this context, eco-friendly innovation plays a key role in meeting evolving consumer expectations while contributing to sustainable food systems. This study aims to explore recent developments in the food sauce sector, with a particular focus on formulation strategies, ingredient selection, functional and nutritional improvements, associated challenges, and emerging market trends. A scoping review methodology was employed to map and synthesize the existing literature on recent advances in clean-label formulations, sustainable ingredient utilization, and eco-friendly production practices. Particular attention was given to the incorporation of dietary fibers, plant proteins, natural antioxidants, and bioactive compounds as alternatives to conventional ingredients. The reviewed literature indicates that agro-industrial by-products can provide valuable nutrients and bioactive phytochemicals and therefore represent promising resources for innovative sauce formulations. The choice of ingredients and processing technologies can substantially influence physicochemical, nutritional, functional, and sensory properties, thereby affecting product quality and consumer acceptance. Major challenges identified across the sector, include maintaining product stability and shelf life while reducing reliance on synthetic additives and ensuring consistent sensory quality. Current market trends further indicate growing consumer interest in clean-label, plant-based, and sustainably produced foods, thereby stimulating innovation in sauce formulation and processing. However, consumer awareness of the potential value of agro-industrial by-products remains limited, which may constrain their market adoption. Increasing consumer awareness, improving communication regarding upcycled ingredients, and integrating sustainability considerations into product development may therefore facilitate the transition toward more circular sauce production. Overall, by-product valorization and upcycling offer promising eco-innovative pathways for transforming underutilized resources into value-added ingredients for sauce production. Furthermore, multidisciplinary collaboration, stakeholder participation, and supportive policy frameworks are essential for promoting meaningful and equitable sustainability transitions across the sauce value chain.**

***Keywords*— Food sauces, agro-industrial by-products, clean-label formulation, eco-innovation, nutritional quality, sensory quality, consumer acceptance, sustainability.**

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I. INTRODUCTION

The increasing consumer demand for healthier foods, associated with environmental concerns, has encouraged the food industry to explore the replacement of animal-derived ingredients with plant-based alternatives [1]. Within the sauce sector, this transition is accompanied by rising demand for functional, clean-label, nutritionally improved, and environmentally responsible products. Globally, consumers are actively seeking foods containing simple, recognizable, and natural ingredients. This growing awareness has driven the food industry to reconsider traditional and natural food-processing approaches, contributing to the development of the clean-label movement [2]. Understanding consumer needs, expectations, and perceptions is therefore essential when developing innovative food products intended to support more sustainable consumption patterns [3], [4].

Contemporary sauce products encompass a much broader range of categories, including sweet, sour, spicy, savory, and composite formulations. Moreover, the growing interest in international cuisines and novel food experiences is contributing to demand for new flavors; a multinational survey reported that 42% of participants were interested in seeking novel flavors and food experiences [5].

As a result, recent research has increasingly focused on the development of vegan and plant-based sauce formulations. Plant proteins derived from pulses and legumes possess diverse functional properties, including water-holding capacity, fat binding, solubility, gelation, foaming, and emulsification, making them promising alternatives to animal-derived proteins in various food applications [6]. Proteins from faba bean, chickpea, and yellow split lentils have been shown to produce stable egg-free mayonnaise formulations with sensory properties comparable to those of egg-yolk mayonnaise [7].

These developments reflect a dual objective: responding to evolving consumer expectations for healthier, plant-based, and ethically perceived foods while simultaneously improving resource efficiency and environmental sustainability.

Accordingly, this study aims to map the current landscape of innovation in the food sauce sector. Particular attention is given to emerging technological and nutritional approaches, sustainable ingredient selection, clean-label formulation, agro-industrial by-product valorization, consumer acceptance, and market drivers. The review also identifies major challenges that may hinder the development and commercialization of more sustainable sauce products and discusses opportunities for future innovation.

II. METHODOLOGY

A scoping review approach was adopted to map and synthesize the existing literature on food sauces, with particular attention to eco-friendly innovation, market trends, formulation challenges, and factors influencing innovation and consumption. A literature search was conducted between February and July 2026, across multiple academic databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar, supplemented by relevant grey literature such as industry reports, policy documents, and market analyses.

Studies were included when they focused on food sauces or related condiment products and addressed at least one of the following dimensions: (i) consumer behavior and acceptance, (ii) technological or product innovation, (iii) nutritional or functional improvement, or (iv) sustainability and resource valorization.

The literature-selection process was structured around identification, screening, eligibility assessment, and inclusion, as summarized in Fig. 1.

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Fig. 1 Criteria used to identify relevant literature on food sauces

III. Results and Discussion

A. Challenges and Opportunities for Eco-Friendly Innovation in the Sauce Sector

Among sauces available on the local market, some formulations contain substantial amounts of added sugars or syrups, while commercial sauces may provide limited amounts of protein, dietary fiber, vitamins, and minerals [8]. These characteristics highlight the need for reformulation strategies capable of improving nutritional quality while maintaining desirable sensory and technological properties.

Considering these concerns, the sauce sector faces several challenges related to health, product quality, sustainability, processing, and consumer expectations. One of the major technological challenges is maintaining microbial safety and shelf stability, particularly for clean-label sauces formulated with fewer or no synthetic preservatives.

This challenge is illustrated by traditional products such as Thailand's chicken-rice sauce, which is characterized by a complex blend of chili, garlic, ginger, and fermented soy derivatives and is an important component of Khao Man Gai. Although such products have strong cultural and gastronomic value, their liquid form can present logistical challenges for commercialization beyond local markets, including relatively high packaging weight and volume, limited shelf life, and potential cold-chain requirements. Similar challenges can affect other traditional dipping sauces, including chili sauce [9] and fish sauce [10].

Converting liquid sauces into shelf-stable powdered forms represents one potential technological strategy for improving transportability, storage, and distribution. Powdered formulations can substantially reduce packaging volume and mass and may lower transportation and storage requirements while facilitating distribution without refrigeration. These approaches are consistent with the broader development of compact, shelf-stable, and reconstitutable food products [11]. However, drying may also affect flavor, color, bioactive compounds, texture, and reconstitution properties; therefore, process optimization remains essential. Fig. 2 summarizes the principal challenges identified in the literature.

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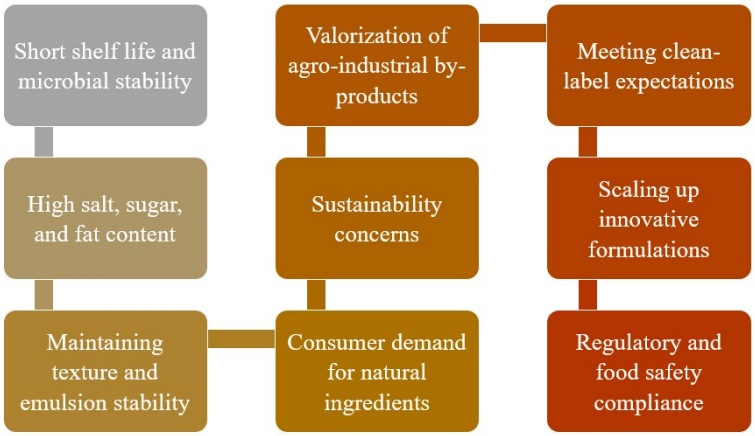


Fig. 2 Main challenges facing the sauce sector

To address some of these challenges, agro-industrial by-products represent an important and underutilized source of potentially functional and nutritionally valuable ingredients. For example, pepper seeds, which represent approximately 40–50% of the total pepper weight, are generated as a by-product of pepper processing. They have been reported to contain approximately 13.0–19.0% protein, 18–30% oil, and 40–65% total dietary fiber, in addition to various minerals and vitamins [12]. Despite this nutritional potential, a substantial proportion of pepper seeds is discarded because of the limited number of established applications [13]. The valorization of such by-products could therefore provide a dual opportunity: improving the nutritional and functional characteristics of sauces while reducing the environmental burden associated with the disposal of food-processing residues.

B. Emerging Trends and Market Drivers

Functionality, sustainability, simplicity, naturalness, plant-based formulation, and clean-label positioning are increasingly shaping innovation in the sauce sector. This evolution is driven by growing consumer awareness of the relationship between diet, health, environmental impacts, and food production practices.

Food fortification represents one potential approach for improving the nutritional contribution of food products. Studies have shown that food vehicles fortified with micronutrients can contribute to improvements in nutritional status among vulnerable population groups [14], [15]. Such evidence suggests that commonly consumed foods, including sauces and condiments, may offer opportunities for targeted nutritional improvement when formulation, dosage, stability, and consumer acceptance are appropriately considered.

Another major trend is green consumerism. Consumers' environmental values and attitudes toward sustainable foods can influence their purchasing decisions [16]. In parallel, evidence suggests that some consumers are willing to pay a premium for clean-label food products, although willingness to pay may vary according to product category, consumer characteristics, perceived benefits, and price sensitivity [17].

These trends indicate that successful innovation must simultaneously deliver acceptable taste, texture, appearance, convenience, affordability, safety, and credible sustainability benefits.

C. Towards Enhanced Awareness of By-Product Valorization Opportunities

The sauce sector represents a promising application area for incorporating agro-industrial by-products as functional ingredients, particularly in response to increasing raw-material costs and the need to diversify sustainable ingredient sources.

However, the technical feasibility of by-product incorporation does not necessarily guarantee market acceptance. Consumer perception remains a critical factor in the commercialization of upcycled food products.

Existing research indicates that consumers' knowledge and understanding of upcycled ingredients and circular food systems remain limited, which may restrict acceptance and purchase intentions [18].

This challenge highlights the importance of transparent communication, consumer education, and appropriate product positioning. When consumers understand the potential nutritional, environmental, and

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resource-efficiency benefits associated with by-product valorization, their willingness to accept such products may increase.

Overall, agro-industrial by-product valorization can be viewed not merely as a waste-management strategy but as a potential source of innovation and value creation within the sauce value chain (Table I).

TABLE I
POTENTIAL FUNCTIONALITY AND FOOD APPLICATIONS OF SELECTED FOOD BY-PRODUCTS [12], [13]

By-Product	Major Compounds	Potential Functionality	Possible Sauce Application	Main Limitation
Pepper seeds	Protein, oil, fiber	Emulsification, nutrition	Dips, dressings	Bitterness
Fruit pomace	Fiber, polyphenols	Antioxidant, texture	Tomato/fruit sauces	Color/flavor
Legume residues	Protein, fiber	Thickening, emulsification	Mayonnaise-type sauces	Off-flavor
Vegetable peels	Polyphenols, fiber	Antioxidant, color	Functional sauces	Consumer perception

IV. CONCLUSIONS

This scoping review highlights a clear transition in the food sauce sector toward healthier, cleaner-label, plant-based, functional, and more sustainable formulations. The literature indicates that plant proteins, dietary fibers, antioxidants, bioactive ingredients, and agro-industrial by-products offer promising opportunities for reformulating sauces and improving their nutritional and functional profiles.

Future research should focus on the systematic evaluation of sustainable ingredient sources, the safe and effective upcycling of agro-industrial by-products. Equally important is the need to improve consumer awareness and communication regarding the nutritional and environmental value of upcycled ingredients.

By combining technological innovation, consumer-centered design, by-product valorization, stakeholder collaboration, and supportive policy frameworks, the sauce sector can contribute to more circular and resilient food systems.

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