Plant Based Meat: A Textural Perspective and Hybrid Products: Insights from Textual and Consumer Insight Studies

PLANT BASED MEAT: A TEXTURAL PERSPECTIVE AND HYBRID PRODUCTS: INSIGHTS FROM TEXTUAL AND CONSUMER INSIGHT STUDIES

A Thesis Presented

By

Kashmira Salgaonkar

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ABSTRACT

PLANT BASED MEAT: A TEXTURAL PERSPECTIVE AND HYBRID PRODUCTS: INSIGHTS FROM TEXTUAL AND CONSUMER INSIGHT STUDIES

May 2024

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Directed by: Professor Alissa Nolden

Plant-based meat and dairy development have been the primary strategies for resolving environmental, health and animal welfare concerns. The estimated market value of plant-based meat was projected to reach $20 Billion by 2023, while the global market for plant-based dairy was valued at USD 25.19 billion in 2022. Sensory replication of animal-based meat and dairy products has been the major challenge faced by food scientists. Within the sensory domain, this study focused on the texture of different plant-proteins for use in meat and dairy alternatives. It first discussed the factors influencing the tribological behavior of plant-proteins and then compared the texture profile of commercially available plant-based hotdogs and sausages to animal-based hotdogs and sausages. The tribological study with its correlation to sensory attributes such as creaminess, slipperiness, smoothness and astringency showcased that each plant-protein exhibits distinct size, rigidity, solubility, protein and fat levels and also shows variation in its behavior with temperature. The Texture Profile Analysis (TPA) results of the 23 commercial products concluded that pea protein resulted in products with weaker structural strength while sausages and hotdogs containing a blend of soy protein and wheat gluten showed better replication to products formulated

from beef and pork than pea protein. The two studies thus provided an insight into the textural domain of plant-proteins which can aid in future product development.

Besides the sensory characteristics, the consumer acceptability of plant-based meat is challenged by several other product-specific and psychological parameters. Additionally, these parameters also prove to be challenging in reducing meat consumption. This study therefore conducted a consumer survey with 454 participants to determine the choice probability for hybrid meat. Hybrid meat products contain a blend of meat and plant-protein and are considered as a potential in reducing meat consumption. However, the results of a choice-based study known as conjoint analysis showed that hybrid meat hotdogs had the lowest preference in comparison to pure plant-based and pure meat hotdogs. The regression analysis determined that the product-specific attributes challenged the choice for hybrid hotdogs, while person-related parameters did not have any relationship, which was contrary to the results obtained for plant-based and beef hotdogs. This influence of the different parameters on the selection of hybrid meat was concluded to be due to the lack of consumer knowledge and familiarity with hybrid products.

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INTRODUCTION

The plant-based meat and dairy industry has been witnessing a steep growth in the past years (Good Food Institute- Plant-based meat, seafood, eggs and dairy, 2022). Consumers are switching to plant-proteins due to numerous reasons such as health, ecological, animal welfare, social, cultural or religious. In order to cater to this growing demand for plant-based meat and dairy mimetics, a variety of products are developed from distinct plant-proteins which offer different physical, chemical, functional and nutritional properties. These varied characteristics together reflect in the sensory attributes of the finished product. Replicating the sensory characteristics of animal protein such as taste, flavor, texture, aroma and appearance has been the biggest challenge to food scientists in the plant-protein industry.

Among the sensory attributes, texture or mouthfeel is a pivotal characteristic that encompasses the structural, mechanical and surface properties which are perceived through vision, hearing, touch and kinetics (Fiorentini et al., 2020). In case of meat, the anisotropic, fibrous structure of animal muscle tissue is responsible for delivering the firmness, juiciness, tenderness, chewiness as well as gelling properties in processed meat products such as hotdogs and sausages (Fiorentini et al., 2020). Similarly, within the dairy industry, the thickness, creaminess, smoothness, slipperiness, and richness which are highly desired characteristics of milk, cheese and yogurts are contributed by the protein and fat content, solubility and rigidity of the dairy proteins (Chojnicka-Paszun et al., 2012; De Wijk & Prinz, 2006; Vlădescu et al., 2023). In order to mimic these sensory attributes, it is necessary to evaluate the textural characteristics of plant-proteins. Sensory evaluation with a trained or untrained panel is an efficient measure of these attributes however sensory tests often prove to be restrictive due to concerns of respondent exhaustion and palate saturation which can affect the results while testing numerous samples (Lawless & Heymann, 2010). They also are known to be time consuming and expensive due to the requirement for consumer prescreening, panel calibration as well as compensation provided to the panelists. Instrumental techniques such as texture profile analyzer (TPA)-a double compression test that mimics the first two bites in the mouth for solid food items (Nishinari et al., 2019; Caine, Aalhus, Best, Dugan, and Jeremiah (2003), rheology and tribology which evaluate the flow characteristics for fluid and semi fluids to measure the flow of these products in the oral cavity (Sarkar & Krop, 2019), are used as reliable first-step tools in gauging the texture of various plant-proteins products and then conducting sensory tests with the shortlisted products.

In addition to the sensory attributes, consumer's choice for plant-based mimetics is also influenced by other product-specific attributes such as price, packaging claims (Escribano et al., 2021; WANG et al., 2023); demographic factors such as age, gender, education, previous exposure to plant-based mimetics, frequency of meat consumption (Shan et al., 2017); as well as by psychological parameters such a meat attachment (Graça et al., 2015), food neophobia (Pliner & Hobden, 1992)and ethical values (Pires et al., 2019) regarding food. Studies have shown that while consumers are incorporating plant-based meat into their diet, the frequency of meat consumption is still remains high (Graça et al., 2019). In order to aid this consumer transition from animal-based products to plant-based mimetics, blended meat that includes a blend of meat as well as plant-protein is formulated (Grasso et al., 2021; Neville et al., 2017; Ryder et al., 2023). This new meat category has shown positive feedback as an idea but has faced lower preference in sensory tests when offered as alternatives against pure plant-based and animal-based products (Jennifer Gregan-Paxton et al., 2005; Neville et al., 2017; Rajagopal & Burnkrant, 2009; Tarrega et al., 2020).

Thus, with the aim to gain further insights about different plant proteins and their texture as well as dive deeper into the attitude behavior gap in regard to blended meat this study has been conducted. The study first will focus on the factors impacting the texture of plant-proteins in fluids and semi-fluids such as milk, cheese and yogurts on grounds of tribology and then progressing into the texture of solid plant-based foods such as hotdogs and sausages the texture profile of these products will be evaluated by comparing them to animal-based products. These texture-focused studies will help to identify the gap in terms of textural attributes between the plant-based and animal-based proteins as well as gain a deeper insight into the properties of various plant proteins which impact the texture of the final product. Lastly, the study will aim to gain a deeper knowledge about the factors affecting the consumer perspective regarding blended meat when it is offered as a choice against pure beef and pure plant-based hotdogs in restaurants or grocery stores. This comparative analysis will be done through a consumer survey and use conjoint analysis as a tool. The selected product for the texture profile analysis and consumer survey is hotdogs and sausages owing to the already established market of the plant-based versions of these products as well as the familiarity of US consumers with them. The entire study will together lead the way to an efficient choice of plant proteins in the future for formulating meat and dairy mimetics as well as identifying ways to package and market these products that can improve consumer acceptability over similar meat-based products.

Chapter 2

TEXTURE OF PLANT-PROTEINS IN FLUIDS AND SEMI-FLUIDS

In the domain of plant-based dairy alternatives, mouthfeel has been a major challenging parameter owing to the different physical and chemical properties of plant proteins. Some of the major complaints have been grittiness due to low solubility of the protein (McClements, 2020), astringency due to polyphenols (Troszyńska et al., 2006), watery or runny texture and less firmness due to low protein and fat levels (Giacalone et al., 2022). Addressing these concerns will require an evaluation of the different factors of the plant-proteins that influence the mouthfeel. Instrumentally it is done by using rheology and tribology which will be discussed in this chapter. The chapter will then expand on the different factors that affect the tribology of plant-proteins such as protein size, concentration, temperature, fat levels, rigidity and solubility and their correlation to the different sensory attributes. The flow of the chapter is better illustrated through Figure 1.

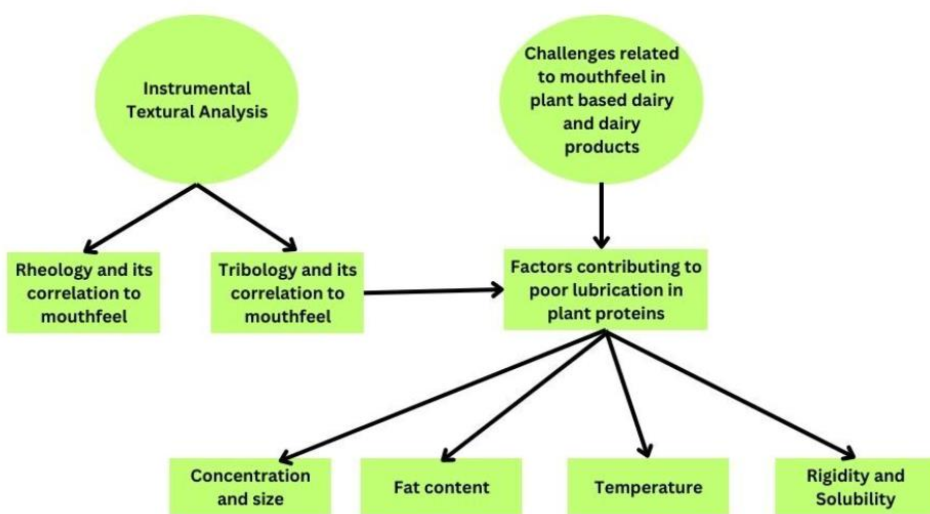


Figure 1: Track to understanding the mouthfeel of plant-proteins

Rheology: Definition, Correlation to mouthfeel and Limitations

Rheology can be defined as the deformation and flow of films separating surfaces in relative motion and is used to determine relations between stress and strain. Food texture is dependent on the deformation time profile and the shear and thermal characteristics (Chen & Engelen, 2012). Food rheology is used as an important tool because of its role in processing, determining the shelf stability and food structure breakdown, and thus estimating the sensorial properties of the product (Joyner, 2018; Stokes et al., 2013). The storage modulus (G') and the loss modulus (G") are indicative of the elastic and viscous properties respectively of semi-fluids. Vickers and colleagues (Vickers et al., n.d.) studied the rheological and sensory properties of beverages thickened to 300 and1500 cP, and reported that perceived thickness, stickiness, adhesiveness, and mouth coating attributes were positively correlated with the flow behavior index. Similarly, Terpstra and colleagues (Terpstra et al., 2005) found a linear correlation between perceived thickness and the calculated shear stress on the tongue for mayonnaise and custard. These findings provide evidence for using rheology as an efficient tool in determining the mouthfeel of fluids and semi-fluids.

Though rheological measurements provide considerable support in predicting the sensory attributes of semi-fluid materials, they cannot account for all sensory perceptions. Attributes such as creaminess, astringency, slipperiness, and smoothness, are experienced due to the rubbing between the tongue and the palate (Prakash et al., 2013). These actions generate lubrication between the tongue and the palate, making oral food processing a surface phenomenon. Since rheology is a bulk phenomenon, it is closely related to mouthfeel during the first bite and cannot measure the frictional wear of food during chew down and mastication (Joyner (Melito), 2018). This limitation of rheology in explaining oral processing has also been previously described by (Brown et al., 2003), noting that the entire mouthfeel of cheese cannot be determined through rheology alone. These, properties of fluids and semi-solids that are experienced over mastication at different time lengths have been more recently been analyzed using tribology thereby providing new insights on the mouthfeel of foods and beverages (Stokes et al., 2013; Sudhakar Scholar et al., 2020).

Tribology: Definition, Correlation to mouthfeel and Limitations

While the field of tribology is not new and has been a scientific discipline known to study lubrication between two rubbing surfaces (Stokes et al., 2013). Its application in evaluating food texture and estimating mouthfeel has only been recently studied, and some refer to this area as oral tribology. Textural attributes of food vary with time, including an interplay of oral surface chemistry and the product-saliva combination (Prakash et al., 2013; Sudhakar Scholar et al., 2020). This product-saliva combination acts as the lubricant in tribological analysis. The main parameter for a tribological test is the friction coefficient, calculated as the ratio of the measured friction against the normal load.

The oral tribological process is generally represented as a Stribeck curve, which is divided into three regimes or regions: Boundary, Mixed and Hydrodynamic. These regimes represent the change in the food texture with time due to the variation in the lubricating film thickness between the tongue and the palate. The film is absent in the boundary region, thin in the mixed regime- leading to occasional friction and wear, and thick in the hydrodynamic region. In the hydrodynamic region, the friction generated varies greatly with the viscosity of the food product and thus, tribological results bear a strong relationship between lubrication and viscosity (Chen & Stokes, 2012; Paul et al., 2022; Pradal & Stokes, 2016; Sarkar & Krop, 2019; Sudhakar Scholar et al., 2020).

Similar to rheology, which is associated with mouthfeel and other texture-specific sensory attributes such as thickness, tribology has been found to correlate with several fat-related attributes such as creaminess, smoothness, slipperiness, and astringency. While, several research articles do show an inverse relationship between friction coefficient and viscosity, these sensory attributes were found to correlate more closely to friction coefficient measured under tribology than the rheological viscosity. In the case of milk, the friction coefficient from the boundary and mixed regimes was inversely correlated with sensory slipperiness and positively correlated with astringency (Chojnicka-Paszun et al., 2012a; Li et al., 2018). Similarly, for the creaminess of yogurts, which is a complex sensory attribute combining thickness, smoothness, mouthcoating, and dairy flavor, is found to be inversely correlated to the friction coefficient from the mixed regime (Chojnicka-Paszun et al., 2012; De Wijk & Prinz, 2006). These correlations aid in identifying the different factors that affect the mouthfeel instrumentally and can be investigated in earlier stages of product development. Conducting tribology measures aids in addressing some limitations often experienced when measuring rheology alone, aiding in accelerating and optimizing the samples for consumer testing. Tribology is, therefore, a valuable tool in predicting oral texture and its optimization.

The next section will elaborate on the different factors influencing the tribological behavior in plant proteins and their correlation to mouthfeel.

Factors influencing the tribological profile in plant-proteins

a. Concentration and size

The lubrication of dairy and dairy products varies directly with their protein content. In milk and yogurts, their high protein levels resulted in high viscosity of solutions and lowered the friction coefficient (Zhu et al., 2019). Dairy mimetics and yogurts prepared from plant-based proteins have also shown similar results. These proteins improve the sliding properties by absorbing onto the tongue and the palate, thereby forming a film with the salivary proteins in the oral cavity (Zembyla et al., 2021). This interaction between the plant-proteins and the salivary proteins depends on several factors such as the size of the protein molecule and their molecular weight, the surface activity of the protein solutions, the stability of the dairy emulsion formed by these non-animal proteins as well as the presence of polyphenols in the protein matrix. All these factors affect the gelling properties by impacting the structural density in yogurts as well as are responsible for the astringency in plant-based dairy mimetics.

Proteins with large molecules can cover the saturate surface faster than smaller ones. As a result, the boundary coefficient for solution prepared with 5%wt of pea protein concentrate was lower than a similar concentration of potato protein isolates and lupin protein isolate solutions. However, as the concentration increased beyond 10%wt, the friction coefficient increased for pea protein solutions and lowered for solutions with potato and lupin protein isolates This was because on increasing the concentration beyond 10%wt, pea protein molecules aggregate and thus cause friction between the sliding surfaces (Kew et al., 2021a). The size also plays a key role when comparing proteins containing polyphenols such as pea proteins and beans since it was found that the large polyphenol containing protein molecules had higher astringency than protein solutions which were filtered and thus had smaller polyphenolic size (Rudge et al., 2021; Vlădescu et al., 2023)

A similar impact of protein size on the lubrication abilities has been found between whey protein isolate and pea protein isolate solutions. The size of whey protein molecules (220±30.9 nm) is smaller than pea protein (244±23.6 nm); thus, the two proteins do not provide the same lubrication under equal concentrations. Therefore, when preparing dairy mimetics, it is important to first determine the lubrication profile for a particular plant protein under different concentrations to provide the required mouthfeel (Kew et al., 2021).

Generally, plant-based dairy products are also emulsified and homogenized as in dairy milk to stabilize the emulsion, to improve ingredient's solubility and surface activity. Different plant proteins respond differently to this process and thus differentially affect the mouthfeel of the created homogenized emulsion. It was found that homogenized stable cream emulsions containing pea and faba bean protein isolates had lower friction coefficients and better creaminess than the non-homogenized unstable emulsions of these proteins. This is because homogenization increases the amount of protein on the surface of the cream droplet. However, following homogenization, the friction coefficients for the stabilized soy protein cream increased and thus, unstable soy protein cream emulsions had a better creaming rate than stabilized emulsions (Ningtyas et al., 2021).

These protein-specific physical factors thus affect the interaction with the salivary proteins' mucins and PRPS and affect the creaminess, smoothness, and astringency in solutions (Selway & Stokes, 2013). It is, therefore, necessary for researchers and manufacturers of plant-based milk and milk products to consider these parameters in order to determine the optimum concentration of the protein to be used because at higher concentrations, since smaller molecules provide better creaminess and smoothness, however, proteins with large molecular size will coagulate the protein solution. For yogurts, gelling is a necessary textural attribute, however adding an amount equal to the protein content in dairy yogurts can produce a runny texture for proteins like quinoa, which have lower gelling abilities and smaller size than dairy proteins (Mårtensson et al., 2000) or can lead to aggregation as in case of soy proteins which have a larger size than milk proteins. As a result, proteins used in non-dairy milk and yogurts are either pre-processed through techniques such as micro-particulation, for proteins with larger molecular sizes, or blended with other proteins, polysaccharides, or salts to provide the desired mouthfeel (Zhang et al., 2020).

b. Fat content

In the case of dairy products such as yoghurts, cream cheese, cheese and milk, creaminess and smoothness are the most desired textural attributes. Similar to dairy, creaminess in coconut milk was found to be related to the release of fat in the oral cavity which increased the viscosity of the milk and made it more adhesive (Aussanasuwannakul et al., 2020). This characteristic is caused due to destabilization of the fat globules, resulting in the absorption of the coagulated fat droplets on the oral palate and facilitating the formation of a thin film between the surfaces. In addition to milk, plant-based cream cheese with lower fat content had remarkable higher traction coefficient ($p<0.05$) in both the boundary and mixed lubrication regimes than the conventional cream cheese

(Laguna et al., 2017). This influence of increasing fat levels in plant-based emulsions was associated to the extension of the mixed regime, caused due to the pressurization of bulk fluid within the oral contact regions leading to the separation of the surfaces at higher entrainment velocities (Ningtyas et al., 2021). The fat content in protein solutions also helps to lower the undesired astringency caused due to tannins present in many plant proteins (Vlădescu et al., 2023).

The influence of fat on the friction profile is, however, found to be impacted by several factors, one of them being the type of fatty acids used. Prior work demonstrates that the difference in chemical composition was found to produce different protein-oil interactions (Michel et al., 2022). Liquid fats and proteins with smaller fat droplets were able to provide better lubrication properties compared to solid fats due to their high consistency and increased separation (Laguna et al., 2021; Michel et al., 2022). It's worth noting that, when fats and proteins are used to enhance lubrication properties, the lubrication regime is dominated by fat and not protein (Gabriele et al., 2022).

Tribology has been demonstrated to be better at detecting the difference in fat levels as compared to sensory trials and can thus be a reliable method for preparing dairy mimetics with different percentages of fat, such as plant-based skim, whole and full-fat milk (Greis et al., 2022) Despite the vital role of fat in providing the necessary mouthfeel, recently, owing to the increased demand for low-fat products, several methods, such as the addition of hydrocolloids, microbubbles, and changing the protein ratio in the products have been at the forefront of tribological research (Laiho et al., 2017; Nguyen et al., 2017) .

c. Temperature

Heat or thermal treatment on proteins is known to greatly impact their structure and functionality. Heating proteins under mild conditions promotes their denaturation. These denatured proteins form crosslinks with salivary proteins and fats in the oral cavity to form a thin lubricating film that separates the interacting surfaces (Zembyla et al., 2021). On the contrary, under severe thermal conditions, it can lead to irreversible changes in the protein structure, causing aggregation and restricting their function (Nikbakht Nasrabadi et al., 2021). This is because heat treatment affects the solubility, surface hydrophobicity, and molecule size, having an impact on the gelling, stability, and emulsifying properties of the protein solution (Drozłowska et al. 2020).

For soy protein isolate, it was found that heat treatment decreased the molecular size of the proteins and thus showed earlier onset of the mixed and hydrodynamic regimes than the non-heat-treated protein solutions (Pang et al., 2023). A similar effect of heat treatment was found for protein solutions containing pea protein isolates, where in heat treated solutions containing 1, 10, and 100 mg/mL solutions had lower friction coefficients and extended mixed regimes than the non-heat-treated counterparts (Zembyla et al., 2021). Additionally, heating helps to provide enhanced lubrication at lower concentrations showing significantly lower friction coefficients than for solutions without heat treatment. For soy protein isolate, heating the protein solutions ruptured the disulfide bonds and thus improved the surface hydrophobicity of the protein solutions (C. Guo et al., 2017). Improved surface hydrophobicity provides better lubrication properties. Heating also improved the emulsifying properties of potato protein, lotus seed, and soy protein isolates (Mu et al., 2020). During heating, the protein undergoes unfolding, reduction in particle size, and thus increased solubility (Drozłowska et al. 2020). The optimum temperature required to provide the desired lubrication varies with the protein source and concentration. Soy protein isolates at 12% concentration provided better lubrication at 75° C than at 25°C and 100 °C (Pang et al., 2023). The influence of heating on lowering the friction coefficient increased with concentration for whey protein isolate; however, in the case of pea protein isolate, the effect was more significant at 10mg/mL concentration than at 100 mg/mL (Zembyla et al., 2021). Thus, heat treatment of solutions under optimum temperature can effectively provide desired lubrication, improve emulsion stability, and enhance the gelling properties.

d. Rigidity and Solubility

Protein rigidity is one of the important factors in providing the desired lubrication and facilitates the formation of the lubricating film. Potato protein-based dairy alternatives have now been developed on a large scale due to the ability to form a rigid surface layer resulting in lower friction coefficients in the boundary regime (Zembyla et al., 2021). Rigidity also helps in making the proteins more elastic and resistant to deformation. This helps to improve their gelling capacities. The rigid layer is more efficient in separating the lubricating surfaces in comparison to a viscoelastic layer. Viscoelastic layer might be easily removed from the contact region, as opposed to a rigid layer which might remain intact, creating a gap between the contact surfaces and reducing the friction coefficient. Viscosity is a desired property for lubrication but is not the sole factor to be considered. It was found that a pea protein solution with a high viscosity, but less rigid film offered a higher boundary coefficient than a more rigid protein (Zembyla et al., 2021).

Water-soluble proteins provide better lubricating properties in comparison to non-soluble proteins. Also, soluble proteins such as whey protein isolate (WPI) and potato protein isolate (PoPI) showed an order of magnitude lower friction coefficient in comparison to pea protein isolate (PPC) and lupin protein isolate (LPI) in the boundary and mixed regimes (Kew et al., 2021). Thus, rigid and water-soluble proteins act as potential mimetics for plant-based dairy products.

Thus, dairy mimetics formulated from plant proteins have different chemical and physical composition and properties in comparison to traditional dairy. These properties influence the tribological behavior of the products under varied concentrations and temperatures due to differences in their size, protein and fat contents, rigidity, and solubility. These differences are eventually reflected in the sensory properties such as creaminess, smoothness, and slipperiness affecting the mouthfeel in dairy mimetics. Optimizing these individual physical characteristics through processing can help to efficiently mimic the mouthfeel of traditional dairy products.

Chapter 3

TEXTURE PROFILE ANALYSIS OF PLANT-BASED HOTDOGS AND SAUSAGES

Texture Profile Analysis (TPA) is an imitative test that aims to provide standardized values for food texture. It is widely used to evaluate the texture of meat analogs by mimicking the two-fold chewing stroke (Nishinari et al., 2019). As a tool for texture evaluation, it was found that beef tenderness determined by TPA parameters correlated well with variations in sensory results than the Warner-Bratzler test (Caine et al., 2003). Within the domain of processed meat and plant-based meat, Krasnowka and his colleagues (Krasnowska et al., 2005) found that the sensory results were influenced by the hardness and springiness parameters for sausages made with different functional proteins when measured using Texture Profile Analyzer. Additionally, it was (Savadkoohi et al., 2014) determined that the meat-free sausage has weaker textural (hardness, cohesiveness, springiness and chewiness) attributes compared to the beef frankfurter. These studies therefore throw light on the gap between the texture of plant-based and animal-based hotdogs and sausages. With the aim to evaluate the current commercially available plant-based and animal-based hotdogs and sausages and to determine how the different plant-proteins currently used in their formulation such as pea protein, soy protein and wheat gluten compared to each other as well as to animal proteins, this study has been designed.

Materials and Methods

1.1 Sample Selection

In order to gain a comprehensive insight into the commercially available meat analogues, the products included in this study were shopped from stores such as Big Y, Stop & Shop, Walmart, Target, Trader Joes and Whole Foods which are common supermarkets in the US. The total sample size consisted of 23 products: 9 hotdogs (plants-based n=6; beef n=3) and 14 Italian sausages (plant-based n=6; chicken n=3; pork n=5). The plant-based hotdogs and sausages used in this study contained either soy protein isolate (SPI) or pea protein (PP) or vital wheat gluten (VWG) as the alternative protein source.

Table 1: Names and protein type for products used in TPA analysis

Group 1	Category	Protein
Ballpark beef franks	Hotdog	Beef
Kayem beef hot dogs	Hotdog	Beef
Nathans famous beef franks	Hotdog	Beef
Field roast signature stadium dog	Hotdog	PP
Smart dogs	Hotdog	SPI+VWG+PP
Jumbo smart dog	Hotdog	SPI+VWG
Morning star farms veggie dogs	Hotdog	SPI+VWG
Upton's naturals vegan hotdog	Hotdog	VWG
Field roast classic smoked plant-based frankfurters	Hotdog	VWG
Perdue chicken sausage	Italian sausage	Chicken
Trader joes spicy Italian chicken sausage	Italian sausage	Chicken
Whole foods my Italian chicken sausage	Italian sausage	Chicken
All-natural sweet Italian sausage	Italian sausage	Pork
Big Y sweet Italian sausage	Italian sausage	Pork
Flame grilled Italian sausage	Italian sausage	Pork
Premio hot Italian sausage	Italian sausage	Pork
Trader Joe’s sweet Italian sausage	Italian sausage	Pork
Beyond sausage hot Italian	Italian sausage	PPI

Lightlife smart sausage Italian	Italian sausage	SP+VWG
Trader Joes Italian sausage-less sausage	Italian sausage	SP+VWG
Field roast garlic & fennel	Italian sausage	VWG
No evil the stallion Italian sausage	Italian sausage	VWG
Tofurkey plant based original sausage Italian	Italian sausage	VWG

1.2 Cooking Procedure and sample preparation

The purchased products were stored as per the manufacturer's instructions. Refrigerated products (n=22) were stored at (3.5 ºC) and frozen products were stored frozen at (0 ºC). The hotdogs and sausages were cooked by steaming to an internal temperature of 72 ºC according to the USDA recommended guidelines for ground meat (USDA, 2021). The products were cooled to room temperature before preparing the samples. The hotdogs and sausages were cut to a height of 2 cm along the middle of the length. The diameter of each sample was variable across commercial products.

1.3 Texture Profile Analysis

The texture profile of the products was examined by using a TA X2- Plus texture profile analyzer (Texture Technologies, Hamilton MA, USA). A double compression test also known as the 'two-bite test' was performed to obtain a force versus time profile. A load cell of 50 kg of 50 mm diameter was used to compress the sample twice to 50% compression strain with a 5 second interval between the two compression cycles. The test, pre-test and post-test speed was set to 2 mm (about 0.08 in)/sec and the trigger force was 15g (Vu et al., 2022). Each product was tested in quintuplicates.

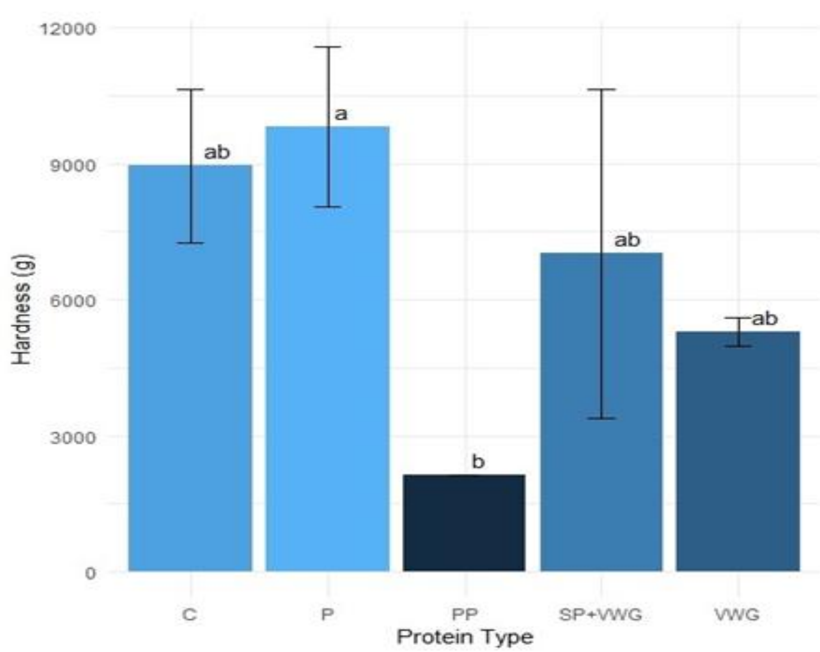
1.4 Statistical Analysis

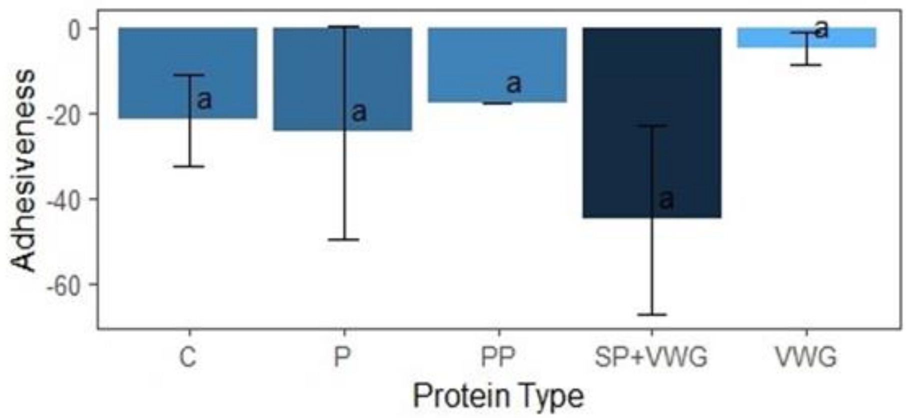
The data was analyzed using R studio 4.1.2. First, outliers were eliminated using Dixon's Q-test. The meat products were compared with the plant-based hotdogs and sausages using a One-way ANOVA. Tukey's post-hoc test was performed to calculate the statistical differences between the products. The bar plots for the textural attributes were developed by using the 'ggbiplot' package in R program.

Results

The texture of plant-based hotdogs and sausages made from soy protein, pea protein and vital wheat gluten as well as their blend was evaluated in this study. Additionally, it was compared to sausages made from chicken and pork and beef hotdogs by using Analysis of Variance (ANOVA) to determine the significantly different plant-protein and simultaneously understand the best plant-based replicate to the textural attributes in animal meat.

2.1 Sausages





Adhesiveness
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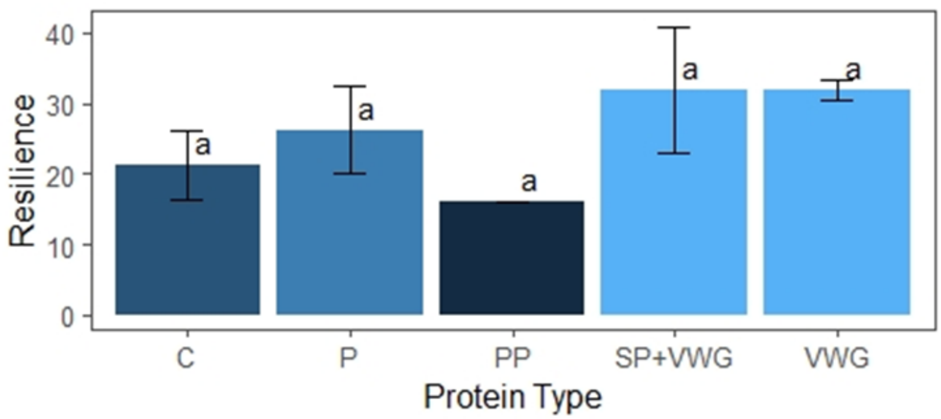
-40
-60
a
a
a
a
a
C
P
PP
SP+VWG
VWG
Protein Type



Resilience
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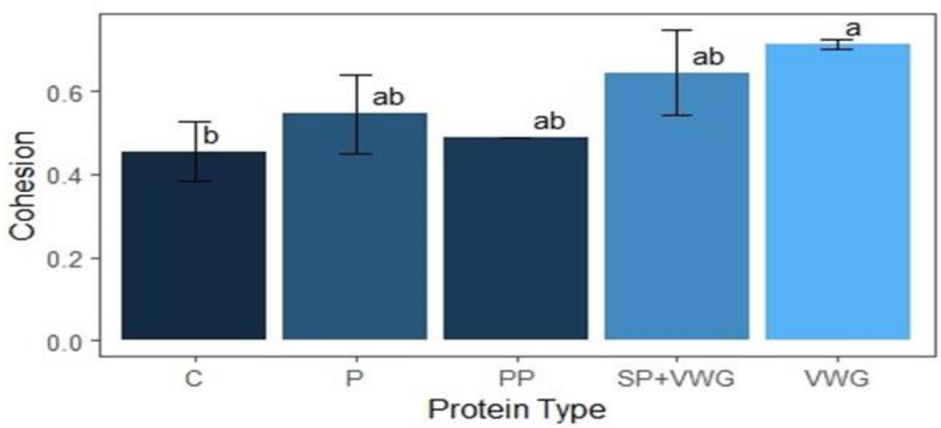
20
10
0
a
a
a
a
a
C
P
PP
SP+VWG
VWG
Protein Type



Cohesion
0.6
0.4
0.2
0.0
b
ab
ab
ab
a
C
P
PP
SP+VWG
VWG
Protein Type

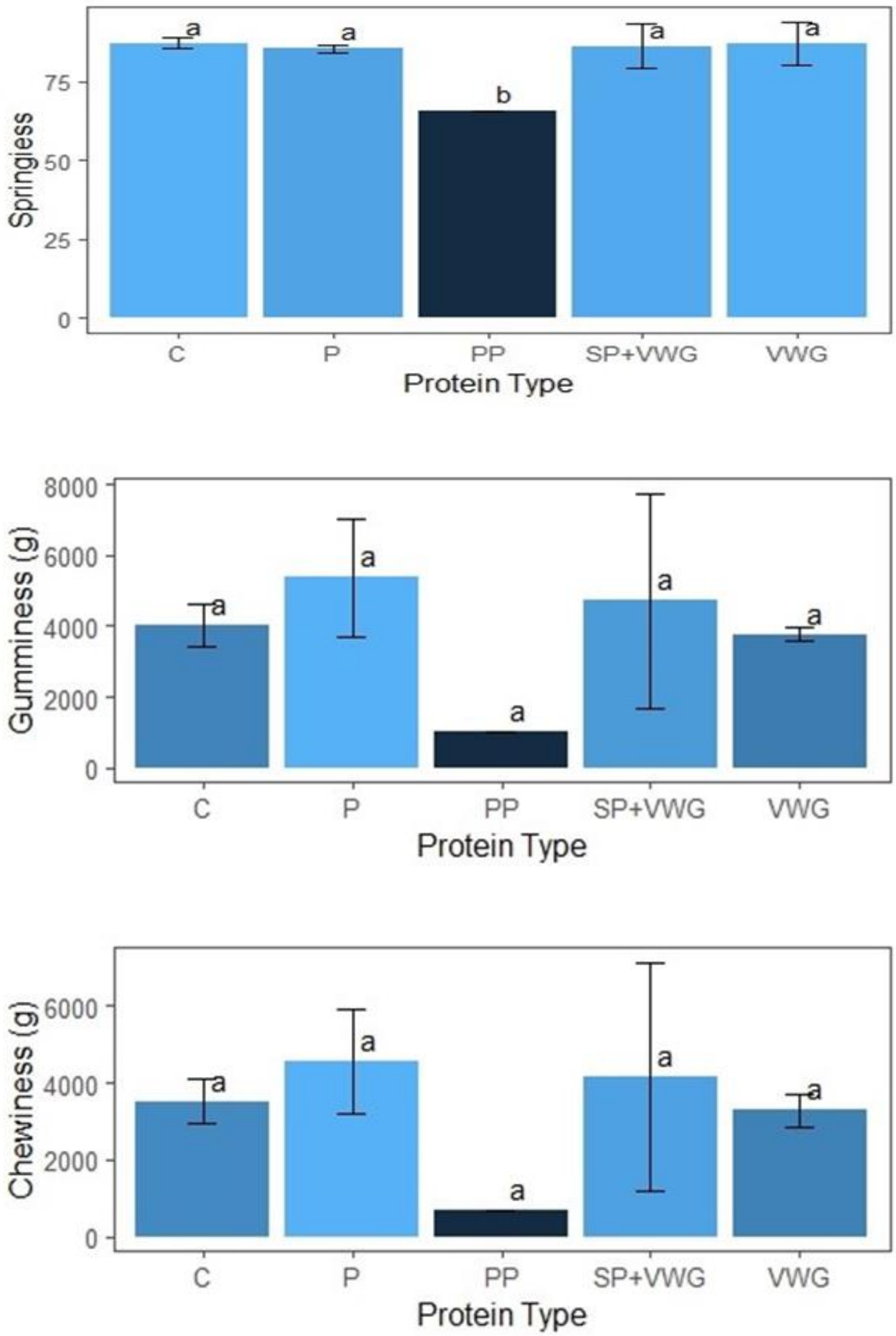


Figure 2: Texture Profile Analysis results for sausages

C-Chicken; P-Pork; PP-Pea Protein; SP+VWG-Soy Protein-Vital Wheat Gluten blend; VWG-Vital Wheat Gluten

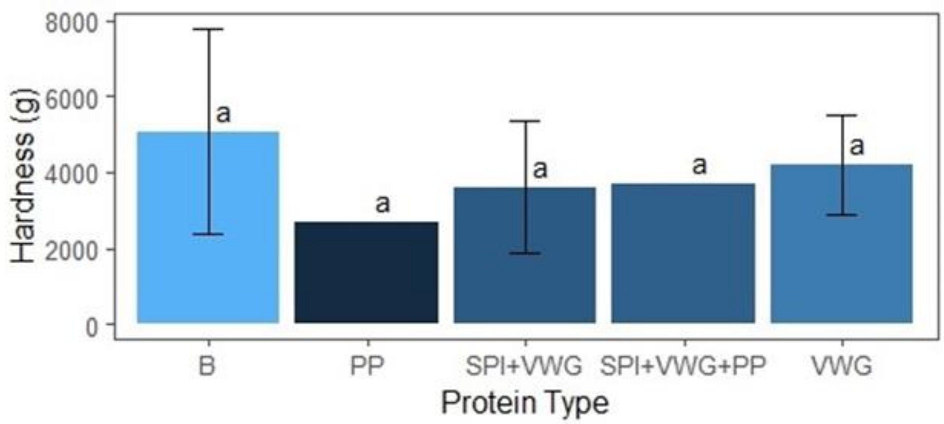
An ANOVA was run for each attribute measured using the Texture Profile Analyzer (TPA) (Figure 2). The average values were calculated by grouping the products based on their protein type (Chicken, Pork, SP+VWG, PP, VWG). In terms of hardness, pork sausages had the highest value followed by chicken and SPI+VWG blend. The hardness of the pork sausages was also significantly more ($p<0.05$) than the pea protein sausages which was determined by the post-hoc analysis. The resilience of the sausages formulated using SPI+VWG blend and VWG alone was almost equal but higher than pork as well as chicken. The cohesiveness of the VWG sausages was the highest and significantly higher ($p>0.05$) than the chicken sausages. Similarly, the cohesive strength of the SPI+VWG blend was higher than pork sausages. The springiness looked almost equal for the sausages except for pea protein sausages which was significantly lower than pork ($p<0.05$). The plots for chewiness and gumminess were almost identical and pork sausages recorded the highest values followed by the SPI+VWG blend.

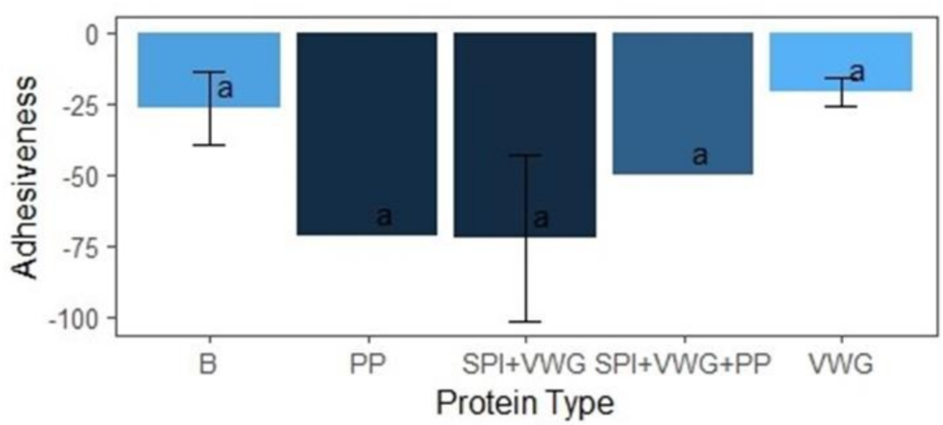
Table 2: ANOVA results showing p-value for the texture attributes of sausages using averages calculated based on protein type

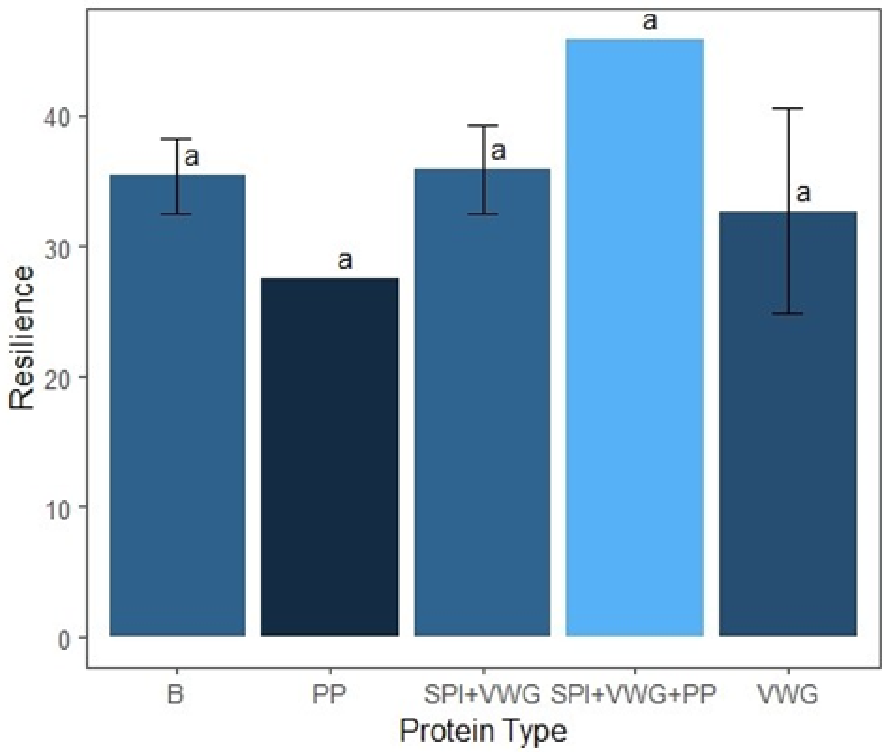
Attribute	**Chicken**	**Pork**	**Pea Protein**	**Soy Protein + Vital Wheat Gluten**	**Vital Wheat Gluten**
Hardness	8949.9^{ab}	9804.1^{a}	2131.6^{b}	7012.8^{ab}	5286.7^{ab}
Adhesiveness	-21.7^{a}	-24.4^{a}	-17.77^{a}	-45^{a}	-4.8^{a}
Resilience	21.3^{a}	26.3^{a}	16^{a}	32^{a}	32^{a}
Cohesiveness	0.5^{b}	0.5^{ab}	0.5^{ab}	0.7^{ab}	0.7^{a}

Springiness	87.3 ^{ab}	85.5^{a}	65.9^{b}	86.2 ^{ab}	87^{ab}
Gumminess	4026.7 ^{a}	5374.2 ^{a}	1040.5 ^{a}	4711 ^{a}	3773 ^{a}
Chewiness	3519 ^{a}	4568.4 ^{a}	686.1 ^{a}	4165.2 ^{a}	3291.7 ^{a}

2.2 Hotdogs







a
40
a
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30
a
Resilience
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10
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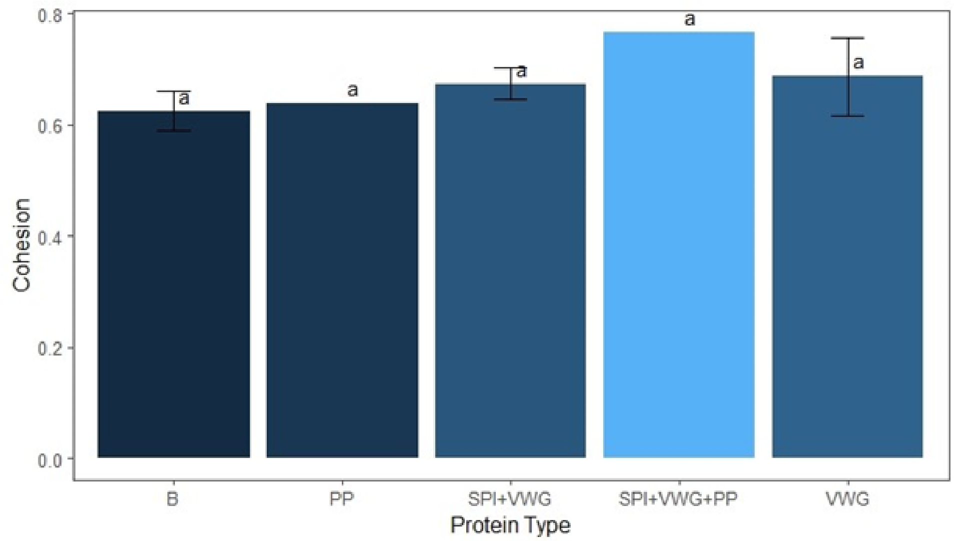
B
PP
SPI+VWG
SPI+VWG+PP
VWG
Protein Type


0.8
0.6
0.4
0.2
0.0
Cohesion
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B
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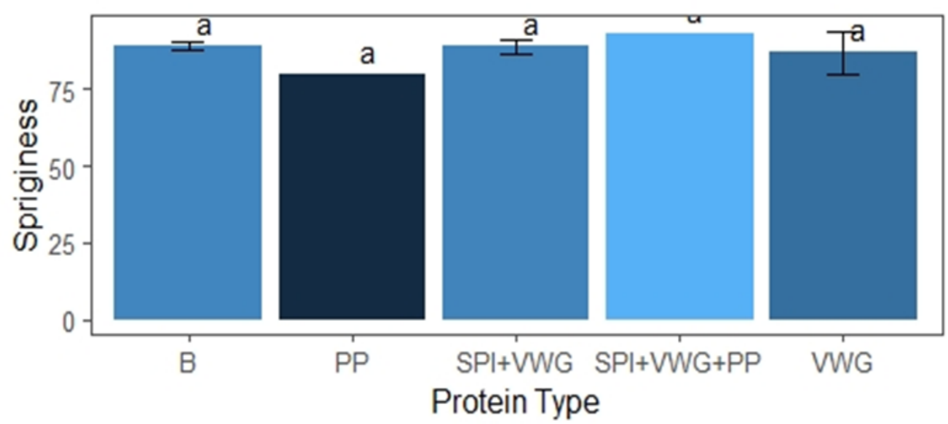
SPI+VWG
SPI+VWG+PP
VWG
Protein Type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Sprigininess
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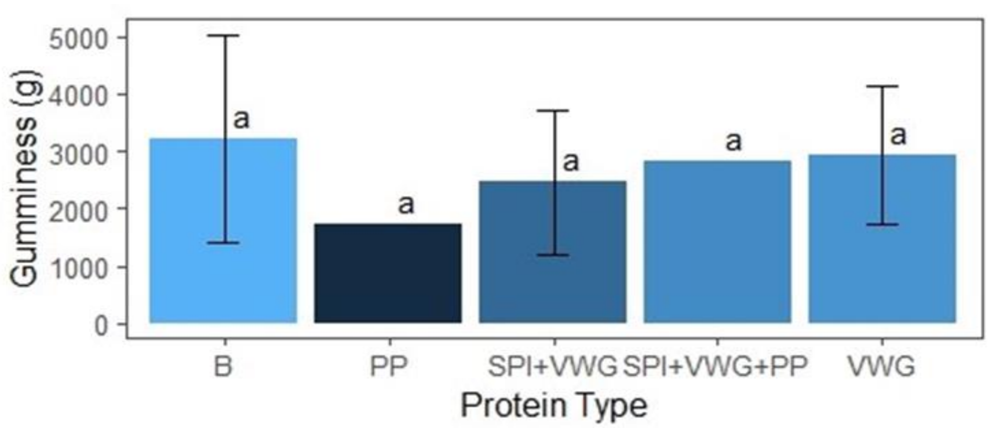
B
PP
SPI+VWG
SPI+VWG+PP
VWG
Protein Type


5000
4000
3000
2000
1000
0
Gumminess (g)
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a
a
a
a
B
PP
SPI+VWG
SPI+VWG+PP
VWG
Protein Type

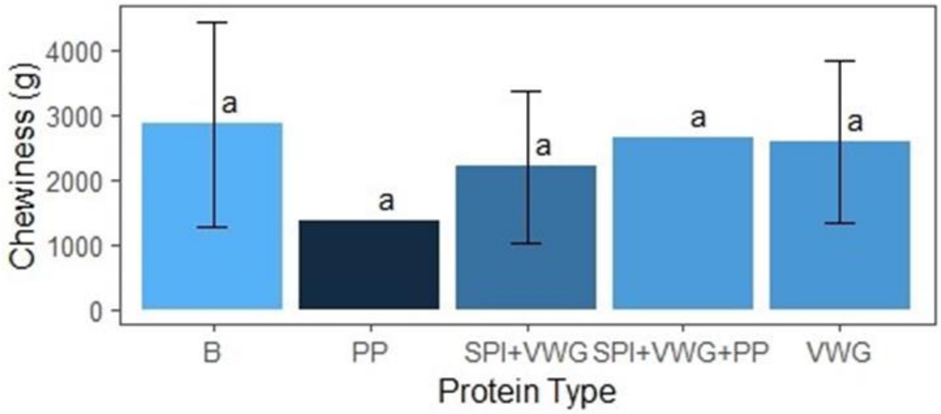

Figure 3: Texture Profile Analysis results for hotdogs

C-Chicken; P-Pork; PP-Pea Protein; SPI+VWG-Soy Protein-Vital Wheat Gluten blend;

SPI+VWG+PP-Soy Protein-Vital Wheat Gluten-Pea Protein blend; VWG- Vital Wheat Gluten

Similar to the analysis performed for sausages, ANOVA was tested on hotdogs based on the protein type (Figure 3). The results showed no significant difference between the textural attributes of the distinct proteins. In terms of hardness, beef hotdogs had the highest value followed by VWG hotdogs and then the SPI+VWG+PP blend. The resilience of the SPI+VWG+PP blend was the highest followed by beef and SPI+VWG blend which were almost equal. The cohesiveness of all the plant-based hotdogs was higher than beef with SPI+VWG+PP blend having the highest average value. The springiness looked almost equal for the hotdogs except for pea protein which was slightly lower. The chewiness and gumminess had almost identical plots with approximately equal values for beef, SPI+VWG+PP and VWG hotdogs.

Table 3: ANOVA results showing p-value for the texture attributes of hotdogs using averages calculated based on protein type

Attribute	**Beef**	**Pea Protein**	**Soy Protein + Vital Wheat Gluten**	**Soy Protein + Vital Wheat Gluten + Pea Protein**	**Vital Wheat Gluten**
Hardness	5069.1 [a]	2698.9 [a]	3711.3 [a]	3615.4 [a]	4193.4 [a]
Adhesiveness	-26.5 [a]	-71.3 [a]	-50.4 [a]	-72.3 [a]	-20.8 [a]
Resilience	35.4 [a]	27.5 [a]	45.9 [a]	35.9 [a]	32.7 [a]
Cohesion	0.6 [a]	0.6 [a]	0.8 [a]	0.7 [a]	0.7 [a]
Springiness	89 [a]	79.5 [a]	92.9 [a]	88.7 [a]	86.7 [a]
Gumminess	3232.2 [a]	1724.2 [a]	2841.8 [a]	2463.4 [a]	2927.7 [a]
Chewiness	2850 [a]	1372.4 [a]	2639.7 [a]	2200.2 [a]	2582.5 [a]

Discussion

The high strength of animal-based products is attributed to their extended microfibril protein network (Feng & Xiong, 2002). In our study, the statistical results and the graphs for the different attributes showed that pea protein has weaker structural properties in comparison to vital wheat gluten and soy protein. This has been associated to the lower number of hydrogen and disulfide bonds formed by the protein resulting in a weaker intermolecular network (Schreuders et al., 2021). Several past studies have attributed this weak network as the primary reason for its lower hardness, gumminess, chewiness as well as elasticity which correlates with our findings (Batista et al., 2005; O'Kane et al., 2004).

The closer replication of the sausages and hotdogs formulated from soy protein in terms of chewiness and gumminess has been associated with the higher water holding capabilities of this protein. These water holding capabilities entrap water molecules into the gel matrix of the sausage or hotdogs and deliver the desired juiciness and tenderness (Wang et al., 2015; Wi et al., 2020). Additionally, soy protein exhibits a higher tendency towards disulfide bonding which enhances its structural strength in comparison to pea protein (Chiang et al., 2019; Lin et al., 2000). Besides the physical characteristics which support the use of soy protein in preparing meat mimetics, the higher protein levels in soy also contribute to its higher hardness and increased similarity to the texture of meat (Lin et al., 2000).

In terms of similarity to texture and in some cases also higher deformation resistance than animal meat, sausages formulated with wheat gluten were found to be promising. Wheat gluten in addition to delivering structural strength to the protein matrix has also been found to provide a fibrous texture similar to animal protein (Grabowska et al., 2014; Krasnowska et al., 2005; Xiong et al., 2008). These characteristics of vital wheat gluten in improving the structural network are attributed to its low polarity of the total amino acid structure which repels water thereby improving the product integrity and is also a result of the close association of gluten molecules (Kumar, 2016). Additionally, the high cohesiveness of the sausages and hotdogs found in our study has been associated to viscoelastic network of the gliadin and glutenin monomers which form intramolecular and intermolecular disulfide bonds respectively (Chiang et al., 2019).

Thus, soy protein and wheat gluten show potential in replicating the meat texture. These two proteins sources when used individually however face limitations in their texture like in our result where in vital wheat gluten exceeded the cohesiveness of animal-based products while soy has shown to result in a porous structure on increasing its concentration (Grabowska et al., 2014). These two protein sources are therefore often blended for preparing meat analogues. In the blend, wheat gluten helps to control the water adsorption in soy due to the pressure exerted by the gluten network thereby regulating its deformation (Cornet et al., 2020; Schreuders et al., 2021). Similarly, soy helps in delivering juiciness and tenderness to the wheat gluten owing to its affinity to water molecules and thus preventing it from delivering a rubbery texture (Grabowska et al., 2014). Meat analogues therefore prepared by blending the two proteins were found to be closest replicates of animal-based product in our study as well as in past studies (Krasnowska et al., 2005; RandalI. C.J., 1975).

Thus, the most significant factor that determined the textural difference between the animal and plant-based products was hardness which was significantly lower in pea protein. On the contrary, hotdogs and sausages formulated only from vital wheat gluten had higher cohesive strength and resilience than animal meat. Lastly, based on the comparative evaluation of the different plant proteins it was concluded that blending soy protein and wheat gluten delivered similar textural attributes to pork sausages and beef hotdogs.

Chapter 4

OPPORTUNITIES FOR HYBRID MEAT PRODUCTS: A COMPETITIVE COMPARISON OF PLANT-BASED AND BEEF HOTDOGS

Introduction

Hybrid meat is considered as a bridge for meat-eaters to lower their meat consumption and transition to a plant-based diet. It consists of a blend of plant-based and animal meat components in varying ratios (Spencer & Guinard, 2018; Rajagopal & Burnkrant, 2009). Despite this optimistic aim towards a healthy and ecological lifestyle, there have been reports of negative consumer opinions about the idea due to skepticism about its formulation and processing. Consumers have labelled them to be artificial, unconventional, and highly processed (Jennifer Gregan-Paxton et al., 2005, Rajagopal & Burnkrant, 2009) and thus have lower preference for hybrid meat. The purpose of the present study is therefore to assess consumers' perceptions regarding hybrid meat in further detail and to determine if and how the different product-specific and psychological parameters that have been influential in the consumption of animal meat and plant-based relate to hybrid meat. In this study, conjoint analysis, a market research tool was used which has been used previously to measure the influence of different attributes linked to plant-based meat (Coucke et al., 2023; Escribano et al., 2021).

Materials and Methods

All procedures were approved by the Institutional Review Board (IRB), and informed consent was obtained before testing. This study recruited interested individuals residing in the USA between the ages of 18 and 65. Using Amazon Mechanical Turk (MTurk), we recruited a sample of 571 respondents, with 454 meeting the inclusion criteria. Respondents received compensation for their time.

1.1 Willingness to Purchase

The willingness to purchase was determined using Choice-Based Conjoint Analysis (CBC). Data was collected using Sawtooth Lighthouse (Provo, UT). Respondents were presented with product descriptions that provided product profiles for each hotdog based on their protein type, fat content, price, and package claims, as described in Table 4. These attributes were selected based on previous studies involving conjoint analysis of meat and meat alternatives (Claret et al., 2012; Kibar & Mikail, n.d.; Shan et al., 2017). Each respondent viewed four sets of products, with each set comprising four products. For each set of products, the respondents were asked to select the product they were most likely to purchase.

Table 4: Parameter and levels for hotdog profiles

Parameters	**Levels**
Protein Type	100% Beef
	100%Plant-based
	50% Beef + 50% Plant-based
Price per (12 Oz) (8 Franks)	$ 4.62
	$ 5.54
	$ 6.00
Fat Content per Frank (43g)	5.12 g
	9.58 g
	14 g
Package Claims	Cholesterol-free
	Non-GMO
	For a healthy heart

1.2. Psychological Questionnaires

The psychological questionnaire comprised of 51 statements. The factors evaluated in this questionnaire were meat attachment, food neophobia, respondent's agreement with food-specific health; ecological; moral and social motives. All these factors were measured on a 5-point Likert scale (i.e., 1 = totally disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, 5 = totally agree).

1.2.1 Meat attachment

The meat attachment questionnaire developed by Graca and colleagues (Graça et al., 2015) was employed in this study and comprised of 20 statements. This questionnaire evaluated an individual's attachment to meat through a four-factorial construct, which included measures such as Hedonism (referring to a high meat consumption for the purpose of pleasure), Affinity (attaching a high degree of affinity to meat consumption), Entitlement (representing the feeling of having a right to consume meat), and Dependence (referring to the feeling of dependence on meat consumption).

1.2.2 Food Neophobia

The food neophobia scale developed by Pliner and Hodben (Pliner & Hobden, 1992) was used to assess consumer attitudes towards novel food products and their consumption. The question block comprised of 10 statements to evaluate the phenomenon.

1.2.3 Health, ecological, and moral and social motives

The health (7 statements), ecological (6 statements), moral (5 statements) and social (5 statements) motivations for consuming plant-based meat were determined through statements included in the study conducted by Pires and colleagues (Pires et al., 2019).

1.3 Demographics

Respondents also answered questions regarding their age, gender, level of education, employment status, diet, frequency of animal-based and plant-based meat consumption, number of children and family members to determine if demographic or consumption habits exhibit any effect on the results. These variables were selected based on previous research examining meat attachment and consumer attitudes towards plant-based food (Graça et al., 2015; Shan et al., 2017).

1.4 Data Analysis

The relative importance of product factors such as protein type, package claims, price, and fat content for selecting different hotdogs was determined using the Hierarchical Bayesian Model through the Sawtooth Lighthouse software package (Provo, UT). The preference for each level under the different labels was expressed in terms of zero-centered part-worth utilities. Average values were calculated for the scores of psychological parameters such as meat attachment, food neophobia, health, social, moral, and green values. A multiple linear regression was conducted to determine the impact of different product-specific and psychological parameters on the level of preference for the hybrid hotdogs and to compare the impact against 100% Beef and 100% Plant-based. For this analysis, the moral, social, and green values were combined and labeled as ethical values. R studio (version 4.1.2) was used to conduct data analysis for the survey.

Results

147 Of the 454 respondents who met the inclusion criteria in our study, 54.1% were male, and 45.6% were female. Roughly half of the respondents (48.4%) were between the ages of 30-50, with 39.9% in the age group of 18-29, while the remainder (11.7%) were in the age bracket of 50-65 years old. The majority of the respondents (95.2%) reported being primary grocery shoppers for their household and had at least one child (77.3%) in their families. Regarding education, most respondents (87.9%) at least had a bachelor's degree, and 95.8% reported being employed. respondents were familiar with both beef and plant-based hotdogs, with 56.8% reporting

consuming plant-based hotdogs and 81.1% being consumers of beef hotdogs at least once weekly. respondents were asked to select which product (plant-based, beef, or both) was healthier, and the results showed that a similar number of respondents considered plant-based meat and conventional meat to be healthy (34.5% and 31.9%, respectively). In terms of environmental friendliness, plant-based meat was chosen by 64.3% of the respondents over meat, while 28.2% considered meat to be more environmentally friendly than plant-based meat.

2.1 Comprehensive Product Selection

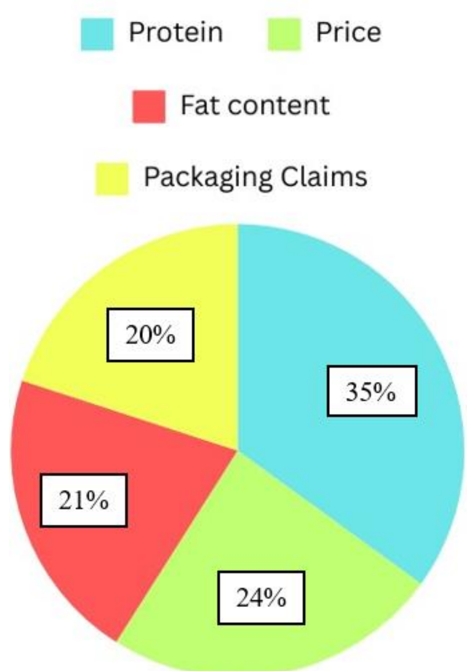

Figure 4: Relative importance of product-specific attributes

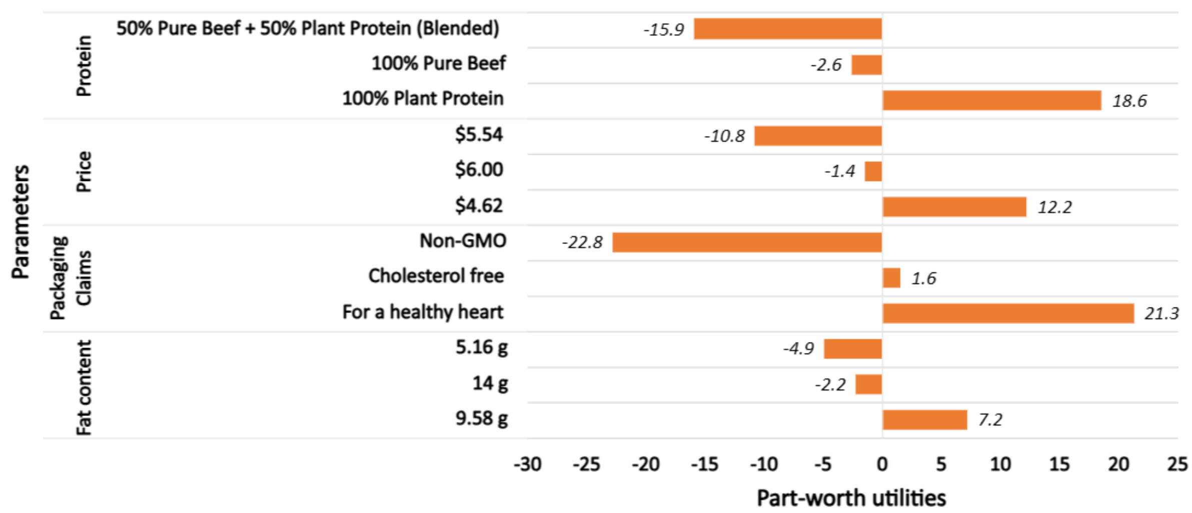

Figure 5: Part-worth utilities for product-specific attributes explaining the preference for different levels under each attribute

The Hierarchical Bayesian Model determined the zero-centered part-worth utility for each level of the different attributes and the relative importance of every attribute (Figure 4 & Figure 5). In terms of relative importance (Figure 4), Protein source (35%) was found to be the most important factor that influenced the product selection. Hotdogs containing 100% plant protein were preferred the most, and the hybrid variety was found to have the lowest utility value. Price (24.5%) was the second-most influential factor in product selection, while Fat content and Package claims (20.55% and 19.4%, respectively) were found to influence the product choice equally. Based on the utilities presented in Figure 5, it was found that respondents had a higher preference for hotdogs with medium to high fat levels, while hotdogs carrying the claim ‘For a healthy heart’ had a higher preference than those that stated to be “Non-GMO’ and ‘Cholesterol free.’

2.2 Product-specific Parameters

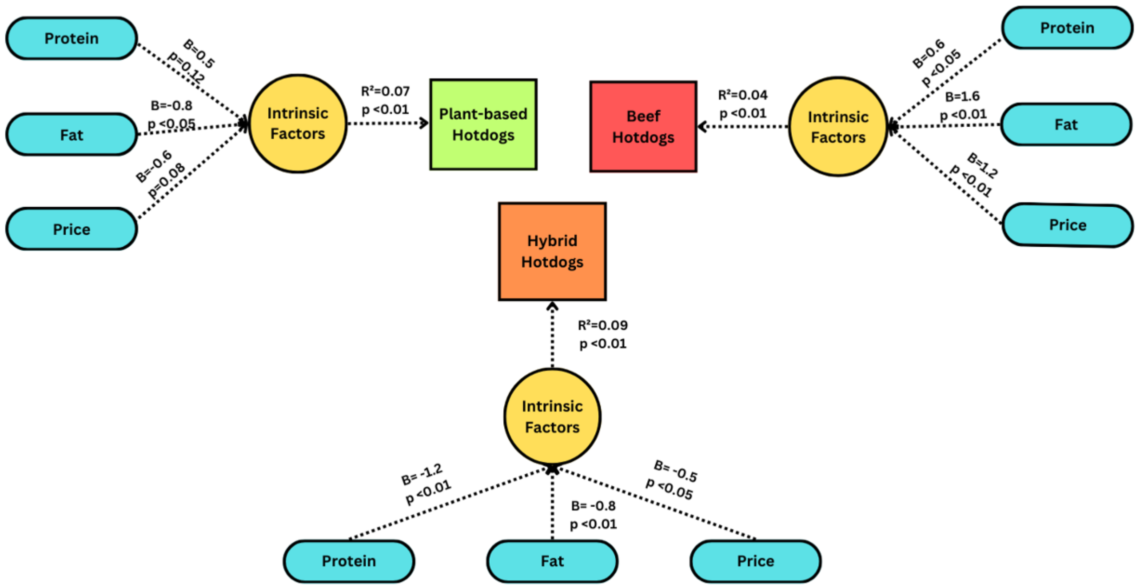

Figure 6: Influence of product specific parameters on hotdog varieties

A multiple linear regression analysis was performed to determine the relationship between product attributes on hotdog selection (Figure 6). The dependent variables included under the intrinsic model were the values of relative importance for protein, fat, and price. The model for hybrid hotdogs explained 9.3% variance via all three intrinsic product attributes ($\beta_{protein}$ = -1.2, β_{price}= - 0.5, β_{fat} = - 0.8) as significant negatively influential parameters. For plant-based hotdogs, one significant parameter was fat, which had a negative effect (β_{fat} = - 0.8), and the model explained 6.6% variance. Protein (p=0.12) and price (p=0.08) had no significant effect on the selection of plant-based hotdogs. The model for beef hotdogs included protein ($\beta_{protein}$ =0.6), fat (β_{fat} =1.6), and price (β_{price} =1.2) as significant predictors, and the model explained 4.3% variance.

2.3 Psychological Parameters

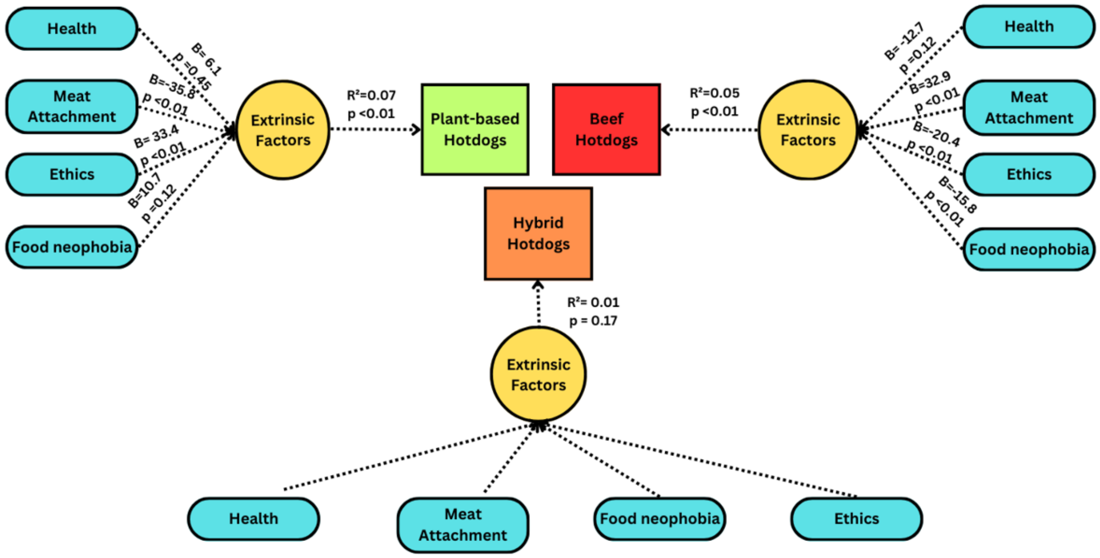

Figure 7: Influence of psychological parameters on hotdog varieties

A similar multiple linear regression analysis was performed to determine the relationship between extrinsic attributes and hotdog selection (Figure 7). The dependent variables included under the extrinsic model were scores for food neophobia, meat attachment, and health and ethical motives. The model for hybrid hotdogs was not significant ($p>0.05$). For plant-based hotdogs, meat attachment ($\beta_{meat\ attachment}$ = -35.8) and ethical motives ($\beta_{ethical\ motives}$ = 33.4) were the significant parameters and explained a 6.6% variance in the selection of plant-based hotdog. For beef hotdogs, 5.2% variance was explained by the model with meat attachment ($\beta_{meat\ attachment}$ = 33.0) and food neophobia ($\beta_{food\ neophobia}$ = -15.8) as the significant parameters.

Discussion

Consumer preferences for hybrid hotdogs compared to plant-based and beef hotdogs to investigate the influence of product-specific and psychological parameters on product choice. The understanding of how these parameters drive selection of plant-based meat, hybrid meat, and beef was explored to better understand the potential of hybrid meat products to be accepted by consumers. In terms of food habits, respondents in the present study reported consuming plant-based meat as frequently as beef. This result was supported by the conjoint analysis results, wherein plant-based hotdogs were most preferred, followed by beef. However, the lowest preference for hybrid hotdogs was contrary to past studies where consumers considered hybrid meat as the first step in meat reduction and thus recorded higher acceptability scores and purchase intent for hybrid meat over plant based (Tarrega et al., 2020). This contradiction in the preferences may be driven by the demographics of our respondents, who reported a higher preference and consumption frequency for plant-based meat. In this study, respondents were not recruited based on dietary habits, outside of consuming hotdogs.

To better understand this low preference of hybrid hotdogs, we examined the relationship between product-specific parameters and product selection. Here, we observed that the choice for hybrid hotdogs was associated with protein source and fat, while for plant-based hotdogs, though protein source was not a significant attribute influencing its selection, fat had a significant negative effect. However, in terms of beef hotdogs both these protein source and fat content had a significant positive impact. The missing significance of protein source in case of plant-based hotdogs can be tied to the incomplete amino acid profile of plant proteins against the complete 20 amino acids in meat (Bakhsh et al., 2021). This difference is described by dieticians to not provide the desired protein content to the body (Hughes et al., 2014). In terms of the fat content, the respondents from our survey had the highest preference for hotdogs containing 9.58 g which was the medium fat level considered for the study and since plant proteins generally have lower fat content the negative association can be explained (Bakhsh et al., 2021).

Despite the difference in protein source and fat content influence on selection of beef and plant-based, there was a similar percentage of respondents who considered plant-based meat to be healthier than meat and vice versa. This is comparable to previous results, where one study identified that 33.6% of respondents considered both plant-based and meat to be equally healthy

(Neuhofer & Lusk, 2022). As a result, neither for plant-based nor for beef hotdogs, health motives were found to be an influencing factor affecting the choice. This absence of health motives as an influencing parameter, can also be attributed to meal context, which in our study was hotdogs, often regarded as a non-healthy food choice and several studies have proved meal context to have an influence on the motivations supporting food consumption (Blanco-Gutiérrez et al., 2020; Elzerman et al., 2011).

The second most important intrinsic attribute in the conjoint analysis after protein was price, which was found to restrict the selection of hybrid hotdogs and had a significant positive effect on the selection of beef hotdogs but was not significant in the selection of plant-based hotdogs. The variation of price as a parameter affecting choice may be attributed to various factors such as the current market share of the product and consumers' consumption frequency. While plant-based meat is widely available in grocery stores, hybrid meat still has limited visibility in the marketplace. Additionally, hybrid meat also showed negative correlation with other product-specific attributes which points out that consumer's might not be willing to pay for the product. On the contrary, since our respondents were also frequent-to-daily consumers of plant-based meat and therefore the price barrier may not be a grave concern as seen in past studies (Blanco-Gutiérrez et al., 2020; Fehér et al., 2020). Thus, respondents in our study showed a tendency to be influenced by price only in the case of beef and hybrid meat but not plant-based meat.

The psychological factors which have been crucial in affecting the acceptance of plant-based meat, correlating them to hybrid meat and comparing the correlation to beef and plant-based meat will help to determine how consumer's perceive hybrid meat as a competitive category to these two existing varieties. The model of psychological parameters for hybrid hotdogs, however, was not significant in our study while the models for plant-based and beef hotdogs were significant with meat attachment and ethical motives as the significant parameters.

Meat attachment, or unwillingness to reduce meat consumption, has been reported to be a major barrier for substituting meat with plant based (Neuhofer & Lusk, 2022) which is in agreement with the present findings. Plant-based hotdogs had a significant negative association with meat attachment while the selection of beef hotdogs was driven by the significant positive correlation. Interestingly, meat attachment was not a significant predictor of the selection of hybrid hotdogs, suggesting this product may provide an acceptable alternative for individuals with high meat attachment. Nonetheless, previous work suggests that consumers are skeptical of hybrid meat products that closely replicates plant-based meat or if it resembles animal meat (Elzerman et al., 2013; Hoeffler & Zhao, 2004; Jennifer Gregan-Paxton et al., 2005; Rajagopal & Burnkrant, 2009). This consumer confusion thus translates in the missing effect of meat attachment in hybrid meat since meat attachment includes all the emotional factors that consumers associate with meat (Jennifer Gregan-Paxton et al., 2005).

Ethical norms comprising of the social, moral and environmental values, have appeared to be a barrier for the acceptance of plant-based and hybrid alternatives (Hoek et al., 2011; Koch et al., 2021; Ryder et al., 2023; "Supplemental Material for The Role of a 'Common Is Moral' Heuristic in the Stability and Change of Moral Norms," 2018). This reasoning is strengthened by consumer studies which found that hybrid meat was positively perceived under blind testing, however had the lowest preference during informed testing conditions (Grasso et al., 2021; Ryder et al., 2023). It is suggested that due to low awareness, familiarity and uncertainty of this product category is having a negative influence on consumers' perception regarding the social or moral impact when considering hybrid products. The social perception has proved to be a significant factor in driving product selection as consumers do not wish to be marginalized for their food consumption choices (Funk et al., 2020; Hartmann et al., 2018; Yantcheva & Brindal, 2013). This reasoning has been derived from studies conducted for plant-based alternatives which showed that consumers were willing to consume plant-based alternatives at home but not at social occasions (Cheah et al., 2020;

Funk et al., 2020; Michel et al., 2021; Yantcheva & Brindal, 2013). In the present study, ethical norms were not significantly associated with selection of hybrid hotdog. Conversely, our findings demonstrate the selection plant-based hotdogs were ethically motivated whereas a negative relationship was reported for beef hotdogs. This positive association has been replicated in several studies which argued that with increased awareness of the altruistic benefits of plant-based alternatives, and the scenario has been reversed, evidence demonstrating consumption may be socially motivated ((Honkanen et al., 2006; Lindeman & Sirelius, 2001; Lindeman & Väänänen, 2000; Rozin et al., 1997).

In the present study, 64.35% respondents considered plant-based meat to be more sustainable than animal meat, thus, it was expected that environmental values would have a significant positive relationship with the selection of plant-based hotdog. However, in the present study this effect was not observed. Additionally, there was no association observed for the selection of hybrid hotdogs. This lack of association is consistent across the literature, which has been linked with consumers' lack of awareness of the environmental impact of food. Additionally, studies also demonstrate that sustainability is assigned the least importance when making a food choice (IFIC, 2022). While perceived degree of processing was not a focus of this study, consumer perception of processing is associated with increased ecological burden and may not align with perceptions of sustainability (Tonsor et al., 2022). Thus, similar to health motives, an individual's food choices can be coupled with the nature of product in consideration and sustainability motives.

While hybrid products are thought to be advantageous from a formulation perspective, addressing limitations in the nutrient profile and sensory characteristics, the present study supports previous reports that consumers report a lower preference for hybrid meat compared to both meat and plant-based options. Product-specific attributes, specifically protein source and fat content along with ethical norms and meat attachment are significant drivers of plant-based and animal hotdogs, which were not observed for hybrid products. also did not show any impact. This can thus be considered as a bold indication of lack of knowledge and familiarity about the product and needs to be addressed effectively.

Chapter 5

CONCLUSION AND FUTURE RESEARCH

Sensory analysis of plant-based meat and dairy alternatives is necessary to improve their consumer acceptability and reduce meat consumption. Among the sensory attributes, texture was found to vary with processing conditions like temperature as well as with the properties of the plant-proteins such as their size, protein and fat contents, rigidity, solubility, tendency for disulfide bonding, water-holding capacities and the structural strength determined by the intermolecular and intramolecular bonding. These distinct properties were found to impact the texture or mouthfeel of the plant-based mimetics by causing variations in attributes such as creaminess, smoothness and slipperiness in case of fluids and semi-fluids and affected the juiciness, tenderness and chewiness in case of solid food such as hotdogs and sausages. These findings thus highlight the need to study the properties of plant-proteins in further depth for better replication of the animal meat mouthfeel.

Additionally, to build further on the acceptability of new products such as meat hybrids which are considered as a route to achieve reduction in meat consumption, the study showed that the hybrid products had the lowest preference when offered as a choice against pure beef and pure plant-based meat. On determining the causes for this lower preference, it was found that among the product-specific factors, consumers considered protein to be the most important factor while choosing a processed meat product followed by the product price. However, both these factors were significant only in the case of meat hybrids and beef but not for plant-based meat. The effect of the product-specific factors on the meat hybrids was however negative and thus showcased a challenge for the hybrid meat industry. Among the psychological factors, it was determined that these parameters were not significant in case of meat hybrids but had strong significance and contrary influences in case of beef and plant-based meat products. The lowest preference, negative correlation with the product-specific parameters and missing significance of the psychological parameters was together attributed to the lack of familiarity and knowledge about the formulation and processing of hybrid meat products,

Thus, the study threw light on the properties that impact the texture of plant-proteins in dairy mimetics as well as concluded that within the current market of processed plant-based meat products, those containing a blend of soy-protein and wheat gluten are the closest replicates to pork and beef when used in sausages and hotdogs respectively. Lastly, hybrid meat can aid to overcome the meat attachment barrier faced by consumers, if its development is supported by efficient marketing strategies and increase in consumer awareness.

As next steps to this research, within the realm of texture, as new proteins are discovered for their potential application in plant-based mimetics the correlation between physical characteristics and sensory properties can vary depending on the characteristics and functionality of the proteins. Additionally, while correlating tribological results to sensory, a major limitation is the difference between the salivary composition of every individual and thus using tribology as the only tool to understand sliding properties is not reliable. The results should therefore be further confirmed by sensory testing to gauge consumer acceptability.

In the consumer survey, the competitive selection across the three protein sources was employed solely for hotdogs. This limits the ability to extend findings to other product categories, such as burgers. Also, in terms of hybrid meat, the present study described blended hotdog as a 50-50 combination of plant–protein and beef, further research is needed to determine how different formulation ratios between the meat and plant-based components, variation in product labelling and information regarding the ingredients and the type of plant protein used, influences consumers' choices and acceptance of hybrid meat products. Furthermore, it should be examined how different consumers segments such as consumers who have never eaten plant-based meat or consumers who eat meat as a part of every meal, respond to hybrid meat products. These studies will help to better gauge consumer perception regarding these products and incorporate effective strategies for their development.

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