Chapter-1
Introduction

Analogues of meat are products that have certain properties (like taste and texture) identical to animal meat and are manufactured to mimic animal products. A meat analogue is a compound that, despite its structural similarity, differs in composition from its original counterpart (Bohrer, 2019; Kyriakopoulou et al., 2019). Meat analogues share much of the same structure as meat, but differ slightly in composition (Ismail et al., 2020). In order for meat substitutes to fulfil the chemical attributes of meat (mainly flavour, texture and appearance), the substitutes need to be made from meat-based compounds, such as surimi, which is a cheap and healthier alternative to meat (Salmon et al., 2003; Jin et al., 2007). A meat analogue will supply its consumers with all the biological, nutritional and characteristic qualities of real meat while containing nutritional and characteristic elements that are not found in meat (Kumar et al., 2017; Kyriakopoulou et al., 2019). A majority of the market of meat analogues consists either of the vegans, vegetarians or the meat-eaters looking for ways to cut back on meat consumption for socio-cultural reasons or for their well-being (e.g., people with religious concerns) (Joshi & Kumar, 2015). Developing products that can function proactively to minimize the consumption of animal meat is considered a promising way to decrease the number of people consuming animal meat (Graça et al., 2015). As a result, the unique characteristics of meat, such as taste, colour, texture, flavour, and sensory properties need to be duplicated in the plant-based meat substitutes since these are the benchmark attributes of animal meat that most of the meat-eating consumers relish (Grunert et al., 2004).

Health awareness in the population has brought the idea for the innovation of plant protein-based meat in many countries (He et al., 2020). Nowadays, the semi-vegetarians or known as “flexitarians” who occasionally include meat in their diet, often prefer non vegetarian foods. In terms of sustainability, excessive meat production has driven environmental change and natural resource depletion (Rosenfeld et al., 2020). Reducing meat consumption especially red meat can play a crucial role in addressing the sustainability challenges possessed by the livestock sector (Gerber et al., 2013). The consumption of vegetable proteins in food products has been increasing over the years due to animal diseases, healthier foods, strong demand for wholesome and religious food and economic reasons (Poore & Nemecek, 2018; Springmann et al., 2018; Willett et al., 2019). As mentioned earlier, the livestock meat-based diet requires more environmental resources than plant protein-based diet (Aleksandrowicz et al., 2016). Currently, the available marketed meat analogue products are plant-based meat in which the quality (i.e., texture and taste) is similar to conventional meat and meat products (Dekkers et al., 2018; Kyriakopoulou et al., 2019). The introduction of meat replacement in food products also known as meat analogue is not new, it was started in the early 1960s (Sanchez-Sabate & Sabaté, 2019). Traditionally, soy protein was used as a popular ingredient in food analogues such as tofu and tempeh (fermented soybean cake). These products have been processed either by simple processing or fermentation techniques, and they have been consumed for centuries as traditional dishes in many southeast Asian products. Meat analogue is a food product which is made from non-animal protein and its appearance and smell are very much similar to meat (Kumar et al., 2017). In addition to these traditional Asian meat analogues, the dry texturized vegetable protein (TVP) was obtained from the extruded defatted soymeal, soy protein concentrates or wheat gluten (Sharma et al., 2022). The introduction of this TVP as meat alternatives emerged in the mid to late 20th century. TVP is made most commonly from soybeans. Texturized soy protein (TSP) for example is extremely versatile for food ingredients due to its meat like texture attributes and also provides similar protein quality to that of animal proteins (Alamu & Busie, 2019). Besides, the ingredients from vegetable proteins are an inexpensive source and they can be modified into meat substitutes such as canned meat (Kumar et al., 2017), meat extender in patties and petfood (Ismail et al., 2020). In the early 21st century, meat alternatives entered the mainstream due to demand towards healthy food. In the last decade, the modern advances technology in food science, technology and manufacturing has been introduced in meat analogue products which can mimic the taste, texture, look and functionality of conventional meat-based products (Kyriakopoulou et al., 2019). The current interest has focused more on the development of non-traditional protein sources in meat analogues such as plant-based meat and cultured meat. The development of a meat analogue to provide alternatives for meat has become a trend. At present, vegetarian foods occupy a larger than ever shelf space in super markets due to the consumer's increasing health concerns and the related environmental issues (Kumar, 2016). A typical meat analogue is composed of a combination of ingredients such as water (50-80%), non-textured proteins (4-20%), textured vegetable proteins (10-25%), fat (0-15%), flavourings (3-10%), binding agents (1-5%) and colouring agents (0-0.5%) (Hamid et al., 2020). Meat analogue is also known as meat substitute, mock meat, faux meat, or imitation meat (Ismail et al., 2020). It may also refer to a meat based healthier and less expensive alternative to a particular meat product. Generally, meat analogue is understood to mean a food made from non-meats ingredients, sometimes without dairy products and are available in different forms such as burgers, sausages, nuggets, meat balls, pizza toppings etc. (Joshi & Kumar, 2015).

The main component of the majority of diets across the globe is meat, and it is considered a staple component of many cuisines. Meat is highly nutritious due to the abundance of macro- and micro-nutrients, including proteins, iron, zinc, vitamins B1, B12, A, D, and niacin (Laskowski et al., 2018). The demand for meat is growing due to a number of factors. However, for enough proteinaceous food to be produced for everyone and to mitigate the harmful effects of meat production, there is a need to increase reliance on plant-based protein sources. Livestock rearing negatively affects the environment through harmful emissions, excessive energy use, soil and water consumption, and poor resource utilization (Nijdam et al., 2012). In addition, meat consumption poses health risks due to pathogenic microbes such as *Salmonella enterica* and *Escherichia coli*, which can cause severe food poisoning if not handled correctly. Further complications, such as colon cancer and breast cancer in women, have also been linked to red meat consumption and hormone usage in meat production (McAfee et al., 2010). Animal welfare concerns within social and cultural contexts also motivate some individuals to reduce meat consumption. Although there are numerous arguments in favour of a plant-based diet, few people adopt such a diet globally (Leroy & Cofnas, 2020). Most people perceive meat as a highly nutritious and delicious food commodity (Verbeke et al., 2010). The most effective way to reduce meat consumption is through consumer awareness education (Stoll-Kleemann & Schmidt, 2017). Increasing consumption of plant-based foods such as beans, legumes, and nuts, or adopting meat analogues, can provide alternatives that mimic the taste, texture, and nutritional quality of meat (Harguess et al., 2020). Tofu and tempeh, traditional Asian foods, are examples of such products, and they are increasingly being promoted in Western countries. Therefore, meat analogues are gaining popularity as healthier and more sustainable substitutes.

The development of plant-based meat analogues has gained momentum in recent years, driven by concerns about environmental sustainability, health impacts of conventional meat production, and ethical issues related to animal welfare. The rising popularity of vegetarian, vegan, and flexitarian diets has further increased demand for protein-rich meat substitutes that mimic the taste, texture, and nutritional value of traditional meat (Galanakis, 2024; Gil et al., 2024). Within this field, plant proteins from sources such as soy, wheat, peas, and legumes have been widely studied, while underutilized resources are gaining attention for their potential to diversify the market and offer functional benefits (Tan et al., 2023). One such promising source is the seed of the Manila tamarind plant.

Manila tamarind (*Pithecellobium dulce*) is a tropical legume tree native to the Americas and widely distributed across Southeast Asia and India, valued for its tangy-sweet fruit. Although the pulp is commonly consumed, its protein-rich seeds are often discarded despite containing essential amino acids, minerals, and antioxidants that make them a valuable raw material for sustainable meat analogue development (Sha & Xiong, 2020; Rao, 2013). Developing Manila tamarind seed-based meat analogues requires efficient protein extraction and texturization techniques to replicate meat’s fibrous structure, with technologies like extrusion and fermentation being investigated (Surasani et al., 2019; Kyriakopoulou et al., 2021). Utilizing these seeds aligns with circular economy principles by reducing food waste, promoting sustainable use of native resources, supporting local economies, and lowering dependence on imported proteins such as soy (Sanchez-Sabate & Sabaté, 2019; Vargas-Madriz et al., 2020). Given that Manila tamarind thrives in arid and less fertile soils, it represents a low-input, sustainable crop with potential to provide affordable protein alternatives in regions where conventional sources are limited (Ayilara et al., 2022).

The functionality of proteins can be modified by a variety of physical, thermal, enzymatic, and chemical processes. Functional, nutritional, and organoleptic properties of food systems are impacted by the methods used to enhance protein properties (Nasrabadi et al., 2021). Autoclaving (moist heat treatment) is the process of heating feeds under pressure with steam. In addition, partial denaturation of proteins reduces their degradability, mainly in highly degradable protein sources. Slowly degrading fractions were autoclaved to increase their soluble fractions that decrease their fractional rate of protein degradation. Heat treatment strongly reduced protein degradation in pea and lupin seeds, moderately reduced it in field bean and bitter vetch (BV), and almost unchanged in vetch seed meal (Seifdavati & Taghizadeh, 2012). Among the non-thermal physical techniques, ultrasound treatment has attracted considerable attention for its ability to modify protein structure (Jambrak et al., 2009). Protein stabilized emulsions have been produced using high intensity ultrasound and they were found to have improved rheological properties because of the improvement in emulsifying properties (Singla & Sit, 2021; Singla et al., 2022). Dissolving the intermolecular bonds and molecular unfolding considerably improved the surface hydrophobicity, solubility, oil absorption, and foaming capabilities of isolates (Malik et al., 2017; Zhu et al., 2018).

A critical frontier in plant-based meat research is flavor replication. Conventional meat flavors result from complex mixtures of volatile compounds, including sulfur-containing heterocycles, carbonyls, and furans generated through Maillard reactions and lipid oxidation (Jayasena et al., 2013; Hu et al., 2023). Replicating these profiles in plant-based matrices is challenging due to compositional differences between plant and animal proteins (Kyriakopoulou et al., 2019). Promising strategies include the use of yeast extracts rich in glutamates, mushroom-derived sulfur compounds, and legume protein hydrolysates subjected to controlled Maillard reactions (Stephan et al., 2018). Emerging technologies such as precision fermentation also allow production of heme proteins like leghemoglobin, enhancing both flavor and color (Fraser et al., 2018). Integrating these compounds into Manila tamarind seed protein matrices requires careful optimization of release kinetics, stability, and interactions with other food components to ensure authentic sensory experiences (Yang et al., 2023). Since flavor authenticity remains a key barrier to consumer acceptance of plant-based meats (Michel et al., 2021), this research aims to design flavor systems tailored for Manila tamarind seed proteins that replicate conventional meat profiles while maintaining nutritional integrity and clean-label standards.

Conventional soy-based meat alternatives have long established benchmarks for cooking performance, including water retention, fat absorption, textural stability, and browning capacity during different cooking methods (Ismail et al., 2020). These parameters strongly influence consumer perception and market adoption of new protein sources (Kyriakopoulou et al., 2021). Manila tamarind seed proteins, like other legumes, possess distinct amino acid profiles, structural properties, and functional characteristics such as gelation, water-holding capacity, and emulsification, which affect their behaviour during cooking (Sha & Xiong, 2020; Asgar et al., 2010). Their inherent fiber content, starch composition, and endogenous enzyme activity may offer unique advantages or limitations when exposed to high-temperature cooking processes such as frying, grilling, or baking (Surasani et al., 2019). Interactions between Manila tamarind proteins and added ingredients such as hydrocolloids, lipids, and flavor compounds also warrant investigation to optimize formulations (Baugreet et al., 2019). Advances in high-moisture extrusion and shear cell technology have improved fibrous structure formation in plant proteins, potentially overcoming textural limitations of novel protein sources like Manila tamarind (Dekkers et al., 2018). To establish their culinary performance and consumer acceptance, this study will conduct comparative cooking quality assessments of Manila tamarind-based analogues against soy-based products using standardized protocols to evaluate cook loss, dimensional stability, textural changes, color development, and sensory attributes.

The preparation of consumer-ready products from Manila tamarind proteins represents the transition from fundamental research to commercial application. Successful development requires integrated knowledge of protein functionality, processing technologies, formulation strategies, and consumer expectations (Bohrer, 2019). Manila tamarind seed analogues offer compositional advantages, including bioactive compounds and distinctive amino acid profiles, that may support differentiated products in the competitive plant-based meat sector (Nadathur et al., 2017). Product optimization using design of experiments (DOE) approaches will address key variables such as protein concentration, oil content, binding systems, flavor delivery, and textural modifiers to achieve desirable sensory quality and stability (Dekkers et al., 2018). Clean-label demands further challenge developers to avoid artificial additives while maintaining shelf life and appeal, requiring innovative approaches to natural preservation and flavor enhancement (McClements & Grossmann, 2021).

Characterization of developed products employs multidisciplinary methods spanning physical (texture analysis, rheology, microscopy), chemical (lipid oxidation, protein degradation, Maillard products), nutritional (protein digestibility, micronutrient bioavailability), microbiological (shelf-life, safety testing), and sensory (descriptive analysis, consumer acceptance) evaluations (Van der Weele et al., 2019; Sha & Xiong, 2020). Advanced techniques such as confocal laser scanning microscopy (CLSM), differential scanning calorimetry (DSC), and dynamic mechanical analysis (DMA) provide insights into structural organization and phase behaviour of these systems (Dekkers et al., 2018). Additionally, *in-vitro* digestion models and metabolomics approaches help assess nutritional quality and bioactive potential (Zhou et al., 2021). Collectively, this framework validates the technological feasibility of Manila tamarind seed-based meat analogues while demonstrating their commercial potential as sustainable, nutritious, and sensorially appealing alternatives.

Despite the promising potential of Manila tamarind seeds for plant-based meat analogue development, several research gaps must be addressed to unlock their full potential. The Manila tamarind seeds have great potential as a protein source for plant-based meat analogues, yet there is no documented case of their application in this field. Their unique protein composition makes them a promising candidate for alternative meat production, especially when subjected to protein modification and texturization techniques that can enhance their functionality. However, research in this area remains limited, highlighting the need for further studies to explore their suitability, optimize processing methods, and develop innovative plant-based meat products with improved texture and sensory attributes. Limited studies have examined the protein extraction process specific to Manila tamarind seeds, which is essential to determine their efficiency in creating texturized proteins suitable for meat substitutes. Current research focuses predominantly on more established protein sources, such as soy and pea, leaving gaps in understanding the optimal methods for isolating and processing Manila tamarind seed proteins. Moreover, the textural and sensory properties required to mimic traditional meat have yet to be fully characterized in these seeds, with little data on how they respond to processing techniques like extrusion and fermentation, both of which are pivotal in replicating the fibrous and juicy texture associated with meat.

The development of plant-based meat analogues from Manila tamarind seeds is justified by the urgent need for sustainable, nutrient-rich, and ethically produced protein sources (Ismail et al., 2020). Traditional animal agriculture contributes significantly to greenhouse gas emissions, deforestation, water and soil degradation, and biodiversity loss, and its environmental burden is expected to grow with rising global meat consumption (Johnson et al., 2007; Poore & Nemecek, 2018). In contrast, plant-based proteins require less land, water, and energy while generating fewer emissions (Searchinger et al., 2019). Manila tamarind seeds, in particular, are an eco-friendly and resilient crop, grown in semi-arid regions with minimal inputs. Their use as a protein source could reduce the environmental footprint of food production while promoting biodiversity through the cultivation of underutilized native species, aligning with global sustainability initiatives that emphasize climate-friendly diets (Jha et al., 2017; Willett et al., 2019). Beyond sustainability, Manila tamarind seeds provide unique nutritional advantages. Rich in proteins, essential amino acids, antioxidants, and bioactive compounds, they offer potential health benefits such as supporting heart health, reducing inflammation, and providing dietary fiber often absent from traditional meat (Kumar et al., 2017; Karlsen et al., 2019). As consumer demand shifts toward functional and wellness-oriented foods, meat analogues derived from tamarind seeds could appeal to health-conscious populations. Incorporating them into food systems also diversifies protein sources, reducing reliance on soy and pea while enhancing global food security and resilience against monoculture risks (Henchion et al., 2017). In addition to environmental and health benefits, Manila tamarind-based meat analogues present socio-economic opportunities. As a widely cultivated tropical and subtropical crop, its seeds can serve as an affordable, local protein source for communities with limited access to conventional protein (Udhayakumar et al., 2024). Supporting their use could create new income streams for smallholder farmers, strengthen rural economies, and reduce food waste by valorizing a resource that is often discarded, in line with circular economy principles (Jurgilevich et al., 2016; Donner et al., 2020). Overall, advancing Manila tamarind as a plant-based protein highlights a multi-faceted innovation with environmental, nutritional, and socio-economic benefits, positioning it as a promising contributor to sustainable food systems.

However, design and development of an innovative food product that satisfies the consumers demand are very challenging. Quality, nutrition, and sensory characters are the first parameters to be taken into consideration before developing the plant protein-based meat analogues. The study was undertaken considering the above facts, at Tezpur University, Tezpur, Assam entitled "Development of plant-based meat analogues from Manila tamarind (*Pithecellobium dulce*) seeds" with the following objectives:

1. To modify and texturize protein extracted from Manila tamarind seeds
2. To develop plant-derived flavoring components from the modified protein to mimic flavor of animal meat
3. To standardize the cooking process of the developed meat analogue and comparison of its cooking quality with existing product such as soy-meat
4. To prepare food product from the developed meat analogue and its characterization

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