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Modern Concepts of Restructured Meat Production and Market Opportunities: A Review

Abstract

Restructured meat (RM) products are gaining importance as an essential component of the meat industry due to consumers' interest in health benefits. RM products imply the binding or holding of meat, meat by-products, and vegetable proteins together to form a meat product with meat's sensory and textural properties. RM products provide consumers with diversified preferences like the intake of low salt, low fat, antioxidants, and high dietary fiber in meat products. From the point of environmental sustainability, RM may aid in combining underutilized products and low-valued meat by adequately utilizing them instead of dumping them as waste material. RM processing technique might also help develop diversified and new hybrid meat products. It is crucial to have more knowledge on the quality issues, selection of binding agents, their optimum proportion, and finally, the ideal processing techniques. It is observed in this study that the most crucial feature of RM could be its healthy products with reduced fat content, which aligns with the preferences of health-conscious consumers who seek low-fat, low-salt, high-fiber options with minimal synthetic additives. This review briefly overviews restructured meat and the factors affecting the quality and shelf life. Moreover, it discusses the recent studies on binding agents in processing RM products. Nonetheless, the recent advancements in processing and market scenarios have been summarized to better understand future research needs. The purpose of this review is to bring light to the ways of sustainable and economical food production.

Keywords

Restructured meat, Hybrid meat, Sensory quality, Processing technique, Market scenario

Introduction

Historically, meat has been a rich source of protein and an essential part of the human diet (Baugreet et al., 2018). The meat contains not only protein but also vital minerals and vitamins. Due to the growing population, Food and Agriculture Organization of the United Nations (FAO, 2014) has projected that worldwide meat consumption will double by 2050. In the next decade, the consumption growth is assumed to be 14% (OECD, 2021). The rising income and population growth are critical factors for the increase in demand for meat (Alam et al., 2023). **Fig. 1** describes the demand for meat with the increasing population. To meet the growing demand for meat in the coming years, there is a need for more resources for meat processing technology. So, to fulfill this meat demand, various alternatives are developed, including cultured meat (Post et al., 2020), hybrid cultured meat (Alam et al., 2023), hybrid meat (Baune et al., 2023), and plant-based meat (Kumari et al., 2023).

The processing of different ingredients (e.g., meat or vegetable protein) and transforming them into a new product with high nutritive values is known as restructured meat (Polášek et al., 2021). Usually, the development of RM involves the inclusion of various additives and binding agents (Carpentieri et al., 2022). The prospect of RM is related to the sustainability of the meat industry by utilizing less used parts of meat or by-products as they are being wasted due to deficient demand. So, there is an opportunity to combine underutilized meat parts and conventional low-cost plant protein sources into a new restructured product (Freire et al., 2016). Various methods, such as meat restructuring and hybrid meat (HBM), have been used to change the meat to include health benefits (functional components) from other sources, such as plants (Mireles et al., 2017) and other protein sources (Baugreet et al., 2018). RM could be a valuable solution for health-conscious consumers to reduce portions of meat in their diet.

Mark Post established the basis for a fundamental change in our comprehension of meat manufacturing and proposed the concept of alternative meat manufacturing in 2012 (Post, 2012). RM is such a kind of alternative processing method. In RM, products can be manufactured by reducing the size of low-value, underutilized meat particles with the help of different processing techniques, e.g., chopping, cutting, sectioning, tenderizing, flaking, and grounding. RM and HBM emulsions are often reformed into restructured steak, patties, and other reformed meat batter-like (Anandh & Villi, 2018). While producing these emulsions, different methods are used to turn meat into a fine slurry and mixed well with starch, fat, and different herbs and spices to improve the flavor of RM products. Researchers are continuously working to explore RM techniques, such as Schonfeldt and Strydom (2011), and explore the nutritional consequences of this non-traditional method. Further studies are required to improve the physiochemical and sensory qualities of meat. Nevertheless, any new technology might have pros and cons; restructured meat is not an exception and has advantages and disadvantages (Freire et al., 2016), illustrated in Fig**. 2.**

RM is taking an entry to the consumers worldwide with variation according to culture and continents. For example, the production rate of restructured meat in Korea is still low; however, in other parts of the world, people are working on restructuring technology to improve meat quality and utilize less valuable meat by combining it with different types of meat. Meat prices are increasing rapidly, and restructured meat products would be cost-effective. For this reason, it is easy for meat consumers to adopt RM products (Gadekar et al., 2015). This review contains techniques and processes of restructured meat and discusses various methods and approaches to overcome quality issues and binding efficiency in restructured meat. It also includes the current developments and trends in restructured meat.

Process of Restructured Meat

Processing of RM involves several steps. The basic principle of RM is to craft a mixture of various meat types or add some plant-based protein and fiber sources. This combination establishes the basis for attaining the end product's intended taste, consistency, and nutritional makeup (Patel et al., 2023). After meticulously choosing the meat or plant source, the vital stage is the grinding process. The mechanical process makes the mixture uniform and helps create the distinct texture of restructured meat (Farouk, 2010).

Bio-adhesives, typically sourced from natural origins, are crucial in improving the cohesion and arrangement of restructured meat. This stage entails carefully and precisely incorporating bio-adhesives to provide the best possible adhesion of meat particles, enhancing the end product's overall quality and stability. The production process of restructured meat relies heavily on temperature and time factors. Ensuring the product's texture, flavor, and safety requires maintaining an ideal temperature for a certain period. The regulated environment guarantees the appropriate bio-adhesive curing and enhances the overall quality of the restructured meat. **In Fig. 3,** the simple process of restructuring meat is elaborated, in which restructured meat is made by combining meat and cereals.

Factors Associated with Qualities of Restructured Meat Products

Physical qualities of restructured meat products

As RM is frequently composed of a blend of several meat origins and occasionally includes plant-based components, it can display a wide variation in color, texture, and flavor. It is necessary to add some additives to boost the quality of restructured meat. The selection of additives and processing procedures is essential in defining the product's ultimate color, taste, and texture. For example, adding natural colors like beetroot extract or annatto can enhance the visual appearance by creating a red or pink color that imitates the look of conventional meat. Nevertheless, the production of restructured meat presents a complicated problem in attaining the appropriate color while preserving nutritional content and ensuring customer approval (Andrade et al., 2023).

The visual aspect of restructured steaks is a significant concern for consumers (Kumar et al., 2023). The fundamental criteria for restructured beef products are vibrant colors, meat resembling entire muscle steaks, and uniform dispersion of tiny fat particles (Cifuentes et al., 2023). The mixing duration affects the meat’s color and will accelerate the degradation of the intended color if it exceeds 12 minutes (Gómez et al., 2020). A study examined the efficacy of vacuum mixing in reducing color degradation in fresh meat. However, the final steaks had a less attractive surface color. Salt can produce discoloration in restructured steak (Mandigo & Osburn, 2019). According to Gadekar et al., 2015 higher amounts of salt lead to a drop in the desirability of color. Sodium tripolyphosphate (STP) can enhance the natural color by countering the impact of salt. Wang et al. (2021) stated that there is a correlation between discoloration and lipid oxidation of restructured steaks. The researchers discovered that the deterioration of color in beef happened earlier during storage compared to the oxidation of lipids. Furthermore, the oxidation of pigments may have facilitated the lipid oxidation process. Meanwhile, Serrano et al. (2006) found no correlation between color degradation and lipid oxidation.

Texture is crucial in determining the mouthfeel and overall sensory experience of meat products. Restructured meat is subjected to a rigorous process to replicate the fibrous composition observed in conventional cuts. Methods such as extrusion and texturization imitate the texture and tenderness commonly found in meat. The study conducted by Ribeiro et al. (2023) investigates the influence of different ingredients and processing conditions on the texture of restructured beef. The continual improvement of restructured beef products prioritizes achieving the correct texture while addressing problems such as dryness or hardness. Hydrocolloids effectively make better meat texture (Dinani et al., 2023). So, they can be added to RM products to enhance meat quality.

Sensory qualities of Restructured Meat products

The taste of restructured meat plays a crucial role in the culinary experience, as it aims to accurately mimic traditional meat's flavor while potentially introducing other functional qualities. The combination of various components, utilization of taste intensifiers, and the culinary procedure collectively influence the ultimate flavor composition. Chen et al. (2021) investigate techniques to augment umami, the savory flavor commonly linked to meat, in restructured food items to bring positive consumer variation. Moreover, the possibility of enhancing the sensory experience of restructured meat by using herbs, spices, and alternative protein sources is an exciting opportunity to introduce new and varied flavors. Salts like NaCl can be used to improve the texture and taste of meat (Cornet et al., 2021). Gyrating and kneading aim to generate favorable characteristics in the final output (Zhang et al., 2024).

Tumbling, homogenizing, or proper mixing enhances the dispersion of all ingredients and augments the ionic strength and pH. This leads to increased product yield, improved water retention, tenderness, juiciness, final product appearance, and better binding of meat chunks. The study conducted by Tsafrakidou et al. (2023) found that the product yield from vacuum and aerobically tumbled meats was similar. However, Muller (1991) reported a higher product yield for restructured chicken meat products. Muller also found that using 10% water chestnut flour (hydrated at a 1:1 ratio) was optimal for these products. Furthermore, the products remained acceptable for up to 10 days when stored in refrigerated conditions. It was confirmed that restructured cooked ham formulation could incorporate up to 38% of fresh liquid whey, yielding comparable outcomes to products cured using a traditional formulation (Dutra et al., 2012). Another use of RM was incorporated to increase the chicken meat yield by treating some parts of 5.0, 7.5, and 10.0% Hydrated Colocasia Flour (HCF). The most effective amount of HCF to use was determined to be 7.5% based on sensory evaluations, physicochemical qualities, and microbiological quality (Talukder et al., 2013). The appropriateness of tetra-potassium pyrophosphate (0.4%), tetra-sodium pyrophosphate (0.4%), and their combination (0.2% each) was assessed for the production of a low-salt reformed goat meat product. Using phosphates and including tetrapotassium pyrophosphate, which has a soapy smell, resulted in a substantial enhancement in the product output. Combining tetra-sodium and tetra-potassium pyrophosphate can create a low-sodium product (Gadekar et al., 2014). Reducing the duration of tumbling before injecting can enhance the yield and tenderness of roast beef (Boles & Shand, 2002). Table 1 provides an overview of the key factors influencing the quality of RM products for better understanding on future work to improve processing and RM product development.

Meat Particle Size and Product Quality

The particle size can significantly affect the texture of restructured meat products. Several studies have been done to check the effect of meat particle size on meat quality. Restructured pork steaks made from smaller flakes exhibited reduced shear force values and were preferable to consumers (Patel et al., 2023). Pork chops and pork shoulder products that were restructured and manufactured with smaller flakes exhibited more excellent softness (Bhaskar et al., 2015)

It was observed that decreasing the size of meat particles can enhance the quality of RM products. Sen & Karim (2003) found that reducing the mutton particle size from 0.7-1.2 mm performed better than 20. mm cut while producing restructured mutton chops. The restructured pork blocks with a chunk size of 2-3 cm exhibited a more significant product yield (89.31%) than those with a chunk size of 4-5 cm (85.12%). The pork block rebuilt using meat chunks measuring 2-3 cm exhibited a considerably lower shear force value and a higher tenderness level than those produced with 4-5 cm meat chunks (Gurikar et al., 2014).

Binding Agents in Processing of Restructured Meat

It is necessary to add binding agents to bind meat particles together to form products properly. Besides muscle proteins, additional non-meat components significantly bind meat chunks or bits. Meat chunks containing 0.1% microbial transglutaminase (MTGase) and 3% salt exhibited superior binding. The enzyme MTGase (0.05-0.1%) and sodium caseinate (0.5-0.1%) effectively made restructured meat with sufficient binding in its raw, refrigerated form without adding salt at 5 ^{0}C for 2 hours (Kuraishi et al., 1997). In another study, the use of beef rolls cooked with 1% salt and 0.5% sodium salt of phytate was shown to be more efficient than using 1% salt + 0.5% sodium pyrophosphate, 0.5% sodium tripolyphosphate in enhancing binding strength and cooked yield (Lee et al., 1998). To increase the strength of binding sites, adding 0.5% Calcium lactate, 0.5% Algin, 0.5 Phosphate, and 1.5% Salt gave significant results (Shao et al.,1999). They further noted that binding capacity was better than the previous treatment (5% Fibrinogen and 0.25 % Thrombin).

An effective combination is crucial to developing an effective RM product, and researchers are conducting studies on this issue. A study by Devatkal and Mendiratta (2001) found that the most practical combination of binding agents for producing restructured pork rolls under refrigeration was 0.7% sodium alginate, 0.125% calcium carbonate, and 0.3% calcium lactate. The utilization of tri-calcium phosphate at a concentration of 0.3% resulted in notable enhancements in both the tenderness of flesh and the binding properties of restructured buffalo meat rolls, as compared to products containing 0.3% sodium tripolyphosphate (Mendiratta et al., 2002). A formulation with 1% SPI (soybean protein Isolates), 0.3% carrageenan, and 3% potato starch can make cheap RM because these binders are more affordable than others (Silva et al., 2021). Fiber-based binders also have potential in RM processing and show good binding strength without affecting the quality of restructured meat (Shafit et al., 2007). Summarized information on the commonly used in the processing of RM is shown in Table 2, which could bring effective physical and sensory characteristics.

Factors mediate the Binding Strength.

Along with including a binding agent, it is essential to have a sufficient capacity for binding multiple materials to form the final product successfully. A study conducted by Serrano et al. (2007) found that microwaved restructured beef steaks exhibited considerably higher Kramer shear force and binding strength compared to steaks that were pan-fried or normally oven-cooked ($P<0.05$). According to Sharma et al. (2014), vacuum tumbling buffalo meat at a pressure of 0.4 bar for 3 hours at a speed of 11 rpm resulted in improved extraction of salt soluble proteins and enhanced binding and cohesiveness of the product compared to aerobic tumbling for the same duration.

To provide the best possible binding and food safety, mechanical measures like performing tumbler and massager processes in cold rooms at 0 degrees Celsius are recommended (Sikorski, 2004). The protein exudates generated during the procedure act as a binding agent, adhering the meat chunks together while cooking. The use of a vacuum during the operation aids in the elimination of air bubbles from the exudates and facilitates the extraction of proteins (Barbut, 2005).

Techniques to improve shelf life

As meat products are perishable and require storage at a minimum temperature of -18^{0}C, enhancing their shelf life during processing is necessary. So, for this reason, different approaches and designs were used to enhance the shelf life of RM products. Using grape seed extract at a concentration of 0.1% improved the duration for which reconstructed mutton slices may be stored without spoiling and can be refrigerated for up to 28 days (Reddy et al., 2013). The inclusion of additives can improve the overall quality of meat products. A study conducted by Gadekar et al. (2014) showed that the addition of sodium ascorbate (500 ppm) and alpha-tocopherol acetate (10 ppm) to restructured goat meat products enhanced the stability of lipids during refrigeration and frozen storage, therefore improving the overall storage stability of the meat. Results from Reverte et al., 2003 showed a positive effect of adding flavoring compounds and antioxidants as they improved beef's shelf life and flavor, which can be incorporated in RM processing. To evaluate the storage condition in a study, Malav et al. (2012) assessed the impact of water chestnut flour on the quality and durability of storage. They got positive results and concluded that water chestnut flour enhances the storage time.

Recent advancements in Restructured Meat research and development

The restructured meat market is growing gradually. Presently, dedicated research is being conducted on RM product development. (Gurikar et al., 2014) Was successful in producing restructured pork blocks by using some processing conditions. In another study, the quality of restructured meat was improved to meet consumer demands (Anandh & Villi, 2018). This study revealed that spent Hen can effectively produce nuggets using salt, sodium tripolyphosphate, and sodium nitrite. Some of the latest techniques are also being used in the field of Restructured Meat, as Zhu et al. (2019) utilized Pressure-transform rolling techniques to make restructured pork chops. Some genes from plant or fungi sources are also used for restructured meat; Yang & Zhang (2019) used a recombinant transglutaminase gene from *Pichia pastoris* (methylotrophic yeast) to restructure the meat. Citric acid (0.2%) was used to restructure fish (Oreochromis mossambicus) by Gu et al. (2021) to improve some of the physical qualities of the meat.

Nowadays, researchers are focusing on functional attributes and trying to improve the health properties of RM products. In such an effort, Ahmad et al. (2021) manufactured restructured buffalo meat pieces that were low in sodium, high in fiber, and full of antioxidants. Gorbunova et al. (2022) used the shockwave (SW) method to restructure fresh meat and make it more tender. Saengsuk et al. (2022) used alginate/calcium and κ-carrageenan to make restructured pork steak. In contrast, the samples supplemented with κ-carrageenan retained their red color better and can be easily chewed while maintaining the unique taste by adjusting hardness following the USDA guidelines. Lemma et al. (2022) used raisin paste as a natural preservative in jerky dressing to make low-fat restructured jerky products. Extrusion-based 3D food printing was used by Park et al. (2023) to make Restructured beef steak. Gupta and Sharma (2023) conducted a study to examine the quality of spent hen meat after adding some binder and extender to meat. They restructured spent hen meat slices by adding soy protein to make the chunks more tender.

Market Scenario

Countries with high incomes also have higher meat demand, which puts significant pressure on livestock meat production (Parlasca & Qaim, 2022). Reducing meat consumption may facilitate the reduction of the environmental impact and minimize the pressure on livestock meat production (Sijpestijn et al., 2022). The increase in meat consumption may aid the growth of RM products. According to Hankyoreh (2023), meat consumption is increasing in Korea by an average of 2.8% per annum, and consumers are becoming health conscious. This could be an opportunity for increased demand for RM products. North America has the biggest market for RM products due to the high population (DI, 2023). Pork is a significant part of RM product development (Saengsuk et al., 2021). Meat scientists are working to improve the quality of RM by improving its color, texture, and taste (Shevchenko et al., 2021). Furthermore, the number of RM customers is also increasing rapidly (DI 2023). Lifestyle, eating habits, and people's priorities have changed rapidly over the past few decades, which has increased the demand for meat (Whitton et al., 2021).

Advancements in technology (Freezing and restructuring technology) and awareness of the benefits of restructured meat can potentially enhance the RM market in the coming years (Ritchie et al., 2021).

According to future market insight (FMI, 2023), efficient marketing is essential for any RM industry's profitability and long-term viability. The demand for restructured meat was predicted to reach 5 Billion US$ by the end of this year, and it is also expected to increase by 18% by 2033 (FMI, 2023). RM in processed food is a new advancement in the meat sector, so meat scientists are assuming that the market value of this type of meat will increase rapidly because restructured meat can be modified according to consumers' demand.

The RM production and selling system requires modernizing. Appropriate processing facilities are necessary to export RM products to the international market. As meat consumption will double in 2050 (FAO, 2014), there is an opportunity to grow the RM market, and that requires potential strategies to meet consumer demand and increase sales by analyzing customer needs, adjusting processing and dispensing methods, developing a solid brand name, implementing rigorous quality control measures, and creating healthier meat products. The majority of this growth is anticipated to occur in developing countries.

The processed meat sector offers significant potential for entrepreneurial development and employment creation, and a gradual increase in RM products (DI, 2023) will open further opportunities. Rigorous quality control measures and producing healthier meat products in response to consumer demand can also be effective for RM product growth.

Conclusion

This review concludes that meat restructuring technology can convert meat trimmings, lesser-value meat cuts, and plant-based protein/fibers into value-added RM products, improving palatability and customer acceptance. Additional studies are required to enhance the processing techniques, product ranges, and functional quality of restructured meat. RM will open opportunities to add different kinds of meat, by-products, plant fibers, and plant proteins to produce HBM, which is healthier for consumers. In addition to its economic impact, the restructuring process can also increase the overall yields and reduce the cost of meat products. The most crucial feature of RM could be its healthy products with reduced fat content, which aligns with the preferences of health-conscious consumers who seek low-fat, low-salt, high-fiber options with minimal synthetic additives. Several reconstructed types of meat, specially HBM with diverse substances, have been created by different existing meat-producing companies, e.g., Tyson Foods, JBS S.A., Inc., Cargill Inc., Smithfield Foods, Inc., Marfrig Global Foods, Hormel Foods Corporation, Maple Leaf Foods Inc. and BRF S.A., etc. However, customer acceptance of these items remains challenging due to clarity on the product formation, a specific declaration of health benefits, and the need for a marketing campaign. Categorizing products to particular consumers, ages, and health groups, along with simultaneous engagement in effective marketing campaigns to educate consumers on the RM products, are crucial to increasing the market share and popularization.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Figures and Table

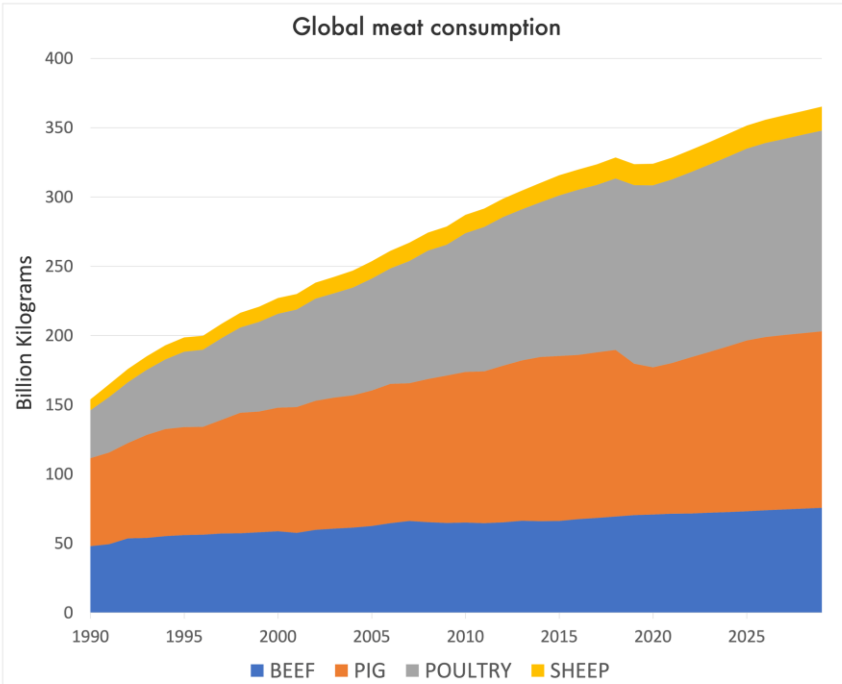

Fig. 1*:* Global Meat Consumption Trends. The figure is reproduced with permission from the authors Blaustein & Smith, (2021)

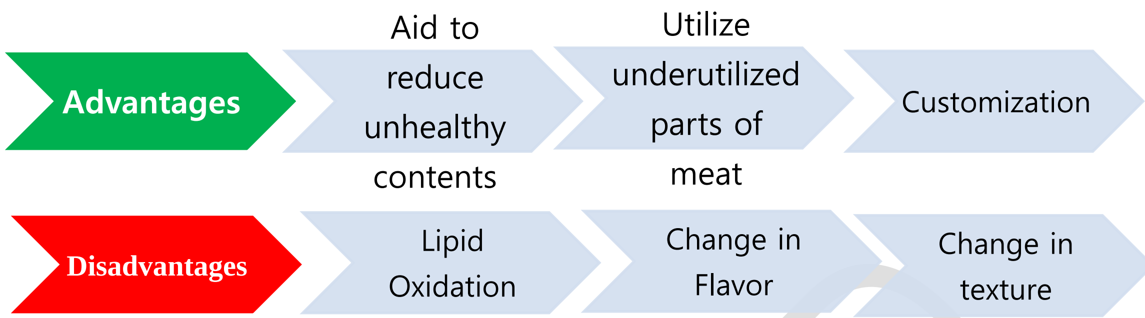

Fig. 2: Advantages and disadvantages of restructured meat

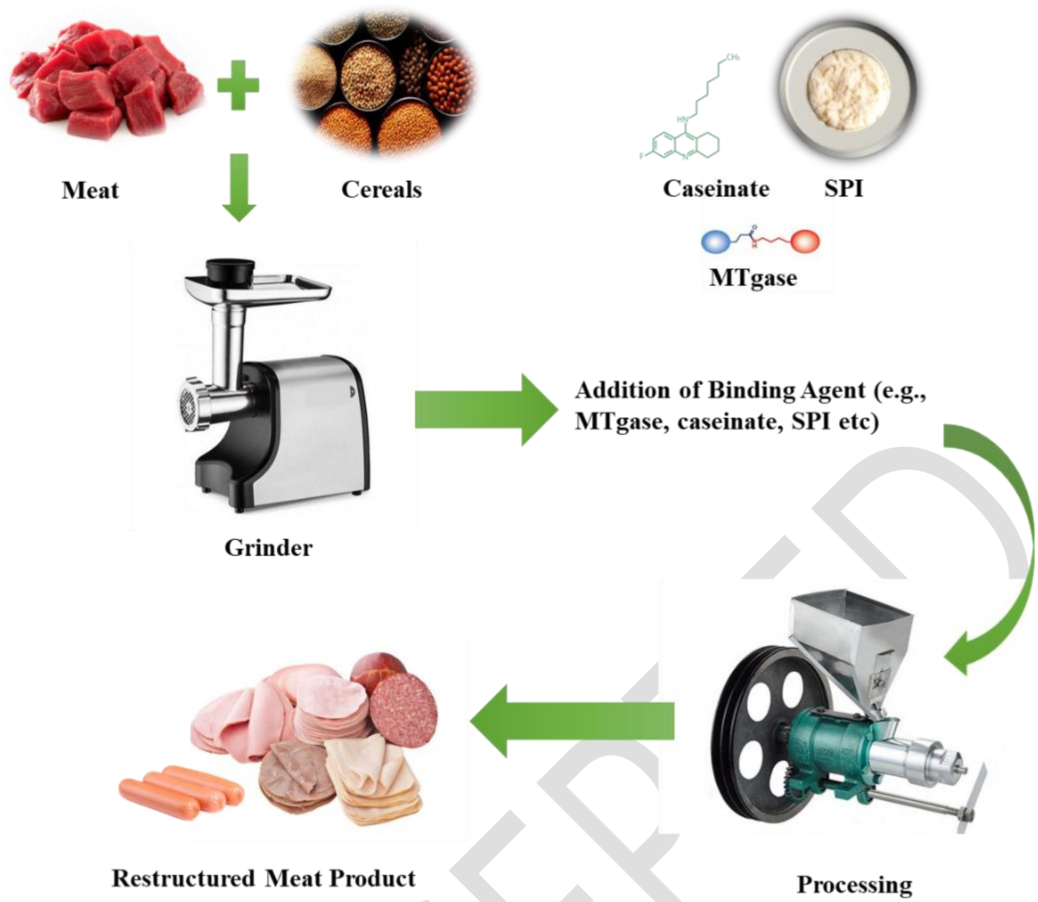

Fig. 3: Schematic diagram showing the restructured meat manufacturing process

Table 1: Factors affecting the quality of restructured meat

Factors	Observations	References
Selection of Ingredient	The selection of different ingredients affects the overall restructured meat quality positively or negatively. Using NaCl as a binding agent in meat can affect the flavor of meat.	Zhou et al., 2020
Processing Techniques	Processing Techniques can affect the overall quality of meat. It was observed that particle size in restructured meat affects the texture.	Xia et al., 2023
Temperature and Time	A range from -2 ℃ to -10 ℃ was found as the ideal temperature for good binding when kept for five hours. Temperature fluctuations have been seen to affect the binding ability and quality of restructured meat.	Sheard, 2002
Additives and Binders	Walnuts can be used as additives because it was observed that walnuts were able to improve the color of Restructured meat	Florowski et al., 2019
	MTgase can bind meat particles together, and in this way, it plays a crucial role in improving the texture.	Xu & Xu, 2021
	Acacia Gum can also help in the preservation of restructured meat	Sharma et al., 2014
Packaging and Storage	In a study, packaging and storage were found to be very important variables, and deviation from standards could be vulnerable to meat microbial contaminations.	Sofos, 2014
	Preservatives that can be used to improve the shelf quality of meat. Alginate is a plant-based alternative and can be used as a preservative of restructured meat without affecting its taste.	Sha & Xiong, 2020

Table 2: Commonly used materials in the processing of restructured meat

Source	Material	Observations	References
Chemical	Calcium alginate	Examined that it helped in restructuring and improving the quality of meat.	Boles, 2011
Chemical	Sodium triphosphate	Have the potential to improve the structure of meat	Hu et al., 2021
Chemical	MT Gase, Caseinate	Efficient to increase the binding ability of meat	Chen et al., 2024
Chemical	Calcium Lactate	Can be used as a salt substitute and improved the taste	Wang, 2023
Chemical	Sodium chloride aqueous solution	Flavor and texture quality were enhanced	Zhang et al., 2023
Plant	Alginate	Used to enhance the shelf life of meat	Montone et al., 2023
Plant	Carrageenan	Improved the microstructure of meat and may improve RM product quality.	Feng et al., 2024
Plant	Soya Bean Protein Isolates	Helped in improving the crosslinking between meat particles	Wei et al., 2023
Plant	Walnut	Improved color and texture	Afshar et al., 2023
Plant	Acacia Gum	Useful as an emulsifier in RM	Inguglia et al., 2023
Animal	Blood Plasma	Aided the binding capacity of meat	Zou et al., 2019