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Allergenic Potential of Ingredients Used in Plant-Based Cheese Analogs and Allergens

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Background

Consumers wish to purchase products with clean labels. Manufacturers must now consider the need for products containing components that are healthy and sustainable, with plant-based foods viewed more positively than animal-derived foods. Very few food categories more clearly epitomize this phenomenon than dairy product analogs. A quick trip to most grocery stores in the US will have you walking past dairy sections with a vast selection of milk, including almond, oat, coconut, soy and more; the options are extensive and expanding every year. Factors that have contributed to this increasing consumption of dairy analogs in the U.S. and globally over the past decade include milk allergies, lactose intolerance, a desire to consume less saturated fats, perceived health-benefits of plant-based foods, and/or demand for sustainable foods. A 2022 survey revealed that 31% of U.S. consumers increased their consumption of plant-based protein sources over the past year (International Food Information Council, 2022). This phenomenon was especially apparent for plant-based dairy alternatives, including plant-based cheese analogs.

Manufacturing a food product from plant-based ingredients to mimic a natural meat or dairy product in taste, appearance, texture, nutrition, and performance requires sophisticated formulation strategies that can involve plant-based ingredients that are not typically part of the average American's diet (Yano and Fu, 2022). While the microbiological, chemical, and allergenic food safety risks of traditional dairy and meat products are well understood, the potential use of novel ingredients in plant-based analogs makes it important to consider food safety concerns that these ingredients might introduce. For example, *Salmonella* outbreaks (often associated with nuts) have been associated with nut-based cheeses (Louvau and Harris, 2023), while at least one *Bacillus cereus* outbreak has been associated with oat milk products (Whitworth, 2022). Beyond microbiological hazards, plants may contain toxic components (sometimes function to prevent their consumption), and the levels of such toxic compounds can vary significantly depending on how and where the plant is grown and processed into food (Mattsson, 2007). A recent outbreak of liver and gallbladder illnesses in almost 400 people was linked to tara flour, a relatively new plant-based ingredient used in meat analogs and smoothies. Experimental evidence points to a non-protein amino acid, baikiain, as the causative agent within the tara flour (Chittiboyina et al., 2023). Before this outbreak, food manufacturers had no knowledge of potential safety concerns of consuming baikiain, making it an unforeseen and unpreventable hazard (Keefe, 2023).

In addition to biological and chemical hazards, allergenic hazards must also be considered when using new plant-based ingredients. The nutritional value and in particular, the protein quality of plant-based dairy products has been scrutinized (Drewnowski et al., 2021; Drewnowski, 2022), which may result in manufacturers designing formulations with protein sources (containing potential allergens) without established patterns of common consumption. Allergenic food safety hazards associated with newer plant-based ingredients have already led to anaphylactic reactions in children consuming a pea-protein-based yogurt analog (Lavine and Ben-Shoshan, 2019).

Among dairy products, the natural cheeses are a diverse group of complex foods that may be especially hard to mimic using plant-based ingredients (Yano and Fu, 2022; Edlong, 2023). This has led to a variety of ingredients being used to make plant-based cheeses. The goal of this project was to identify the ingredients most commonly used in plant-based cheese analogs (PBCA) marketed in the U.S. and to perform a literature search to identify what is currently known about the allergenic potential of these ingredients.

Methods and Results

A Google search was conducted in late 2022 to identify PBCA marketed in the U.S. A total of 26 PBCA were identified. The ingredients listed on the labels of these PBCA are shown in Table 1.

Table 1. Ingredients Used in Plant-based Cheese Analogs

Plant-based Cheese Analog	Ingredients
Daiya Cheddar-style Shreds	Filtered water, tapioca starch, coconut oil, canola oil, safflower oil, natural flavors (vegan), chickpea protein, salt, potato protein, tricalcium phosphate, lactic acid (vegan), konjac gum, yeast extract, xanthan gum, annatto color, turmeric color, inactive yeast, potassium chloride
Daiya Cheddar-style Slices	Filtered water, potato starch, coconut oil, canola oil, safflower oil, tricalcium phosphate, natural flavors (vegan), salt, pea protein, xanthan gum, lactic acid (vegan), konjac gum, fruit juice color, vegetable juice color, annatto color, yeast extract, vegan enzyme, vitamin B12
So Delicious Cheddar Flavored Shreds	Filtered water, coconut cream (organic), palm oil, modified potato starch, modified corn starch, corn, salt, navy bean flour, yeast extract, cultured sugar (to retain freshness), cultures, natural flavor, xanthan gum, konjac gum, lactic acid, annatto extract (color), cellulose (to prevent caking)
Treeline Aged Artisanal Plant-based Cheese Wheel	Cashew nuts, filtered water, vegan lactic acid, vegan *L. acidophilus*, hickory smoked sea salt
Treeline Plant-based French-style Cheese	Cashew nuts, filtered water, sea salt, lemon juice, green peppercorns, vegan *L. acidophilus*
Field Roast Vegan Chao Slices	Filtered water, coconut oil, modified corn starch, modified potato starch, potato starch, soybeans, water, salt, sesame oil, calcium sulfate, sea salt, natural flavor, olive extract, beta carotene
Follow Your Heart Dairy-free Cheddar Shreds	Filtered water, palm fruit oil (organic), modified food starch, natural flavors (plant sources), pea fiber, pea starch, bamboo fiber, nutritional

Plant-based Cheese Analog	Ingredients
	yeast, calcium phosphate, rice flour, vegetable glycerin, sunflower lecithin, sea salt, sunflower oil, lactic acid (vegetable source), carrageenan (vegetable source), calcium sulfate, citric acid, enzymes, annatto (for color), xanthan gum, disodium phosphate, sodium citrate
Follow Your Heart Medium Dairy-free Cheddar Slices	Filtered water, coconut oil, modified potato starch, modified corn starch, potato starch, sea salt, lactic acid (plant sources), citric acid, natural flavor (plant sources), yeast extract, olive extract, annatto extract, beta carotene
Follow Your Heart Parmesan	Filtered water, palm fruit oil (organic), modified food starch, canola oil, natural flavors, vegetable glycerin, lactic acid (vegetable source), calcium lactate (vegetable source), sea salt, sodium phosphate, carrageenan, bamboo fiber, nutritional yeast, calcium phosphate, handmade rice koji (organic), chickpeas (organic), sea salt, water, koji spores, sunflower lecithin, citric acid, annatto
Teese Vegan Mozzarella Cheese	Filtered water, coconut oil, tapioca maltodextrin, carrageenan, salt, pea protein, natural flavors, lactic acid, natural white color
Teese Vegan Cheddar Cheese	Filtered water, coconut oil, tapioca starch, tapioca maltodextrin, carrageenan, salt, pea protein, yeast extract, lactic acid, natural white color, annatto, natural flavors, citric acid
Violife Epic Mature Cheddar Flavor Block	Filtered water, coconut oil, modified potato starch, modified corn starch, potato starch, sea salt, organic ground sunflower kernel, cheddar flavor (vegan sources), lactic acid, olive extract, beta carotene (color), vitamin B12
Violife Just Like Mozzarella Shreds	Filtered water, coconut oil, modified potato starch, modified corn starch, corn starch, sea salt, mozzarella flavor (vegan sources), olive extract, beta carotene (color), vitamin B12, powdered cellulose
Sister River Foods Vegan Parmesan Original	Nutritional yeast, organic sunflower seeds, walnuts, Himalayan crystal salt, hemp seeds (organic)
Miyoko's Fresh Vegan Mozz	Filtered water, cashews (organic), coconut oil (organic), tapioca (organic), agar, cultured sugar (organic), sea salt, sunflower lecithin (organic), cultures
Dr. Cow Aged Cashew Cheese	Raw cashew nuts, acidophilus, Himalayan pink salt
Tofutti American Cheese Slices	Water, tofu, soy protein, maltodextrin, apple cider vinegar, corn starch, calcium phosphate, potato flakes, sea salt, potassium phosphate, lactic acid (non-dairy), adipic acid, soy, natural colors
Oatzarella	Water, steel-cut oats (organic), extra virgin olive oil (organic), tapioca flour (organic), natural flavors, sea salt, agar (organic), lactic acid (vegan)
Esti Plant-based cheddar-style	Coconut oil, filtered water, starch, modified starch, sea salt, extra virgin olive oil, olive extract, citric acid, vegan flavoring, beta-carotene, paprika extract (vegan color)
Good Planet Dairy-free Cheddar	Water, refined coconut oil, modified potato starch, modified tapioca starch, sea salt, tricalcium citrate, vegan flavor, sorbic acid (natural preservative), beta carotene (natural color), paprika extract (natural color)
Nafsika's Garden Swiss Style	Water, refined coconut oil, modified potato starch, modified tapioca starch, sea salt, natural vegan flavors, sorbic acid (natural preservative), beta carotene (color)
Nuts for Cheese Chipotle Cheese Wedge	Cashews (organic), coconut oil (organic), rejuvelac (organic), water, nutritional yeast, sea salt, rice (organic), chickpeas (organic), koji spores, onion (organic), tomato paste (organic), chipotle peppers (organic), maple syrup (organic), apple cider vinegar (organic), olive oil (organic), garlic (organic), organic oregano, raw cane sugar (organic), active cultures, spices (organic)
Mozzarisella Organic Smoked	Water, sprouted brown rice (organic), apple cider vinegar (organic), salt,

Plant-based Cheese Analog	Ingredients
Vegan Cheese	water, cold-pressed coconut oil (organic), lemon juice (organic), agar-agar, gum Arabic, xanthan gum, carob bean gum, natural smoke flavoring, turmeric (organic)
Parmela Creamery Sharp Cheddar Shreds	Nutmilk, coconut oil, modified food starch, potato starch, nutritional yeast, sea salt, annatto, natural flavor, cultures, tree nuts
Parmela Creamery Mozzarella Shreds	Nutmilk, coconut oil, modified food starch, potato starch, nutritional yest, sea salt, annatto, natural flavor, cultures, tree nuts
365 Non-Dairy Mozzarella Shreds	Filtered water, high refined coconut oil, modified potato starch, modified tapioca starch, sea salt, olive extract, natural flavor, tree nuts

The ingredients of these PBCA were then summarized by the frequency with which they were found in products, with similar ingredients consolidated (Table 2).

Table 2. Ingredients Found in Plant-based Cheese Analogs

General Classification	Ingredient	Number of Analogs with Ingredient	Percent of Analogs with Ingredient
Acid	Lactic acid	12	46%
	Citric acid	5	19%
	Apple cider vinegar	3	12%
	Lemon juice	2	8%
	Sorbic acid	2	8%
	Adipic acid	1	4%
Carbohydrate	Potato starch (including modified potato starch)	12	46%
	Tapioca (including tapioca starch, modified tapioca starch, tapioca maltodextrin, and tapioca flour	8	31%
	Corn starch (including modified corn starch)	6	23%
	Food starch (modified)	4	15%
	Bamboo fiber	2	8%
	Cellulose (or powdered cellulose)	2	8%
	Maltodextrin	2	8%
	Rice (including sprouted brown rice)	2	8%
	Oats	1	4%
	Pea fiber	1	4%
	Pea starch	1	4%
	Rice flour	1	4%
	Sugar	1	4%
Color	Annatto (including annatto color or extract)	9	35%

General Classification	Ingredient	Number of Analogs with Ingredient	Percent of Analogs with Ingredient
	Beta carotene	6	23%
	Natural white color	2	8%
	Paprika extract	2	8%
	Turmeric	2	8%
	Natural color (vegetable juice color, fruit juice color)	1	4%
	Tomato paste	1	4%
Fat	Coconut oil (or cream)	18	69%
	Canola oil	3	12%
	Olive oil	3	12%
	Palm oil (including palm fruit oil)	3	12%
	Sunflower oil	1	4%
	Sesame oil	1	4%
Flavor	Natural flavors (including vegan flavor and natural smoke flavor)	19	73%
	Olive extract	6	23%
	Yeast (including nutritional yeast, yeast extract, inactive yeast,	4	15%
	Cheddar flavor, vegan	1	4%
	Chipotles	1	4%
	Green peppercorns	1	4%
	Maple syrup	1	4%
	Mozzarella flavor	1	4%
	Natural smoke flavoring	1	4%
	Natural vegan flavors	1	4%
	Onion	1	4%
	Oregano	1	4%
Gum/emulsifier	Xanthan gum	5	19%
	Carrageenan	4	15%
	Agar	3	12%
	Konjac gum	3	12%
	Sunflower lecithin	3	12%
	Carob bean gum	1	4%
	Gum Arabic	1	4%
Legume	Chickpeas (or garbanzo beans)	3	12%
	Navy bean flour	1	4%
	Soybeans	1	4%

General Classification	Ingredient	Number of Analogs with Ingredient	Percent of Analogs with Ingredient
	Pea protein	3	12%
	Tofu	1	4%
Microorganisms /culture	Koji spores	2	8%
	Cultures	8	31%
	Rejuvelac	1	4%
	Rice koji	1	4%
Salt and other simple chemical	Salt (including sea salt, Himalayan, hickory smoked)	26	100%
	Calcium phosphate (or tricalcium phosphate)	5	19%
	Calcium sulfate	2	8%
	Sodium phosphate (or disodium phosphate	2	8%
	Calcium lactate	1	4%
	Potassium chloride	1	4%
	Potassium phosphate	1	4%
	Sodium citrate	1	4%
	Tricalcium citrate	1	4%
Nut	Cashew nuts	5	19%
	Tree nuts, unspecified	3	12%
	Nut milk	2	8%
	Walnuts	1	4%
Seed	Sunflower seeds or kernels	2	8%
	Hemp seeds	1	4%
Other	Water (including filtered water)	22	85%
	Vitamin B12	3	12%
	Glycerin	2	8%
	Cultured sugar	2	8%
	Potato protein (including potato flakes)	2	8%

The potential of each of these ingredients to elicit food allergies (and other types of allergic responses or sensitivities for foods) was investigated by searching the Web of Science collection of databases (all databases) for relevant published literature. This information is summarized in Table 3, with the ingredients listed in order of their prevalence in the identified plant-based cheese analogs.

Table 3. Allergenic Potential of Ingredients Found in Plant-based Cheese Analogs Is there a difference between considerations with or without a bullet point? I don't think the bullet points are needed.

Ingredient	Products with Ingredient	Allergenic Considerations	Reference
Salt (including sea salt, Himalayan salt, hickory smoked salt)	26/26	• Sodium chloride is not allergenic. Impurities or flavorings in specialty salts such as metals or plant material could theoretically cause allergic responses, although no reports of such reactions from impurities related to salt consumption were identified.	(More et al., 2002; Chamani et al., 2023; Deng et al., 2023)
Natural flavor(s)	19/26	• Natural flavors usually contain plant ingredients, some of which may have allergenic potential. • In the U.S., labels are not required to list specific potential allergens in natural flavors unless they are major allergens.	21 CFR Part 501.22; (Joshi et al., 2002; U.S. Food and Drug Administration, 2022)
Coconut oil	18/26	• While refined coconut oil is free from protein, unrefined coconut oil can rarely cause allergic reactions upon consumption. • Allergenic cross-reactivity or co-sensitization between coconut and other tree nuts has been reported.	(Kruse et al., 2021); Iddagoda et al. (2022)
Potato starch	12/26	• Potato allergies are very rare, but one case study of a boy who developed anaphylaxis after eating potato starch has been reported.	(Kobayashi et al., 2021)
Annatto	9/26	• Some reports of type 1 hypersensitivity and rare anaphylaxis following oral exposure to annatto have been published.	(Lucas et al., 2001); (Auttachoat et al., 2011; Gultekin and Doguc, 2013)
Tapioca (including tapioca starch, modified tapioca starch, tapioca maltodextrin, and tapioca flour	8/26	• Several case reports exist of patients with latex allergies who were also shown to exhibit anaphylaxis after eating cassava (tapioca).	(Ibero et al., 2007; Sanchez et al., 2015; Allergen Bureau, 2022)
Cultures (including *Lactobacillus acidophilus*)	8/26	• Some bacterial or fungal compounds are allergenic, although oral administration of some bacterial cultures (probiotics) has been shown to prevent or treat some food allergies. • Cultures may contain residual milk, soy, or wheat from the growth media.	(Nordengrün et al., 2018; Allergen Bureau, 2022; Gu et al., 2023)
Beta carotene	6/26	• Vitamin A supplementation has been associated with atopy. • Beta-carotene's color can be stabilized with tocopherol, and tocopherol may be derived from soy or wheat.	(Lucas et al., 2001); (Ruhl et al., 2010); (Allergen Bureau, 2022; Su et al., 2022)
Corn starch (including modified corn starch)	6/26	• Some reports of severe allergic reactions to corn (maize) exist, but its prevalence is unclear but may be higher in southern Europe and Mexico. • Corn starch has been linked to "baker's asthma,", but reports of ingested corn starch triggering a food allergy were not identified. • In a serological study, corn starch was found to be less allergenic than corn flour in dogs and cats sensitized to corn.	(Scibilia et al., 2008; Venter et al., 2008; Olivry and Bexley, 2018)

Ingredient	Products with Ingredient	Allergenic Considerations	Reference
Olive extract	6/26	• Rare cases of allergic responses to ingestion of olives have been reported.	(Prados-Castaño et al., 2022)
Cashew nuts	5/26	• Cashews are an established and common allergen; tree nuts allergies as a group have a prevalence of up to 4.1% in the U.S.	Borres et al. (2022); U.S. Food and Drug Administration (2022); Ertuğrul et al. (2021)
Xanthan gum	5/26	• A few reports suggest xanthan gum may cause contact allergic reactions.	(Aerts et al., 2015; Bouvier, 2017)
Carrageenan	4/26	• One clinical trial found that 20% of participants had an IgE-specific immune response to carrageenan. • Several case reports have demonstrated allergy to carrageenan (ingested or in barium enemas).	(Vakaljan et al., 2019; James et al., 2023)
Food starch (modified)	4/26	• In the U.S., modified food starch can be made from many different sources, including corn (most common), potato, tapioca, and wheat. • Processing of starch and modified starch does not remove all protein. • If the modified food starch is derived from wheat, it must be labeled as containing wheat.	(Allergic Living, 2019; National Celiac Association, 2023)
Yeast (including nutritional yeast, yeast extract, inactive yeast)	4/26	• Antibodies to baker's yeast (*Saccharomyces cerevisiae*) have long been associated with patients with Crohn's disease. • Fungal allergens, including those from yeasts, introduced through inhalation or ingested in food can result in IgE antibodies and sensitization. • The substrate used to grow the yeast could contain allergens such as wheat or soy.	(Main et al., 1988) (Joneja, 2013; Allergen Bureau, 2022)
Agar	3/26	• Rare allergic reactions to agar (via inhalation) have been reported. • Agar is derived from seaweed. Food allergy to seaweed appears to be uncommon but not well characterized.	(Criep and Riley, 1951; Thomas et al., 2019; James et al., 2023)
Apple cider vinegar	3/26	• One case report of an anaphylactic reaction to apple cider vinegar that was sulfite-free has been reported.	(Nanagas et al., 2016)
Canola oil	3/26	• Allergic reactions to refined canola oil are rare and mild. • The refining process used affects allergen levels in the oil.	(Food Standards Agency, 2022)
Chickpeas (garbanzo beans)	3/26	• Allergies to chickpeas and other legumes are well documented. • Higher rates of sensitization to legumes are possible in those with peanut sensitivities. • 3.8% of children with any IgE-mediated food allergy also demonstrated clinically relevant allergy to chickpea.	(Hildebrand et al., 2021)
Konjac gum	3/26	• No published studies have described an allergenic response to oral consumption of konjac gum, although a food manufacturing worker exposed to konjac glucomannan has developed respiratory sensitization.	(Bernstein et al., 2007; Gultekin and Doguc, 2013; EFSA, 2017)
Olive oil	3/26	• Occupational allergic contact dermatitis to olive oil has been reported (a pizza maker and pedicurists and masseurs). • Ingestion of olive fruit can cause rare allergic reactions.	(Wong and King, 2004)
Palm oil (including palm fruit oil)	3/26	• Allergic reactions to refined canola oil are rare and mild. • The refining process used affects allergen levels in the oil.	(Food Standards Agency, 2022)

Ingredient	Products with Ingredient	Allergenic Considerations	Reference
Pea protein	3/26	• Pea protein is a well-known allergen, and children eating nondairy yogurt that contained pea protein have had allergenic reactions	(Taylor et al., 2021); (Lavine and Ben-Shoshan, 2019)
Sunflower lecithin	3/26	• Food allergies to lecithin from soy and egg have been reported. Food allergies to sunflower kernels (where the lecithin comes from) are also known.	(Gultekin and Doguc, 2013; Seve et al., 2023)
Tree nuts, unspecified	3/26	• Established and common allergen; tree nuts allergies as a group have a prevalence of up to 4.1% in the U.S.	(Borres et al., 2022); (Cianferoni and Muraro, 2012; U.S. Food and Drug Administration, 2022)
Bamboo fiber	2/26	• A recent study in Taiwan found bamboo shoots to be a common food allergen in children, with a prevalence of 0.8%. • Case reports suggest that oral ingestion of bamboo shoots in rare cases cause anaphylaxis. • Bamboo shoots caused a contact allergy in one case report. • Occupational exposure to bamboo wood resulted in contact dermatitis in one case report.	(SCHIFF, 1951; Kitajima, 1986; Ji et al., 2009)
Cellulose (or powdered cellulose)	2/26	• Cellulose itself does not appear allergenic, but derivatives of cellulose such as carboxymethylcellulose are also used in foods and pharmaceutical products and can cause rare allergic reactions, including anaphylaxis.	(Wasser et al., 1989; Townsend et al., 2021; Hotta et al., 2022)
Cultured sugar	2/26	• See “Culture” above	NA
Enzymes	2/26	• Enzymes used in plant-based analogs of dairy products can include amylases, glucosidases, hemicellulases, glucanases, pectinolytic enzymes, peptidases, lipases, phospholipases, cellulases, phytases and peroxidases. • Enzymes cover a large category of proteins and have the potential for allergenicity. However, their catalytic nature means that only small amounts are needed. Are needed for what?	(EFSA, 2023)
Glycerin	2/26	• Glycerin is used in subcutaneous immunotherapy extracts and does appear to cause higher rates of local reactions.	(Calabria et al., 2008)
Koji spores	2/26	• Koji spores are the spores of the filamentous fungus *Aspergillus oryzae* and are used to make many types of fermented foods, including soy sauce and miso. • *Aspergillus oryzae* (and other *Aspergillus* species, especially *A. fumagatus*) are common indoor airborne fungi associated with asthma. • Many food enzymes are purified from non-GMO *Aspergillus oryzae*, and oral consumption of some of these enzymes has been associated with food allergies.	(Shen et al., 1998; Lohrenz and Kanani, 2023)
Lemon juice	2/26	• Allergic reactions to citrus fruits (usually oranges) and their seeds have been reported and are usually associated with cross-reactivity and sensitization to other plants and pollen. At least one case report of a man who had anaphylactoid symptoms when he ingested lemon juice has been published.	(Iorio et al., 2013; Armentia et al., 2016)

Ingredient	Products with Ingredient	Allergenic Considerations	Reference
Maltodextrin	2/26	• Maltodextrin is derived from starches; in the U.S., the starch is usually from corn, potatoes, or rice. When derived from wheat, maltodextrin may contain very low levels of proteins and peptides, and the product label must indicate this. EFSA's Scientific Panel reviewed the literature and concluded the wheat-based maltodextrin is unlikely to trigger a severe allergic reaction in susceptible individuals.	(EFSA, 2007; Beyond Celiac, 2011)
Natural white color	2/26	• The specific ingredients in the product may not be indicated; however, titanium dioxide is a natural mineral and is found in some products that are called "white natural food color". Contact dermatitis triggered by titanium dioxide has been reported. • Other natural white colors contain calcium carbonate, which does not seem to be an allergen (although household water containing high calcium carbonate levels was associated with higher rates of eczema in children with a mutation in the skin protein filaggrin).	(McAvoy; de Graaf et al., 2018; Jabbar-Lopez et al., 2020; Natural Candy Store, 2023)
Nut milk	2/26	• Nut milks are made from many types of tree nuts and sometimes peanuts. Tree nuts and peanuts are among the foods most commonly implicated in food-induced anaphylaxis.	(Cianferoni and Muraro, 2012)
Paprika extract	2/26	• Allergic respiratory disease and asthma to chili peppers can occur from occupational exposures. • Food allergies to paprika are "extremely rare" and usually occur in adults sensitized to mugwort or birch. • Allergens present in paprika are mostly destroyed during processing, with those remaining usually destroyed during digestion.	(Chen and Bahna, 2011; van der Walt et al., 2013; Kular et al., 2019)
Potato protein (including potato flakes)	2/26	• Oral food allergy to raw potatoes can occur in adults; the allergens responsible are destroyed upon cooking. Other heat-stable allergens can be found in proteins, and anaphylactic reactions to cooked potatoes in children have been reported.	(Przekora et al., 2020)
Rice (including sprouted brown rice)	2/26	• Although usually considered a hypoallergenic food, rice allergies, although uncommon, have been documented, with most cases associated with contact with raw rice or dust from rice.	(Musken et al., 1991; Wuthrich et al., 2002; Nambu et al., 2006)
Sorbic acid	2/26	• No reports exist of sorbic acid causing a food allergic reaction, but it can rarely cause allergic contact dermatitis.	(Dendooven et al., 2021)
Sunflower seeds or kernels	2/26	• Allergies to sunflower seeds upon ingestion have been documented in a number of case reports.	(Patel and Bahna, 2016; Domínguez-García et al., 2018; Nemni et al., 2020; Seve et al., 2023)
Turmeric	2/26	• A 2001 report said that no convincing evidence exists of allergic reactions to turmeric. • However, more recently, turmeric and its component (turmeric) have been reported to cause allergic contact dermatitis.	(Lucas et al., 2001; Chaudhari et al., 2015)
Adipic acid	1/26	• One case report of contact dermatitis upon occupational exposure has been published.	(Guin, 2001)
Carob bean (locust bean) gum	1/26	• Some reports of urticaria, facial rash, occupational asthma, and other positive reactions to carob bean have been reported in the literature.	(Gultekin and Doguc, 2013)

Ingredient	Products with Ingredient	Allergenic Considerations	Reference
Cheddar flavor, vegan	1/26	• Ingredients within such flavorings may not be specified and may vary between sources.	NA
Chipotles	1/26	• Allergic respiratory disease and asthma to chili peppers can occur from occupational exposures. • Allergens present in hot peppers are mostly destroyed during processing, with those remaining usually destroyed during digestion, which may result in an oral allergy syndrome without systemic symptoms upon consumption.	(Chen and Bahna, 2011; van der Walt et al., 2013)
Green peppercorns	1/26	• Ingestion of piper nigrum (the ripened form of green peppercorns) has been known to cause rare allergic reactions. Most occur after sensitization with inhalant allergens from plants or occupational exposures.	(Schöll and Jensen-Jarolim, 2004; Gimenez and Zacharisen, 2011)
Gum Arabic (Acacia gum)	1/26	• Both occupational exposure and eating foods with gum Arabic have been reported to cause allergenic symptoms.	(Gultekin and Doguc, 2013)
Hemp seeds	1/26	• With increasing exposure to Cannabis sativa, hemp seed allergies have been observed, although hemp seed-associated anaphylaxis is rare. • There is some indication of cross-reactivity between hemp seed and hazelnuts.	(Beriziky et al., 2023; Olivieri and Skypala, 2023; Reese et al., 2023)
Maple syrup	1/26	• Ingestion of raw maple sap caused allergic reaction symptoms in an individual with nut and tree pollen allergies, but fully processed (boiled) maple syrup did not cause problems.	(Binkley, 1994)
Mozzarella flavor	1/26	• Ingredients within such flavorings may not be specified and may vary between sources.	NA
Natural color (vegetable juice color, fruit juice color)	1/26	• Ingredients within such coloring agents may not be specified and may vary between sources.	NA
Natural smoke flavoring	1/26	• Ingredients within such flavorings may not be specified and may vary between sources.	NA
Natural vegan flavors	1/26	• Ingredients within such flavorings may not be specified and may vary between sources.	NA
Navy bean flour	1/26	• Legumes are well-known to trigger food allergic reactions.	(Soller et al., 2021)
Oats	1/26	• Oat can cause non-IgE-mediated reactions; at least one case of anaphylaxis to oat has been reported.	(Cruz et al., 2016)
Onion	1/26	• Contact allergies to onions are not unusual, but allergic reactions to onion ingestion are uncommon. However, at least one case report of anaphylaxis after eating cooked onions has been reported.	(Albanesi et al., 2019)
Oregano	1/26	• Although apparently rare, at least one systemic allergy to oregano (with cross-reactivity to other plants in the Labiatae family such as basil, lavender, and mint) was reported.	(Benito et al., 1996)
Pea fiber	1/26	• The legume pea is known to cause food allergic responses in sensitized individuals and has been cited as an emerging food allergen concern given its increasing use in plant-based foods.	(Sabouraud-Leclerc et al., 2023)
Pea starch	1/26	• The legume pea is known to cause food allergic responses in sensitized individuals ans has been cited as an	(Sabouraud-Leclerc et al., 2023)

Ingredient	Products with Ingredient	Allergenic Considerations	Reference
		emerging food allergen concern given its increasing use in plant-based foods. What about pear starch?	
Rejuvelac	1/26	• Rejuvelac is a fermented sprouted grain beverage that may be used as a starter culture in making other products such as cashew cheeses. The grain used to make the rejuvelac (wheat or quinoa) may be allergenic to sensitive people.	(Chen et al., 2020)
Rice flour	1/26	• Contact with raw rice has been known to cause urticaria. Ingestion of cooked rice rarely causes hypersensitivity (and is usually considered hypoallergenic); however, some case reports of food allergies to cooked rice exist.	(Wuthrich et al., 2002)
Rice koji	1/26	• Contact with raw rice has been known to cause urticaria. Ingestion of cooked rice rarely causes hypersensitivity (and is usually considered hypoallergenic); however, some case reports of food allergies to cooked rice exist.	(Wuthrich et al., 2002)
Sesame oil	1/26	• Sesame is a known allergen, and sesame oil contains more protein than other vegetable oils. Sesame oil, however, was less likely than other forms of sesame (tahini and seeds) at eliciting reactions, particularly anaphylaxis, in those with sensitivity to sesame in one study.	(Alonzi et al., 2011; Shah et al., 2023)
Sodium citrate	1/26	• Citrate/citric acid is a simple chemical and does not cause food allergic reactions.	(American Academy of Allergy Asthma & Immunology, 2020)
Soybeans	1/26	• The prevalence of soy allergy in infants and children within the general population is <0.3%, although a higher prevalence is found in patients with other allergic reactions.	(Katz et al., 2014; Pi et al., 2021)
Sunflower oil	1/26	• Allergy to sunflower seeds upon ingestion has been reported in a number of case reports. Food allergies to sunflower oil appear to be rare.	(Patel and Bahna, 2016; Domínguez-García et al., 2018; Nemni et al., 2020; Seve et al., 2023)
Tofu	1/26	• Soy is a known food allergen, as are many products made from it, including tofu. Anaphylaxis after eating tofu has been reported.	(Adachi et al., 2009; Katz et al., 2014; Pi et al., 2021)
Tomato paste	1/26	• Tomato food allergy is relatively common; although most reactions from ingestion involve local effects (oral allergy syndrome), more serious reactions including anaphylaxis can occur.	(Włodarczyk et al., 2022)
Tricalcium citrate	1/26	• Citrate/citric acid is a simple chemical and does not cause a food allergic reaction.	(American Academy of Allergy Asthma & Immunology, 2020)
Walnuts	1/26	• Tree nuts including walnuts are among the most common foods implicated in anaphylaxis.	(Cianferoni and Muraro, 2012)

NA: not applicable

Discussion

As can be seen from Table 3, many of the ingredients used in plant-based cheese analogs have not been associated with food allergies. However, the wide variety of ingredients used in plant-based cheese analogs includes some well-known allergens, including several "Big Nine" allergens that require precautionary labeling in the U.S. (tree nuts, soy, and sesame). Several ingredients (food starches, maltodextrin, rejuvelac) could contain trace amounts of another "Big Nine" allergen, wheat.

The growing demand for plant-based protein sources has led to the use of legumes and seeds in plant-based cheeses (Nemni et al., 2020; Olivieri and Skypala, 2023). In some cases, their use may have been chosen to avoid known allergenic concerns with nuts or soy (Keefe, 2023) (Farley and Segran, 2023). Increased consumption of plant-based cheeses containing these and other novel ingredients may lead to increased rates of allergic reactions.

Food processing such as thermal processing, fermentation, sprouting, high hydrostatic pressure can alter and sometimes reduce or eliminate allergenicity of foods (Sathe and Sharma, 2009; Cabanillas and Novak, 2019; Chen et al., 2020; Pi et al., 2021). However, foods with minimally processed ingredients ("raw", "unrefined", "whole-grain") may be more popular with those consuming plant-based foods, as both are considered to be more healthy, natural, and sustainable (McGuruther, 2020; International Food Information Council, 2022), could retain more components of the original plant, some of which may be allergens. Unrefined (or cold-pressed) plant-derived oils, touted as healthier than refined oils in the media (Sutherlin, 2020) may contain potential allergens from the parent plant (Kotecka-Majchrzak et al., 2020).

Unexpected allergens may also be found in some ingredients used in plant-based cheese analogs (Allergen Bureau, 2022):

- Microbiological media used to grow and produce cultures, cultured sugar, yeast extract, might contain soy or wheat or other allergens (Talor and Baumert, 2013).
- Cross-contamination between grains can lead to contamination of other grain products (corn or oats products might be contaminated with wheat, for example) (Reese and Schmid, 2013).
- Insects present in grains may lead to allergic reactions (Babaei and Vadas, 2020).
- Flavorings may contain milk, fish, soy, wheat, etc. (Allergen Bureau, 2022).
- Tree nuts, peanuts, and starches (wheat, cassava) have been used to adulterate spices, including cumin, cinnamon, etc. (Allergen Bureau, 2022).
- Tree nut or soy oil may adulterate olive and other oils (Allergen Bureau, 2022).

Unexpected allergens in plant-based foods are not always possible to predict, however, and may occur as a result of an increasingly complex supply chain. In England, a woman with a severe milk allergy died after eating a vegan wrap at a chain restaurant. The wrap contained a vegan yogurt dressing made by another company, which purchased the starch used to make the dressing

from yet another company. The starch carried the warning that it was manufactured in a factory that handled milk, eggs, and other potential allergens. However, the vegan yogurt manufacturer apparently failed to notify the restaurant chain of the potential for milk to contaminate the dressing, with tragic consequences (The Caterer, 2022).

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