International Journal of Food Science and Nutrition
www.foodsciencejournal.com
ISSN: 2455-4898
Received: 06-07-2025, Accepted: 05-08-2025, Published: 20-08-2025
Volume 10, Issue 4, 2025, Page No. 63-67

Development of plant-based hard-boiled vegan eggs as an alternative to eggless diets

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Abstract

The rising demand for plant-based foods has led to the development of innovative alternatives to animal-derived products. This study focuses on the creation of a plant-based hard-boiled vegan egg, developed as an alternative for individuals following eggless diets due to health, ethical, or sustainability concerns. The vegan egg formulation comprises tofu, cashew nuts, agar, and other natural ingredients, designed to replicate the sensory and structural properties of conventional hard-boiled eggs. Sensory evaluations, conducted by semi-trained panelists, revealed that a treatment containing 75% tofu and 20% cashew nuts received the highest overall acceptability score of 8.28, demonstrating its successful resemblance to traditional eggs in taste, texture, and appearance. Nutritional analysis revealed that the vegan egg has a significantly lower fat content (1.38%) than conventional eggs and is cholesterol-free, aligning with health-conscious dietary needs. The product's protein content (6%) is lower compared to traditional eggs, but it still offers a balanced nutrient profile. The shelf life was found to be 5 days under refrigeration, posing challenges for further product development. This plant-based vegan egg contributes to the growing trend of sustainable, cruelty-free, and health-focused dietary options while addressing consumer demands for plant-based alternatives that provide similar nutritional and sensory qualities to animal-derived eggs.

Keywords: Plant-based, vegan egg, sustainable food, eggless diet

Introduction

The development of plant-based hard-boiled vegan eggs has emerged as a response to the rising demand for sustainable, ethical, and health-conscious alternatives to conventional eggs (Hatta *et al*., 2023) [5]. This demand is propelled by increasing awareness of the environmental consequences of animal agriculture, ethical considerations regarding animal care, and health hazards linked to cholesterol and allergens in conventional eggs. With the increasing adoption of plant-based diets among consumers, the food industry has developed novel ways to mimic the sensory and nutritional attributes of animal-derived goods (Jang and Lee, 2024) [6]. Plant-based eggs, made from raw materials such as pulses, legumes, cereals, or algae, offer a promising alternative to traditional eggs produced by hens or other avians (Nyambayo and Borusiak, 2024) [9]. These eggs offer various advantages over conventional eggs as they are made with natural components derived from plants. Furthermore, they are free of allergens and cholesterol which could prove advantageous for individuals who are allergic to albumin and egg proteins (Khalifa *et al*., 2025) [7] Plant-based eggs are resistant to animal and bird-related viruses, such as avian flu and salmonella, which can also be transmitted to humans. Besides, plant-based eggs provide a more reliable alternative to the egg market's severe price volatility (Skorbiansky and Saavoss, 2023) [11].

Companies and researchers have explored various plant proteins, starches, and natural flavor enhancers to develop products that satisfy both sensory expectations and nutritional requirements (Yano and Fu, 2022) [16]. The market for plant-based eggs is expanding rapidly, with projections indicating significant growth driven by health-conscious consumers, increased vegetarianism, and a shift toward sustainable food choices. For instance, global projections estimate the market will reach nearly $3.3 billion by 2031, underscoring its rising significance (Sandua, 2024) [12]. Some companies have successfully introduced liquid egg substitutes, demonstrating the potential for plant-based innovations. However, replicating the structural complexity of hard-boiled eggs, with distinct white and yolk layers, presents unique challenges. Achieving an appealing texture, flavor, and appearance in a sustainable and allergen-free formulation remains a significant hurdle (Khalifa *et al*., 2025) [7].

Despite these challenges, the demand for robust plant-based alternatives is apparent. This study seeks to fill this gap by creating a plant-based protein formulation that replicates the sensory characteristics, structural integrity, and nutritional composition of conventional hard-boiled eggs. This research enhances the broad goal of developing sustainable, cruelty-free dietary options by emphasizing innovation and consumer requirements, while also broadening the range of plant-based alternatives in the eggless food category.

Materials and methods

The study was carried out in the College of Food and Dairy Technology, Tamil Nadu Veterinary and Animal Sciences University, Koduveli, Alamathi, Chennai – 600052.

1. Preparation of hard-boiled vegan egg

To prepare a hard-boiled vegan egg, the egg white is crafted by blending tofu, agar powder, black salt, salt, boiled

cashew nuts, sugar, and jeera extract into a smooth and creamy mixture, ensuring no lumps for a cohesive structure and flavor. For the egg yolk, turmeric, nutritional yeast, and soy protein isolate are added to the blended egg white base and mixed thoroughly. The treatment details are listed as: T_1 –Treatment 1:75% Tofu, 0% cashew nut; T_2 – Treatment 2:75% tofu, 15% cashew nut; T_3 – Treatment 3:75% tofu, 20% cashew nut; T_4 – Treatment 4 75% tofu, 25% Cashew nut. The ratio of the ingredients is presented in table 1.

The prepared blend for the egg white is cooked for 15 minutes to eliminate the raw flavor of tofu and to activate the gelling properties of agar. The temperature is maintained between 85°C and 90°C during this process to ensure proper gelation, as exposure to excessively high temperatures can cause the gel to dissolve. Once the mixture begins to gel, it is carefully poured into silicon molds to attain the desired egg structure. The egg white is then allowed to set, either at room temperature for 30 minutes or under refrigeration for 10 minutes. After setting, a cavity is scooped out from the center of the egg white to accommodate the egg yolk blend. The yolk mixture is then poured into the cavity and allowed to set within the egg white. Finally, the vegan egg is gently unmolded, completing the process (Figure 2).

2. Evaluation of sensory properties

The sensory panelists (10 semi-trained) were academic staff and students of the College of Food and Dairy Technology, Koduveli. The panelist was instructed to assess the quality of vegan egg for the basic sensory attributes such as appearance, flavor, texture, and overall acceptability using 8 point descriptive scale where,

8 = like extremely,
7 = like very much,
6= like moderately,
5=like slightly,
4 = dislike slightly,
3 = dislike moderately,
2 = dislike very much and
1 = dislike extremely.

3. Evaluation of proximal properties

The moisture content was determined using a Hot Air Oven by measuring the mass of the food sample before and after moisture removal through evaporation. The ash content was analyzed using a Muffle Furnace, where the organic matter was incinerated, leaving behind the mineral residue. The protein content was assessed using the Kjeldahl Apparatus, which quantifies nitrogen content to estimate protein levels. The fiber content was measured using a Fiber Analyzer, while the fat content was determined through solvent extraction with a Soxhlet Apparatus. The carbohydrate content was calculated by the difference method, subtracting the sum of moisture, protein, fat, ash, and fiber contents from 100.

Table 1: Ratio of the Egg white and Egg Yolk

Egg white			
S. No.	**Ingredients**	**Percentage (%)**	**Quantity (g)**
1.	Tofu	75.0	100
2.	Boiled Cashew Nut	15.0	20.0
3.	Agar Powder	5.00	7.00
4.	Jeera Extract	3.60	5.00
5.	Black Salt	0.70	1.00
6.	Salt	0.30	0.50
7.	Sugar	1.40	2.00
Egg Yolk			
1.	White Mixture	90.0	50.0
2.	Soy Protein Isolate	5.00	3.00
3.	Nutritional Yeast	4.00	2.00
4.	Turmeric	1.00	0.50

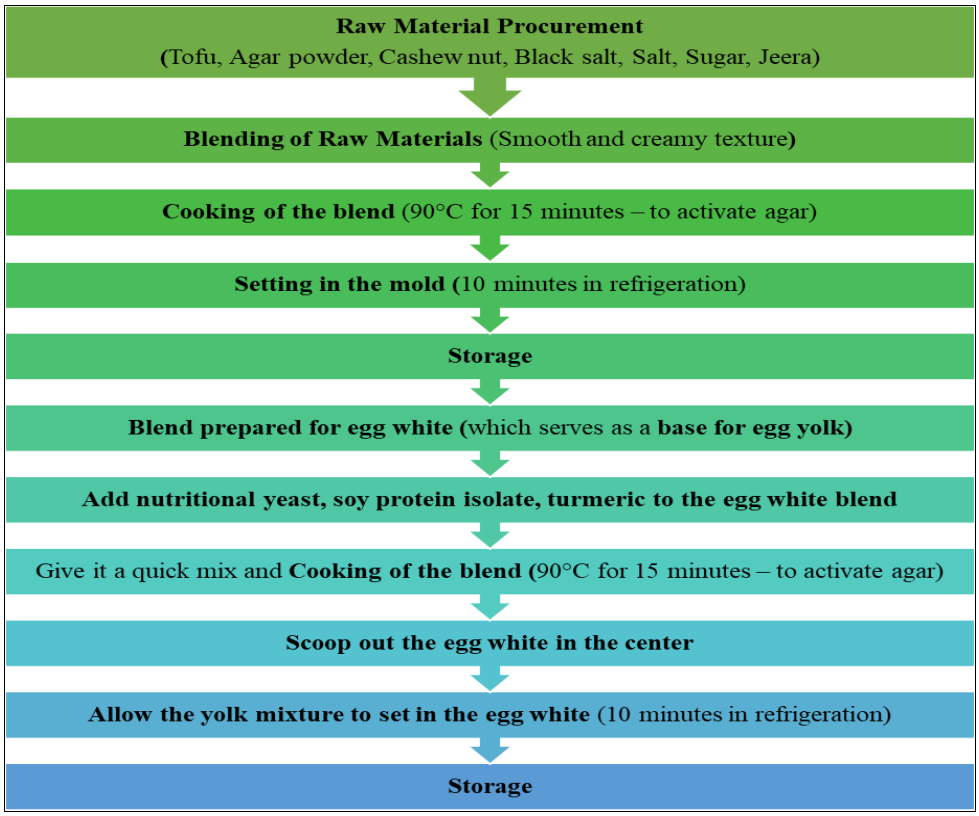


Fig 1: Flowchart of the plant-based hard-boiled egg preparation

Fig 2: Developed Vegan egg

Results and discussion

The sensory evaluation and proximate analysis of the developed hard-boiled vegan egg alternative provide important insights into its potential as a sustainable and health-conscious substitute for conventional eggs. The treatment containing 75% tofu and 20% cashew nut achieved the highest acceptability among sensory attributes, with an overall score of 8.28 ± 0.13, closely matching the control. This highlights the successful formulation of a plant-based product that appeals to consumer preferences for taste, texture, and appearance, essential factors for market acceptance.

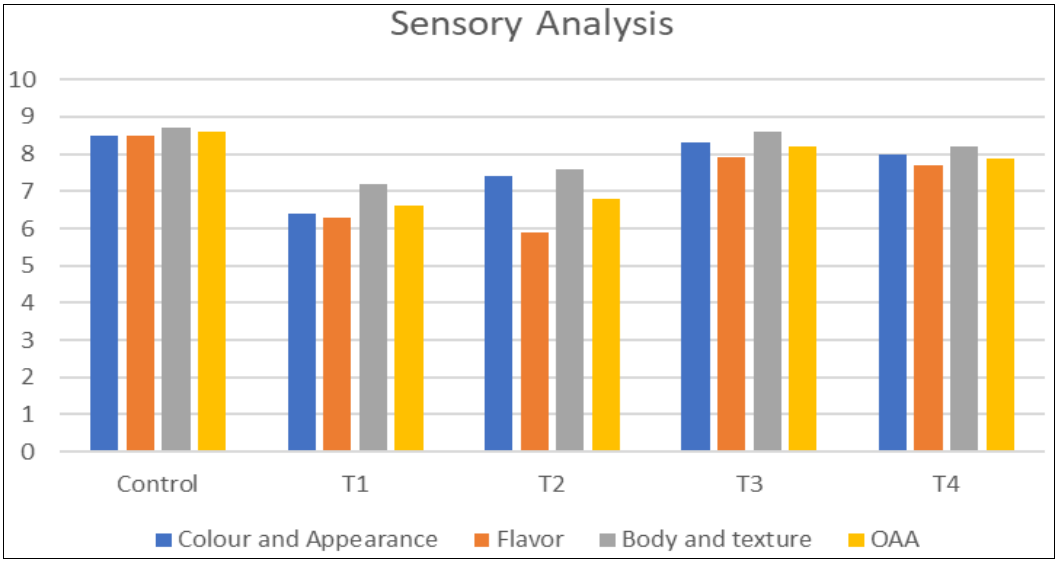
1. Sensory attributes

Tofu and cashew nuts are well-documented for their ability to contribute to both texture and flavor. Tofu's neutral taste and soft, gel-like texture are ideal for mimicking the egg white structure (Dang *et al*., 2023) [3], while cashew nuts provide creaminess and mild sweetness that enhance overall palatability (Wojdylo *et al*., 2023) [17]. Previous studies on plant-based dairy and egg alternatives have also emphasized the importance of blending multiple plant-based ingredients to achieve sensory profiles comparable to traditional products (Jang and Lee, 2024) [6].

Table 2: Sensory analysis of different hard-boiled vegan egg alternatives

Parameters / Treatments	Colour and Appearance	Flavor	Body and Texture	Overall acceptability
Control	$8.56^{e}\pm 0.20$	$8.54^{d}\pm 0.13$	$8.74^{d}\pm 0.10$	$8.64^{d}\pm 0.10$
T_1	$6.40^{a}\pm 0.16$	$6.30^{a}\pm 0.15$	$7.20^{a}\pm 0.24$	$6.64^{a}\pm 0.15$
T_2	$7.40^{b}\pm 0.16$	$5.90^{a}\pm 0.27$	$7.60^{a}\pm 0.16$	$6.80^{a}\pm 0.15$
T_3	$8.30^{d}\pm 0.21$	$7.90^{c}\pm 0.23$	$8.60^{c}\pm 0.16$	$8.28^{c}\pm 0.13$
T_4	$8.00^{c}\pm 0.25$	$7.70^{b}\pm 0.26$	$8.20^{b}\pm 0.20$	$7.86^{b}\pm 0.21$
F value	16.97**	17.94**	9.94**	19.75**

**Statistically highly significant ($p<0.001$)



2. Nutritional Composition

The proximate analysis of the hard-boiled vegan egg alternative demonstrated the following nutritional composition: moisture (60.46%), ash (1.71%), protein (6%), energy (158.22 kcal/100g), carbohydrate (29.65%), fiber (0.89%), and fat (1.38%). This showed that the vegan egg alternative is a nutritionally balanced option with significant differences compared to conventional eggs.

The fat content of the vegan egg (1.38%) is significantly lower than that of conventional eggs (11%) and entirely free of cholesterol. This aligns with consumer demand for heart-healthy foods, as high cholesterol intake has been linked to cardiovascular diseases (Rashwan *et al*., 2023) [10]. Plant-based products, such as the one developed in this study, cater to this health-conscious demographic while offering an alternative for individuals with dietary restrictions (Tachie *et al*., 2023) [15].

The protein content of the vegan egg (6%) is lower than that of conventional eggs (13%), primarily due to the plant-based protein sources used. However, this value is consistent with other vegan egg alternatives, as plant proteins often have lower concentrations of essential amino

acids (Singh *et al*., 2025) [14]. Protein enhancement strategies, such as fortification with pea or fava bean protein isolates, could be explored to improve the protein profile in future formulations (Benkovic *et al*., 2023) [1].

The higher carbohydrate content (29.65%) is attributable to ingredients like cashew nuts and starches, which contribute to the product's structure and sensory properties (Kim *et al*., 2021) [8]. While conventional eggs have negligible carbohydrate content, the vegan egg's carbohydrate profile may appeal to individuals seeking plant-based energy sources or adhering to vegetarian diets (Du *et al*., 2023) [4].

Despite differences in macronutrient composition, the energy content of the vegan egg (158.22 kcal/100g) is comparable to that of conventional eggs. This ensures that the product can serve as a caloric equivalent for consumers seeking a direct replacement (Yano and Fu, 2022) [16].

3. Shelf life

The shelf life of the vegan egg was observed to be 5 days under refrigeration and 2 days at room temperature. This highlights the product's perishability, which is a challenge for many plant-based alternatives (Shaw *et al*., 2022) [13]. Proper packaging and the use of natural preservatives like rosemary extract or citrus fiber could extend shelf life without compromising the product's sensory qualities (Chen *et al*., 2023) [2].

The development of a cholesterol-free, lower-fat vegan egg alternative supports growing consumer preferences for plant-based diets and aligns with sustainability goals. Conventional egg production has been linked to high greenhouse gas emissions, water use, and animal welfare concerns (Singh, 2025) [14]. Transitioning to plant-based alternatives can significantly reduce these environmental impacts while addressing global protein demands (Rashwan, 2025) [10].

Conclusion

The development of a plant-based hard-boiled vegan egg offers a promising alternative for individuals seeking an eggless dietary option, while also aligning with the rising global trend towards sustainability, animal welfare, and health-conscious food choices. Through the incorporation of tofu, cashew nuts, and other plant-based ingredients, this study successfully replicated the texture, appearance, and flavor of conventional eggs, meeting sensory expectations.

Nutritionally, the vegan egg offers a lower fat content, being entirely free of cholesterol, making it a suitable choice for individuals seeking heart-healthy food options. The protein content, while lower than that of conventional eggs, provides a solid foundation for future improvements through protein fortification strategies. The higher carbohydrate content, driven by ingredients like cashew nuts, provides an alternative energy source for those following vegetarian or plant-based diets.

Overall, the development of plant-based hard-boiled vegan eggs aligns with consumer demands for sustainable and ethical food choices. The potential of these alternatives to replace conventional eggs on a broader scale supports the shift towards plant-based diets and sustainable food systems, with the potential to reduce the environmental impact associated with animal agriculture. As the market for plant-based foods continues to grow, plant-based eggs can play a crucial role in meeting the nutritional needs of a growing population while addressing environmental and health concerns.

Acknowledgement

Part of the project work was submitted to College of food and Dairy Technology, Koduveli, Tamil Nadu Veterinary and Animal Sciences University, Chennai - 52 by the project student in partial fulfilment for the award of B. Tech degree.

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