SENSORY CHARACTERIZATION OF COMMERCIAL PLANT-BASED MEAT ALTERNATIVES

Master thesis in Technology
University of Turku
Department of Life Technologies
Master's Degree Programme in Food Development
24th of June 2023
Onyinyechi Stella Kpaduwa

The originality of this dissertation has been checked in accordance with the University of Turku quality assurance system using the Turnitin Originality Check service.

UNIVERSITY OF TURKU
Department of Life Technologies
Onyinyechi Stella Kpaduwa: Sensory Characterization of Commercial Plant-based Meat Alternatives
Master`s Thesis in Technology, 64 pages., 4 appendix pages
Food Development
June 2023

Consumers are increasingly interested in plant-based meat alternatives (PBMAs) as dietary protein sources, so the demand for products that closely mimic animal meat, especially in taste and texture, has grown. While few sensory studies on PBMAs exist, which are mostly focused on new formulations using functional ingredients or under-utilized plant proteins, there is little sensory information on different categories of commercial plant-based food products. This study aimed to evaluate the sensory attributes of a variety of commercially available plant protein alternatives with a focus on taste and texture.

The descriptive-analytical method was used to identify differences among commercial plant-based protein alternatives. Nine samples (n=9) from two categories, 'mildly processed and refined products', were selected from a doctoral study and purchased from the Kuppitta city market in Turku, Finland. Trained panelists (N = 10) compared the samples' taste and texture attributes with references on a line scale from 0 to 10 (0 – no intensity, 10 – high intensity). Panel performance was investigated to ascertain the important attributes.

The significant difference observed between the samples and their attributes was benchmarked at $p<0.05$. Principal component analysis revealed that umami, saltiness, and sweetness were positively correlated but all showed a negative correlation with softness. Similarly, a positive correlation was observed between rubbery and moistness while correlating negatively with crumbliness. The study revealed that the refined products were more meat-like in taste and texture than those of the mildly processed category. The outcome of this study establishes that plant-based food sensory characteristics are influenced by the manufacturers' choice of processing techniques, ingredient formulations, and/or the type of plant protein utilized during processing.

Keywords: Sensory characterization, plant-based meat analogs, taste, texture, descriptive analysis, multivariate analysis.

Contents

Appendices

List of Abbreviations

PBMAs	Plant-based meat alternatives
PBFs	Plant-based foods
WG	Wheat gluten
SPI	Soy Protein Isolate
PPI	Pea Protein Isolate
SPC	Soy Protein Concentrate
HME	High Moisture Extrudate
TSP	Textured Soy Protein
TVP	Textured Vegetable Protein
LM-TVP	Low Moisture Textured Vegetable Protein
HM-TVP	High Moisture Textured Vegetable Protein

1. Introduction/Literature Review

1.1 Background information of plant-based meat analogs

Universally, animal meat is known to be an essential source of dietary protein but nowadays, it stirs some concerns in its production and consumption as regards the environment and public health respectively (Font-I-Furnols & Guerrero 2022). Owing to the growing human population, consumer demand for meat is increasing drastically. This agrees with the Food and Agricultural Organization of the United Nations (FAO) estimation which states that by 2050, there will be a need to increase overall food production (including livestock) by 70% for an increased world population of over 9.1 billion people (FAO, 2009). Boosting livestock production would eventually cause a negative impact on the environment, mainly due to the generation of greenhouse gas (GHG) emissions. The collective contribution of a rising population, increased meat consumption, and GHGs poses a critical burden on the earth's natural resources and subsequently contributes significantly to climate change, soil loss, and environmental pollution (Ettinger et al. 2022; Greisinger et al. 2016; Sun et al. 2022). Apart from the challenges mentioned above, a plethora of scientific research results reveal that overconsumption of meat (especially red and highly processed meat) is associated with a potential risk of disease incidence and mortality. Due to the reasons stated above, other meat alternatives are being developed by food manufacturers to efficiently contribute to satisfying food demand in a sustainable and nutritionally balanced way while maintaining a safe environment.

Plant-based meat analogs (PBMAs) have recently gained noticeable popularity, especially in the food and research community. These PBMAs are imitation food products formulated with protein derived from plants to mimic traditional meat in its functional and sensory properties. The most harnessed plant proteins are especially from soy, pea, and wheat in the form of isolate, concentrate, or textured protein. However, due to the combined challenge of deforestation-related issues and soy/gluten-intolerant consumers (Do Carmo et al. 2021), food manufacturers are encouraged to harness other plant protein sources, such as chickpeas, fava beans, and lupins (Do Carmo et al. 2021; Wang et al. 2022).

Interestingly, there is an escalating demand for PBMA as a substitute for muscle meat thus, the meat alternative market is estimated to increase from $4.6 billion in 2018 to $85 billion by the year 2030 (Bakhsh et al. 2022; Sha and Xiong, 2020; Singh et al. 2021). Several companies are leading the way in developing and commercializing plant-based meat products. Beyond Meat and Impossible Foods are two of the most well-known companies, with their products available in many supermarkets and restaurants across the United States and other developed countries where consumers are beginning to embrace the consumption of plant-based meat alternatives. Regardless of the continuous development and advanced research within the food sector, consumers are unwilling to fully accept and adopt PBMAs. This unwillingness is mainly due to the nutritional and sensory appeal of the PBMAs (Szejda et al. 2020; Ishaq et al. 2022; Corrin & Papadopoulos, 2017).

1.2 Traditional PBMAs

Processed plant-based protein products have been consumed since the dawn of civilization in nations like China and India. Seitan (Day, 2011), tempeh (Babu et al. 2009), and tofu (Shurtleff & Aoyagi, 2013) are examples of plant-based protein products that have been consumed in these nations for a very long time. These conventional plant-based foods are frequently used in vegetarian and Buddhist cuisine as a protein substitute. More plant-based products have been developed because of the growing vegetarian population, especially in developed nations (Leahy et al. 2010). When textured vegetable protein (TVP) was created in the 1960s and used as the main component of vegan versions of meat-based foods like burgers and bacon, the formulations of PBMA were further developed (Riaz, 2011).

1.2.1 Tofu

Tofu production is believed to have started during the Chinese Han Dynasty some 2000 years ago. According to Chang and Hou (2003), historically, Tofu is prepared by coagulating soymilk with salt or acid to create curds. The resulting curds are then pressed into solid white blocks. As tofu production technology spread to other nations in East and Southwest Asia, including Japan, Vietnam, and Thailand, food developers began to innovate different varieties of the product. Each variation's production techniques, tofu's texture, flavor, and application differed slightly, but the fundamental principle remained the same (Shurtleff & Aoyagi, 2013; He et al. 2020). Tofu is said to be associated with off-flavors and its consumption causes certain allergenic reactions like flatulence Wang et al. (2018). This has led to an increased demand for a superior healthy protein known as soy protein isolate (SPI) used as a raw material for packaged tofu (Singh & Sit, 2022).

1.2.2 Tempeh

Another meat substitute made from soybeans, 'Tempeh' was first produced in Indonesia several centuries ago (Babu et al., 2009; He et al. 2020). Soybeans are first soaked, dehulled, and partially cooked for the preparation of tempeh, which is then thoroughly fermented by the Rhizopus fungus to produce a solid structure. To create the moderate aeration conditions required for mold growth without sporulation that would be excessive, the prepared soybeans are frequently wrapped in banana leaves or other suitable plastic materials. The whole beans are turned into a dense, nutty cake by the fungi, and mold eventually develops on the soybeans. White mycelium binds and permeates the soybeans to produce a compound cake for premium tempeh (Owen & Owen, 201; He et al. 2020).

1.2.3 Seitan

Another vegetarian meat substitute that was created in China in the sixth century is Seitan, also known as wheat gluten (WG) (Mal'a et al. 2010). Since it is made from gluten, a significant protein found in wheat, seitan differs from tempeh and tofu. When making seitan, a wheat flour dough is washed with water until all the starch granules are gone and only the gummy, insoluble gluten is left as an elastic mass. Since the resulting elastic mass resembles meat structurally, it is sometimes referred to as wheat meat or gluten meat (Day, 2011; Schmidinger, 2012). The ability of WG to be manipulated and shaped to resemble unique meat products, like vegan chicken wings, burgers, nuggets, and mock ducks.

1.2.4 Modern PBMAs (TVP)

Though seitan, tempeh, and tofu are now frequently used in place of meat, they are traditionally viewed as meat in their countries of origin. In Western nations, consumer demand and approval for these meat substitutes are also very low (Dekkers et al. 2018). Textured vegetable protein (TVP) is, therefore, one of the most widely used options for consumers because of the development of improved technologies in the processing of PBMAs (Riaz, 2011). Textured vegetable proteins (TVP) are very common meat extenders and are processed either as low-moisture TVP (LM-TVP) or high-moisture TVP (HM-TVP). The process enables meat-like structures by transforming powder protein material into sponge-like or fibrous-like structures respectively (Featherstone, 2015; Zhang et al. 2019; Baune et al. 2022).

Vegetarians who don't care for real meat's flavor are open to traditional PBMA and mildly processed TVP-based products (Rohall et al.2009; Wild et al., 2014). Recent advancement in

PBMA formulations is prompted by the fact that meat consumers are frequently dissatisfied with the visual appeal, flavor, and taste of these products when considered as meat alternatives (Rohall et al. 2009; Wild et al. 2014). These meat alternatives also depend on TVP production technologies to create a meat-like texture, but they also resemble real meat in terms of appearance, nutritional value, aroma, and flavor. Table 1 shows a summary of the nutritional information of a few commercially available plant-based burgers and beef burgers. Though the ingredients used in processing these meat substitutes determine their nutritional outcome, an advantage that PBMAs have over animal meat is their rich fiber content and zero cholesterol content (Table 1). The new generation PBMAs are sometimes referred to as ‘ultra-processed’ or ‘refined’ PBFs due to the complexity of their formulations and technological processes. Some notable producers include Beyond Meat™, Light life™, and Impossible Foods™.

The new generation of PBMAs aims to resemble fresh raw meat in terms of color and appearance. For instance, Impossible Foods uses soy leghemoglobin to give its burger products a red color, while Beyond Meat and Light Life "bleed" their burger patties with beet juice or powder (Bohrer, 2019). The iron-rich heme found in soy leghemoglobin also contributes to the distinctive meat flavor released during cooking in plant-based burgers (Fraser et al. 2018). Currently, the main products of this new PBMA generation are burger patties, though ground beef, sausage, bacon, and hotdogs are also common.

1.3 Ingredients

Based on their functionality, Guy (1994) grouped PBMA ingredients into six categories namely, structure-forming, disperse-phase filling, lubricating, soluble solids, nucleating, coloring, and flavoring ingredients. In other words, an ideal recipe for PBMAs includes proteins, fat, water, flavoring, binding agents (polysaccharides), and coloring agents. The key functions of different ingredients used in the processing of PBMAs are seen in Table 2 and it is shown that each ingredient has a distinct role in the production of meat alternatives. However, certain ingredients like plant protein sources, fat, and polysaccharides contribute to the texture of the final product due to their individual functional properties. Nowadays, other ingredients are incorporated into the processing of PBMAs including food additives and preservatives, antioxidants, thickeners, acidulants, stabilizers, and bulking agents (Lima et al. 2023).

Table 1. Nutritional contents comparison of some commercially available beef burgers and plant burgers (He et al. 2020).

Product	Energy (kcal/100 g)	Protein (g/100 g)	Fat (g/100 g)	Saturated fat (g/100 g)	Cholesterol (mg/100 g)	Carbohydrate (g/100 g)	Dietary fiber (g/100 g)	Na (mg/100 g)	Fe (mg/100 g)
Great value Meatless burger	176.99	16.81	8.85	0.44	0.00	10.62	5.31	300.88	10.09
Yves Veggie Bistro burger	147.73	17.05	5.11	0.45	0.00	9.09	3.41	420.45	4.20
Wholly veggie burger	146.67	9.33	4.67	0.40	0.00	18.67	4.00	226.67	1.68
Beyond burger	221.24	17.70	15.93	5.31	0.00	2.65	1.77	345.13	3.72
Light life Burger	238.94	17.70	15.04	2.21	0.00	8.85	3.54	477.88	3.36
Impossible burger	212.39	16.81	12.39	7.08	0.00	7.96	2.65	327.43	3.72
Great value Beef burger	221.24	15.04	16.81	7.96	70.80	3.54	0.88	451.33	4.20
Pre Grass Fed Beef burger	198.68	19.21	13.91	6.62	62.91	0.00	0.00	76.16	0.84
M&M Classic Beef Burger	274.34	13.27	22.12	6.19	57.52	5.31	0.00	442.48	0.84

[1] Plant-based burgers from Beyond Meat™, Light life™, and Impossible Foods™ are more like beef burgers than other plant-based burgers in terms of energy, protein, and fat content. Note: Data were obtained and calculated according to the information on the product package.

Table 2. Plant-based meat substitute ingredients and their key functions. (Boukid, 2020).

Ingredients	Sources	Main roles
Non-animal proteins	-Plant sources: soy, wheat, legumes, pea, lupin, rice, and potato -Novel sources: microalgae and seaweed	Nutrition, structure, color, texture, and flavor tech-functional properties
Lipids	-Rich in saturated fatty acids (e.g., coconut oil and cocoa butter) -Rich in unsaturated fatty acids (e.g., sunflower oil, canola oil, sesame oil, and avocado oil) •Fat replacers: oleogels and fibers	Flavor, texture, and mouthfeel
Polysaccharides	-Native starches -Flours -Fibres	Consistency and water binding
Flavoring ingredients	Savory yeast extract, paprika, sugar, spices, and herbs	Flavor
Coloring agents	Lycopene, beet juice extract, or leghaemoglobin	Meat color
Fortification ingredients	Tocopherols, zinc gluconate, thiamine hydrochloride, sodium ascorbate	Nutritional value

Some of the commercial plant-based meat products available on the market include tempeh, nuggets, steaks, tofu, sausages, hotdog, chunks, patties, ground beef-like products, chicken-like blocks, etc. Figure 1 shows a schematic illustration of different ingredient combinations to form these commercial products. The ability of plant-based meat ingredients to stick together is crucial because their unique behavior can significantly affect the outcome of the analogy. Common binding agents used in commercial PBMAs are egg solids, hydrocolloids, milk protein, and starch (Singh et al. 2021). The type of fat to be used in PBMAs should depend on the processing technique, the product type, and the desired sensory quality. There are many different types of fats that can be used in PBMAs. However, the texture and volatile compounds that are unique to meat make most vegetable oils difficult to use for recreating the flavor and texture of meat. As a result, meat substitutes frequently contain fats from coconut and vegetable oils like rapeseed and sunflower (Moss et al. 2023).

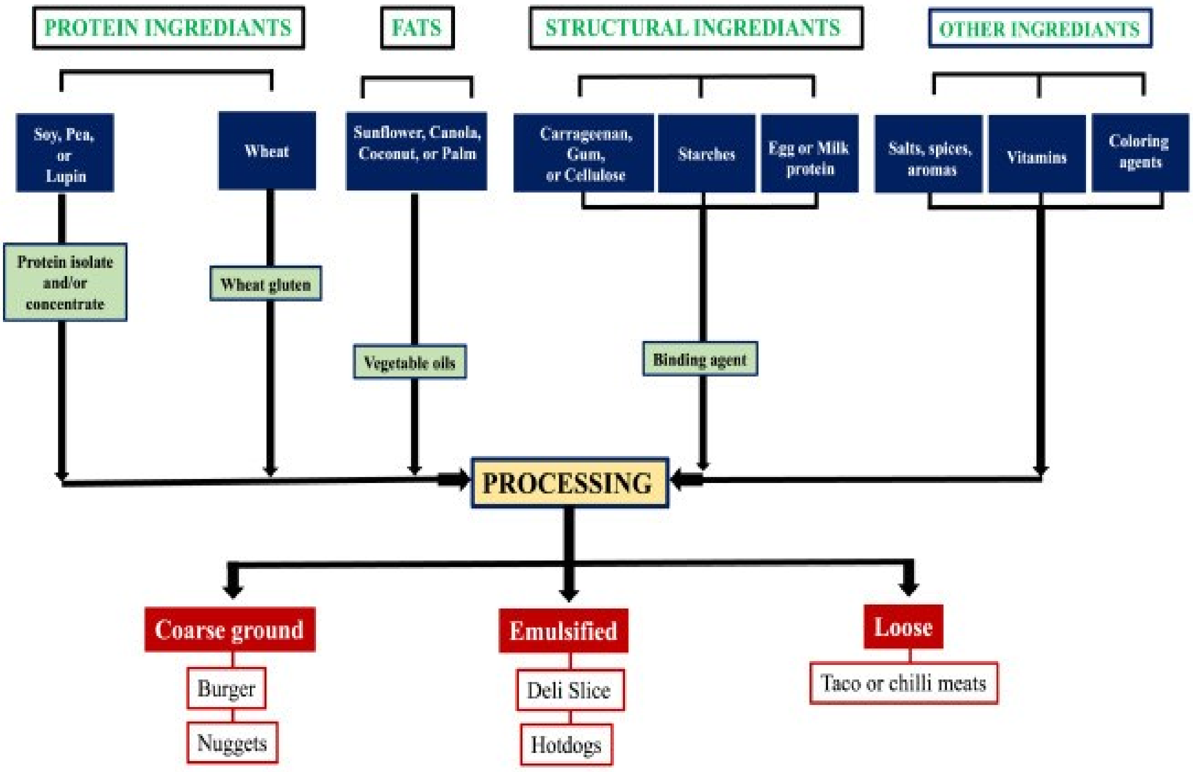


Figure 1. Schematic illustration of PBMAs formulation showing how ingredients are combined to produce different types of commercial plant-based meat (Ishaq et al. 2022).

Plant proteins exhibit certain properties such as emulsification, gelation, fat absorption capacity, and water-holding capacity which are crucial in the commercial production of meat analogs. The most notable proteins are soy protein isolate (SPI), pea protein isolate (PPI), soy protein concentrate (SPC), and wheat gluten (WG). The challenge with these plant-based protein sources is that they consist primarily of globular proteins that are not capable of forming the structure of traditional meat. As a result, intensive processing of plant proteins and other functional ingredients is required to achieve a texture that is appealing to consumers. Grabowska et al. (2016) reported that SPC (45 wt%) forms better meat analog structures compared to SPI when subjected to a temperature of 140 °C due to the presence of dry matter and carbohydrates. Textured vegetable meat substitutes exhibit a desirable appearance, mouthfeel, and texture compared to raw proteins. Therefore, commercial PMBA formulations usually contain both textured and non-textured soy protein (Sun et al. 2021).

In their study, Zahari et al. (2020) recommended the substitution of SPI up to 60% with hemp protein concentrate to give an extruded mixture with a comparable texture to 100% SPI. Nawrocka et al. (2017) recognized the excellent binding capacity of WG due to its dough forming, leavening, cohesive, and viscoelastic capacities. However, one drawback with the use of WG is the allergies associated with gluten. A potential solution is found in zein, a prolamine protein from maize, which can be harnessed in future formulations of meat analog products. The incorporation of another gluten-free protein (PPI) causes increased hardness, chewiness, and viscoelasticity of meat analog as reported by Yuliarti et al. (2021). However, the gelling capacity of pea protein is weaker than that of soy protein thus, pea-based analogs are much softer and less elastic than those of soy-based products (Sun et al. 2021).

Generally, plant-based protein sources are primarily made up of globular proteins that cannot take on the structure of traditional meat (Kyriakopoulou et al. 2021). This challenge brings about the need to extensively process plant proteins and their additives to produce acceptable meat alternatives. Despite the proteins contained in plants, many of them naturally lack one or more of the essential amino acids. Consequently, combinations of different plant proteins are recommended in the manufacturing formulations of PMBAs to maximize nutrition and functionality (Sun et al. 2021). The functional quality and application potential of various soy ingredients, as well as other protein-rich ingredients, are summarized in Table 3. Protein sources that are deficient in texture-enhancing functionality like soy milk are processed with the appropriate technology to produce a satisfactory meat-like structure. Furthermore, to enhance the protein properties, it is advisable to adopt post-treatment processing, such as toasting or moisture heating, or even mixing with polysaccharides (Lin et al. 2017; Geerts et al. 2018). Protein purity is not important in applications that mimic meat as strong mixtures of soy protein isolate (SPI) and gluten or soy protein concentrates (SPC) are mostly used to make TVP-based patties.

Table 3. Commonly used protein sources for meat analog applications (Kyriakopoulou et al. 2021).

Protein Ingredient	Composition (%*w*/*w*)	Functionality	Application in Meat Analogues
Soy isolate (alkaline/acid precipitation treatment)	~90 % protein	Good solubility, gelling, and emulsification	Structuring process: Extrusion, shear cell, spinning, freeze structuring Role: Protein source, texture, binder, base for fat substitutes, emulsifier Products: Burger patties, minced meat, sausages
Soy isolate (additional heat treatment/ toasted isolate)	~90 % protein, denatured due to heat treatment	Decreased solubility, increased water holding capacity, good gelling	Structuring process: Extrusion, shear cell Role: Protein source, texture, binder, a base for fat substitutes Products: Burger patties, minced meat, sausages
Soy concentrate	~70 % protein	Good texturization properties	Process: Extrusion, Shear cell Role: Protein source, texture, binder Products: Burger patties, minced meat, sausages, muscle-type products
Soy milk (spray-dried powder)	>45% protein, ~30 % fat	High solubility, good emulsification properties	Process: Freeze structuring Role: Emulsifier, texture Products: Tofu and Yuba production
Soy flour/meal (defatted)	~43–56% protein, ~0.5-9% fat, ~3–7% crude fibre, >30% total carbohydrate	Water binding capacity and fat retention, native protein	Process: Extrusion Role: Texture, Binder Products: Burger patties, minced meat, sausages, muscle-type products
Wheat Gluten isolate	75–80% protein, 15–17% carbohydrates, 5–8% fat	Binding, Dough forming/ Cross-linking capacity via S-S bridges, low solubility	Structuring process: Extrusion, shear cell Role: Adhesion, texture Products: Burger patties, muscle-type products
Pea isolate	~85% protein	Water and fat binding, emulsification, and firm texture after thermal processing	Process: Extrusion, shear cell, spinning Role: Emulsifier, texture, Binder Products: Burger patties, minced meat, sausages, muscle-type products

1.4 PBMAs Processing

In the 1980s, the fiber spinning technique was developed to produce PBMAs. This technique involved extruding alkaline protein solution through spinnerets into an acidic coagulating base. The precipitated filaments eventually become the meat analogs with the incorporation of binding materials. This technique was considered inadequate because it required highly concentrated plant solution, was expensive for large-scale application, and it is a complex spinning process (Sun et al. 2021). In the last few years, other techniques such as extrusion cooking, shear, freeze structuring, and 3D printing are being used to develop meat-like fibrous textured products (Wang et al. 2022).

However, the thermal extrusion process is known to be the predominant technique used in the production of PBMAs due to its high productivity and energy efficiency. Dry extrusion (moisture < 30%) of PBMAs has limited acceptance because of their poor mouthfeel. On the other hand, “wet extrusion” (under high moisture conditions between 40%–80%) enables the production of fresh and premium PBMAs, with a muscle meat-like texture as well as a similar appearance and chewing experience to cooked traditional meat as shown in Figure 2. The extrusion technique of processing PBMAs is typically mixing defatted plant protein with carbohydrates, edible lipid material, water, salts, and flavoring. The mixture is fed into a twin-screw extruder under a high temperature and varying moisture conditions for the formation of a meat-like fibrous structure.

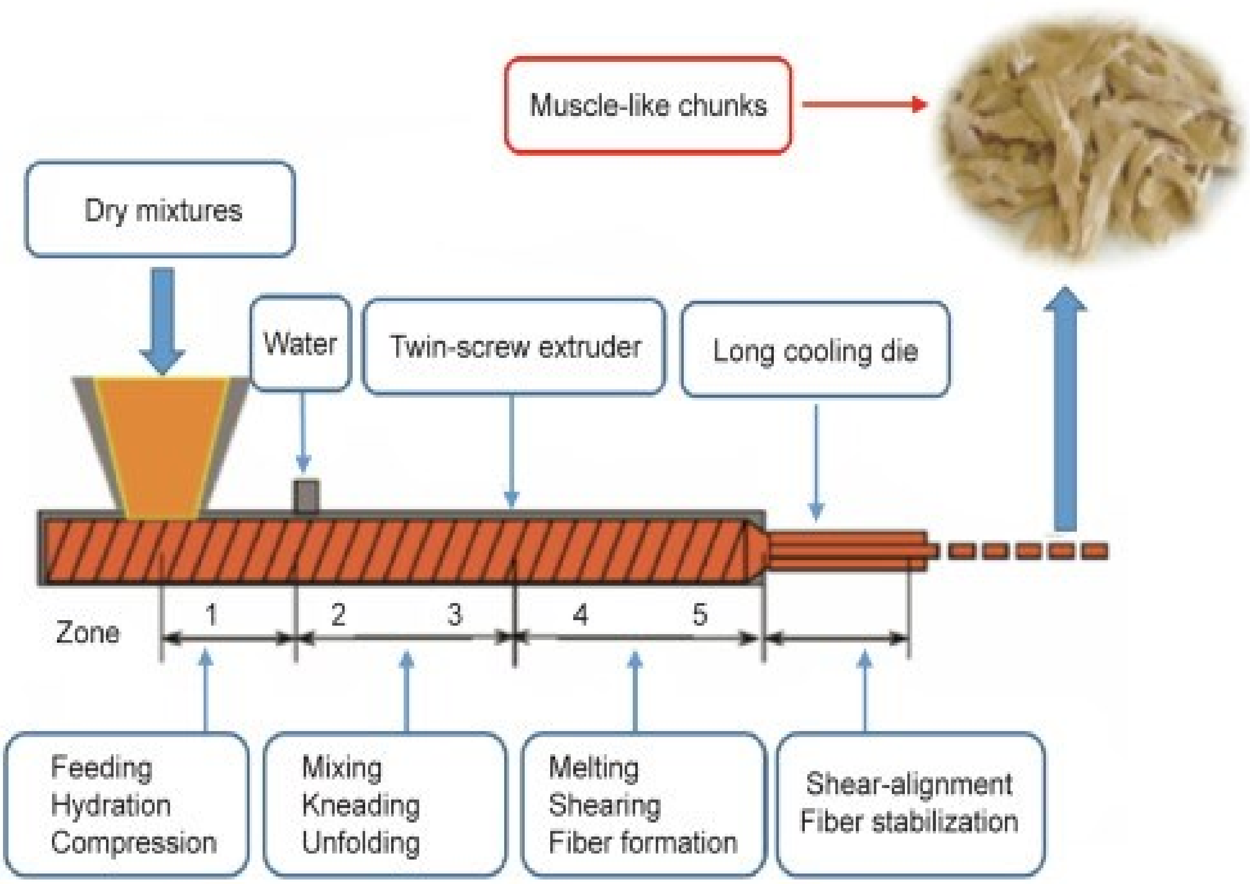


Figure 2: Scheme of a twin-screw extruder for HME of proteinaceous materials into fibrous analogs (Liu & Hsieh 2008).

The diagram above (Figure 2) explains the fibrous structure formation of protein-protein molecules from the study of Liu and Hsieh (2008). The five temperature-controlled zones (1 - 5) in the clamshell-style barrel were heated by an electric cartridge heating system. To quickly remove and clean the barrel and the screws, the barrel could be split horizontally and opened. The raw material used comprised unaltered wheat starch, soy protein, and wheat gluten in the following proportions: 60:40:5. Three different moisture levels—72.12, 66.78, and 60.11%—were tested while the extrusion temperature was maintained at 170 °C. Protein molecules underwent significant structural changes and unfolding in the extruder barrel, which provided the ideal environment for molecular rearrangement in the extruder zones (2-5). Under the described extrusion conditions, the study suggested that protein phase separation and rearrangement caused a clearly defined meat-like fibrous structure to form at a moisture level of 60.11% in the cooling die zone junction.

The freeze-structuring technique depends largely on the plant protein quality to yield a fibrous-like meat structure. This technique involves subjecting protein emulsion to freezing temperatures. The subsequent removal of trapped ice crystals in the protein would yield a fibrous and porous structure like the animal muscle, which is known to have highly stretched protein linkage (Dekkers et al. 2018; Singh & Sit, 2022). Proteins from soy, pea, and wheat are mostly used in the freeze-structuring process to develop PBMAs with meat-like structures because of their unique functional properties such as gelation, hydration, and solubility (Meade et al. 2005; Singh & Sit, 2022).

3-D printing is another PBMA development technology that uses a significant form of additive manufacturing which includes the fused deposition modeling of photographic and stereolithographic techniques (Severini et al. 2018). The processes that can be combined with 3D print technology in meat substitute production include Extrusion, inkjet printing, binder jetting, and bioprinting. 3D-printed meat replacers use an extrusion process to create structures out of fibrous meat materials (Min et al. 2019). The extrusion process is the most feasible and economical, even though other methods are being developed for 3D printing meat products with the desired design. This technique uses a nozzle to extrude three-dimensional geometric structures one layer at a time. In 2018, a Spanish company called NOVAMEAT manufactured beef and chicken using 3D printing technology. The product's organoleptic study revealed that its fibers, which had diameters ranging from 100 to 500, tasted like standard beef steaks. The production of a 50-g steak cost $1.50 USD, demonstrating the affordability of these procedures (Youssef & Barbut, 2011).

In recent times, a novel method based on motion structuring has been created (Peighambardoust et al. 2004). The shear cell was created for this reason, and it operates on the same principles as cone-plate rheometers by using a cone-cone geometry. While the cone on the device's bottom side rotates, the cone on its top side remains stationary. In an oil bath, both cones can be heated and cooled. In contrast to extrusion, the device's internal deformation during processing is more precise and constant. Simple shear and heat are used to align proteins, resulting in the formation of a fibrous structure (Manski et al. 2008). It has been demonstrated that even dairy proteins (calcium caseinate) can be fibrilized by shear cells. The shear rate for the protein sample is not constant throughout the volume because the radius of the shear cell increases with the distance between the cones. This design can only be employed for lab-scale testing due to its limited scalability.

1.5 Sensory Evaluation

Sensory evaluation involves the systematic measurement and analysis of human responses to various sensory stimuli, including taste, smell, appearance, texture, and overall sensory experience. By employing well-designed sensory methods, researchers can obtain valuable insights into consumer preferences and perceptions of PBMAs. The major sensory evaluation methods are descriptive, discrimination, and acceptance (Lawless & Heymann, 2010). However, for the purpose of this study, only the descriptive method is discussed.

1.5.1 Descriptive Analysis

Descriptive sensory analysis is a scientific methodology used to evaluate and describe the sensory properties of products or materials. It involves systematic observation and measurement of sensory attributes such as taste, aroma, texture, and appearance. The goal of the descriptive method is to provide a detailed and objective description of these attributes, allowing researchers, product developers, and marketers to understand and optimize the sensory characteristics of a product (Stone et al. 2020).

Descriptive sensory analysis typically involves a panel of trained assessors who use their senses to evaluate and describe the product attributes. These assessors undergo rigorous training to develop their sensory skills and establish a common sensory language. They learn to identify, discriminate, and quantify specific sensory attributes, ensuring consistency and reliability in their evaluations. Well-designed descriptive sensory methods either by using a hedonic scale or check-all-that-apply (CATA) give valuable insights into the characterization and perception of PBMAs. Most of the sensory studies (Table 4) have used untrained panels and the analyses were mostly focused on preference rather than descriptive. Hedonic scales were used because the sensory studies involved untrained participants. This is because consumers may find intensity scales confusing if the scales are many, and trained panelists typically use intensity scales. While it is advised that consumer studies be conducted with untrained participants between 75 and 150 in number, the studies used fewer participants than were necessary. Moss et al. (2023) suggested that sensory science researchers must either go beyond consumer acceptability/preference trials or develop more thorough acceptability trials (e.g., with more consumers, attribute diagnostics, segmentation, blinded and informed conditions) to enhance the development of PBMAs.

Table 4. Summary of sensory studies, test method, number of participants, product type, and some lexicon used.

Sample type	Sensory method	Number of participants	PBMA Lexicon used	Study
TSP Meat balls	9-point hedonic scale, CATA	60 untrained panel	Taste/Flavor: Tasty, bland, cheesy, weak meaty, strong meaty, wheat-cereal like Texture: Juicy, dry, hard, soft, solid & difficult to cut, crumbly & easy to cut	Grasso et al. (2019)
Extruded meat analog	9-point hedonic scale	46 untrained panel	Texture: Hard, fibrous, tender, firm, soft, tough	Chiang et al. 2019
Chicken and shrimp flavored TSP	Scale of 0 – 150	14 trained panel	Taste/Flavor: Beany, oily, chicken, fishy, shrimp, salty. Texture: Crispy, chewy.	Katayama & Wison, 2008
Vegan Sausage	9-point hedonic scale	8 trained panel	Texture: Hardness, chewiness, springiness, cohesiveness	Kamani et al. 2019
Meat-free sausage	7-point hedonic scale	24 untrained panel	Texture: Chewiness, hardness, springiness, cohesiveness	Majzoobi et al. 2017
Extruded meat analog	6-point hedonic scale	18 untrained panel	Texture: Firmness, elasticity, juiciness, fibrousness	Palanisamy et al. 2017
Meat-free sausage with tomato pomace	9-point hedonic scale	30 trained panel	Texture: Juiciness, tenderness, hardness, cohesiveness, springiness, chewiness	Savadkoohi et al. 2014
TSP analog with non-animal based liquid additive	7-point hedonic scale	10 untrained panel	Taste: Soy taste, oil taste Texture: Juiciness, elasticity, firmness, stickiness, roughness, compactness	Wi et al. 2020
TSP analog	Descriptive analysis	9 trained panel	Texture: Tough, mushy, moist, layered, cohesive, springy, chewy	Lin et al. 2002
Pea and wheat protein composite nugget	1–5 point descriptive scale	42 untrained panel	Texture: Hardness, chewiness, springiness	Yuliarti et al. 2021
Pea and oat protein composite analog	11-point hedonic	7 trained panel	Taste: Sweetness, bitterness, saltiness, Astringent, umami, off-taste, aftertaste Texture: Chewiness, springiness, moistness, graininess, hardness, cohesiveness	De Angelis et al. 2020

1.5.2 Test environment

The test environment is designed to minimize external influences that could affect the sensory perceptions of the participants. This includes controlling temperature, humidity, lighting, and background noise. Ideally, the temperature should be between 20-22°C, the humidity should be between 50-55% and the illumination should be neutral (300-700 lux) (Stone et al. 2020). The sensory booths are usually designed with demarcations such that panelists are unable to influence the decision of one another. The test area should be easily accessible, void of odors, and separated from the sample preparation area so that participants can give their judgments without biased opinions (Lawless & Heymann, 2010).

1.5.3 Test design

Designing a sensory study requires adequate coordination and planning. The first step is to understand the suitability of the method to employ based on the study objective. The sample storage and preparation, sample portions, temperature, and serving containers are usually standardized to prevent the panelists from having trouble evaluating the samples. An adequate amount of the samples should be served at their optimum temperature for example, fruit juice is best consumed cold while oat porridge is best consumed warm. It is always advised to adopt a 3-digit randomization system for sample labeling to ensure that the panelists deliver unbiased and objective results. Clear and concise instructions on how the panelists should answer the questionnaire must be made available (Lawless & Heymann, 2010).

1.5.4 Selection of Panelist

Motivation and sensory analytical skills are important factors to consider when selecting a panel, especially for descriptive sensory evaluations. The ability to evaluate and identify attributes is usually an advantage. Usually, companies employ highly trained experts while at other times, semi-trained ones could be used. Participation is mostly voluntary but there could be provision for incentives at the end of the study. The study organizers must ensure that evaluating the samples would not pose any health risk to the participants. Information regarding the product ingredients such as allergens or non-nutritive food additives must be indicated in the recruitment form. It is advisable to recruit more panelists than required in case one or two participant decline in the middle of the evaluation. Another reason is to be able to choose the best assessor at the end of the evaluation because of the variation in human taste receptors (Lawless & Heymann, 2010).

1.6 Taste and texture characteristics of PBMAs.

The taste and texture characteristics of PBMAs are key drivers of consumer acceptance and purchase (He et al. 2020; Moss et al. 2023). Consumers enjoy animal meat because of its savory taste, tender texture, and juicy mouthfeel. These characteristics are what food developers target to be replicated in PBMA. Despite the improvement in the taste and texture of the PBMAs in the market space, consumers still express dissatisfaction.

1.6.1 Texture

Texture is a vital sensory attribute that mimics the feel and mouthfeel of traditional meat. PBMAs aim to replicate the fibrous and chewy texture of meat. The texture of PBMA is determined by factors such as protein composition, protein structure, and processing techniques. Isolates or concentrates of soy protein, wheat gluten, or pea protein are commonly processed into a meat-like texture. Texture is a defining aspect of meat products and replicating it in plant-based analogs is crucial for consumer experience and satisfaction (Starowicz et al. 2022). The descriptive analysis combined with instrumental texture analysis aid in evaluating parameters like tenderness, springiness, cohesiveness, elasticity, chewiness, juiciness, and fibrousness. Outcomes of texture profile analysis enable food manufacturers to optimize formulations and processing techniques, ensuring that PBMAs deliver a similar sensory experience to their animal-based counterparts (Moss et al. 2023).

1.6.2 Taste

Taste refers to an experience initiated by the chemical reaction when food reacts with taste receptors (stimulus sensors) on the palate of the tongue. Contrastingly, when volatiles released from the food in the mouth react with olfactory receptors in the nasal cavity prior to exhalation, the taste sensation is connected to another sensation experienced through olfaction called 'aroma'. The former which is caused by non-volatile compounds (Roland et al. 2017) includes basic taste sensations such as bitter, sweet, sour, salty, and umami while the latter is most times combined with the basic tastes to describe the flavor' of food products (Chigwedere et al. 2022). Other taste sensations that are associated with PBMAs are astringent, spicy, metallic, fatty, and bland (Forientini et al. 2020; Roland et al. 2017). Though astringency is a measure of quality for certain foods/beverages, it is undesirable in PBMAs and described as a puckering, dry, and unpleasant mouth sensation. Nowadays, sensory researchers (Zhang et al. 2023; Bakhsh et al. 2022) combine descriptive and instrumental (electronic tongue system) analysis to evaluate the taste of PBMAs which has proven to give a more objective result.

1.6.3 Amino acid contribution to sensory attributes

The taste-imparting properties of amino acids were first discovered by Ikeda at the University of Tokyo in 1908. He found that a type of seaweed, known as monosodium L-glutamate (MSG) was a major ingredient in Japanese food flavor enhancers (Kirimura et al. (1969). The taste of food is a complex sensory experience influenced by various factors, including the combination of different amino acids, sugars, acids, and other compounds. Since the discovery that amino acids developed during ripening process are responsible for the taste of cheese, researchers have explored several ways to produce these taste enhancers. They are commercially produced by chemical synthesis, extraction, or fermentation to enhance the nutritive value of processed foods and otherwise improve the taste characteristics of natural foods.

According to Wang et al. (2020), amino acids effect on food can either be synergistic (modulate sweetness and enhance saltiness) or suppressive (decrease bitterness and sourness). Magnetic resonance imaging and sensory analysis have shown that glutathione enhances the umami and salt tastes (Goto et al. 2016). L-Arg is employed as a tactical tool to alter tasters' perceptions of sucrose, umami flavor, caffeine bitterness, the saltiness of NaCl, and the sourness of citric acid (Melis & Barbarossa, 2017). The enzyme reaction of beta-cyclodextrin caused wheat gluten protein hydrolysate to have an increased umami taste, specifically due to hydrolysis and the amount of aspartic and glutamic total free amino acids (Wang et al. 2016). Some studies have analyzed and compared the amino acid contents of different protein-based foods and beef (Table 5), emphasizing the potential for a complete switch to a more plant-based diet. However, there is a lack of information on the relationship between amino acids and the sensory characteristics of PBMAs.

When replacing meat with plant-based alternatives, it is important to consider their nutritional profile in addition to their functional and textural qualities. Researchers are trying to develop other methods to meet the recommended requirements for meat analogs in terms of amino acids considering that animal protein is still superior to plant protein. Plant-based proteins are regarded as being nutritionally deficient because they lack the amino acid, lysine, and contain low amounts of the essential amino acids, methionine, and cysteine, which contain sulfur (Zahari et al. 2022). Further, the complexity related to PBMAs processing could reduce the amino acids' availability and hence decrease their nutritional value and digestibility (Schmid et al. 2022). Therefore, the combination of two or more protein sources could improve the quality of the nutrients, allowing the mixture to satisfy FAO requirements.

TABLE 5. Some amino acid values (g/100 g of raw product) from major foods consumed across the globe (Haytowitz et al. 2019).

Amino acid	**Wheat**	**Tofu**	**Soybeans**	**Peas**	**Beef**
Isoleucine	0.23	0.32	0.81	0.98	0.92
Histidine	0.16	0.19	0.45	0.59	0.71
Leucine	0.45	0.50	1.36	1.68	1.70
Lysine	0.22	0.43	1.12	1.77	1.86
Methionine	0.14	0.08	0.22	0.20	0.55
Phenylalanine	0.30	0.32	0.87	1.15	0.80
Threonine	0.20	0.27	0.72	0.81	0.91
Tryptophan	0.07	0.10	0.24	0.16	0.21
Valine	0.28	0.33	0.83	1.04	0.99

1.7 Previous studies on the sensory characterization of PBMAs

Sensory analysis of meat alternatives is mostly part of a larger study that includes instrumental measurements and focuses mainly on soy-based meat-alternative products. Table 6. below gives a summary of findings from some previous PMBA sensory studies on taste and texture. Examples are seen in the study of Katayama and Wilson (2008) which involved aroma and flavor sensory evaluations of soy-based meat analogs and Lin et al. (2002) analyzed the texture and structure properties of PBMA made from soy protein isolates using a descriptive method. Other PBMA sensory studies incorporated functional ingredients or used composite plant protein. For instance, Yuliarti et al. (2021) adopted a freeze-structure technique to develop PBMAs of different plant-based composites with unique texture profiles. Wi et al. (2020)

reported on the sensory characterization of PBMAs made with soy protein isolate and wheat gluten.

Bakhsh et al. (2022) studied the synergistic effect of lactoferrin and red yeast rice on the quality characteristics of novel plant-based meat analog patties. Findings from their study showed that the incorporation of coloring agents (lactoferrin, red yeast rice, and a combination of both) had a significant effect on the chemical composition, textural attributes, and tenderness of plant-based patties. In addition, combining the colorants had a positive impact on the taste attributes and fatty acid profile of the patties. De Angelis et al. (2020) analyzed the sensory profile of meat substitutes processed with oats, peas, or de-fractionated soy protein and their composite at different ratios. The result from this study revealed that meat analogs produced with a combination of dry-fractionated pea protein and oat protein has more odor and taste intensity compared to analogs produced from protein isolates.

In the study by Grahl et al. (2018), cyanobacterium Arthrosporic platensis (Spirulina) was used to fortify a meat analog. The Soy PBMAs were made using a high moisture extrusion technique. A trained panel created some of the descriptors, cutting force, and texture profile analysis. The panelists evaluated the PBMAs using a variety of descriptors, including those for color, smell, texture, and taste. For example, 'firmness' was the descriptor for texture, and 'umami' was the descriptor to evaluate aftertaste. It's interesting to note that, even with only 50% spirulina incorporation, extrusion at low moisture contents (57%), produced a texture resembling fibrous meat. The cutting force and hardness of the PBMAs did not significantly change as spirulina was added. However, high spirulina content increased the intensity of the aroma, flavor, aftertaste, and color. This is because spirulina naturally has a strong flavor and vibrant color. Additionally, PBMA with higher spirulina concentrations had a softer texture and less fibrosity and elasticity. Considering the abundant nutrients in spirulina, they concluded that spirulina could be partially incorporated into a soy-based meat analog product.

For taste evaluation, Bakhsh et al., (2022) adopted a modern method called the electric tongue system (ETS) which has various sensor arrays, attached to a reference and lipid/membrane electrodes and a digital analysis software package. PBMA patties modified with lactoferrin, and red yeast rice were analyzed using ETS with respect to the five taste traits (astringency, bitterness, sourness, saltiness, and umami) of the intelligent technology. The outcome showed that the saltiness and sourness of the patties were negatively affected whereas the umami taste attribute displayed a positive result. Most PBMA sensory studies are trials of novel or modified formulations to improve the sensory of PBMAs of which soy is usually used as the main protein ingredient.

Table 6. Summary of findings from different PMBAs sensory studies (Fiorentini et al., 2020)

Sensory Attributes	Approach	Control	Findings	References
Taste, Flavor, Aroma	Addition of nutritional yeast to a TSP hybrid meatball	100% beef meatball	15% TSP with yeast received the highest flavor and overall acceptability scores were most associated with the term "tasty" and less associated with "bland"	Grasso et al. (2019)
	Addition of MRP at 10%, 20%, 30%, 40% to a soy meat analog	0% MRP	20% MRP resulted in the highest sensory scores for meaty aroma and meaty taste	Chiang et al. (2019)
	Addition of vegetable-based "chicken" or "shrimp" flavor at 3% and 4% to four shapes of soy meat analogs prepared with two cooking methods (fried or baked)	Unflavored sample	The highest flavor concentration with the frying method received higher scores in terms of flavor intensity and saltiness	Katayama and Wilson (2008)
Texture	Addition of SPI and WG at 80%, and 100% to a chicken sausage	100% chicken	Samples with partial and total replacement of meat with plant proteins received higher liking scores for texture due to reduced cooking loss and better emulsion stability	Kamani et al. (2019)
	Addition of j-carrageenan, konjac mannan, and xanthan gum at 0.3%, 0.6%, 1.0%, and 1.5% to an SPI sausage	0% hydrocolloids	0.3–0.6% kappa-carrageen or 0.6% konjac mannan resulted in the highest acceptability scores	Majzoobi et al. (2017)
	Addition of ICGN at 0.75%, 1.5%, 2.25%, 3% to a soy meat analog	0% ICGN	1.5% ICGN was the optimal level for acceptance of texture	Palanisamy et al. (2018)
	Addition of bleached tomato pomace at 1%, 3%, 5%, and 7% to an SPI meat-free sausage, a beef frankfurter, and beef ham	0% bleached tomato pomace	3% and 5% bleached tomato pomace in meat-free sausage resulted in the highest scores for juiciness	Savadkoohi et al. (2014)
	Addition of non-animal based liquid ingredients at different concentrations ranging from 15–35%	N/A	Water treatment affected juiciness more than the oil treatment	Wi et al. (2020)
	Extrusion of a soy meat analog with moisture content at 60%, 65%, and 70% and cooking temperature at 138, 149, and 160 °C	N/A	Moisture content had a greater effect on sensory attributes than cooking temperature	Lin et al. (2002)

Sensory Attributes	Approach	Control	Findings	References
	Changing ratios of PPI to WP: 7:0; 13:4; 8.5:8.5; 4:13, 0:17	Commercial 100% PPI and 100% WP meat analogs	A 4:13 PPI to WP ratio resulted in the highest acceptance scores	Yuliarti et al. (2021)

Considering the literature associated with PBMA sensory analysis, it is evident that an information gap exists for sensory characterization of commercially packaged PBMAs is unavailable. To achieve a more informative result, it is suggested that sensory studies on PBMAs should be conducted jointly with a more sophisticated approach like the electronic tongue system (ETS) or oral processing and chemical analysis of flavor precursors (Ross, 2021). Analyzing the combined data with multivariate analysis would help to identify underlying associations between the chemical properties and sensory descriptors of PBMAs.

Plant protein concentrates and isolates, two major PBMA ingredients have typically been evaluated (in water solutions of 2-4%) for their key undesirable characteristic intensities such as bitterness and astringency (Wang et al. 2022). Ettinger et al. (2022) characterized pea protein taste as astringent, beany, bitter, and earthy. In a recent literature review conducted by Chigwedere et al. (2022) to investigate the sensory attributes used for pulses and pulse-derived ingredients, some inconsistencies were identified in the use of descriptive terms in the sensory studies. For example, similar words are used interchangeably for (taste, flavor, odor), and (texture, mouthfeel). The result of the study highlighted a standardized sensory lexicon for the categories discussed.

The shift to plant-based diets is nevertheless hindered by the low sensory qualities of the available commercial products, which do not sufficiently mimic those of meat, despite the expanding availability of meat analogs (Hoek et al. 2011; Onwezen et al. 2021). Similar sensory qualities must exist for plant-based meat analogs (PBMAs) to be accepted as a replacement for meat. Although, Hoek et al. (2011) discovered that with continuous consumption of PBMAs comes less expectation for the meat analogs to have exact similarities to meat. For this reason, the desirability of plant-based meat alternatives to have an equal resemblance to muscle meat is of utmost importance.

However, PBMAs are targeted typically at flexitarians and omnivores, who are more concerned about the sensory properties, mainly flavor (taste) and texture of these products to traditional meat (Michel et al. 2021). The varying flavor and texture of commercial plant-based meat analogs are dependent on factors such as the type of plant protein, ingredients, and processing technique. Non-volatile constituents such as amino acids, lipids, peptides, sugars, and inorganic salts contribute to the meat-like taste of PBMA due to the chemical reaction initiated during the heating process (Sun et al. 2022). Meanwhile, the texture attribute of PBMAs like fibrousness is developed when a mass of protein is transformed during the texturization process like extrusion (Godschalk-Broers et al. 2022).

1.8 Objective of the Study

Sensory characterization studies of PBMAs are mostly focused on modifying existing formulations by incorporating functional ingredients or harnessing under-utilized plant proteins. According to the information at my disposal, there is inadequate information on the sensory characteristics of commercially available plant-based alternatives. Therefore, the aim was to conduct a sensory characterization analysis to identify the key sensory properties in commercially available plant-based meat alternatives from two categories, mildly processed products, and refined products. The mildly processed PBMAs are minimally processed, still have most of the plant components in them, and have little or no extra ingredients in their formulations. On the other hand, refined PBMAs refer to products developed with protein isolates/concentrates and have undergone extensive processing that changes the protein structure and contains much more ingredients and additives. The study is ongoing research in the Food Science Unit, Department of Life Sciences of the University of Turku. Another aspect of the study is to find an association between taste and amino acids with respect to PBMAs. The data would be collected from another student whose thesis entails analyzing the amino acid contents of the commercial samples used in the sensory study. Results from this study will reveal if amino acids have an influence on the taste attributes of the products. The outcome of this study would provide the information required for manufacturers to make decisions on the category of plant-based foods suitable for their brands and help them modify their plant-based products for better consumer acceptability.

2. Methodology

2.1 Sample Selection and Preparation

The metabolomics results of the 168 commercial plant-based protein alternatives from a doctoral research study informed the selection of 16 samples from three major categories: products with whole legumes, products with whole legumes processed into food (mildly processed foods), and products with legume protein concentrates/isolates (refined foods). A total of nine products from all categories except the first category were included in the study. All the samples were prepared according to the instructions on each package. A laboratory induction burner and stainless-steel cooking utensils were used in preparing the samples. Table seven (7) below shows the different categories of samples and instructions for their preparation as written on each package. Samples were prepared with a laboratory induction burner and utensils in the sensory laboratory of the University of Turku. NB: The frying method used was dry frying. No oil was used in the preparation to prevent influence on the sensory characteristics of the samples.

Table 7. Categories and method of preparation for each sample.

Mildly processed samples	**Preparation**	**Refined samples**	**Preparation**
Beanit	Ready to eat, need only heating	Beyond burger	Fry for 3.5 – 4 mins on each side
Bean better	Fry for 4 mins	Fallero	Heat in a pan (8 mins)
Jalotempe	Fry until crispy	Soyappetit	Measure one part soy strip to two parts water and boil for 5 – 10 mins
Pirkka tofu	Dry with paper, fry for 3 mins	Vegem	Fry for 3 mins or just heat
So Fine tofu	Fry for 4 mins		

Figure 3: Commercial PBMAs selected for the study as listed in Table 5.

Figure 4. Some of the prepared samples, ready to be portioned prior to evaluation. From L-R: Pirkka Tofu, Vegem Seitan, Fallero and Soyappetit.

Table 8. The commercial PBMA samples, their protein sources, and their ingredients.

Brand and product	Protein source	Ingredients
Beyond meat, beyond burger	Peas	Water, pea protein isolates 16%, rape seed oil, coconut oil, rice protein, aroma, stabilizer, potato starch, apple extract, color (beetroot extract), maltodextrin, pomegranate extract, salt, kalium chloride, lemon juice concentrate, corn vinegar, emulsifier.
Fallero, härkäpapu-herne-lehtikaalifalafel	Fava beans	Fava beans 40%, peas 30%, rape seed oil, kale 3%, fava bean flour, spices (cumin, cilantro, turmeric, cayenne pepper, fennel), salt, emulsifiers, garlic, lemon juice, psyllium, raising agent
Jalotempe, härkäpapu	Fava beans	Fava beans, water, fungi
Pirkka, luomu tofu	Soy	Soybeans 67%, water, coagulant
SoFine, tofu natural	Soy	Water, soybeans 38%, coagulant
Beanit, härkäpapusuikale	Peas	Water, pea protein, fava beans, rapeseed, oil
Bean better, Lempea härkapapumuru naturel	Fava beans	Fermented fava beans, water, sea salt
Vegem, original seitansuikale	Wheat	Wheat gluten, chickpea flour, water, rape seed oil, syrup, vinegar, crushed tomatoes, black pepper, cayenne pepper, smoked paprika, kimion, garlic powder, chili, smoke aroma, thickening agents (E412, E415), preservatives (E202, E211).
Soyappetit, soijapalat	Soy	Soybeans

2.2 Ethical Pre-evaluation

The sensory study, which involved human subjects consuming samples, was subjected to an ethical pre-evaluation by the human sciences ethics committee at the University of Turku. Some of the commercial samples used in the study contained food ingredients that might be allergens to study participants, and this analysis was used to collect human data. As a result, it was important to consider the ethical standards that the ethics committee had approved. The ethical evaluation of the research design included, among other things, considerations for potential health effects on the research participants, the appropriateness of the information provided to participants, their consent, data management, and participant privacy (Appendix 3). To ensure legal compliance and the protection of research participants, the ethical pre-evaluation process calls for some level of transparency from the researcher.

2.3 Sample Pre-testing and method validation

While awaiting ethical approval, a preliminary sensory test was conducted using some of the commercial samples and a few participants with knowledge of sensory analysis. The samples were prepared following the instructions on their packages. The panelists were asked to evaluate and describe the inherent taste and texture attributes in each sample. On the next page of the questionnaire, they were asked to select all attributes that could be perceived in the samples using the check-all-that-apply (CATA) method. Important points were noted for sample preparation time, test instructions, test design, results, and panelist feedback. Pre-testing the samples prompted a better understanding of handling the samples during the training and evaluation sessions with respect to storage, cooking, and portioning. In other words, the feedback was maximized in ensuring an adequate plan for the study. The method validation was essential to maintain consistency, reliability, and minimize errors during the training and actual evaluations.

2.4 Selection of Panel

An electronic link was sent as an invitation via email to the university and student community. The link contained simple questions on the participants' familiarity with PBMAs and diet types. Also, interested participants were asked to choose suitable training and evaluation time slots made available in the invitation. Those who were soy or gluten intolerant were advised to withdraw as some of the commercial samples were made from soy and wheat. Priority was given to participants who already have knowledge of sensory evaluations. Consequently, participants were majorly the staff and students at the University of Turku. Their participation was voluntary and based on their availability. All participants were encouraged to complete all training and evaluation sessions, but sick participants were asked to withdraw from the study.

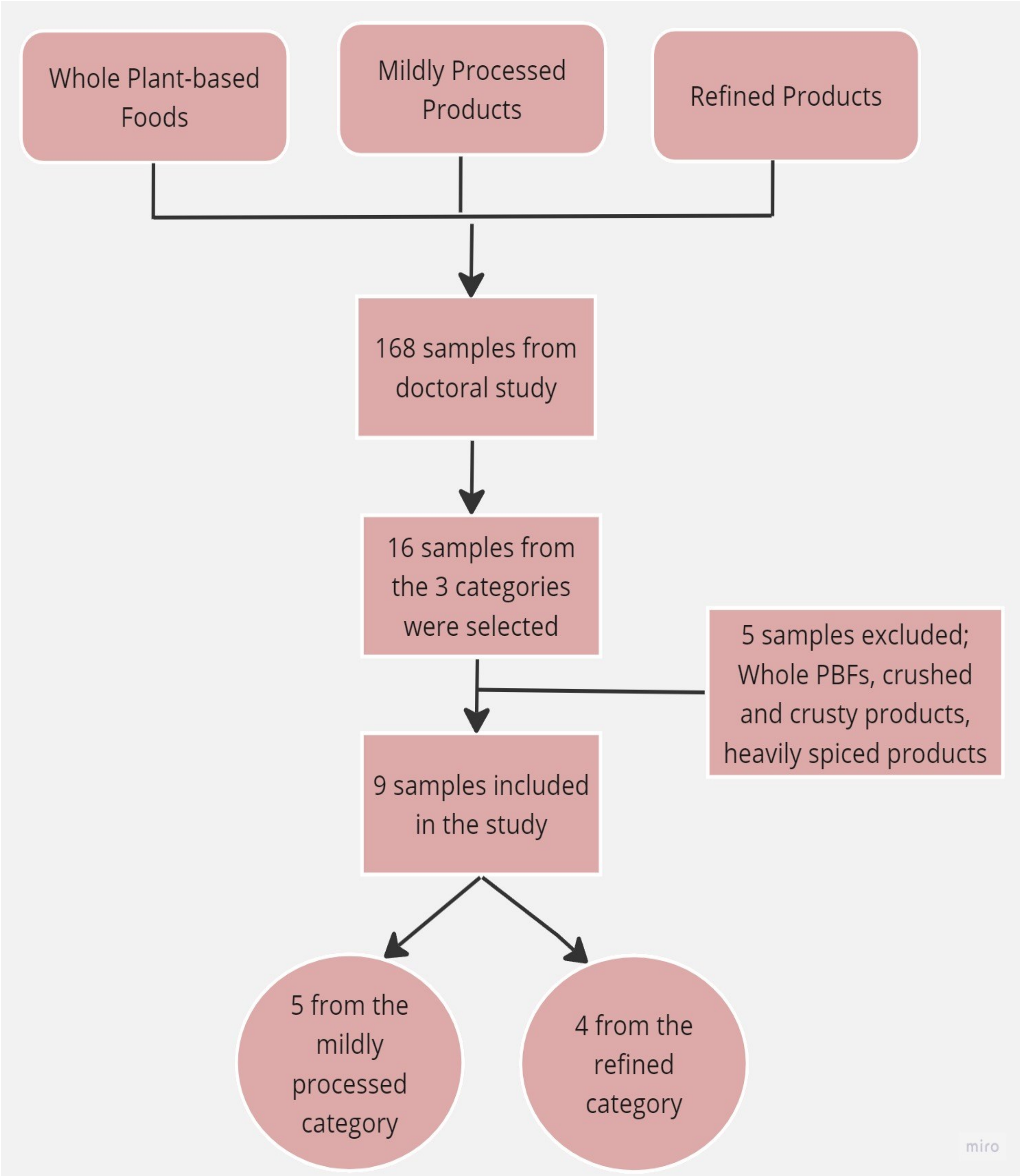


Figure 5. Flow chart showing how the samples were selected for the descriptive sensory study.

2.5 Panel Training

The training sessions were held in the sensory training room of the University of Turku and each panelist was present during all sessions based on their preferred time slots. A brief introduction about the study was given before the first training session commenced after which, each participant was asked to sign a consent form. First, the panelists were asked to evaluate the reference intensity of each identified attribute on a line scale of 0 – 10 (0 not intense, and 10 very intense). Next, they analyzed each sample's attribute intensity in comparison to the reference intensities already evaluated. The panelists were asked to give their opinion about the suitability of the average attribute intensities, sample presentation, and the questionnaires. Based on the panel feedback, adjustment was made to the reference concentrations of some taste attributes to ensure a more realistic taste perception with respect to the commercial PBMAs being analyzed. Eventually, the panel unanimously agreed on a benchmark on the line scale for each attribute. The panelists had to be trained so that they could evaluate and agree on reference intensities, identify, and compare sample intensities to reference intensities.

Figure 6. Table set before the commencement of a training session.

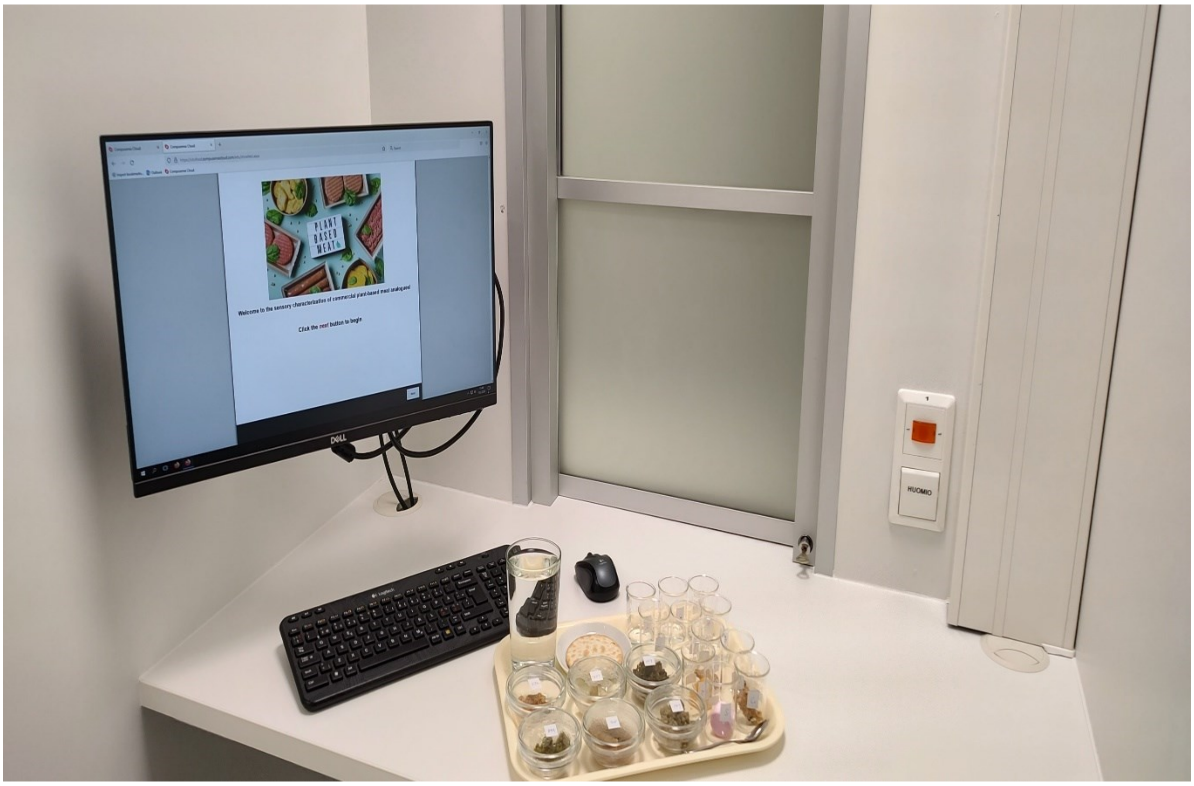


Figure 7. Sensory analysis booth with a serving tray containing commercial samples and references properly labeled with unsalted crackers and water as palate cleansers.

2.6 Lexicon creation

For the taste, there was no need to create a lexicon. Six different taste attributes were established to be evaluated in the study. The taste attributes were sweet, salty, sour, bitter, umami, and astringent. Food-grade chemicals were prepared in different concentrations as reference samples. Table 9 below shows the taste attributes, codes, descriptions, concentrations of references used, and reference intensities. Apart from astringency, other taste attributes were described as 'basic' because it is believed that most peoples' taste receptors can identify them. However, the degree of perception of the taste attributes varies from person to person which could cause difficulty in agreement among the panelists.

Table 9. Description of taste attributes in order of evaluation, the concentration of references, and their intensities on a line scale of 0 - 10 (0 not intense and 10 very intense). NB: The taste reference quantity per evaluation of each reference sample was 2 ml.

Taste Attributes and Coding	Descriptions	Reference Concentrations	Reference intensities on the line-scale
Sweetness (Sw)	Basic	1% Sucrose	5
Saltiness (Sa)	Basic	0.2% Sodium chloride	5
Sourness (So)	Basic	0.07% Citric acid	6
Bitterness (B)	Basic	0.07% Caffeine	6
Astringency (A)	Puckery or drying sensation created in the mouth or throat	0.07% Aluminium chloride	6
Umami (U)	Basic	0.06% Monosodium glutamate	5

For texture attributes, there was lexicon creation. Panelists were asked to first identify the texture attributes in the PBMA samples presented to them. After identification, panel check software was used to analyze the relevant attributes and six texture attributes were found to be the common choice among the panelist. The initial texture attributes identified by the panel include, hardness, chewiness, dryness, graininess, crumbliness, and rubbery. Hardness and dryness were eventually replaced with softness and moistness respectively based on the panel suggestion. Though some PBMA sensory study include hardness and dryness in their lexicon, the decision was valid because hardness and dryness were barely identified in the samples compared to the references provided. Finally, the six agreed texture attributes were softness, chewiness, moistness, rubbery, graininess, and crumbliness. References were sourced with respect to the textures identified in the samples. Given the short time frame, deciding on reference samples for the texture attributes was a tough process because of their peculiarity and differences. Table 8 below shows the texture attributes descriptions, codes, references, quantity, and intensities used. The panelists first evaluated the intensities of the references on a line scale of 0 to 10 (0 not intense, 10 high intensity). After this, the training samples were evaluated with respect to the reference intensities. The outcome was thoroughly discussed especially on attributes with disagreement among the panelists. After much deliberation, the training sessions ended on the third day with a decisive consensus on the intensities to use for each attribute.

Table 10. Description of texture attributes in order of evaluation, the concentration of references, and their intensities on a line scale of 0 - 10 (0 no intensity and 10 high intensity)

Texture attributes and coding	Descriptions	References	Quantity of reference per evaluation	Reference intensities on the line-scale
Softness (S)	Smooth, without much resistance when bitten.	Marshmallow	One marshmallow	8
Crumbliness (Cr)	Breaks apart easily into small pieces or crumbs when bitten.	Elovina biscuit	One-quarter of biscuit	7
Chewiness (Ch)	Requires a lot of mastication before swallowing.	Liquorice candy	One candy	7
Graininess (G)	Presence of small particles that can be felt while chewing.	Rye biscuit	One-quarter of biscuit	6
Moistness (M)	Level of liquid or wetness in the food.	Canned peach	One peach fruit was diced into 12 parts.	7
Rubbery (R)	Chewy and elastic-like.	Liquorice candy	One candy	6

2.7 Descriptive sensory analysis

The sensory evaluation room was equipped with computers, adequately lit up, and had an environmental condition of 21°C and 54 RH. The samples were served in glass dishes labeled with random 3-digit codes in a Williams' Latin square design based on the method described by De Angelis et al. (2020). The serving size for the mildly processed samples was 3g each while those of the refined samples were 2 cm in three parts. Figure 7. shows the sensory evaluation booth with a serving tray containing the samples, references, a glass of water, unsalted crackers, and cutleries. The samples were covered to retain their flavors and kept warm at a temperature of 70°c on a laboratory heating surface prior to evaluation. One assessor (P6) from the 11 who started the evaluation withdrew from the study due to ill health. Each of the ten remaining panelists evaluated 14 attributes including total taste intensity and total texture intensity, using a line scale of 0 – 10 (0 no intensity, 10 high intensity) based on the descriptive lexicon established during the training sessions. Attribute definitions were provided on the questionnaires to help the panelists make informed judgments. There were 2 mins break time between tests during which the panelists neutralized their palates with water and unsalted crackers before a new test commenced or as required. Each panelist evaluated 6 samples per session (day) and the 9 samples were analyzed in two replicates for three days.

2.8 Data Processing and Statistical Analysis

The collected data from panelists' evaluations were analyzed statistically to derive meaningful insights. First, the panel sensitivity, reproducibility, and agreement were analyzed with PanelCheck 1.4.2 (Nofima, Tromsø, Norway). The benchmark for statistical significance for the study was fixed at $p < 0.05$. The data were subjected to multivariate analysis like the principal component analysis (PCA) using Unscrambler X software (version 10.5, Camo Inc., Norway) and spider chart using Excel.

The amino acid data were retrieved from another student's thesis study while the protein and fat contents data were collected as stated on the sample packages. These two categories of data were combined with data from the descriptive sensory analysis and subjected to principal component analysis to find a potential association.

3. Results and Discussion

3.1 Panel Performance

Following the workflow recommended by Tomic et al. (2010), the sensory data was analyzed with PanelCheck software to provide crucial information regarding the panel's sensitivity, agreement, and repeatability. To assess the important attributes, a mixed model three-way ANOVA was performed on the data. As illustrated in Figure 8, attributes like sourness (F value = 2.72, p = 0.011), astringency (F value = 3.46, p = 0.002), and softness (F value = 3.74, p = 0.012) were not differentiated among the PBMA samples while other attributes (sweetness, saltiness, bitterness, umami, graininess, chewiness, moistness, crumbliness and rubbery) revealed a significant product effect ($p \leq 0.000$).

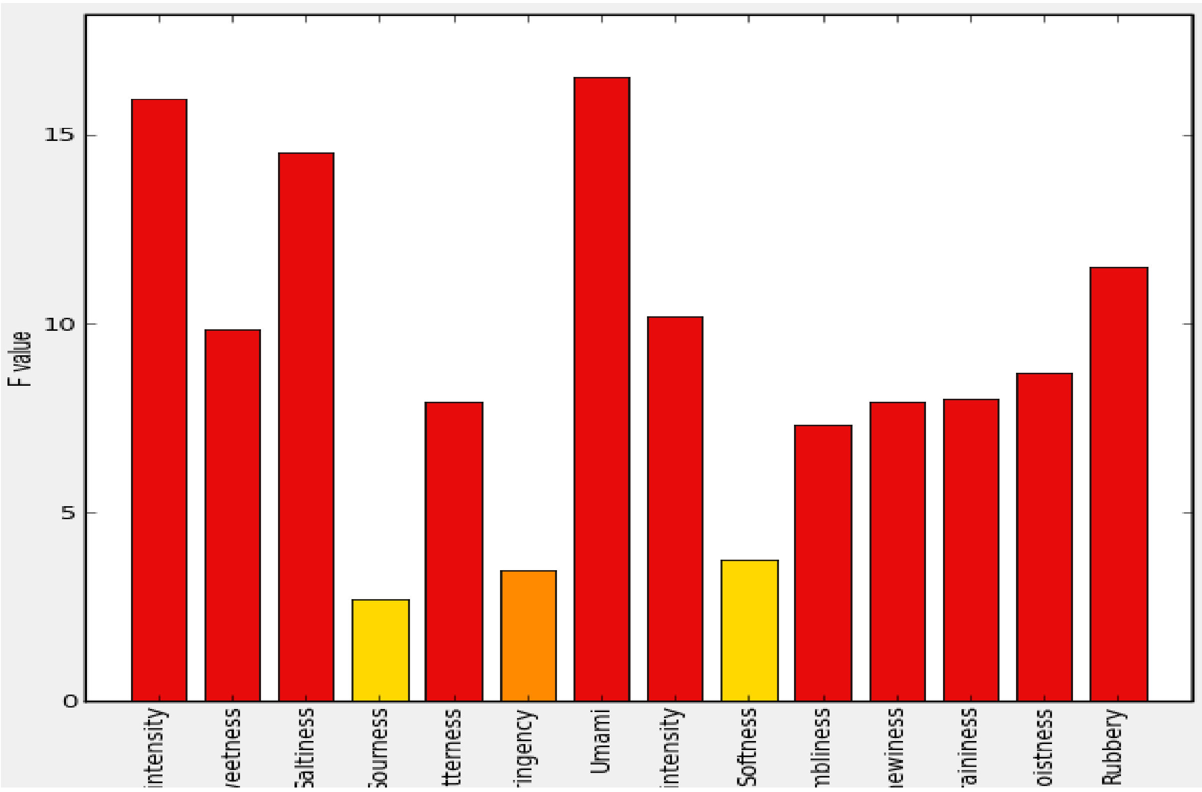


Figure 8. Graphical representation of three-way ANOVA on commercial PBMA sensory data: F-values of sample effect. Significance: *** indicates $p < 0.001$.

A tucker-1 plot test was used to evaluate the alignment among the panelists. The panelists performed fairly for Umami (Figure 9A) even though it is obvious that some panelists are clustered at a point (good agreement) causing two assessor groups. This implies that panelists P7, P5, P2, P4, and P6 have similar taste perceptions of umami in the samples. A relatable agreement is observed for panelists P9, P8, and P10. An identical occurrence exists in the two plots for panelists P3 and P1 as they both have obvious disagreements with the rest of the panel. Screening through the plots in Figure 9B, it is evident that the overall performance between the 10 panelists for softness was very poor as it depicts bad agreement. The poor assessor performance for sourness may have resulted from disagreement errors such as magnitude error, crossover error, non-discriminator error, or non-perceiver error. Further explanations for these types of errors can be found in the study of Kermit & Lengard, (2005).

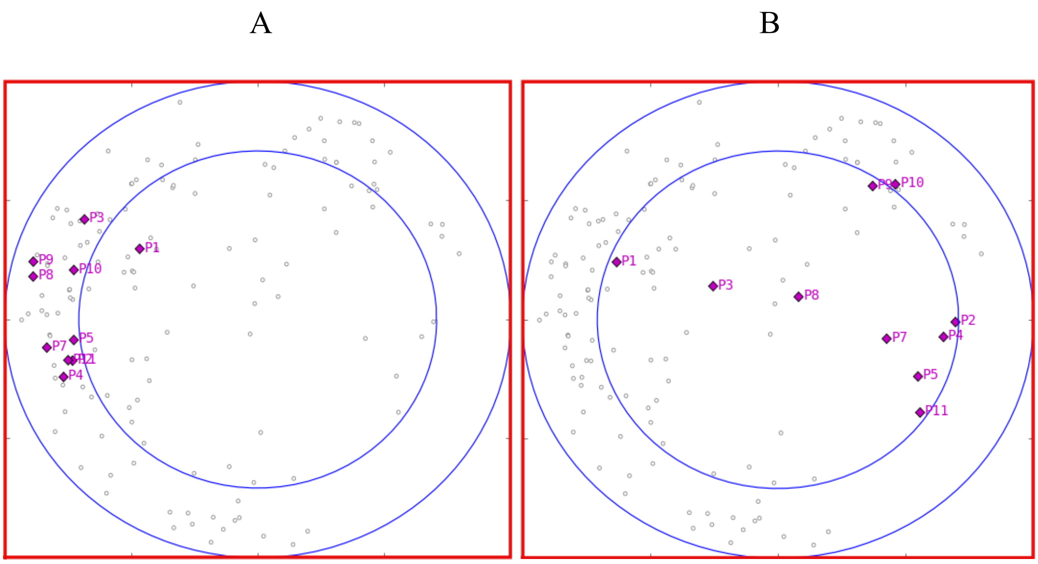


Figure 9. Examples of Tucker-1 plots (PanelCheck) showing agreement among panelists (P1-P11) for the A plot (umami) with a good agreement and the B plot (softness) with a bad agreement. Clustered panel = good agreement, non-clustered panel = bad agreement.

The p-MSE plot in Figure 10, reveals panelists' sensitivity and repeatability for rubbery and sour attributes respectively. Almost all the panelists showed good discrimination and about three of the panels (P2, P8, & P9) lacked reproducibility for rubbery texture in the test samples. However, the plot for Sourness shows that some of the panelists (P1, P7, & P3) with larger p values lacked good sensitivity while P1 and P7 lacked repeatability to sourness in the samples. Sourness as a taste attribute is said to be difficult to discriminate in food compared to other taste attributes but some studies have reported that children are more sensitive to sour taste than adults (Vennerød et al. 2018). This could be the reason for the wide variation in sensitivity and repeatability for sourness as all participants were adults.

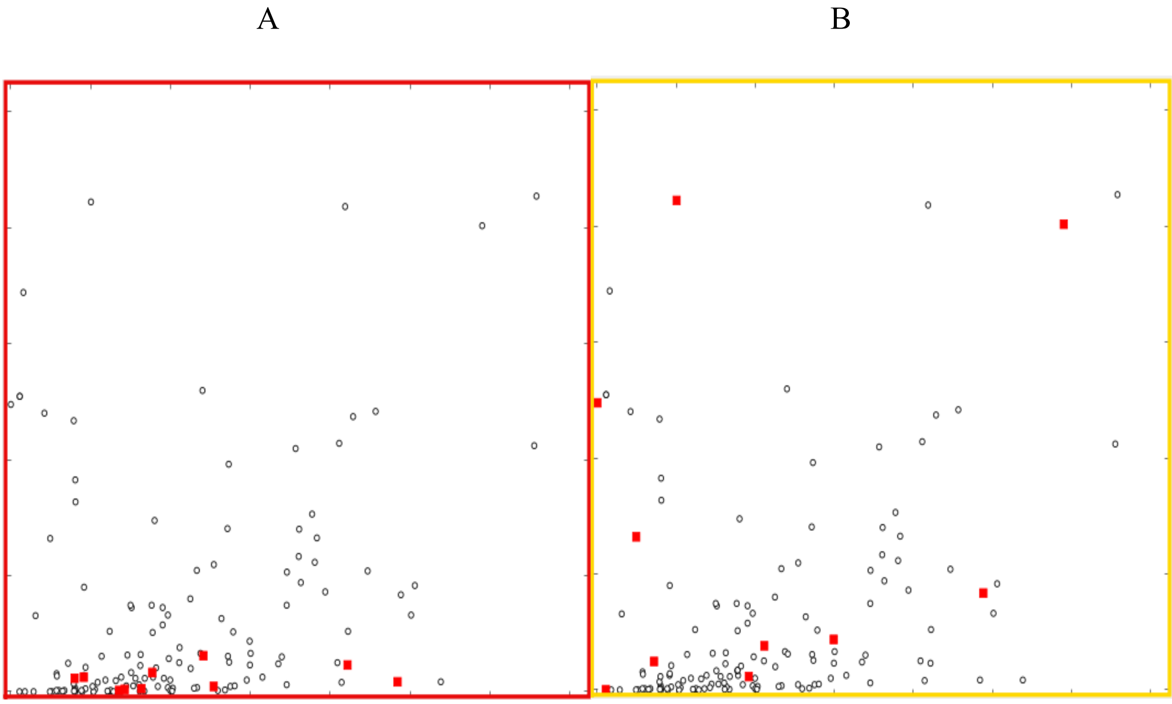


Figure 10. p-MSE plots (PanelCheck) showing sensitivity (y-axis, p-values) and repeatability (x-axis, mean square of errors) of the panelists for the attribute, rubbery (A plot), and sourness (B plot). Sensitivity explains the ability of the panelists to discriminate between the samples. Repeatability focuses on the ability of the panelists to consistently replicate a judgment for the samples.

3.2 Differences between the sample ingredients

The commercial samples were produced with different ingredients, formulations, and technological processes which inform the variations in their sensory characteristics. As seen in Table 5, the samples are products of four different types of protein sources: soy, fava beans, peas, and wheat (gluten). Based on the study's categorization, the mildly processed samples are products having most of the plant components intact (except the product is produced with a process that completely alters its structure). Samples in this category evidently have few ingredients in their formulations and retained the taste of their protein sources thus, preventing the possibility of a meaty taste perception during evaluation. This category may be referred to as plant-based products with unique features even though tofu is traditionally referred to as meat analog, the panelists thought the taste is better described as neutral or bland.

On the other hand, refined samples are products strictly made with protein isolate/concentrate (except the product is formulated with a lot of ingredients that could mask the taste of the protein source). A close observation of Table 8 shows the list of ingredients for each product as labeled on their packages. The refined samples (beyond burger, fallero, and vegem) are loaded with ingredients except for soyappetit with only soybeans as its ingredient. Soyappetit qualifies as a refined sample because the protein structure was completely altered through the texturization process. While soyappetit retained the taste of its protein source, the other refined meat alternatives had the taste of their protein sources masked due to the various flavor enhancers added in their formulations. As an old practice, the food industry successfully achieves taste/flavor masking by adding acid, salt, sugar, and flavoring (Roland et al. 2017). More spices are seen on the ingredients list of fallero and vegem than beyond burger, which is reflected in their distinct taste and aroma as evaluated by the panel. The combination of ingredients in the refined sample formulation is an indication that the manufacturers intended to develop products with a savory meat-like taste.

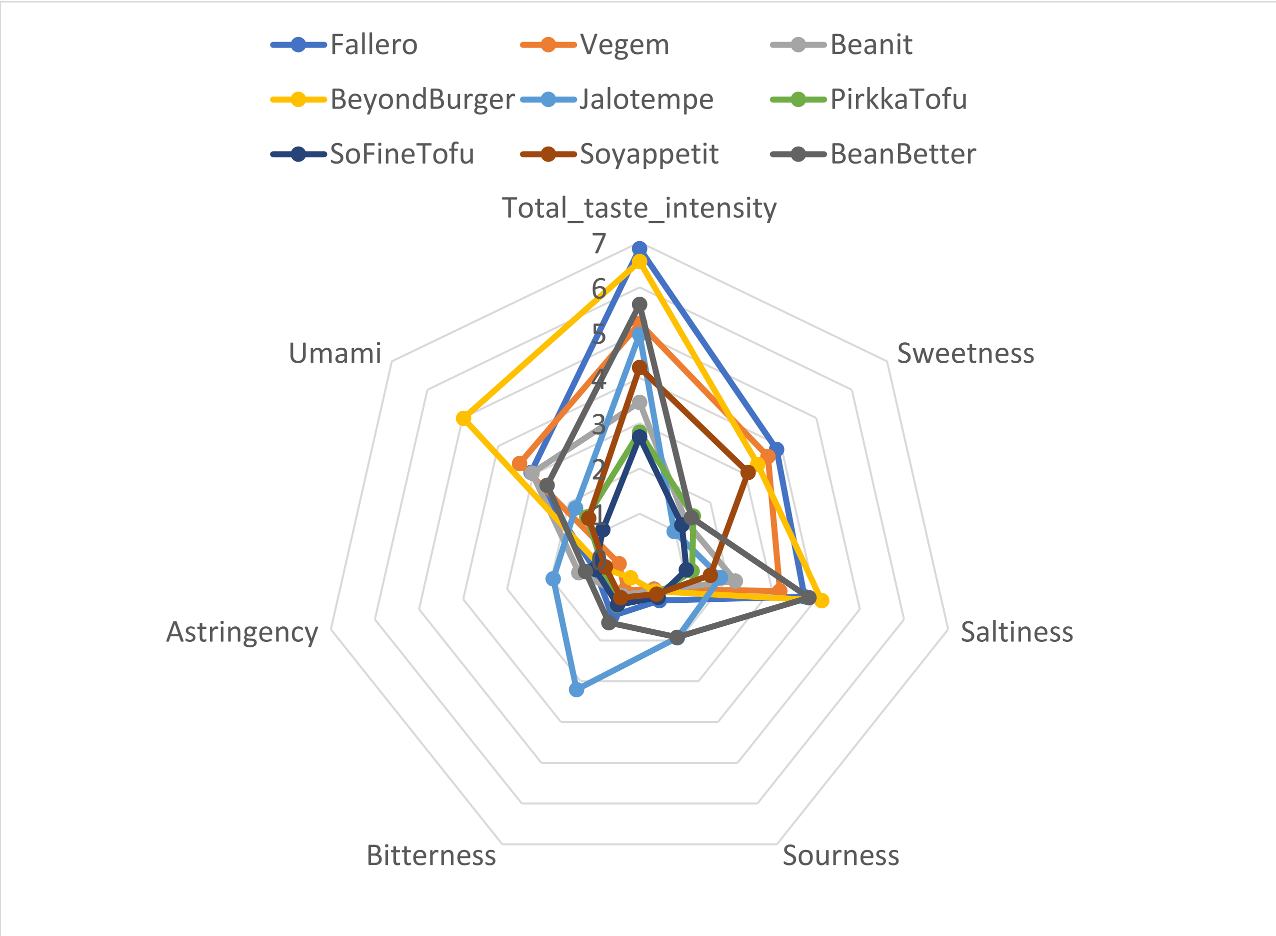


Figure 11. Spider chart of the commercial samples showing mean differences in taste attributes evaluated by panelists (N=10) with descriptive sensory method on a scale of 0 – 10 (0 no intensity, 10 high intensity). To clearly observe the variation between the samples (n=9), the scale is zoomed to a range of 0 – 7.

3.3 Identification of differences between the PBMAs attributes

The spider chart above shows how the samples differ in taste. The taste of the samples is a function of the ingredients in their formulations. The panelists evaluated samples from the refined category to have the highest total taste intensity, particularly Beyond burger and Fallero. Astringency, bitterness, and sourness had low intensities in the samples. However, Jalotempe stood out as the most bitter sample in the mildly processed category. This agrees with the study of Rousta et al. (2021) where commercial patties were evaluated for taste and texture and compared with patties produced from the biomass of an edible fungi '*Aspergillus oryzae* biomass. In their research, most of the sensory participants preferred beyond burger while describing the fungi vegan burger as salty, bitter, sour, and stale. Therefore, the bitter undesirable taste of Jalotempe may be due to the presence of fungi and protein source in its formulation (Table 8). Additionally, catechins, isoflavones, and phenolic acids found in the protein sources of the minimally processed samples are said to be associated with astringency and bitterness (Kyriakopoulou et al. 2019; De Angelis et al. 2020).

An increased intensity of umami and saltiness is seen for samples in the refined category, especially beyond burger. The result is congruent with the descriptive analysis of Hernandez et al. (2023). In their study, 9 trained panelists evaluated and compared commercial plant-based patties to ground beef. They speculated that the high umami and salt intensities may have been influenced by added salt and yeast extract while adding that yeast extract contains taste-active compounds such as amino acids and peptides.

For sweetness, it is easy to see a difference from the chart (Figure 11), where the refined samples are grouped together above the samples with mild processing. Ingredients like syrup and certain spices may have contributed to the sweetness of the refined samples. For saltiness, fallero, beyond burger, vegem, and bean better have the highest intensity. Adding spices, herbs, and salt to refined PBMAs enhances the aroma/taste and masks the unwanted flavor of plant-based foods (Kyriakopoulou et al. 2019; Bohrer et al. 2019). The presence of sea salt and fermentation explains the high salt intensity of bean better which some of the participants described to have a strong yeasty taste. A different product of the bean better brand which was used during the training was unavailable at the time the evaluation was to commence. A new product of the same brand was purchased which turned out to be a fermented product. Pirkka tofu, so fine tofu, and beanit were bland in taste because there was no taste-enhancing ingredient in their formulation.

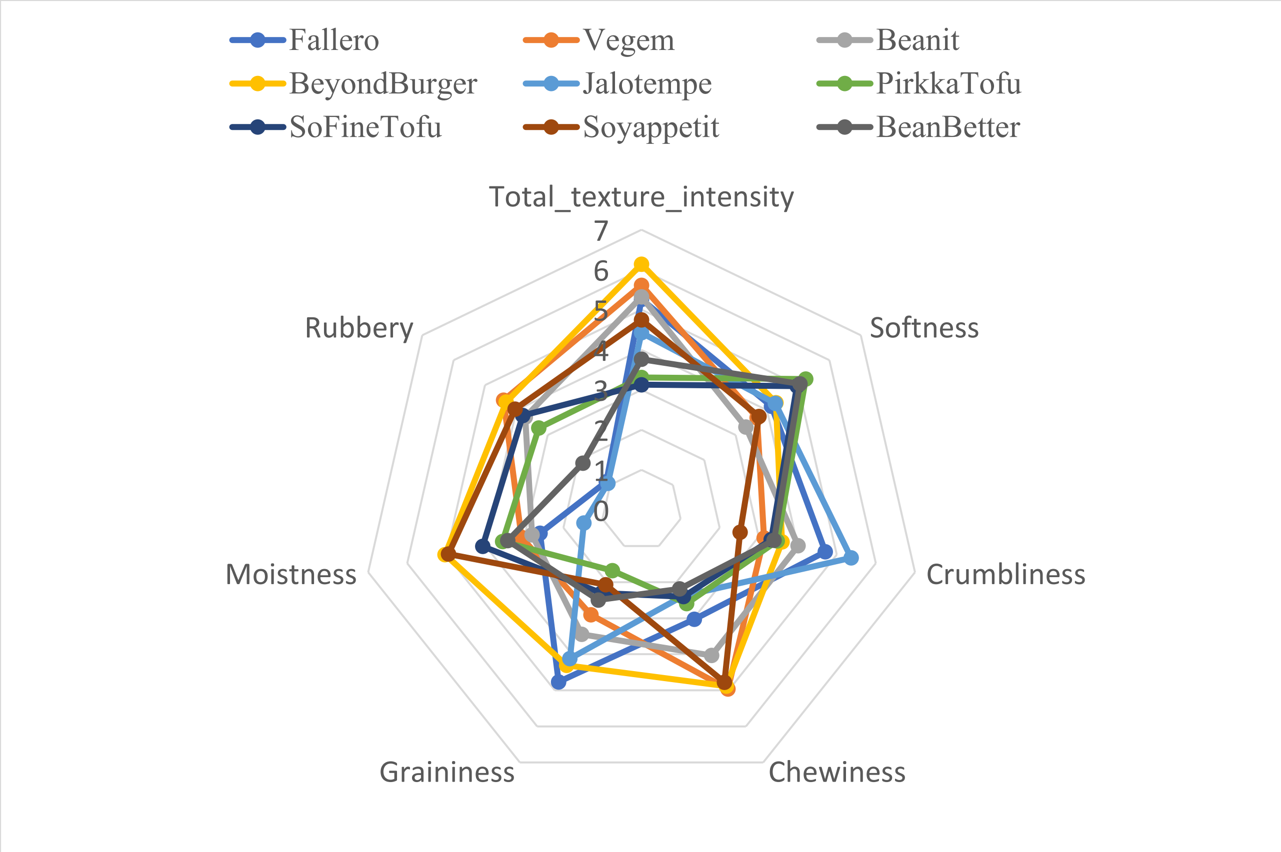


Figure 12. Spider chart of the commercial samples showing differences in texture attributes evaluated by panelists (N=10) with descriptive sensory method on a scale of 0 – 10 (0 no intensity, 10 high intensity). To clearly observe the variation between the samples (n=9), the scale is zoomed to a range of 0 – 7.

The texture attributes evaluated by the panelists were seven in total; total texture intensity, softness, crumbliness, chewiness, graininess, moistness, and rubbery as seen in Figure 12. The Samples in the refined category, beyond burger and soyappetit were observed to have the highest texture intensity. Although the samples are of different protein sources and possibly different processing techniques, they were most likely produced with either protein isolate/ concentrate or gluten. The result of the study showed that the texture of commercial PBMAs is a function of the synergistic effect of processing technique and added functional ingredients. Several studies have reported the use of soy protein isolates or in combination with other protein sources to develop PBMAs with meat-like structures (Lin et al. 2002; Zahari et al. 2020; Zahari et al. 2022). Beyond burger, soyappetit, and vegem were the most rubbery and chewy samples. Bakhsh et al (2021) observed a wide difference between soy/wheat-based patties and beef patties due to a chewy, elastic, rubbery, sensation and poor mouth feel of the plant protein sources.

Higher moistness which could also be referred to as 'juiciness' was perceived in beyond burger and soyappetit. The absorption of water during boiling of soyappetit buttressed by Wi et al. 2020 and Godschalk-Broers et al. 2022 suggested that water treatment affects juiciness as a desired attribute in PBMA. On the contrary, the oils and gelling agent in beyond burger may have influenced high moistness (Zahari et al. 2022). Meanwhile, Godschalk-Broers et al. (2022) speculated that juiciness in plant-based burgers may be due to the linkage between their composition and structures. Water may have contributed to the high soft texture of the tofus. Crumbliness and graininess were found mostly in jalotempe and fallero respectively. These samples however had the lowest intensity for moistness since their preparation was void of any form of liquid. Fallero, which is a meatball sample, shares similar characteristics with TSP meatballs produced by Grasso and colleagues. According to their result, the key drivers for the liking of 15% TSP meatballs were identified as crumbly and easy to cut, soft, juicy, and moist looking (Grasso et al. 2019).

Though all the samples were prepared following the instructions on the package, they were prepared on different days. This means that there may have been some inconsistencies in the prepared samples. For example, tofu is prepared by first pressing out excess water before cooking. The amount of pressure applied to press out excess water on the first evaluation day may have differed on the other evaluation days. Therefore, it is advisable to have the samples prepared all at once and stored properly so that the perception of the panelists remains consistent throughout the evaluation sessions.

The least significant difference (LSD) test (Table 11) explains the analysis of variance (ANOVA) conducted on the data set. Evidently, there is a wide variation between the means of the refined samples and the mildly processed samples. Beyond burger showed the most statistically significant difference ($p<0.001$) but, the tofu samples only showed a significant difference in their moistness which may have been caused by inconsistency during sample preparation. Other samples showed varying degrees of significant differences between their means including soyappetit, fallero, and jalotempe.

Table 11. Mean and the least significant difference (LSD) for taste and texture attributes of the nine commercial samples.

	Sweetness	Saltiness	Sourness	Bitterness	Astringency	Umami	Softness	Crumbliness	Chewiness	Graininess	Moistness	Rubbery
Fallero	6.860***	3.880***	3.740	1.020	1.015	3.070	4.150	4.705***	3.035	4.765***	2.600	1.130
Vegem	5.210***	3.635	3.185	0.735	0.460	3.390	3.690	3.135	4.965***	2.905	3.075	4.405***
Beanit	3.465	1.315	2.175	0.775	1.375**	3.040	3.325	4.010	4.035***	3.445	2.805	3.715***
Beyond burger	6.575***	3.345***	4.130	0.790	0.855	4.980***	4.295*	3.595	4.885***	4.305***	5.030***	4.320***
Jalotempe	4.965	0.980	1.840	1.930***	1.955**	1.810	4.265*	5.365***	2.385	4.120***	1.475	1.070
Pirkka Tofu	2.805	1.525	1.190	0.870	0.825	1.490	5.240*	3.470	2.595	1.685	3.560	3.280***
So Fine Tofu	2.695	1.200	1.065	0.945	1.005	1.040	4.960*	3.320	2.405	2.300	4.070***	3.790***
Soyappetit	4.230***	3.070	1.610	0.865	0.775	1.440	3.750	2.520	4.775***	2.075	4.945***	4.040***
Bean better	5.625	1.465***	3.845*	1.920	1.225	2.610	5.055*	3.390	2.190	2.495	3.425	1.875

* = significant at $p < 0.05$, ** = significant at $p < 0.01$, *** = significant at $p < 0.001$

3.4 Principal Component Analysis of the Sensory Data

The average attribute of duplicates for each sample was analyzed and the data was standardized before subjecting the data to principal component analysis (PCA). The PCA scores plot in Figure 12A shows how the 10 panelists discriminated between the nine evaluated samples. In other words, it shows that the two-first principal components explain 76% of the total variability contained in the dataset. The scores plot shows that the first axis discriminates between the mildly processed samples on the left side versus the refined samples on the right side. As expected, the two tofus are close together which means the samples share similar attribute intensities. The loadings plot (Figure 12B) shows how the attributes influence the variation in the combined data set. The distance between the attributes defines their correlations. The close distance between sweetness, umami, saltiness, chewiness, total taste intensity, and total texture intensity signifies a strong positive correlation. On the other hand, bitterness, sourness, and astringency are positively correlated. This emphasizes the difference in the ingredient formulations and processing techniques between the refined samples and the mildly processed ones. The loading of graininess on PC1 is lower compared to other attributes, indicating that graininess has no contribution to the variation in the data set. Crumbliness negatively correlates with rubbery and moistness and has the most influence on PC2.

The mildly processed samples are characterized by high intensity for the attributes ‘bitterness’, ‘sourness’, ‘astringency’, ‘softness’, and ‘crumbliness’ (see loadings plot in Figure 12B). However, the refined samples are characterized by high intensity for attributes ‘moistness’, ‘chewiness’, ‘umami’, ‘saltiness’, ‘sweetness’, ‘rubbery’, and to a certain degree ‘graininess’. Similar results were recorded in other PBMAs sensory studies. Hernandez et al. (2023) compared the descriptive attributes and volatile flavor compounds between commercial PBMAs and ground beef. They reported that sensory attributes associated with commercial PBMAs include sweet, salty, umami, nutty, buttery, musty/earthy, smoky/charcoal, and fat-like aromatics. As expected, the tofus are close together which means the samples share similar attributes. Similarly, Godschalk-Broers et al. (2022) combined instrumental and sensory analysis to find a link between the structure, texture, and sensory perception of commercial chicken pieces and nuggets. Their findings established a correlation between measured texture attributes of PBMAs like cohesiveness, chewiness, and hardness with their sensory profile. Additionally, they suggested that food manufacturers should focus on enhancing the juiciness and meaty flavor because they are key determinants for the liking of PBMAs.

3.5 Amino acid association with the taste of PBMAs

The amino acid composition data of the commercial samples were retrieved from another thesis study while the nutritional contents (protein and fat) of the samples were collated from the product packages. To understand the influence of amino acids and nutritional content on the samples’ taste attributes, principal component analysis (PCA) was conducted on the data set (Figure 11A and 11B). The PCA shows the first two principal components PC1 and PC2 which explains 67% of the total variation contained in the data. Taste attributes represent the dependent variable while the amino acids and nutritional contents serve as the independent variable. PC1 in the scores plot (Figure 11A) separates the samples based on the most ingredient-intensive and the least ingredient-intensive PBMAs. As a result, soyappetit falls in the mildly processed sample. Recall that it was categorized as a refined product due to its meat-like structure, but it is a product without added ingredients except for its protein source.

The loadings plot (Figure 11B) reveals how the taste attributes of the samples are influenced by amino acids and nutritional content. Sweetness and umami are negatively loaded on PC1 and are associated with fat. Saltiness and total taste intensity has a positive loading on PC1 and are associated with the following amino acids, glutamic acid, serine, phenylalanine, arginine, valine, leucine, methionine, lysine, tyrosine, tryptophan, and isoleucine. Other taste attributes with positive loading are astringency, bitterness, and sourness. From the loadings plot, protein has no association with taste (Solm, 1969) while fat is known to contribute to the mouthfeel and texture of PBMAs. In as much as the protein sources of the samples are rich in amino acids, there is a possibility that some of the products may have been fortified with amino acids or gained more amino acids through processing techniques like fermentation. Taste-active compounds such as peptides, amino acids, and their derivatives are formed during food fermentation (Zhao et al. 2016).

Researchers focus on the amino acid composition of plant protein sources (Table 5) because animal meat nutrients must be replicated in PBMAs. Chiang et al. (2019), found that the major amino acids in meat analogs processed with SPI/WG were proline, leucine, glutamic acid, and aspartic acid, and cysteine was lesser in firm tofu and cooked chicken than the meat alternatives. Advanced processing techniques for PBMA have produced goods that resemble meat in terms of flavor and texture but lack the necessary nutrients. As a result, the impact of amino acids on flavor is not given much attention.

Extensive research has established amino acid associations with the taste of green tea. Mao et al. (2018) investigated the roasting treatment effect on amino acid taste in green tea. In their study, thiamine, aspartic, and glutamic acids were associated with an umami taste. A bitter taste was found in tryptophan, valine, lysine, isoleucine, phenylalanine, arginine, and histidine. The sweet amino acids were serine, glycine, threonine, alanine, proline, and methionine. They concluded that bitter amino acids reduced with increased temperature while sweet amino acids increased with increased temperature. The bitter amino acids in the green tea study align with amino acids associated with astringency, bitterness, and sourness in the loadings plot of this study. The samples with those taste attributes are fermented products, hence, have a large amino acids cluster.

Added ingredients in PBMAs may also enhance the taste-active effect of amino acids. Table salt (NaCl) has a salty taste, enhances the umami taste, and suppresses bitter and metallic tastes (Zhao et al. 2016). On the other hand, amino acids and peptides may intensify the salty flavor, enabling the reduction of salt content in food. According to Careri et al. (1993), the concentrations of glutamate and aspartate were correlated with the salty flavor of dry-cured meat. Although umami and salty tastes are perceived by different receptors, the simultaneous presence of both intensifies taste perception. Interestingly, the umami flavor of soy sauce was improved by the subthreshold presence of bitter aromatic amino acids. Thus, the intensity of other taste attributes can be impacted by subthreshold concentrations of other amino acids (Lioe et al. 2005).

In conclusion, establishing an association between amino acids and the taste of PBMAs is complex considering the different ingredients incorporated during processing. Surprisingly, there were no amino acid clusters around umami and sweetness in this study. It is uncertain if amino acid was one of the added ingredients because none of the sample packages contained amino acids in their formulations. However, it is evident that amino acids influence the saltiness and total taste intensity of PBMAs and have a strong association with the bitter, sour, and astringent tastes of the mildly processed samples. Future studies can employ instrumentation to objectively establish the taste impact of amino acids in PBMAs.

A

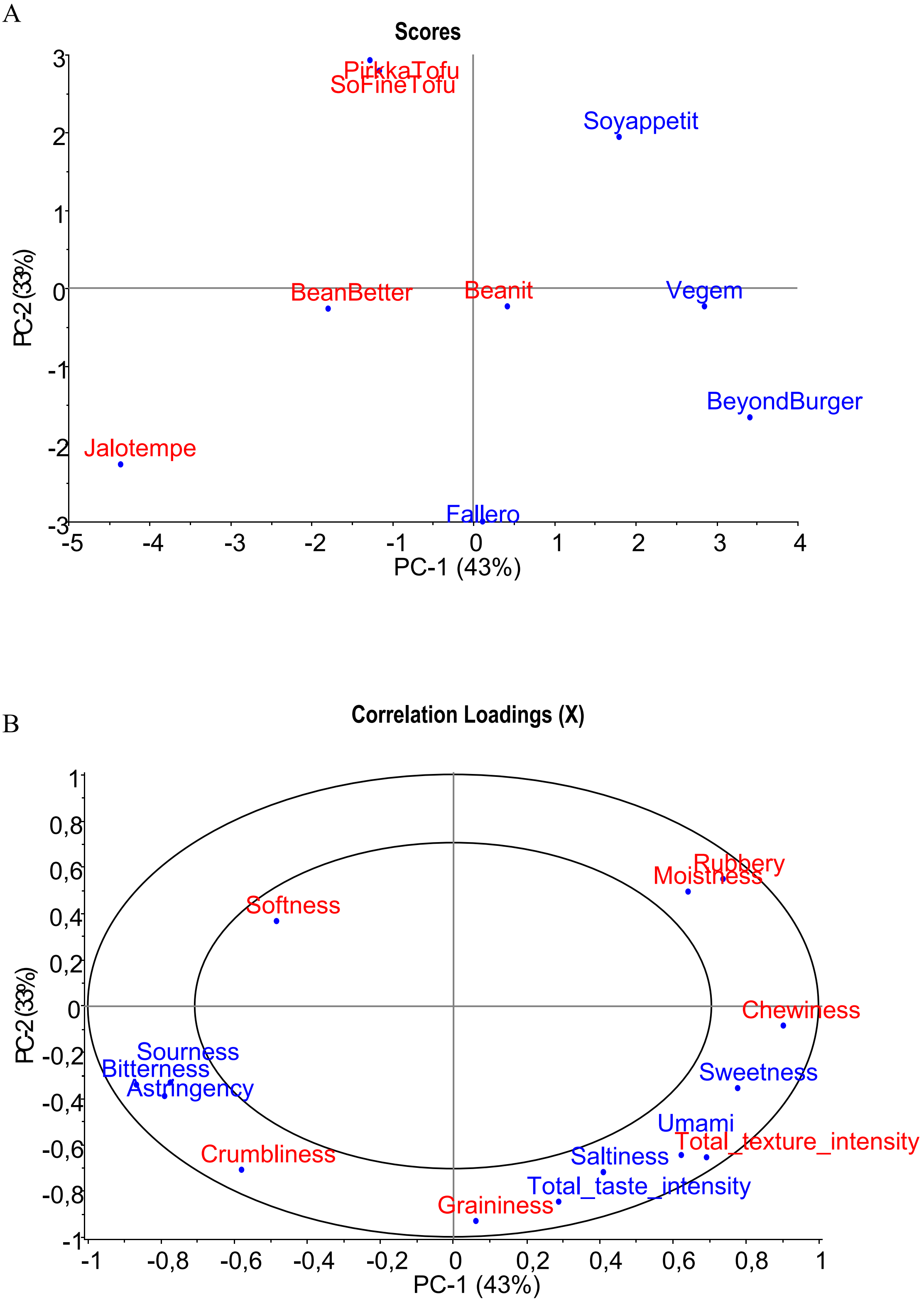
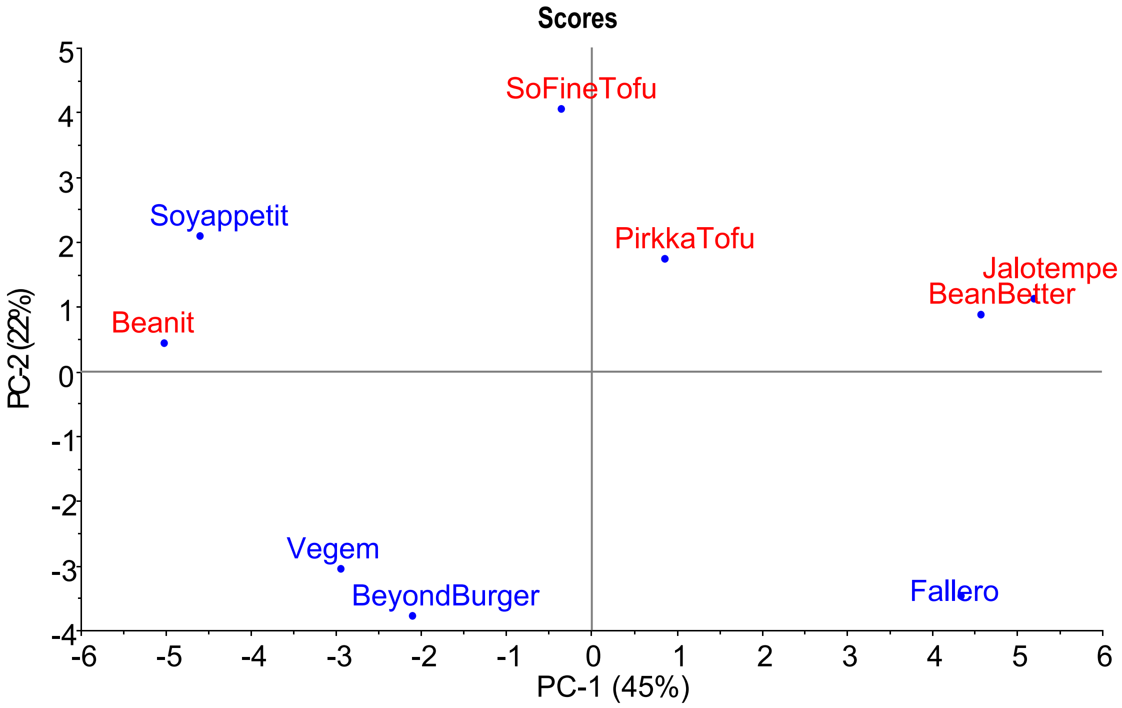


Figure 12. PCA plots for sensory evaluation of the samples. A is the scores plot showing the refined samples in blue and the mildly processed ones in red. B is the loadings plot showing the taste attributes in blue and the texture attributes in red.

A



B

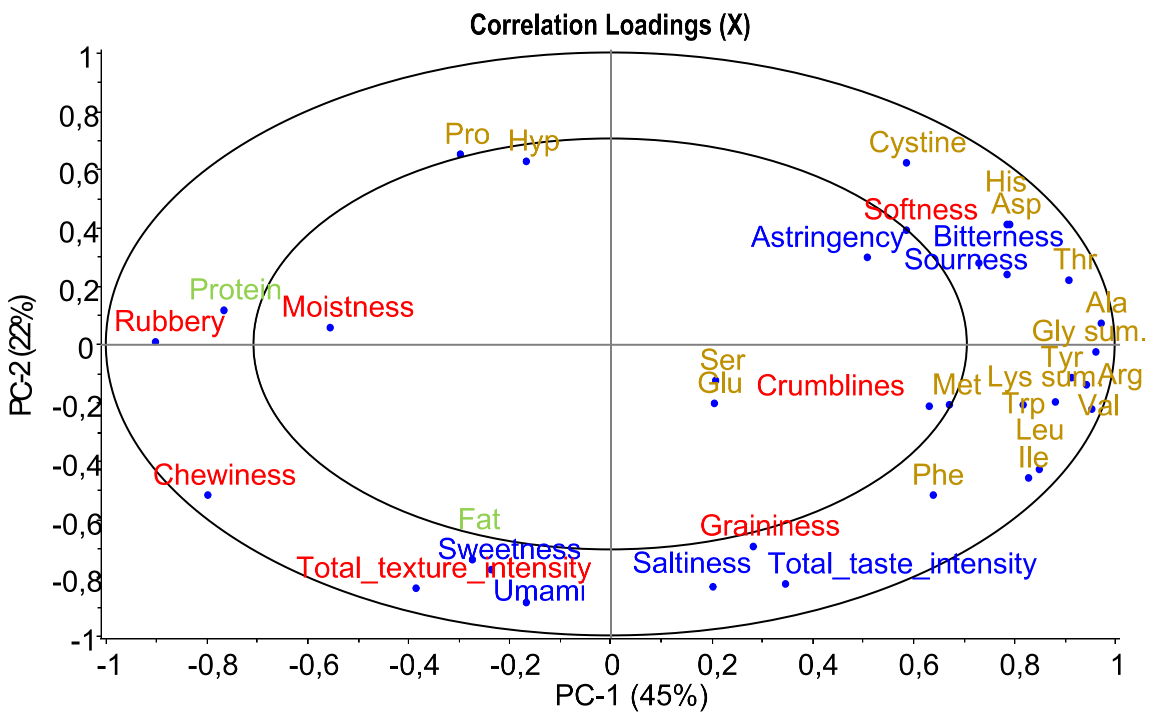


Figure 13. PCA plots show the association between sensory attributes and amino acids of the samples. A is the scores plot showing the refined samples in blue and the mildly processed ones in red. B is the loadings plot showing the taste attributes in blue, texture attributes in red, amino acids contents in yellow and nutritional content in green. The amino acid data was retrieved from another student's thesis study while the protein and fat data were collected as stated on the sample packages.

3.6 Limitations and Future Research

Several challenges faced during the study include training difficulty, texture reference sorting, and incomplete sample coverage. The training was problematic especially for taste attributes because the participants were more inclined to their individual taste receptors. For example, the taste buds of some participants were of high umami taste while others had less umami taste receptors. This indeed contributed to the varying agreement of the panelists for some of the samples. Sorting the references for texture attributes was another difficult task because all the samples were very different. This was also the reason why animal meat was not used as a reference because a larger number of the samples were mildly processed. To prevent biased judgments, we opted for edibles that closely matched the texture attributes from the chosen lexicon. More samples were planned to be evaluated but were later canceled as fewer participants showed interest.

Nowadays, a lot of innovations are being reported for plant protein substitutes. To address the limitations above, future research should focus on the sensory characterization of one category of sample per study to achieve a more objective outcome. For example, refined samples should not be analyzed alongside mildly processed ones or even fermented products because the different product groups have distinct sensory properties. Refined samples could be referred to as “plant meat alternatives” while the mildly processed ones could be referred to as “plant protein alternatives”. To have a well-defined study objective, samples could also be grouped based on protein sources/types e.g., protein isolate products, protein concentrate products, TVP products, etc. To avoid panelist discrimination difficulty, more time should be allocated for intensive training, or better still, persons from a particular demography or trained sensory experts should be allowed to participate.

4. Conclusion

The descriptive sensory analysis of the commercial PBMA samples revealed variations due to their compositions, added ingredients, and processing methods. Although, similarities were observed in the different categories where the refined samples had better taste and texture intensities than the mildly processed samples. Therefore, this study suggests that umami, saltiness, chewiness, moistness, and rubbery could serve as quality measures for PBMAs as seen in the beyond burger sample. Therefore, food producers are more likely to achieve plant meat alternatives reminiscent of animal meat when they maximize the use of appropriate ingredients and protein isolate/concentrate in their formulations coupled with advanced technological processing techniques.

A low sensory appeal is one of the most common barriers to PBMA consumption. To promote acceptance, it is pertinent to sort suitable protein sources to improve the quality and sensory attributes of the final products, explore novel structure formation mechanisms, and develop analytical methods and standards for the quality and sensory evaluation of PBMAs. Information from this study would guide manufacturers in optimizing formulations, refining cooking methods, and developing marketing strategies that align with consumers' expectations.

5. References

Babu, P. D., Bhakyaraj, R., & Vidhyalakshmi, R. (2009). A low-cost nutritious food “tempeh” -a review. *World J Dairy Food Sci*, *4*(1), 22-27.

Bakhsh, A., Lee, E. Y., Bakry, A. M., Rathnayake, D., Son, Y. M., Kim, S. W., ... & Joo, S. T. (2022). Synergistic effect of lactoferrin and red yeast rice on the quality characteristics of novel plant-based meat analog patties. *LWT*, *171*, 114095.

Baune, M. C., Terjung, N., Tülbek, M. Ç., & Boukid, F. (2022). Textured vegetable proteins (TVP): Future foods standing on their merits as meat alternatives. *Future Foods*, 100181.

Bohrer, B. M. (2019). An investigation of the formulation and nutritional composition of modern meat analog products. *Food Science and Human Wellness*, *8*(4), 320-329.

Boukid, F. (2020). Plant-based meat analogs: from niche to mainstream. European Food Research and Technology, 1-12. https:// doi.org/10.1007/s00217-020-03630.

Careri, M., Mangia, A., Barbieri, G., BOUONI, L., VIRGILI, R., & PAROLARI, G. (1993). Sensory property relationships to chemical data of Italian-type dry-cured ham. *Journal of Food Science*, *58*(5), 968-972.

Chang, K. C., & Hou, H. J. (2003). Science and technology of tofu making. In *Handbook of Vegetable Preservation and Processing* (pp. 530-572). CRC Press.

Chiang, J. H., Loveday, S. M., Hardacre, A. K., & Parker, M. E. (2019). Effects of soy protein to wheat gluten ratio on the physicochemical properties of extruded meat analogs. *Food Structure*, *19*, 100102.

Chigwedere, C. M., Wanasundara, J. P., & Shand, P. J. (2022). Sensory descriptors for pulses and pulses-derived ingredients: Toward a standardized lexicon and sensory wheel. *Comprehensive Reviews in Food Science and Food Safety*, *21*(2), 999-1023.

Day, L. (2011). Wheat gluten: production, properties, and application. In *Handbook of food proteins* (pp. 267-288). Woodhead Publishing.

De Angelis, D., Kaleda, A., Pasqualone, A., Vaikma, H., Tamm, M., Tammik, M. L., ... & Summo, C. (2020). Physicochemical and sensorial evaluation of meat analogues produced from dry-fractionated pea and oat proteins. *Foods*, *9*(12), 1754.

Dekkers, B. L., Boom, R. M., & van der Goot, A. J. (2018). Structuring processes for meat analogs. Trends in Food Science & Technology, 81, 25–36. https://doi.org/10.1016/j.tifs.2018.08.011

Ettinger, L., Falkeisen, A., Knowles, S., Gorman, M., Barker, S., Moss, R., & McSweeney, M. B. (2022). Consumer Perception and Acceptability of Plant-Based Alternatives to Chicken. Foods, 11(15), 2271.

Featherstone, S. (2015). Ingredients used in the preparation of canned foods. *A complete course in canning and related processes*, 147-211.

Fiorentini, M., Kinchla, A. J., & Nolden, A. A. (2020). Role of sensory evaluation in consumer acceptance of plant-based meat analogs and meat extenders: A scoping review. Foods, 9(9), 1334.

Food and Agriculture Organization of the United Nations (FAO). (2009). High-Level Expert Forum—How to Feed the World in 2050.

Font-i-Furnols, M., & Guerrero, L. (2022). Understanding the future meat consumers. Meat Science, 193, 108941.

Fraser, R. Z., Shitut, M., Agrawal, P., Mendes, O., & Klapholz, S. (2018). Safety evaluation of soy leghemoglobin protein preparation derived from Pichia pastoris, intended for use as a flavor catalyst in plant-based meat. *International journal of Toxicology*, *37*(3), 241-262.

Geerts, M.E.J.; Dekkers, B.L.; van der Padt, A.; van der Goot, A.J. (2018) Aqueous fractionation processes of soy protein for fibrous structure formation. *Innov. Food Sci. Emerg. Technol. 45*, 313–319.

Geny, A., Zobel, H., ... & Sahlstrøm, S. (2021). Meat analogs from a faba bean concentrate can be generated by high moisture extrusion. Future Foods, 3,100014.

Grabowska, K. J., Zhu, S., Dekkers, B. L., de Ruijter, N. C., Gieteling, J., & van der Goot, A. J. (2016). Shear-induced structuring as a tool to make anisotropic materials using soy protein concentrate. Journal of Food Engineering, 188, 77-86.

Grahl, S., Palanisamy, M., Strack, M., Meier-Dinkel, L., Toepfl, S., & Mörlein, D. (2018). Towards more sustainable meat alternatives: How technical parameters affect the sensory properties of extrusion products derived from soy and algae. Journal of Cleaner Production, 198, 962-971.

Grasso, S., Smith, G., Bowers, S., Ajayi, O. M., & Swainson, M. (2019). Effect of texturized soy protein and yeast on the instrumental and sensory quality of hybrid beef meatballs. Journal of food science and Technology, 56(6), 3126-3135.

Godschalk-Broers, L., Sala, G., & Scholten, E. (2022). Meat analogues: relating structure to texture and sensory perception. *Foods*, *11*(15), 2227.

Gómez, I., Ibañez, F. C., & Beriain, M. J. (2019). Physicochemical and sensory properties of sous vide meat and meat analog products marinated and cooked at different temperature-time combinations. International Journal of Food Properties, 22(1), 1693-1708.

Goto, T. K., Yeung, A. W. K., Tanabe, H. C., Ito, Y., Jung, H. S., & Ninomiya, Y. (2016). Enhancement of combined umami and salty taste by glutathione in the human tongue and brain. *Chemical Senses*, *41*(7), 623-630.

Greisinger, S., Jovanovski, S., & Buchbauer, G. (2016). An interesting tour of new research results on umami and umami compounds. Natural Product Communications, 11(10), 1934578X1601101040.

Guy, R. C. E. (1994). The technol. Extrusion cook.

He, J., Evans, N. M., Liu, H., & Shao, S. (2020). A review of research on plant-based meat alternatives: Driving forces, history, manufacturing, and consumer attitudes. *Comprehensive Reviews in Food Science and Food Safety*, *19*(5), 2639-2656.

Hernandez, M. S., Woerner, D. R., Brooks, J. C., & Legako, J. F. (2023). Descriptive Sensory Attributes and Volatile Flavor Compounds of Plant-Based Meat Alternatives and Ground Beef. *Molecules*, *28*(7), 3151.

Ishaq, A., Irfan, S., Sameen, A., & Khalid, N. (2022). Plant-based meat analogs: A review with reference to the formulation and gastrointestinal fate. Current Research in Food Science.

Kamani, M. H., Meera, M. S., Bhaskar, N., & Modi, V. K. (2019). Partial and total replacement of meat by plant-based proteins in chicken sausage: Evaluation of mechanical, physicochemical, and sensory characteristics. Journal of food science and Technology, 56(5), 2660-2669.

Katayama, M., & Wilson, L. A. (2008). Utilization of soybeans and their components through the development of textured soy protein foods. Journal of food science, 73(3), S158-S164.

Kermit, M., & Lengard, V. (2005). Assessing the performance of a sensory panel–panellist monitoring and tracking. *Journal of Chemometrics: A Journal of the Chemometrics Society*, *19*(3), 154-161.

Kim, K., Choi, B., Lee, I., Lee, H., Kwon, S., Oh, K., & Kim, A. Y. (2011). Bioproduction of mushroom mycelium of Agaricus bisporus by commercial submerged fermentation for the production of meat analog. Journal of the Science of Food and Agriculture, 91(9), 1561-1568.

Kirimura, J., Shimizu, A., Kimizuka, A., Ninomiya, T., & Katsuya, N. (1969). Contribution of peptides and amino acids to the taste of foods. *Journal of Agricultural and Food Chemistry*, *17*(4), 689-695.

Knaapila, A., Michel, F., Jouppila, K., Sontag-Strohm, T., & Piironen, V. (2022). Millennials' Consumption of and Attitudes toward Meat and Plant-Based Meat Alternatives by Consumer Segment in Finland. Foods, 11(3), 456.

Kyriakopoulou, K., Keppler, J. K., & van der Goot, A. J. (2021). Functionality of ingredients and additives in plant-based manalogsgues. Foods, 10(3), 600.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: principles and practices* (Vol. 2). New York: Springer. p. 57-76.

Leahy, E., Lyons, S., & Tol, R. S. (2010). *An estimate of the number of vegetarians in the world* (No. 340). ESRI working paper.

Lima, D. C., Noguera, N. H., Rezende-de-Souza, J. H., & Júnior, S. B. P. (2023). What are Brazilian plant-based meat products delivering to consumers? A look at the ingredients, allergens, label claims and nutritional value. *Journal of Food Composition and Analysis*, 105406.

Lin, D.; Lu, W.; Kelly, A.L.; Zhang, L.; Zheng, B.; Miao, S. (2017). Interactions of vegetable proteins with other polymers: Structure-function relationships and applications in the food industry. *Trends Food Sci. Technol. 68*, 130–144.

Lin, S., Huff, H. E., & Hsieh, F. (2002). Extrusion process parameters, sensory characteristics, and structural properties of a high moisture soy protein meat analog. Journal of Food Science, 67(3), 1066-1072.

Lioe, H. N., Apriyantono, A., Takara, K., Wada, K., & Yasuda, M. (2005). Umami taste enhancement of MSG/NaCl mixtures by Subthreshold L-α-aromatic amino acids. *Journal of Food Science*, *70*(7), s401-s405.

Liu, K., & Hsieh, F. H. (2008). Protein–protein interactions during high-moisture extrusion for fibrous meat analogs and comparison of protein solubility methods using different solvent systems. *Journal of agricultural and food chemistry*, *56*(8), 2681-2687.

Majzoobi, M., Talebanfar, S., Eskandari, M. H., & Farahnaky, A. (2017). Improving the quality of meat-free sausages using κ-carrageenan, konjac mannan, and xanthan gum. International Journal of Food Science & Technology, 52(5), 1269-1275.

Mal'a, P., Baranová, M., Marcinčáková, D., & Nagy, J. (2010). Organoleptic evaluation of poultry meat products with wheat protein–seitan, colored by microbial natural pigment. *Assam University Journal of Science and Technology*, *5*(1), 1-5.

Manski, J. M., van der Goot, A. J., & Boom, R. M. (2007). Formation of fibrous materials from dense calcium caseinate dispersions. *Biomacromolecules*, *8*(4), 1271-1279.

McClements, D. J., Weiss, J., Kinchla, A. J., Nolden, A. A., & Grossmann, L. (2021). Methods for testing the quality attributes of plant-based foods: Meat-and processed-meat analogs. Foods, 10(2), 260.

Melis, M., & Tomassini Barbarossa, I. (2017). Taste perception of sweet, sour, salty, bitter, and umami and changes due to l-arginine supplementation, as a function of genetic ability to taste 6-n-propylthiouracil. *Nutrients*, *9*(6), 541.

Min, S., Ko, I. K., & Yoo, J. J. (2019). State-of-the-art strategies for the vascularization of three-dimensional engineered organs. *Vascular specialist international*, *35*(2), 77.

Mao, A., Su, H., Fang, S., Chen, X., Ning, J., Ho, C., & Wan, X. (2018). Effects of roasting treatment on non-volatile compounds and taste of green tea. *International Journal of Food Science & Technology*, *53*(11), 2586-2594.

Moss, R., LeBlanc, J., Gorman, M., Ritchie, C., Duizer, L., & McSweeney, M. B. (2023). A Prospective Review of the Sensory Properties of Plant-Based Dairy and Meat Alternatives with a Focus on Texture. Foods, 12(8), 1709.

Nawrocka, A., Szymańska-Chargot, M., Miś, A., Wilczewska, A. Z., & Markiewicz, K. H. (2017). Aggregation of gluten proteins in the model dough after fiber polysaccharide addition. Food Chemistry, 231, 51-60.

Palanisamy, M., Töpfl, S., Aganovic, K., & Berger, R. G. (2018). Influence of iota carrageenan addition on the properties of soya protein meat analogs. Lwt, 87, 546-552.

Peighambardoust, S. H., Van Der Goot, A. J., Hamer, R. J., & Boom, R. M. (2004). A new method to study simple shear processing of wheat gluten-starch mixtures. *Cereal chemistry*, *81*(6), 714-721.

Rehrah, D., Ahmedna, M., Goktepe, I., & Yu, J. (2009). Extrusion parameters and consumer acceptability of a peanut-based meat analog. International journal of food science & technology, 44(10), 2075-2084.

Riaz, M. N. (2011). Texturized vegetable proteins. In *Handbook of food proteins* (pp. 395-418). Woodhead Publishing.

Rohall, S., Ballintine, J., Vowels, J., Wexler, L., & Goto, K. (2009). Who's your patty? Consumer acceptance and sensory properties of burger patties made with different types of meat or plant-based products. *Californian Journal of Health Promotion*, *7*(SI), 01-06.

Roland, W. S., Pouvreau, L., Curran, J., van de Velde, F., & de Kok, P. M. (2017). Flavor aspects of pulse ingredients. *Cereal Chemistry*, *94*(1), 58-65.

Ross, C. F. (2021). Considerations of the use of the electronic tongue in sensory science. *Current Opinion in Food Science*, *40*, 87-93.

Rousta, N., Hellwig, C., Wainaina, S., Lukitawesa, L., Agnihotri, S., Rousta, K., & Taherzadeh, M. J. (2021). Filamentous fungus aspergillus oryzae for food: From submerged cultivation to fungal burgers and their sensory evaluation—A pilot study. *Foods*, *10*(11), 2774.

Savadkoohi, S., Hoogenkamp, H., Shamsi, K., & Farahnaky, A. (2014). Color, sensory, and textural attributes of beef frankfurter, beef ham, and meat-free sausage containing tomato pomace. Meat science, 97(4), 410-418.

Schmid, E. M., Farahnaky, A., Adhikari, B., & Torley, P. J. (2022). High moisture extrusion cooking of meat analogs: A review of mechanisms of protein texturization. *Comprehensive Reviews in Food Science and Food Safety*.

Schmidinger, K. (2012). Worldwide alternatives to animal-derived foods–overview and evaluation models. *The solution to global problems caused by livestock. University of Natural Resources and Life Sciences. Vienna, Austria*.

Severini, C., Derossi, A., Ricci, I., Caporizzi, R., & Fiore, A. (2018). Printing a blend of fruit and vegetables. New advances on critical variables and shelf life of 3D edible objects. *Journal of Food Engineering*, *220*, 89-100.

Sha, L., & Xiong, Y. L. (2020). Plant protein-based alternatives of reconstructed meat: Science, technology, and challenges. Trends in Food Science & Technology, 102, 51-61.

Sharima-Abdullah, N., Hassan, C. Z., Arifin, N., & Huda-Faujan, N. (2018). Physicochemical properties and consumer preference of imitation chicken nuggets produced from chickpea flour and textured vegetable protein. International Food Research Journal.

Schmid, E. M., Farahnaky, A., Adhikari, B., & Torley, P. J. (2022). High moisture extrusion cooking of meat analogs: A review of mechanisms of protein texturization. *Comprehensive Reviews in Food Science and Food Safety*.

Shurtleff, W., & Aoyagi, A. (2013). *History of tofu and tofu products (965 CE to 2013)*. Soyinfo Center.

Singh, M., Trivedi, N., Enamala, M. K., Kuppam, C., Parikh, P., Nikolova, M. P., & Chavali, M. (2021). Plant-based meat analog (PBMA) as a sustainable food: A concise review. European Food Research and Technology, 247(10), 2499-2526.

Singh, A., & Sit, N. (2022). Meat Analogues: Types, Methods of Production and Their Effect on Attributes of Developed Meat Analogues. *Food and Bioprocess Technology*, *15*(12), 2664-2682.

Solms, J. (1969). Taste of amino acids, peptides, and proteins. *Journal of Agricultural and Food Chemistry*, *17*(4), 686-688.

Starowicz, M., Poznar, K. K., & Zieliński, H. (2022). What are the main sensory attributes that determine the acceptance of meat alternatives? *Current Opinion in Food Science*, 100924.

Stephan, A., Ahlborn, J., Zajul, M., & Zorn, H. (2018). Edible mushroom mycelia of Pleurotus sapidus as novel protein sources in a vegan boiled sausage analog system: functionality and sensory tests in comparison to commercial proteins and meat sausages. European Food Research and Technology, 244(5), 913-924.

Stone, H., Bleibaum, R., & Thomas, H. A. (2020). *Sensory evaluation practices*. Academic press.

Sun, C., Fu, J., Chang, Y., Li, S., & Fang, Y. (2021). Structure design for improving the characteristic attributes of extruded plant-based meat analogs. Food Biophysics, 1-13.

Sun, C., Ge, J., He, J., Gan, R., & Fang, Y. (2021). Processing, quality, safety, and acceptance of meat analog products. Engineering, 7(5), 674-678.

Sun, A., Wu, W., Soladoye, O. P., Aluko, R. E., Bak, K. H., Fu, Y., & Zhang, Y. (2022). Maillard reaction of food-derived peptides as a potential route to generate meat flavor compounds: A review. Food Research International, 151, 110823.

Szejda, K., Urbanovich, T., & Wilks, M. (2020). Accelerating consumer adoption of plant-based meat. Five Work. Pap.

Taylor, J., Ahmed, I. A. M., Al-Juhaimi, F. Y., & Bekhit, A. E. D. A. (2020). Consumers' perceptions and sensory properties of beef patty analogs. Foods, 9(01), 63.

Tomic, O., Luciano, G., Nilsen, A., Hyldig, G., Lorensen, K., & Næs, T. (2010). Analysing sensory panel performance in a proficiency test using the PanelCheck software. *European Food Research and Technology*, *230*, 497-511.

Vennerød, F. F. F., Nicklaus, S., Lien, N., & Almli, V. L. (2018). The development of basic taste sensitivity and preferences in children. *Appetite*, *127*, 130-137.

Wang, L., Xu, B., Li, L., Zhang, M., Feng, T., Wang, J., & Jin, Z. (2016). Enhancement of umami taste of hydrolyzed protein from wheat gluten by β-cyclodextrin. *Journal of the Science of Food and Agriculture*, *96*(13), 4499-4504.

Wang, X., Luo, K., Liu, S., Zeng, M., Adhikari, B., He, Z., & Chen, J. (2018). Textural and rheological properties of soy protein isolate tofu-type emulsion gels: influence of soybean variety and coagulant type. *Food Biophysics*, *13*, 324-332.

Wang, Y., Tuccillo, F., Lampi, A. M., Knaapila, A., Pulkkinen, M., Kariluoto, S., ... & Katina, K. (2022). Flavor challenges in extruded plant-based meat alternatives: A review. Comprehensive Reviews in Food Science and Food Safety.

Wichchukit, S., & O'Mahony, M. (2015). The 9-point hedonic scale and hedonic ranking in food science: Some reappraisals and alternatives. Journal of the Science of Food and Agriculture, 95(11), 2167-2178.

Wi, G., Bae, J., Kim, H., Cho, Y., & Choi, M.-J. (2020). Evaluation of the physicochemical and structural properties and the sensory characteristics of meat analogs prepared with various nonanimal-based liquid additives. Foods, 9, 461.

Wild, F., Czerny, M., Janssen, A. M., Kole, A. P., Zunabovic, M., & Domig, K. J. (2014). The evolution of a plant-based alternative to meat. *Agro FOOD Industry Hi Tech*, *25*(1), 45-49.

Wong, K. M., Corradini, M. G., Autio, W., & Kinchla, A. J. (2019). Sodium reduction strategies through the use of meat extenders (white button mushrooms vs. textured soy) in beef patties. Food Science & Nutrition, 7(2), 506-518.

Yuliarti, O., Kovis, T. J. K., & Yi, N. J. (2021). Structuring the meat analog by using plant-based derived composites. Journal of food engineering, 288, 110138.

Youssef, M. K., & Barbut, S. (2011). Effects of two types of soy protein isolates, native and preheated whey protein isolates on emulsified meat batters prepared at different protein levels. *Meat science*, *87*(1), 54-60.

Zahari, I., Ferawati, F., Helstad, A., Ahlström, C., Östbring, K., Rayner, M., & Purhagen, J. K. (2020). Development of high-moisture meat analogs with hemp and soy protein using extrusion cooking. Foods, 9(6), 772.

Zahari, I., Östbring, K., Purhagen, J. K., & Rayner, M. (2022). Plant-Based Meat Analogues from Alternative Protein: A Systematic Literature Review. *Foods*, *11*(18), 2870.

Zhang, J., Liu, L., Liu, H., Yoon, A., Rizvi, S. S., & Wang, Q. (2019). Changes in conformation and quality of vegetable protein during texturization process by extrusion. *Critical reviews in food science and nutrition*, *59*(20), 3267-3280.

Zhang, Z., Zang, M., Zhang, K., Wang, S., Li, D., & Li, X. (2023). Effect of two types of thermal processing methods on the aroma and taste profiles of three commercial plant-based beef analogues and beef by GC-MS, E-nose, E-tongue, and sensory evaluation. *Food Control*, *146*, 109551.

Zhao, C. J., Schieber, A., & Gänzle, M. G. (2016). Formation of taste-active amino acids, amino acid derivatives and peptides in food fermentations–A review. *Food Research International*, *89*, 39-47.

Appendix

Sensory characterization of commercial plant-based meat analogs

Mandatory questions are marked with a star (*)

We are looking for 8-15 volunteers to participate in the sensory characterization of commercial plant-based meat analogs (PBMAs). The evaluations shall be carried out by evaluating the taste and texture of the samples. Participants as a panel will be trained to assess the selected attributes. Averaged data by the panel will be used to create sensory profiles of the PBMAs and to observe differences among samples.

The evaluations include:
Three training sessions (approximately 60-120 minutes/session), depending on the prior experiences in sensory tests by the participants.
Three evaluation sessions (approximately 45-60 minutes/session). All participants are encouraged to participate in all 6 sessions.

Selection criteria: Participants are selected based on their voluntary availability and motivation to participate. Potential dietary restrictions and/or allergies to certain foods may prevent participation in the test. Tests will be conducted in English. Prior experience in sensory tests is not necessary to participate, although the students and staff of the department with prior experience may be prioritized. Participants are asked and reminded to participate in the study only in good health and if their senses of smell and taste work normally.

Rights: You may cancel your participation at any time without any questions from the organizers.
You may also ask for more information at any point.

Location: All evaluations will be conducted in the Sensory Evaluation Laboratory of Food Sciences Unit (Department of Life Technologies, University of Turku) at Pharmacity 7th floor (C corridor; address Itäinen pitkäkatu 4C, 20520 Turku).

More information:
MSc student: Onyinyechi Stella Kpaduwa (oskpad@utu.fi; +358466608897)
Supervisor: Oskar Laaksonen, University Lecturer, Ph.D. (oskar.laaksonen@utu.fi; +358505974650)

2. Participant contact information

Email:

3. Do you eat plant-based meat alternatives?

○ Yes

○ No

4. Are you soy or gluten intolerant?

○ Yes

○ No

If yes, please continue the survey. If no, please decline your participation.

5. Please select suitable times for Tuesday (**11/02**) training session *

☐ 10:30-11:30

☐ 12:00-13:00

☐ 13:30-14:30

6. Please select suitable times for Thursday (**12/02**) training session *

☐ 10:30-11:30

☐ 12:00-13:00

☐ 13:30-14:30

7. Please select suitable times for Friday (**13/02**) training session *

☐ 10:30-11:30

☐ 12:00-13:00

☐ 13:30-14:30

PRIVACY NOTICE FOR SCIENTIFIC RESEARCH
EU General Data Protection Regulation Art. 13 and 14
Date: Click or tap to enter a date.

Information for participants of the research project "Sensory Characterization of Commercial Plant-based Meat Analogues"

You are taking part in a scientific study conducted at the University of Turku. This notice describes how your personal data will be processed in the study.

1. Data Controller

University of Turku, Food Sciences, Department of Life Technologies (visiting address: Itäinen Pitkäkatu 4, 20520 Turku)

2. Description of the study and the purposes of processing personal data

The goal of this Master thesis work is to evaluate the sensorial properties of the commercial plant-based meat analogues. The sensory evaluation consists of a descriptive analysis with a trained panel focusing on appearance, taste and texture characteristics of the samples. Afterwards, averaged data produced by the panel will be linked to chemical composition of the berries, which may be used in scientific peer-reviewed publication.

Panellists' personal data collected will only be used for identification and communication purposes during the panel training and evaluations, and they will be deleted after the evaluation is done. The MSc thesis or the publication do not contain any personal data. Personal data consists of full name and email addresses.

3. Research group

MSc student

Name:

Address: Food Sciences, Department of Life Technologies, University of Turku

E-mail:

Supervisor

Name:

Address: Food Sciences, Department of Life Technologies, University of Turku

E-mail:

Tel:

4. Contact details of the Data Protection Officer

The Data Protection Officer of the University of Turku is available at contact address: dpo@utu.fi.

5. Persons processing personal data in the study

Personal data will not be transferred outside the research group.

6. Name, nature and duration of the study

Name of the study: Sensory Characterization of Commercial Plant-based Meat Analogues

Duration of the processing of personal data: the study will take approximately 3 months to conclude, and after that all personal information will be deleted and data is further assessed as averaged for the panel.

7. Lawful basis of processing

Personal data is processed on the following basis, which is based on Article 6(1) of the General Data Protection Regulation:

☐ data subject's consent;

☐ compliance with a legal obligation to which the controller is subject;

☐ processing is necessary in order to protect the vital interest of the data subject;

☒ performance of a task carried out in the public interest or in the exercise of official authority vested in the controller:

- ☒ scientific or historical research purposes or statistical purposes;
- ☐ archiving of research materials or cultural heritage materials;

8. Personal data included in the research materials

The data collected from the participants include full name, e-mail address, gender, year of birth, consumption patterns and familiarity related to strawberries and responses related to perceived intensities from sensory evaluations.

Each participant will be assigned a random code by the Compusense20 software, and the code will be the only information remaining from the participant after the sensory evaluation analysis is completed.

9. Sensitive personal data

Following categories of sensitive personal data will be processed in the study: None

10.Sources of personal data

Participants can register to the sensory evaluation study from online surveys, where their names and addresses are collected.

Date: Click or tap to enter a date.

11. Transfer and disclosure of the personal data to third parties

The personal data will not be transferred to other recipients outside the research group.

12. Transfer or disclosure of personal data to countries outside the EU/European

Economic Area

Personal data will not be transferred outside the EU/ European Economic Area.

13. Automated decisions

No automated decisions are made. Direct identifiers are only kept by the responsible of the study and are deleted after the sensory evaluation is completed.

Safeguards to protect the personal data:

☒The data is confidential.

☒ Protection of manual material:

All possible data collected on paper forms are stored by the supervisor behind locked doors

☒ Personal data processed in IT systems:

All data is primarily collected using Compusense20 software. Access is limited to the research group with passwords.

14. Processing of personal data after the completion of the study

The personal data material will be deleted after the sensory evaluation analysis is completed. After that, only a code with no personal data or identification is used.

15. Your rights as a data subject, and exceptions to these rights

The data subject has the right to access their personal data retained by the Data Controller, the right to rectification or erasure of data, and the right to restrict or object the processing of data. The right to erasure is not applied in scientific research purposes as far as the right to erasure is likely to render impossible or seriously impair the achievement of the objectives of that processing. The realization of the right to erasure is assessed on a case-by-case basis. The data subject has the right to lodge a complaint with the supervisory authority.

Exceptions to data subject rights

Under the General Data Protection Regulation and the Finnish Data Protection Act, certain exceptions to the rights of data subjects can be made when personal data is processed in scientific research and fulfilling the rights would render impossible or seriously impair the achievement of the objectives of the processing (in this case, scientific research).

The need to make exceptions to the rights of data subjects will always be assessed on a case by case basis. It is likely that exceptions to the following rights will be necessary in this study:

☐ Right of access (GDPR Article 15)

☐ Right to rectification (GDPR Article 16)

☐ Right to erasure (GDPR Article 17)

☐ Right to restriction of processing (GDPR Article 18)

☐ Right to data portability (GDPR Article 20)

☐ Right to object (GDPR Article 21)

Right to lodge a complaint

You have the right to lodge a complaint with the Data Protection Ombudsman if you think your personal data has been processed in violation of applicable data protection laws.

Contact details of Data Protection Ombudsman:

Office of the Data Protection Ombudsman

Visiting address: Lintulahdenkuja 4, 00530 Helsinki

Postal address: P.O. Box 800, 00531 Helsinki, Finland

E-mail: tietosuoja(at)om.fi

Switchboard: +358 (0)29 566 6700