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Exploring natural colourants for enhanced sausage appeal: A review of sourcing, extraction methods, and applications, with emphasis on beetroot as an example

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ABSTRACT
Incorporating natural colourants in sausage production offers an avenue to enhance product desirability while meeting consumer preferences for clean-label ingredients. This paper thoroughly examines the selection, formulation, processing, and quality control aspects involved in utilizing natural colourants in sausages, with particular attention to beetroot. Key subjects explored encompass a variety of natural colourant sources and types, diverse extraction techniques, factors influencing colour stability, regulatory considerations, and consumer perception. Furthermore, the paper delves into emerging trends and advancements in sausage manufacturing, such as plant-based alternatives, functional fortification, and sustainability initiatives. By strategically harnessing the potential of natural colourants, including beetroot, sausage producers can customize their offerings to align with consumer preferences, distinguish their products, and bolster their competitiveness in the market.

Keywords: Natural colourants, sausage production, beetroot, clean label ingredients, formulation, processing, quality control, extraction methods, colour stability, regulatory considerations, consumer perception, plant-based alternatives, functional fortification, sustainability initiatives, market competitiveness

INTRODUCTION
Natural colourants are widely employed in the food business to improve the visual appeal of goods. They can be used in place of or in addition to synthetic colourants. Natural colourants can be produced from botanical, mineral, or microbiological sources. They are prized for their capacity to produce vivid colours while satisfying consumer demands for minimally processed and clean-label materials. These colourants fall into two general categories: extracts and pigments. Carotenoids, anthocyanins, chlorophyll, and betalains are examples of pigments; paprika, beetroot, turmeric, annatto, and spirulina are extracts **[1]**. With their distinct qualities, these natural colourants are used in various food items to improve aesthetic appeal and satisfy customers' desire for natural ingredients. Spirulina and other naturally occurring food colouring sources in beverage model solutions. The study used UV-Vis Spectrophotometry and Colourimetry to test colour and stability and assess the storage conditions **[2]**. Other findings show that algae's antioxidant qualities allow them to be used as natural colourants and have various uses in different sectors. They emphasize how crucial it is to assess the patterns and key elements influencing the synthesis of algal pigments **[3]**.

Additionally, the antioxidant qualities of anthocyanins are naturally occurring pigments found in a wide variety of meals, fruits, and vegetables, particularly berries. It contributed to the trend of using antioxidants produced from natural products by highlighting the advantages of anthocyanins for health and their usage as colourants because of their antioxidant activity **[4]**. Considering the latest developments in pH-sensitive indicator films made of natural colourants for intelligent food freshness monitoring, it covered several kinds of natural pigment markers and how they are used to check the freshness of different foods, such as curcumin and anthocyanins **[5]**.

The food sector is using more and more natural colourants from various sources in place of synthetic colourants. These natural pigments come in various hues and may be found in plants, fruits, vegetables, and minerals. Natural colourants, such as anthocyanins, carotenoids, betalains, and chlorophylls, have major environmental and biological sources that have been discovered. Furthermore, natural colourants have become a viable and healthy alternative that gives food systems intriguing technical and sensory features **[6]**.

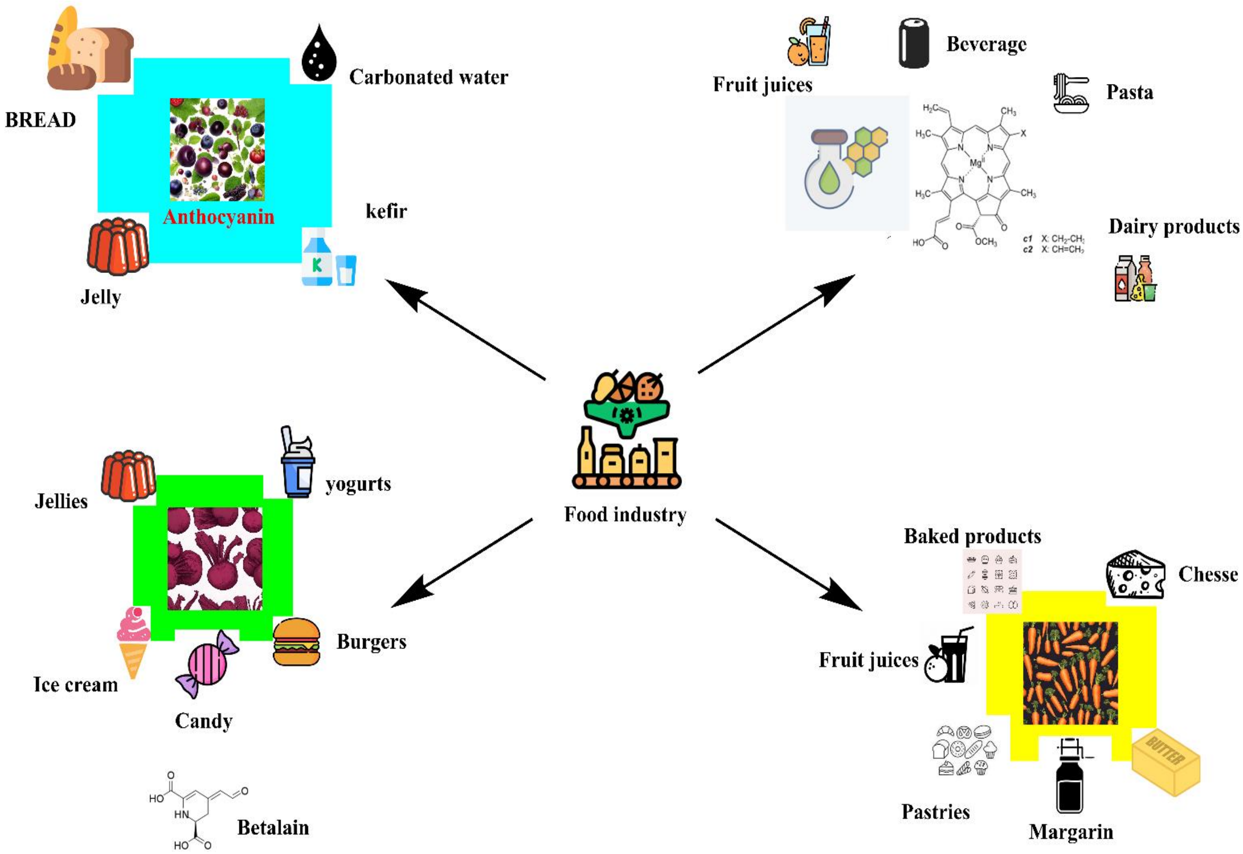

Figure 1 Scheme of the application of natural colourant in different food industries.

This has spurred research into novel natural hair dye supplies and environmentally friendly production and application technologies. It has also been highlighted how anthocyanins, ubiquitous in human diets and found in a wide variety of foods, fruits, and vegetables, have antioxidant qualities. In addition to being utilised as colourants, anthocyanins have strong antioxidant properties, which supports the trend toward using antioxidants sourced from natural sources **[7]**.

Fruits include a variety of colourant molecules, including anthocyanins, betalains, carotenoids, and chlorophylls, making them a dependable supply of food colourants. Furthermore, fruits have bioactive qualities, making natural food colouring substitutes desirable. However, there are issues with raw material sustainability and stability when extracting and applying natural colourants from fruits. It has been found that optimum stabilisation and extraction techniques can overcome these drawbacks. Recent developments have shown that natural fruit colourants may enhance the colour of various food products. But colour constancy is still difficult to maintain **[8]**, **[9]**.

Additionally, using natural colourants in intelligent packaging has been investigated to track the freshness of food items, with encouraging outcomes in terms of real-time food quality monitoring. Fruit natural colourants may have advantages, but it's vital to consider how they could affect your health. Certain naturally occurring colourants, including curcumin, anthocyanins, and catechins, have been shown to suppress the growth of different cell types, indicating their potential as drugs that prevent cancer through chemotherapy. Nonetheless, more investigation is required to validate these results and ascertain the ideal concentrations and modes of administration for natural colouring agents. The growing consumer desire for minimally processed and clean-label goods has increased the demand for natural food colourings. As a result, despite stability, sustainability, and affordability issues, interest in natural substitutes—like fruits—has surged again. To overcome these constraints, creative alternatives are being explored, such as the creation of novel, safer, and more effective natural compounds derived from fruits **[8]**, **[10]**.

Natural colourants are categorised according to their chemical composition and place of origin. Pigments are the main agents responsible for the vivid colours found in fruits, vegetables, and other natural sources. The four main pigment categories frequently used as natural colourants are betalains, chlorophyll, anthocyanins, and carotenoids. The pigments known as carotenoids are found in many fruits, vegetables, and plants. They are the cause of the hues red, orange, and yellow. Carrots and sweet potatoes contain beta-carotene, known for its antioxidant qualities and vivid orange colour **[11]**.

Tomatoes, watermelons, and pink grapefruits are rich sources of lycopene, which gives them a rich red colour and heart health advantages. Green leafy vegetables, such as spinach and kale, contain lutein, which helps maintain eye health and gives these veggies their yellow hue. Water-soluble pigments called anthocyanins, which are part of the flavonoid group, are responsible for the red, purple, and blue hues found in various fruits, vegetables, and flowers. Anthocyanins, which give their vivid colours, are abundant in berries, including blueberries, strawberries, raspberries, and blackberries **[12]**.

Red wine and other products made from grapes are coloured by anthocyanins found in the skins of grapes, especially the purple and red kinds. Red cabbage's rich purple hue is caused by anthocyanins, frequently employed as a natural pH indicator. Green leafy vegetables and herbs are rich in chlorophyll, a green pigment that helps plants perform photosynthesis. Chlorophyll also acts as a natural colourant, giving green hues to many objects. Common sources of chlorophyll that give food items vivid green hues are spinach, parsley, and mint. Beets and certain cacti are the main sources of betalains, which include betacyanins and betaxanthins. Because of the betacyanins in their roots, beets provide vivid red and purple colours frequently utilised as natural food colouring ingredients. The prickly pear cactus's fruits, blooms, and stems generate betalain pigments, which come in red, purple, and yellow hues **[12]**.

These pigments – carotenoids, anthocyanins, chlorophyll, and betalains—contribute to various natural colours in fruits, vegetables, and plants. Their availability and distinct chemical properties make them valuable ingredients in food colouring applications, providing visual appeal and potential health benefits.

Fruits and vegetables colourant

Because of its bright red colour and possible health advantages, tomato juice—made from the Solanum lycopersicum plant—has attracted much attention in the food business as a natural colourant. Tomato juice is used in sausage manufacturing as a colouring agent and a source of bioactive ingredients, which are important in attracting consumers' attention **[13]**.

Investigating tomato juice's colour stability, nutritional qualities, flavour modification, and application techniques is part of science. Tomato juice's deep red hue results from its high quantity of carotenoid pigments, especially lycopene, which has strong antioxidant qualities. The striking red colour is mainly attributed to lycopene, which also shows remarkable stability when processed differently. However, lycopene and other colours in tomato juice can become unstable due to several circumstances such as pH levels, temperature swings, and exposure to oxygen during processing and storage **[13]**, **[14]**.

Tomato juice has several nutritional advantages since it contains essential vitamins, minerals, and phytochemicals. It also improves appearance. The main pigment in tomato juice, lycopene, has been linked to several health benefits, such as anti-inflammatory, antioxidant, and maybe anti-cancer qualities. Tomato juice is a great way to improve the appearance of sausage recipes while adding nutrients to the finished product and satisfying customer demands for healthier food alternatives. Tomato juice adds taste to sausages beyond its colour and nutritional value. It adds a hint of sweetness and acidity to balance the savoury flavours of the meat **[15]**, **[16]**.

Tomato juice may be more effective as a colourant and taste enhancer by using pre-treatment procedures (e.g., concentration, enzymatic treatment) and formulation alterations (e.g., pH modulation, antioxidant addition). Furthermore, thorough sensory research and consumer testing are essential to determine if tomato-enhanced sausage products are acceptable and to identify areas that require further optimisation **[16]**.

Complex taste profiles are produced by the interaction of tomato-derived chemicals with other components in the sausage matrix, which are impacted by various processing settings and ingredient proportions. Sausage producers may create goods with well-rounded and enticing flavour profiles by carefully adjusting formulation parameters and utilising tomato juice's synergistic effects with other flavour-enhancing ingredients. Tomato juice must be carefully included in sausage recipes while considering all processing factors to provide the best possible colour stability, taste retention, and nutritional integrity **[15]**, **[17]**, **[18]**.

Functional properties and chemical composition

Natural colourants offer several functional properties in food and beverages. Firstly, they provide vibrant hues, enhancing the aesthetic appeal of products and influencing how consumers perceive them. Additionally, many natural colourants contain antioxidant compounds like polyphenols and carotenoids, which protect against oxidative damage and contribute to overall health and wellness. Furthermore, certain natural colourants, especially those sourced from spices and herbs, can enhance flavour in food products, adding depth and complexity to the overall sensory experience. Natural colourants come in a variety of chemical forms, and each one gives food and drink goods special qualities:

Carotenoids, known for their antioxidant qualities, come in yellow, orange, and red hues. Anthocyanins have pH-dependent colours that range from red to purple to blue. They also have anti-inflammatory and antioxidant properties. Chlorophyll is the green pigment that gives many foods and drinks their distinctive hue **[19]**.

The water-soluble pigments called betalains, mostly present in beets and certain cacti, give reddish-violet and yellow-orange hues. There is growing interest in using Beta vulgaris variants as sources of nitrate for cured meats. Artificial nitrate and nitrite salts were traditionally used in meat curing for colour stability and taste improvement. However, interest in natural alternatives has increased due to the need for clean-label products. Beetroot, spinach beet, and Swiss chard are examples of beta vulgaris, which shows promise as a natural source of nitrate **[20]**.

The varying nitrate levels in these veggies result from farming techniques and fertiliser. Their promise as natural healing agents resides in their ability to perform functions similar to synthetic additions without posing health risks. The benefits of adding Beta vulgaris extracts to meat processing include less lipid oxidation, better colour stability, and increased sensory qualities. Utilising the potential of Beta vulgaris to produce meat products that are healthier and more natural is made easier by methods like direct addition or fermentation-induced nitrite production. Notwithstanding, obstacles continue to exist, such as guaranteeing uniform nitrate concentrations in Beta vulgaris cultivars and thoroughly evaluating the safety and quality consequences of meat processing. More studies must investigate their use in reformulated meat products that correspond with customer expectations for healthier, clean-label choices. Investigating Beta vulgaris as a natural supply of nitrate offers a viable route toward more **[21]**.

The successful application of natural colourants in food and beverage products requires understanding their functional properties and chemical composition. By utilizing these unique properties, formulators can meet consumer demand for natural and healthy ingredients by creating visually appealing and nutritionally enhanced products. The search results also revealed additional information about extracting natural colourants from different botanical sources using different methods, such as aqueous and ultrasound-assisted extraction. These methods offer alternative approaches for obtaining natural colourants with potential applications in food production and textile colouration **[22]**.

Different extraction techniques

Ultrasound-assisted Extraction (UAE): is a novel, environmentally friendly method that has been researched for its advantages in the extraction process, such as its high yields, quick extraction periods, and lack of need for high temperatures. Nevertheless, the non-standardization of the UAE factors makes comparisons more difficult and impedes advancing this topic's research. Standardizing the UAE process parameters can make it easier for the scientific community to compare the findings **[23]**.

Aqueous Extraction for Textile Colouration: This research examines whether it is possible to create natural textile colourants using a variety of botanical sources. The study's successful use of the aqueous dye extraction method prevents solvent toxicity and provides a new environmentally safe dye and a straightforward colouring technique **[24]**.

Extraction of Anthocyanins: This research's central focus was the extraction of anthocyanins from Aronia melanocarpa skin waste, aiming to utilise it as a sustainable source of natural colourants. Implementing an integrated extraction-adsorption process enhanced anthocyanin yields of superior quality compared to traditional batch methods, thereby increasing extraction yield and purity **[25]**.

Aqueous and Solvent Extraction for Colouration of Cellulosic Substrates: Natural dyes derived from plant sources were extracted using aqueous and solvent extraction techniques to colour cellulosic substrates. The recovered colourants demonstrated Excellent colouring capacity, which may eventually replace synthetic dyes as a sustainable method of clean manufacture **[26]**.

Several crucial processes are involved in the solvent extraction method used to separate natural colourants from botanical sources. First and foremost, the choice of solvent is crucial; frequent options include acetone, ethanol, methanol, hexane, and ethyl acetate. The selection of these solvents considers several aspects, such as availability, cost, polarity, toxicity, and regulatory compliance. After that, the plant material is prepared by drying, grinding, and screening it until the particle size is consistent. This formulation increases pigment extraction efficiency and solvent penetration. The first step in the extraction process is to combine the prepared plant material with the selected solvent in the right vessel, like an ultrasonic bath, reflux device, or Soxhlet extractor. The pigments are transferred from the plant material to the solvent phase more easily by agitation and heating. Several extraction cycles may be carried out under different circumstances to guarantee the highest possible pigment recovery. Following extraction, solid plant material is separated from the solvent containing dissolved pigments using centrifugation or filtering. The pigment extract is concentrated by solvent evaporation, eliminating any remaining remnants **[27]**, **[28]**.

Additional purification procedures, such as chromatography or precipitation, can be utilised to separate certain pigments or eliminate contaminants. The process's characterisation and quality assurance are crucial components. Mass spectrometry, chromatography, and spectrophotometry are used to evaluate the extracted pigment concentrate's colour, purity, and chemical makeup. Quality control tests assess variables, including colour stability, solubility, and sensory characteristics, to ensure the extract is suitable for the planned uses. Research on the effects of different solvents on pigment yield and extraction efficiency has been conducted on a variety of sources, including red shrimp shell wastes, brown algae, *Nannochloropsis oculata*, and red fruit **[28]**, **[29]**.

Supercritical extraction technique

The ecologically friendly method of obtaining natural colourants from botanical sources is called supercritical fluid extraction (SFE). This technique uses supercritical fluids—like carbon dioxide (CO_2)—as the extraction solvent, and it operates under certain pressure and temperature parameters. Because of its favourable characteristics, such as low toxicity, nonflammability, and ease of removal from the extracted product, carbon dioxide is the recommended supercritical fluid. However, additional supercritical fluids such as nitrous oxide, propane, and ethane may be used based on the particular needs of the extraction process. Temperature and pressure changes above the critical point in the SFE process improve the supercritical fluid's solvent qualities, such as improved diffusivity and solubility. The plant material pulverised and dried to contain the appropriate pigments is put into an extraction vessel, usually a column or chamber made of stainless steel. After that, supercritical CO_2 is poured into the extraction vessel, which works as a solvent to dissolve the desired pigments while removing unwanted substances. The dissolved pigments are gathered in an expansion chamber or separator after being removed from the extraction vessel containing the supercritical CO_2. After leaving the extraction vessel, the supercritical CO_2 returns to its gaseous state due to a drop in temperature and pressure. This transformation precipitates the dissolved pigments and may be separated from the CO_2. To get a concentrated extract, the recovered pigments go through further processing to get rid of any remaining solvent residues **[30]**, **[31]**.

The optimisation of SFE parameters, such as temperature, pressure, CO_2 flow rate, and extraction time, is highlighted in studies using SFE for pigment extraction from a variety of sources, including brewer's grains, maise yellow powder, red pitaya fruit peel, and Malaysia tiger shrimp waste. This is done to achieve high pigment yields **[32]**.

SFE, in general, has several benefits over conventional solvent extraction techniques, such as increased environmental sustainability, less solvent residues, and greater selectivity. It is widely used to extract natural colourants and other bioactive components from plant sources in the food, pharmaceutical, and cosmetic sectors **[33]**.

Pressing and Maceration: Traditional techniques for removing natural colourants from plant sources include pressing and maceration. Plant materials are pressed to release their juices, which include various chemicals and natural colourants. Colourants from high-moisture fruits, vegetables, and seeds are frequently extracted using this technique. On the other hand, maceration involves immersing plant materials in a liquid solvent for some time to extract their soluble chemicals, including natural colourants. It works well for removing colour from plant materials, including roots, bark, and dried plants that are difficult to press or have a low moisture content **[34]**, **[35]**.

Enzyme-assisted extraction

An advanced technique for removing bioactive substances and natural colourants from botanical sources is enzyme-assisted extraction. This method releases the desired components from the plant material by breaking down the cell walls with the help of enzymes. Choosing the right enzymes, prepping the plant material, processing it enzymatically under controlled circumstances, and extracting and recovering the released chemicals are the usual steps. Enzyme-assisted extraction has advantages over chemical extraction methods, including sustainability, gentle extraction conditions, and selectivity. Research has indicated that the extraction yield of natural colourants and other bioactive chemicals from plant materials may be considerably increased by using enzyme-assisted extraction. In contrast to aqueous extraction alone, the inclusion of enzymes boosted the number of water-soluble compounds by 30% in a study on the extraction of water-soluble antiviral compounds from the macroalga Solieria chordalis. A further investigation demonstrated the effective use of thermostable cellulase and immobilised β-glucosidase in the enzyme-assisted extraction and conversion of polydatin to resveratrol from Polygonum cuspidatum, highlighting the potential of this technique to extract certain bioactive chemicals. In conclusion, the gentle and selective extraction of natural colourants and other bioactive substances from botanical sources appears to be a promising use of enzyme-assisted extraction. Its benefits for sustainability, product quality, and selectivity make it a desirable choice for a range of uses in the food, medicine, and cosmetics sectors **[36]**.

Colour stability

Depending on the kind of pigment, the pH sensitivity of natural colourants considerably impacts their durability and colour manifestation. For example, the pigments called anthocyanins, which give fruits and vegetables red, purple, and blue hues, change colour in response to pH. Similarly, betalains, present in certain cacti and beets, demonstrate varying degrees of stability throughout various pH values. The green pigment in plants, called chlorophyll, is generally stable across a broad pH range but can change colour under extremely acidic or alkaline conditions. Changes in pH have less of an impact on carotenoids like lycopene and beta-carotene; in certain cases, acidic environments can increase their stability **[37]**.

The formulation pH, processing conditions, and packaging are some elements that affect natural colourants' pH sensitivity and colour stability. To achieve desired colour outputs and preserve stability in food and beverage items, it is important to comprehend these elements. Manufacturers may enhance the quality of their products and maximise the effectiveness of natural colourants by meticulously regulating the pH of the formulation and the processing conditions. Research has indicated that adding natural colourants to food goods can improve their colour permanence. For example, because purple carrot puree has a high amount of anthocyanins and total phenols, adding it to strawberry jam was found to increase the colour stability of the jam **[38]**.

A higher concentration of purple carrot puree led to a progressive increase in pH, viscosity, total anthocyanin, and total phenol levels, decreasing anthocyanin degradation throughout storage. Additionally, studies have demonstrated that natural colourants with high anthocyanin content may be produced by extraction process optimisation, making them appropriate for mass production in various sectors. To get a dark red extract from roselle calyces with a high anthocyanin concentration, stirring-assisted extraction (SAE) conditions were more successful than simple maceration and ultrasound-assisted extraction. These results emphasise how crucial it is to optimise extraction methods to maximise the potential of natural colourants for industrial applications **[39]**.

Exposure to light and oxygen

The durability of natural colourants in various goods can be greatly impacted by exposure to light and air. Natural colourants, especially those sourced from plants, may fade, degrade, or change in colour due to light exposure, particularly ultraviolet (UV) radiation. Colour-sensitive items must be protected by opaque or UV-blocking packaging since low-light barrier materials, such as clear glass or plastic containers, can worsen light-induced deterioration. Conversely, exposure to oxygen can trigger oxidation processes in natural colourants, resulting in colour changes, loss of brightness, or the development of off-flavours **[40]**.

Oxygen-impermeable packaging, such as vacuum-sealed or nitrogen-flushed packaging, is frequently used to reduce oxygen exposure and maintain colour stability. Important variables impacting light and oxygen exposure and their effects on natural colourants include selecting packing materials and formats, storage conditions, and processing techniques. The durability of natural colourants is greatly enhanced by appropriate storage conditions, which include temperature, humidity, and light exposure **[41]**.

Furthermore, natural colourants may degrade due to processing procedures such drying, grinding, and mixing that expose them to light and oxygen. Colour stability may be preserved by limiting exposure during processing and using safeguards like antioxidants or inert environments. Through comprehension of the effects of light and oxygen exposure on natural colourants and the implementation of suitable safeguards, producers may guarantee the stability and excellence of goods that are sensitive to colour throughout their shelf life **[42]**.

Temperature

Natural colourants are highly sensitive to temperature, influencing their molecular mobility, chemical reactions, and interactions in food and beverage items. For example, thermal degradation must be considered, especially for heat-sensitive pigments, such as chlorophyll and anthocyanins. Elevated temperatures may hasten its disintegration, leading to colour changes or fading. The anthocyanins compounds, which give red, purple, and blue colours, are especially prone to deterioration, resulting in unfavourable colour shifts **[43]**. Similarly, extended exposure to high temperatures can also impact chlorophyll, which gives a green hue, causing colour alterations or loss **[44]**. Furthermore, freezing temperatures can affect the durability of colour, particularly in frozen goods where the production of ice crystals can damage cell structures and cause colour migration or bleeding **[45]**.

Additionally, temperature affects natural colourants' oxidative stability, especially in goods that include lipids. Elevated temperatures can potentially hasten lipid oxidation processes, leading to peculiar tastes, smells, and colour alterations. Natural colourant stability is largely dependent on variables, including formulation design, storage temperatures, and processing conditions. Manufacturers can guarantee the stability and quality of colour-sensitive items for the duration of their shelf life by closely managing these variables **[46]**.

Advantages of natural colourant

Natural colourants have several benefits, and they align with current wellness and health trends. These advantages include several important areas:

Clean Label: To enhance their perception of being natural and healthful, natural colourants are obtained from botanical, animal, or mineral sources and are frequently extracted using straightforward procedures. Natural colourant-containing products can thus make clean-label claims, which indicate minimum processing and no artificial chemicals or additions **[47]**.

Nutritional Value: Rich concentrations of bioactive chemicals with possible health advantages may be found in several naturally occurring colourants, including anthocyanins, carotenoids, and chlorophyll. These substances may have antioxidant qualities and improve the health of the immune system and the eyes, among other bodily systems. Manufacturers can improve the nutritional profile of their products by adding natural colourants **[47]**, **[48]**.

Allergen-Free and Non-Toxic: Natural colourants are often considered less harmful than synthetic equivalents, especially for people with allergies or sensitivities to artificial additives. Their natural origin decreases the possibility of negative responses or intolerance in vulnerable people. Sustainability and Environmental Concerns: Plant extracts and mineral pigments are two examples of sustainable and renewable resources frequently used in creating natural colourants. Compared to synthetic colourants derived from petroleum, this sustainable method leaves a smaller environmental impact, which aligns with customer demands for environmentally friendly goods **[47]**, **[49]**.

Clean label

Food producers are refining their recipes to remove artificial ingredients and incorporate natural substitutes. Customers identify authenticity, well-being, and health with natural and healthful components. Food producers are emphasising the naturalness and purity of their goods by labelling them as "organic," "all-natural," and "non-GMO" to appeal to customers who are concerned about their health. Customers are looking for third-party certifications and verifications that vouch for the integrity and legitimacy of product claims as their interest in clean-label items rises. Consumers may feel reassured by certifications like USDA Organic, Non-GMO Project Verified, and Clean Label Project that goods fulfil strict requirements for processing, sourcing, and ingredient quality. As manufacturers take advantage of consumers' perceptions of the healthfulness and transparency of their products, clean label promises have emerged as a central theme in product marketing and branding tactics **[50]**.

The clean label movement is a burgeoning trend propelled by consumer demand and typified by a propensity for food and drink products with easily identifiable, uncomplicated ingredients that have undergone little processing. Consumers seeking products that align with their values of sustainability, wellness, health, and transparency are transforming the food industry in various ways. Consumers carefully read ingredient lists because they are pickier about products that contain ingredients they can recognise and comprehend. Consequently, manufacturers simplify ingredient labels and replace synthetic chemicals, preservatives, and artificial additives with well-known, natural components. Artificial additives are becoming less common due to the trend since they are considered unnecessary or even hazardous. These include flavourings, colours, sweeteners, and artificial preservatives **[51]**.

Sustainability and environmental factors

Through several important methods, the use of natural colourants greatly minimizes environmental impact and promotes sustainability in a variety of sectors. First, plants, fruits, vegetables, and minerals are common renewable sources of natural colourants. These sources can be restored by using sustainable agriculture methods, and the need for finite fossil fuel-based materials for synthetic colourants may be decreased. Second, compared to the creation of synthetic colourants, the production procedures involved in extracting natural colourants usually take less energy and produce less greenhouse gas emissions. This lower energy use and carbon footprint help lessen climate change's effects. The biodegradability of natural colourants is an additional factor **[52]**.

They minimise harm to ecosystems and lower the danger of environmental contamination since they may break down over time into organic molecules without leaving behind persistent contaminants. Furthermore, compared to manufacturing synthetic colourants, extracting natural colourants often uses fewer synthetic chemicals and easier methods. As a result, there is less chemical pollution and less environmental damage brought on by the production and disposal of chemicals. Additionally, the production and preservation of these plants are aided by natural colourants frequently drawing their supply from a wide variety of plant species **[53]**, **[54]**.

This promotes ecological equilibrium, habitat preservation, and biodiversity protection. In addition, natural colourant extraction techniques often utilise less water than industrial methods for producing synthetic colourants. This reduces the environmental effect of water extraction and treatment while also aiding in conserving freshwater supplies. Finally, the natural colourant market encourages sustainable farming methods, including regenerative agriculture, agroforestry, and organic farming. This reduces dependency on artificial fertilisers and pesticides while promoting soil health, biodiversity, and ecosystem resilience **[55]**.

To improve visual appeal, offer uniqueness, and satisfy consumer desire for clean-label ingredients, natural colourants are frequently used in the meat and sausage sector. In this business, colouring meat products is one of the main uses for natural colourants Beetroot powder, annatto, and paprika extract are some ingredients used to preserve or improve the natural colour of meat products. They shield food against unintended discolouration when processed, stored, or cooked. Natural colourants like turmeric and paprika extract are employed in sausage compositions to provide colour and improve or balance the product's flavour **[56]**. As a result, producers may produce desired tastes without using flavour enhancers or artificial additives. Additionally, natural colourants assist meat and sausage producers meet clean label requirements. They increase the marketability of the product by substituting natural ingredients for synthetic ones, which appeals to customers who want ingredient lists that are clearer and simpler. Additionally, using natural colourants satisfies customer inclinations toward wellness and health. These colourants are seen as more healthful than artificial ones, which aligns with consumer aspirations for whole, minimally processed foods. Natural colourants have an aesthetic value that goes beyond their practical use in meat and sausage products. They pique consumers' curiosity and affect their purchase decisions by introducing vivid, enticing hues **[57]**, **[58]**.

Meat and sausage products

The meat and sausage sector, which provides a wide range of goods such as beef, pig, chicken, and other kinds of sausages, is an essential part of the world food market. Production in this sector happens in several steps, from packaging and processing to distribution and sale. Key variables driving the meat and sausage sector are evolving consumer demands, regulatory compliance, and ongoing technical improvements. The creation of fermented meat products, the utilization of secondary raw materials for sausage manufacturing, and the optimization of sausage recipes to increase economic efficiency are just a few of the facets of the meat and sausage sector that have been the subject of a recent study. These studies reflect the industry's continuous attempts to fulfil customer demand and enhance manufacturing procedures through innovation and optimization **[59]**. Study of the meat processing sector in certain areas, including Kazakhstan and Ukraine, has also been conducted. This study has focused on changes in the market, changes in consumer behaviour, and initiatives to improve the productivity of meat processing businesses. Other research papers and industry studies can offer more information on particular subjects within the meat and sausage business. These resources can offer in-depth insights into various facets of this dynamic sector. Several important factors impacting its operations and worldwide reach define the meat and sausage sector. First, it provides a wide selection of goods, such as processed, frozen, and fresh meats in addition to a range of sausages made with various tastes and components. This broad product line accommodates many customer tastes and culinary customs. Second, a considerable portion of the world's production and consumption of meat and sausage products comes from big players in continents, including North America, Europe, and Asia. Their existence highlights the industry's pervasive impact on global food markets. In addition, the sector works under strict regulations designed to protect public health and ensure food safety. The regulation and standardization of different manufacturing, distribution, and labelling areas maintain strict quality and safety standards **[60]**, **[61]**. Moreover, the business is driven by innovation because of continuous technical developments in meat processing and sausage preparation. These developments demonstrate the industry's dedication to ongoing improvement by boosting productivity, raising the calibre of products, and strengthening food safety protocols. Finally, consumer trends and preferences greatly influence industry marketing tactics and product innovation. Businesses respond to shifting customer needs by launching new goods, tastes, and packaging alternatives that suit changing dietary preferences and way-of-life decisions. Altogether, these salient features underscore the fluid character of the meat and sausage sector, which endeavours to satisfy heterogeneous consumer preferences while conforming to legal guidelines and harnessing technical advancements. Efforts to optimize production processes, address consumer preferences, and ensure product safety underscores the industry's commitment to innovation and sustainability **[62]**.

Additional research can be done to understand better particular facets of the meat and sausage sector, such as market trends or production methods. Slaughtering and dressing are essential in meat processing, turning animals into edible meat products. While dressing includes the subsequent phases of corpse preparation and basic processing, slaughtering is the compassionate and effective killing of animals for sustenance. Before the actual killing procedure, animals are usually stunned during the slaughtering phase to make them insensible to pain. This compassionate procedure guarantees the least pain and conforms with legal and ethical requirements. After the animals are stunned, they are killed using techniques like throat-cutting or stunning, which is followed by exsanguination, which guarantees quick and efficient bleeding. Depending on the species, the dressing removes the animal's skin, hair, feathers, or outer covering after slaughter. Careful handling is required in this phase to avoid contamination and preserve product quality. The process of evisceration, which involves removing internal organs such as the kidneys, liver, and intestines, comes after skinning **[63]**.

To avoid spoiling and microbial infection, these organs must be removed immediately. Strict sanitary regulations and hygiene standards are necessary during the dressing and slaughtering procedures to guarantee the safety and quality of the meal. To limit the danger of contamination and achieve customer expectations for safe and healthy meat products, facilities must comply with industry standards and regulatory norms. The meat processing stages are crucial for setting the groundwork for later procedures like chilling, chopping, and packing, including slaughtering and dressing. Meat processors may create premium meat products by ensuring animals are treated humanely, keeping environments clean, and using the right handling methods **[64]**.

Beetroot

Beta vulgaris, or beetroot, contains water-soluble pigments called betalains, especially the reddish-violet betacyanins, which naturally colour meat products. These pigments enhance the colour of meat products, such as fermented beef sausage (sucuk) and emulsified pork sausage, making them more visually attractive and in line with customer expectations for natural additions. Beetroot colourant usage is part of a more significant movement in food processing toward natural, health-promoting additives and more straightforward labelling. Beetroot extract is added to beef sausages as a natural substitute for artificial nitrites, frequently used in meat products due to their ability to preserve the meat. Although synthetic nitrites help prevent the growth of pathogenic germs and preserve the distinctive red colour of cured meats, they have been connected to several health hazards, such as a higher chance of methemoglobinemia and several types of cancer. According to the relevant study, nitrite levels in beef sausage can be decreased using beetroot extract during manufacture, which may lessen the health hazards related to nitrite consumption. Beetroot extract is added to beef sausages as a natural substitute for artificial nitrites, frequently used in meat products due to their ability to preserve the meat. Although synthetic nitrites are useful in preventing the growth of dangerous germs and preserving the distinctive red colour of cured meats, they have been connected to several health problems, such as an elevated risk of certain cancers and methemoglobinemia. The study in question demonstrates that using beetroot extract in beef sausage production can decrease sausage nitrite levels, potentially reducing the health risks associated with nitrite consumption **[65]**.

It has been investigated if adding beetroot and radish powders to dry fermented sausages as natural sources of nitrites may improve the final product's safety and nutritional value. Studies have shown that although these powders may lower the amount of residual nitrite in sausages, adding them might negatively impact their colour and lipid oxidation. Furthermore, because beetroot and chestnut extracts have a high polyphenol content that offers antibacterial and antioxidant qualities, they have become viable substitutes for sodium nitrite. To enhance the health profile of meat products, it is important to consider customer perception and preferences during the reformulation process. Labelling must be precise and easy to read to inform customers of changes. As a naturally occurring source of nitrate, beetroot has gained popularity as a practical way to lower the nitrite content in meat products. It has been demonstrated that adding beetroot powder to dry-fermented sausages helps nitrites develop during the ripening phase, offering a workable method for reducing nitrites. But betalains—natural pigments that give beetroot its characteristic purple colour—may hurt the sausages' colour. Furthermore, research has shown that treatments containing 1% beetroot powder had TBARS values that were higher than the threshold for rancidity detection using sensory means after prolonged storage. Consequently, even though beetroot appears to have promise in lowering nitrite concentration, cautious assessment is required to minimise any possible negative effects on other quality attributes of meat products **[65]**.

A thorough literature review will yield important information about using beetroot powder and extract as natural colourants in meat products. It will also emphasise how they improve sensory perception, nutritional value, and competitiveness in the market. Food scientists and industry experts may make informed judgments by clarifying the processes underlying the sensory impacts of colourants generated from beetroot to address consumer requests for clean-label products with higher sensory quality. Beetroot powder's natural food colouring qualities can improve the visual attractiveness of the sausage without the need of artificial chemicals, making it a possible filler and colouring ingredient in chicken sausage preparation. Talain, a naturally occurring pigment found in beetroot powder, gives the sausage a red hue, increasing its commercial appeal. Furthermore, beetroot powder has a high antioxidant capacity and is rich in phenolic acids, which can enhance the product's nutritional value and safety. Additionally, the study discovered that using beetroot powder instead of tapioca improved the chicken sausage's softness and ability to hold water. This implies that beetroot powder may also improve the sausage's texture and ability to hold moisture. However, there can be disadvantages to consider when making chicken sausages using beetroot powder. One disadvantage is adding beetroot powder might give the sausage an earthy flavour that some customers may not find appealing. The study also found that increased beetroot powder concentrations can alter the sausage's taste and perhaps lower its appeal overall. Moreover, geosmin, a substance in red beets that affects the sausage's sensory qualities, is responsible for the earthy flavour. When utilising beetroot, it's crucial to carefully weigh the intended colour increase against any potential taste impacts **[66]**.

The increasing need for natural food colouring in meat products highlights customer preferences for components with clear labels and apprehensions about artificial additions. In response, scientists have considered plant colourant substitutes for conventional synthetic dyes. Of these substitutes, beetroot extract is distinguished by its vivid red colour, which comes from betalains, which are also recognized for their antioxidant qualities. Beetroot extract and extract powder can improve sausage's nutritional profile and aesthetic appeal while satisfying consumer demands for clean-label products. The sausages' pH and moisture content are both greatly impacted by red beet, with increased amounts of both following. The sausages' colour characteristics were also significantly affected by the inclusion of red beet, which resulted in a drop in lightness and a significant rise in redness with a matching decrease in yellowness. This change in colour characteristics persisted throughout the storage period, suggesting that red beet continues to impact sausage colour. Despite the notable changes in colour features, the addition of red beet powder did not significantly affect other sensory attributes, including taste, tenderness, juiciness, and overall acceptability. Similarly, the addition of red beet did not affect the textural attributes of the sausages, such as their gumminess, cohesion, hardness, and springiness. But it's important to remember that although red beet helped the sausages' colour, further processing, including concentration and extraction as a juice, may be necessary to fully utilise its antioxidant properties in meat products **[67]**.

Case studies

According to the findings regarding the betalain content and antioxidant properties of concentrated beetroot extract used by researchers provide valuable insights into its potential as a natural colourant and functional ingredient in food products. While the betacyanin and betaxanthin content in the beetroot extract sample was slightly lower compared to previous studies, indicating potential variability due to processing methods, the total betalain pigment content remained substantial. This suggests that despite variations, beetroot extract can serve as a rich source of betalain pigments known for their antioxidant properties. The high antioxidant activity observed in our beetroot extract sample underscores its potential health-promoting benefits. The presence of phenolic compounds, particularly 4-Hydroxy benzoic acid, contributes to its antioxidant capacity, protecting against oxidative stress and potential health risks associated with free radicals. The natural colour provided by beetroot extract contributed to the sausage's enhanced sensory quality, leading to higher acceptability scores among panellists. In contrast, carmine, with its artificial dark pink colour, hurt panellists' perception of appearance and colour. This highlights the importance of natural colourants like beetroot extract in meeting consumer preferences for clean-label products with improved sensory characteristics. The observed differences in colour stability between sausages processed with fermentation and heat treatment methods underscore the importance of processing techniques in preserving the colour quality of beetroot-derived colourants. While both methods effectively enhanced the red colour of sausages, factors such as storage conditions may influence long-term colour retention. The potential of beetroot extract and powder as natural colourants and functional ingredients in meat products offer improved sensory attributes, oxidative stability, and consumer acceptance compared to traditional colourants. These results contribute to developing clean-label products with enhanced nutritional and sensory profiles, meeting the evolving demands of health-conscious consumers in the food industry **[68]**, **[69]**.

Aykın-Dinçer et al. conducted a study to examine the use of beetroot extract and extract powder as natural food colourants in sausages and compare their results with those of typical colourants like carmine. The study sought to determine how beetroot-derived colourants affected the end goods' quality qualities by evaluating criteria such as betalain concentration, total phenolic substance content, antioxidant capacity, and sensory attributes. For sausages to be formulated and accepted in the food sector, it is essential to comprehend how beetroot extract and powder affect colour stability, lipid oxidation, pH, moisture content, and sensory qualities. Natural ingredients used in food processing have become more popular due to customer desire for clean-label goods. Varieties of Beta vulgaris, such as spinach, chard, and beetroot, have come to light as possible nitrate sources to improve meat products' nutritional content and quality. Due to their high nitrate content, these vegetables provide a healthy substitute for the artificial nitrate/nitrite salts often used in meat curing. Nitrate and nitrite are essential for improving colour stability, slowing oxidative processes, and giving meat products their distinct tastes during the age-old curing process. The investigation of *Beta vulgaris* extracts in meat processing seeks to improve meat products' nutritional profile and sensory qualities while extending their shelf life **[70]**.

In another study, researchers aim to evaluate the physical characteristics of natural colourants for potential integration into sausage formulations. Utilizing laboratory methodologies, parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and colourimetric properties (Lab*) were meticulously analysed. Results indicated a negligible impact of the natural colourants on the aforementioned parameters, suggesting their viability for food colouring applications. Furthermore, the study underscored the imperative of embracing natural colourants in food formulations, elucidating the potential health hazards posed by synthetic counterparts and extolling the virtues of natural alternatives. Conclusively, the investigation determined that the TDS values of the assessed natural colourants fell within permissible thresholds for food use, with the beetroot-derived colourant notably approximating the visual characteristics of commercial sausage hues. These findings furnish invaluable insights into the physical scrutiny of natural colourants, particularly within the context of sausage production, resonating with contemporary consumer preferences favouring natural and health-conscious food constituents **[71]**.

Furthermore, the studies explore the possibility of using radish and beetroot powders in fermented dry sausages instead of nitrite to reduce health and safety risks related to using sodium nitrite. This study explains how adding vegetable powders impacts important sausage characteristics such as moisture content, weight loss, and water activity by analysing six treatment variants during the ripening and storage phases. Interestingly, it is noticed that the beetroot powders and radish create nitrite, which is more noticeable in treatments with larger concentrations. Specifically, beetroot powder significantly affects colour and pigments, indicating that these powders can be used as viable substitutes for nitrite through a simple drying procedure. An analysis of the sausages' colour progression, nitrite and nitrate concentration, and pigments is conducted. Powdered beetroot and radish affect colour development during processing; differences in colour characteristics from the control treatment are apparent. Furthermore, during the manufacturing of sausages, nitrate is converted to nitrite, and the amounts of nitrite and nitrate vary noticeably throughout treatments **[72]**. The colour properties of beet juice and powdered beet juice are also evaluated in the investigations. The results indicate a preference for darker colours in both varieties, with the powdered form having a more prominent dark colouration, probably due to the concentration effect during the drying process. According to a chromaticity study, both the beet juice and the powdered beet juice showed a colour spectrum spanning from red to yellow. Humidity decreased due to dehydration, which made the colour characteristics more intense since the pigments were concentrated. The study also highlighted how betalains are easily degraded in the presence of light and oxygen, and their high water solubility makes them more likely to be lost during sanitation operations. It has been determined that maintaining pH stability is essential to maintaining the integrity of betalains. These observations provide insightful analysis of the stability and colour characteristics of beet-derived colourants, essential for guiding their use in food items **[73]**.

To reduce the health concerns connected to chemical additions in meat products, the usefulness of beetroot powder in substituting nitrite was also investigated in Turkish fermented beef sausage or sucuk. Four different sausage recipes were created with different amounts of beetroot powder and sodium nitrite. Beetroot powder significantly improved the samples' red colour (a* value) and successfully maintained the intended shade during storage. Surprisingly, residual nitrite levels did not substantially vary between samples at the end of the trial. Furthermore, there was a correlation between elevated lactic acid bacteria counts and greater amounts of beetroot powder. Throughout the storage period, the sensory assessment ratings of beetroot powder samples were similar to those of control samples. The results indicate that it is possible to preserve the quality of Turkish fermented sausage by reformulating it using beetroot powder instead of nitrite and storing it in vacuum-sealed bags at 4°C for up to 56 days. The study also emphasises how natural additions, such as beetroot powder, can take the place of artificial additives in meat products, thereby satisfying customer demands for safer and clean-label food alternatives. Its all-encompassing method, which includes taste analysis and quality assessment, offers insightful information on the suitability of beetroot powder as a nitrite substitute in meat products. The food sector may benefit from this research by creating clean-label goods free of artificial ingredients, and satisfying customer needs for natural and safe meat options. The study essentially confirms that beetroot powder might serve as a good substitute for nitrite in Turkish fermented sausage, offering a natural source of nitrate with antioxidant and colour-enhancing properties. These findings contribute to ongoing efforts in the food industry to develop safer and natural meat products without compromising quality or sensory **[74]**.

Future Perspectives

Beetroot powder's use in the chicken sausage as a colouring and filler creates opportunities for more study and advancement in the meat processing sector. Subsequent research endeavours may delve into refined blends and processing methods to improve the advantages of beetroot powder while minimizing any possible disadvantages. Furthermore, examining the impact of varying concentrations of beetroot powder on shelf life, consistency, and nutritional value would offer a significant understanding of its use in manufacturing chicken sausages. Additionally, consumer research is required to determine preferences for the flavour and colour profile of chicken sausages that contain beetroot powder. This will help manufacturers create goods that meet the needs and expectations of their target market.

CONCLUSION

In conclusion, adding beetroot powder to chicken sausage as a colouring and filler presents exciting chances to improve the product's visual and sensory qualities. The study showed that beetroot powder enhances product quality by positively impacting softness, colour, and water-holding capacity. To guarantee customer acceptability, the sensory elements—specifically, the taste profile—must be carefully considered. Beetroot powder offers a natural and maybe advantageous component for creating chicken sausages, opening doors for creativity and uniqueness in the meat processing sector. Additional research and development work is necessary to fully realise the potential of beetroot powder and satisfy customer demand for meat products that are more enticing and healthier.

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