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Review

Healthier Meat Products Are Fashionable—Consumers Love Fashion

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Abstract: Meat manufacturers are nowadays in a very unenviable position. Both meat and meat products require the utilization of various additives due to their chemical composition. On the other hand, consumers demand fresh, additive-free, and high-quality products with extended shelf-life, which might be considered as healthier, even functional food. These facts push manufacturers and researchers in pursuit of modern technologies and supplements to meet these high demands. Since a high daily intake of sodium and fat might cause severe health issues, reducing these ingredients in meat products is the first task towards healthier food. Sodium can be reduced by ultrasound, high-pressure processing, pulsed electric field, and replacement of NaCl with KCl, calcium gluconate, calcium glycerophosphate, calcium lactate, and monosodium glutamate. The reduction of the fat content can be achieved through a decrease in the amount of fatty tissue in the inital mixture and/or replacement with non-lipid components, or by partial fatty tissue replacement with oils rich in polyunsaturated fatty acids. Utilization of plant proteins (soy, wheat gluten, pea, chickpea, lentil, potato, barley, oat, rice, etc.), mycoproteins or micro-algae proteins, plant fats (palm and coconut fat, canola, sunflower, soy and corn oil, etc.), and polysaccharides (starches, fibers), accompanied by a meat-like fibrous structure, resulted in delicious "meat" products, which are considered a healthier alternative to real meat. Growing interest in the replacement of potentially adverse synthetic meat additives favors the use of plant (herb, fruit and vegetable) extracts, as an endless source of bioactive substances with strong antioxidant and antimicrobial activities. These extracts can be used either in raw meat or meat products, as well as in the fodder. Reformulation strategies strengthen and ensure the willingness of consumers to pay a higher price for their own demands regarding the naturalness of synthetic, clean-labeled, additive-free meat products. After a gradual alignment with strategic national/international recommendations and legal/sub-legal frameworks, the added value of such meat products opens wide the door to new segments/entire markets.

Keywords: reformulation strategy; meat products; consumer's perception; human health hazards

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1. Introduction

Meat and a diverse range of meat products are important sources of high-quality proteins, fats and minerals as essential nutrients [1]. Among all these essential ingredients, proteins and their amino acid profile are the most important indicators of food nutritional value. The protein dietary quality can be determined by the quantity and availability of essential amino acids that cannot be synthetized by humans and must be supplied through the diet [2]. In addition to non-essential, meat proteins contain all nine essential amino acids [3], which makes them superior to many plant proteins, especially cereals and legumes that generally lack lysine and methionine [4,5]. Additionally, meat proteins have a very high PDCAAS (Protein Digestibility-Corrected Amino Acid Scores) of 0.92, although still lower than egg white and casein, which have PDCAAS of 1.00 [6]. The proliferation of microorganisms and rapid oxidative rancidity are predominantly characterized by the creation and accumulation of toxic/harmful compounds, changes in texture, color and nutrients, and reduction of shelf life. All these changes cause a decline in the nutritional quality of meat products [7]. Fat oxidation is the most common cause of spoilage in meat and meat products, due to the high fat content and low water activity (a_w), which results in the loss of nutritional value, water binding capacity (WBC), unpleasant taste and texture [8,9]. Many consumers consider processed meat to be unhealthy due to the high levels of sodium, fat, and harmful additives [10–14]. In October 2015, the World Health Organization (WHO) through its International Agency for Research on Cancer (IARC) published a monograph classifying meat products as carcinogenic (Group I), and red meat as a potential carcinogen (Group IIa). This classification was proposed based on the published results of human and animal research on the connection between meat consumption and the occurrence of colorectal and other types of cancer. This claim of the IARC has a larger number of opponents. In their review, Jiang and Xiong [15] present the claims of several authors that processed meats are unhealthy because of the ingredients added during processing as well as the processing conditions themselves. In addition to carcinogenicity, they also described the mutagenic and genotoxic effects of meat product consumption [15]. Many studies report the negative effects that meal compositions rich in table salt, sugar, saturated fat, and additives and low in dietary fiber and bioactive compounds can have on nutritional quality, which are usually associated with industrially produced food formulations [16].

Certainly, innovative strategies for meat processing and the selection of ingredients and supplements must be intensively developed in order to minimize the possibilities for provoking the emergence of health problems. Such strategies must contribute to an improvement in the overall sensorial and biological quality of products and their health safety [17,18]. Oxidation of lipids and proteins caused by free radicals determined when cooking products at a high temperature contributes to the creation of a large number of substances potentially harmful to human health. The group of cytotoxic and genotoxic compounds based on carbonyl advanced lipid oxidation end products (ALEs) includes: 4-hydroxynonenal and malonaldehyde [19,20], mutagenic heterocyclic aromatic amines formed at high temperatures, such as 2-amino-1-methyl- 6-phenylimidazo [4,5-b]pyridine (PhIP) and 2-Amino-3,8-dimethylimidazo[4,5-f] quinoxaline (8-MeIKk) [21,22], and carcinogen nitrosamines in nitrite-cured products [23].

Today's meat processing is characterized as a period of improvement in quality, food safety and nutrition/health [24]. Consumer concern over the excessive use of table salt has a growing trend due to health problems associated with high blood pressure and cardiovascular risks. In China, the incidence of hypertension has tripled since 1958, and cardiovascular disease has become the number one killer (2.6 million deaths per year) [25]. A number of studies indicate a relationship between salt intake, *Helicobacter pylori* infection and gastric cancer mortality [26–28]. The WHO has sent strong support to the governments of a number of countries to start implementing the "Global Action Plan to reduce non-infectious diseases". One of the nine global goals is to reduce salt intake by around 30% by 2025 [29].

About 50–60 years ago, research started to correlate the diet rich in fats and saturated fatty acids (SFA) with the occurrence of various diseases, such as heart disease, cardiovascular disease and colon cancer. Moreover, when a lower frequency of heart diseases was found among Greenlandic Inuits despite a diet rich in fat and cholesterol (as a result of the intake of n-3 long-chain polyunsaturated fatty acids (PUFA) from fish and seafood), interest in n-3 fatty acids increased [30]. As a result, recommendations on dietary fat intake were drafted. The Food and Agriculture Organization of the United Nations (FAO) [31] recommends (for healthy adults) 15–35% of energy intake (E) from fat, while $\leq$10%E from SFA and 6–11%E from PUFA. The total n-3 fatty acid intake can be within the range 0.5–2%E. Fat content in meat products can be as high as up to 40%, as was the case in some dry-fermented sausages, [32] or even more [33]. Fat is of great importance for the overall quality of meat products because, in general, it contributes to technological and sensory properties (e.g., processing yield, color, flavor, texture) [34]. Therefore, improving the nutritional properties of meat products achieved by the (partial) substitution of fatty tissue with non-fat fractions and/or oils rich in PUFA (and/or monounsaturated fatty acids; MUFA) poses quite a challenge since such changes should not alter the technological and sensory properties [35].

Meat analogues are also called imitation meat, meat substitutes, plant-based meats, etc. [36]. Research studies reported that plant-based products are cholesterol free, low in saturated fatty acids, and rich in polyunsaturated fatty acids and essential amino acids [37]. They have an appearance, texture, mouthfeel, flavor, and nutritional profile that resemble their meat counterparts [38,39] and are made from protein sources that do not come from animals [40].

Food additives are substances of natural or synthetic origin, which are intentionally added during the production and processing of food in order to improve its properties [41]. We have seen a rise in consumer demand for additive-free food, such as the "clean-label" movement, which has reawakened the readiness of consumers to consume food products without synthetic additives [42–45]. "Clean-label" products must be free of added synthetic additives, preserved by minimal food processing or traditional processing methods, with a concise list and easy-to-understand selection of the raw materials used, and the ingredients of the product must be clearly indicated on their packaging [46,47]. Food business entities have begun to evaluate the use of eco-friendly additives of natural origin, instead of synthetic additives [48,49]. Natural resources of plant, animal and microbial origin can be used for food preservation [50]. Plants are an inexhaustible source of natural bioactive substances (BAS). BAS have proven their strong antimicrobial (AM) activity against food spoilage agents and foodborne pathogens. Moreover, they exhibit strong antioxidant (AOX) effects [51,52]. Plants synthesize a wide variety of secondary metabolites, whose AM activity protects them from predators and pathogenic microorganisms. The most abundant groups of compounds in secondary metabolites are polyphenols and phenols. Their subgroups (flavonoids, quinones, coumarins, phenolic acids, tannins, phenols, flavones, and flavonols) inhibit the activities of microorganisms extremely powerfully [52].

The food industry is implementing the reformulation of recipes for processed foods in order to improve the quality of nutrition, as required by health agencies. The reduction of NaCl and fat content is carried out, as well as the replacement of harmful/toxic additives with ingredients of natural origin that exhibit different bioactivities [53].

2. Reduction of Sodium (Na) Content in Meat Products

Meat and meat products require considerable amounts of sodium (12 to 20% of the total food intake) therefore these products are a priority in terms of the need to reduce the NaCl content [54]. Fermented dry and semi-dry sausages and dry-cured meat products are meat products that are preserved without heat treatment, using only drying and salting/brining, hence they have a higher NaCl content compared to other groups of meat products. The WHO recommends a daily intake (DI) of NaCl of less than 5 g for adults (<2 g of Na) [55]. In a large number of EU countries, this amount is exceeded by more than two-fold. A high daily intake of Na and an insufficient intake of potassium (less than 3.5 g per day) leads to frequent disease resulting from increased blood pressure, which is reflected in a higher risk rate of coronary heart disease, heart attack and brain stroke [56]. As a consequence of this condition, the trend of reduction is inevitable to lower the content of sodium chloride that has been added to meat products [57]. In meat products, Na is essentially incorporated by the addition of NaCl, and on a smaller scale through some other additives widely used as preservatives in meat products (sodium nitrate and nitrite), Na-lactate (added as an emulsifier or flavor enhancer), or Na-ascorbate (used as an antioxidant). The quantity of Na in a fresh meat sample is low (48–80 mg/100 g) [48], and meat products contribute 20–30% of the total amount of salt ingested through the diet [58]. A range of high-value meat products, such as fermented and dry-cured meat products (sausages, hams, or loins) have the greatest amounts of NaCl, which is related to the technological process of dehydration during processing [59].

Salt was probably the first and is nowadays the most common ingredient in meat product preparation. It is very important for technological and sensory properties of meat products as well as for their shelf-life and safety [60,61]. Moreover, sodium (Na^+) and chloride (Cl^-), together with fluorine and iodine (as well as potassium and magnesium) which are often included in table salt, are of great importance for the proper functioning of human organism [42]. The influence of salt on technological and sensory properties depends on the salt content, the type of meat products (e.g., whole muscle, grounded) and the applied production procedures (e.g., drying, heat treatment, grounding, tumbling). In general, salt enables protein solubilization, extraction, activation and hydration, it improves the water-holding capacity (and thus cooking yield and juiciness), meat emulsion formation, and sliceability [42]. In emulsion-type meat products the values of hardness, springiness, cohesiveness and chewiness are higher with higher salt contents which is associated with protein solubilization and extraction [62]. As for dry-fermented sausages, salt promotes gel formation, which leads to the desirable texture and sliceability [63]. The literature data indicate that the reduction of the salt content to about 1.7% in emulsion-type meat products (without phosphates added) and to about 2.2% in dry-fermented sausages is possible without changes in texture properties [63,64]. In the concentrations between 0.7% and 2.5% salt promotes lipid oxidation due to the inhibition of antioxidant enzymes, while for contents higher than 3% it can protect lipids [42]. Lipid oxidation could promote protein oxidation which could also be associated with the inhibition of antioxidant enzymes by salt [42]. Regarding colour characteristics, potassium and sodium chloride accelerate the formation of red-coloured nitrosylmyoglobin [65].

Food manufacturers face a dilemma: "How can the NaCl content in food be reduced without affecting and modifying its taste too much?" This concern of the meat industry is evident by the fact that clean-label meat products can now be found on the market. Trends indicate that consumers increasingly opt for "healthy" food, and taste remains the main factor when purchasing food items. Manufacturers choose to simply reduce the NaCl content, without changing the taste. One of the scientific review papers published a significant account of innovative patents on the reduction of salt content in food [66]. On a daily basis, we can see an increasing demand for healthier meat products, with lower fat and salt contents. Therefore, multiple possibilities of salt reduction in meat products are continuously being investigated [67,68]. Recently, one of the most complete and illustrative current tabulations/overviews of available substitutes for NaCl in meat products has been published, with up-to-date data, including the nature of compound, application/purpose, effects, product trade name, and literature reference [42]. Review papers have observed that a lower concentration of NaCl in meat products can reflect on the quality parameters and product shelf life, as well as that the decreasing NaCl content differs by product and is specific to it [69,70]. A very informative short review [71] summarizes current trends on green technologies to produce healthier meat products by reducing NaCl and phosphate levels. The following are shown as the most prosperous technologies: ultrasound (US), high-pressure processing (HPP), and pulsed electric field (PEF), environmentally friendly processes. In addition, US, HPP, and PEF can modify the protein structure and improve its functional properties, allowing the reduction of the content of additives in meat products. The main limitation for the stated reduction of NaCl content is the acceptance of "healthier" products by consumers.

Bitter, metallic, pungent, sweet and sour tastes in meat products are often attributed to the addition of magnesium or calcium salts, as a substitute for NaCl. The bitter taste is most often associated with the use of metal salts, and manufacturers often use salt mixtures [72]. If 33% of NaCl is replaced with KCl in the brine used for treating dried ham, the salty taste is equivalent to the saltiness of the control sample. However, a slight bitter taste is also present. Calcium gluconate, calcium glycerophosphate, and calcium lactate resulted in weaker saltiness and a less bitter taste than when $CaCl_2$ was used as a substitute for NaCl [42].

The taste of monosodium glutamate in concentrations 10 times lower than the NaCl content is similar to the salty taste of NaCl [73]. Moreover, it acts in synergy with NaCl to form the salty taste of meat products [74]. An experimental range of fermented sausages was developed with decreased contents of fat and salt [75]. Product formulations included different contents of fat (10 g/100 g–20 g/100 g), NaCl (0–2 g/100 g) and KCl (0–1 g/100 g). NaCl was substituted with KCl. Instrumental analysis showed significant ($p < 0.05$) differences in hardness, brittleness, cohesiveness and chewiness between different sausage formulations. Sensory analysis revealed no texture changes after salt replacement or fat reduction. The product with the highest fat content and KCl as a substitute for NaCl was found to have the highest level of bitter taste. A significant interaction was identified between the added KCl and the fat content in terms of the perception of bitter taste. Partial replacement of NaCl with KCl and $CaCl_2$ had an effect on the reactions of lipolysis and lipid profile in salted meat with a reduced amount of Na [76]. Mixtures with reduced sodium applied in the production of hot dogs were designed [77]. They were made by combining four salts: NaCl, Na tripolyphosphate (TPPNa), KCl, and tetrapotassium pyrophosphate (TKPP), with ten formulations. Texture profile (TPA), ionic strength (IS), and cooking loss (CL) were determined. Experimental group T2 (mixture of 78% NaCl and 22% TPPNa) demonstrated the best results (lowest cooking losses and most desirable texture). The lowest cooking losses were found when the NaCl content was reduced using the highest levels of TPPNa (T2, T4, T6, and T9). Formulations with higher amounts of TPPNa and TKPP (T2, T3, and T6) had the highest values for hardness, cohesiveness, and chewiness.

Taking into account the differences in thiobarbituric acid reactive substances (TBARS) values between treatments and all the results presented in this study, $CaCl_2$ had the greatest oxidative capacity and impact on the lipid profile, compared to NaCl and KCl. Within one study, an evaluation was performed on the effects of partial replacement of NaCl with mixtures of $CaCl_2$, MgCl, and KCl on changes in the quality of emulsified sausages prepared from pork, with reduced fat content [78]. All salt mixtures increased the proportion of red color ($p < 0.001$) and decreased the proportion of yellow color ($p < 0.001$) during the storage period. Replacing 15% NaCl with $MgCl_2$ favorably affected texture and chewiness, but negatively affected lipid oxidation after a five-week chilling period. In sausage samples in which NaCl was partially replaced by 5% $CaCl_2$, no quality improvements were detected, despite their highest ionic strength. Sausages modified with a mixture of all chloride salts (replacing 70% NaCl: 5% $CaCl_2$, 15% $MgCl_2$ and 50% KCl) did not have an acceptable sensory quality at the beginning of cooling ($p < 0.01$). However, this decreased during the three weeks of storage ($p < 0.05$). Apart from this modified formulation, mixtures with one or two other substitutes for NaCl ($CaCl_2$, $MgCl_2$, and KCl) are an acceptable partial replacement of NaCl in the manufacturing of emulsified sausages with reduced fat content, as their quality remains unchanged.

When assessing trout production analysis parameters, either in natural or controlled production conditions, it was established that it is possible to replace NaCl with KCl. Sensory properties of trout were acceptable with NaCl replaced by KCl to 15% [79]. Based on their previous research [80], it was revealed that there is a continued interest in the application of various Na reduction technologies in various meat products. Previous research on the use of traditionally cooked soy sauce (SS) and fermented flavor enhancer (NFE) shows that they are effective as ingredients that enable the reduction of the Na content. However, their ability to produce similar results in different meat products with different requirements (e.g., taste and functionality) for NaCl has not been sufficiently elucidated. No differences ($p > 0.05$) were observed in the overall palatability of bacon at 30% (SS and NFE) and 50% (SS) reductions containing KCl, as well as for the overall palatability of beef (NFE) and boneless ham (SS) with a reduction of 30%, using SS or NFE, as a procedure to reduce the NaCl content. Results for saltiness were not significantly altered ($p > 0.05$) when the NaCl content of bacon, beef, and boneless ham was reduced by

30%, while a reduction in palatability ($p < 0.05$) was observed in summer sausage containing SS and NFE. The results showed that SS and NFE are suitable ingredients for reducing the Na content of meat products and that each product has unique and variable sensory property responses, which must be taken into account.

The production of salami with a low sodium content using salt substitutes (KCl and $CaCl_2$) can be effectively carried out with no risk to the main sensory attributes [81].

A salt content of up to 1.4% NaCl determined in cooked sausages and 1.75% in lean meat was sufficient to produce a thermostable gel, with acceptable saltiness and firmness, WBC and fat retention [64]. If the protein content increases (e.g., in lean meat), the feeling of saltiness in meat products decreases, and the opposite correlation occurs in the case of an increase in fat content and the perception of saltiness. The required NaCl content for acceptable gel firmness depends on the product formulation. When phosphates are added or the fat content is high, the addition of reduced amounts of salt provides a more stable gel compared to products with no added phosphates and where the fat content is low. Small differences in the NaCl content are at the level of 2% and have no significant effects on the sustainability of the product.

The aim of studies [82,83] was the evaluation of the effects of replacing nitrite curing salt with sodium nitrite with the finished mixture of NaCl and KCl for human consumption (Na-max 27 g/kg-min K 16 g/kg) at a rate of 25%, 50%, 75%, and 100% on the physico-chemical quality and microbiological safety of the cooked sausages—hot dogs. Five different production batches (PB) were manufactured, each 10 kg in weight. The first PB (control) was prepared according to the manufacturer's original recipe. Experimental PB I was made by adding 50 g of mixed sodium-potassium salt (25%) and 150 g nitrite salt into 10 kg of stuffing. PB II was prepared with 100 g of combined sodium-potassium salt (50%) and 100 g nitrite salt, while PB III was made with 150 g of combined sodium-potassium salt (75%) and 50 g nitrite salt. Hot-dogs from PB IV were made by adding 200 g (100%) of combined Na/K salt into 10 kg of stuffing. Tested samples originating from all experimental batches were microbiologically safe, not altered by this substitution, according to the criteria laid down by Serbian food safety regulations. The replacements of nitrite salt by mixed Na/K salt promote healthier characteristics of hot dogs produced with low levels of Na and high K level. The physico-chemical quality varied, and statistical differences were observed in the moisture, protein and fat content, pH and aw values, Na and K content among the treatment. Ash content was not significantly different between the samples of hot dog originating from the control and experimental groups. Replacing sodium nitrite curing salt with the mixture of sodium and potassium chloride did not significantly affect the examined color (CIE L*, a*, b*) of experimentally prepared hot-dogs.

The effects of fat content reduction from 30% to 20% and salt concentration from 1.5% to 1.0% on the physico-chemical properties of meat emulsion was investigated [84]. These reductions were achieved by a partial replacement of fat and NaCl with a combination of phosphate and edible algae *Undaria pinnatifida*. Cooking losses and emulsion stability, hardness, elasticity and cohesiveness were similar in reduced fat and NaCl emulsions (samples with 20% lard and 1.2% NaCl with incorporated phosphate and *Undaria pinnatifida*) were similar to control samples (with 30% solid pork fat and 1.5% NaCl). The results showed higher viscosity in emulsion samples with reduced fat/low NaCl content, and that the addition of phosphate and the edible algae *Undaria pinnatifida* to the formulation of the emulsions successfully decreased their fat content and the intensity of the salty taste.

Intriguing research [85] promoted the healthier characteristics of the Bologna sausage made with low sodium and high potassium contents. The authors replaced 50% of the NaCl content with KCl. Physico-chemical quality and microbiological safety of products with reduced salt content were not impaired by salt replacement and addition of herbs and spices. However, the decision to purchase such modified products, expressed by evaluators, and was reduced. Two combinations of herbs and tested spices effectively removed the sensory deficits caused by the addition of KCl. We can conclude that using these herbs and spices (0.5% coriander, 0.4% onion; 0.1% white pepper, 0.3% onion, 0.5% cardamom and 0.2%

Jamaican pepper) and partially replacing NaCl with KCl can be deemed an appropriate procedure for the production of the Bologna sausage with a lower sodium content, without impairing product safety and sensory quality. Further studies are necessary to evaluate the impact of this technological strategy on product shelf life, physico-chemical, sensory and microbiological quality. Moreover, the contribution of other additives and ingredients used in recipes, which are a source of Na, should be determined (quantified). It is necessary to investigate alternative compounds that can help achieve lower Na levels in cooked emulsions of meat products.

In Table 1, we have shown certain ingredients that allow sodium reduction in today's food processing.

Table 1. Various types of replacers for NaCl in meat products—application and effects.

Trade Name®	**Substitute for NaCl**	*Application*	**Effects**	**Reference**
Pansalt® *AlsoSalt®*	KCl	*Technological and sensory*	More intensive ham cohesiveness and minor cooking loss. KCl has similar antimicrobial effects as NaCl, confirmed by tests with pathogenic bacteria.	[70,86,87]
/	$CaCl_2$	*Technological and sensory*	Microbiological effects and very variable technological impact. Increase of water activity.	[88,89]
/	$MgCl_2$	*Technological and sensory*	Leads to off-flavour (or bitter, metallic, soapy aftertaste). Microbiological effects and variable technological influence. Partial substitution of NaCl with $MgCl_2$ was recorded and showed higher water activity inside the product for the same amount of total added salt.	[90–92]
/	Mixture of 1% NaCl, 0.5% KCl, and 0.5% $MgCl_2$	*Technological and sensory*	Provided the best emulsion stability in mortadella, and poor flavor.	[93]
KcLeanTM salt®	NaCl + KCl	*Reducing the Na content*	Exibited no differences in flavor, texture, and color. Product safety and stability both showed same ability to control microbial, pH, and water activity. Reduce sodium up to 50% and 35%, respectively.	[70,94]
/	Blend of 45% NaCl + 25% KCl + 20% $CaCl_2$ + 10% $MgCl_2$	*Reducing the Na content*	Significantly reduced water retention, elasticity, and gel strength of myofibril protein, when the replacement rate was higher than 50%.	[95,96]
Pansalt®	$MgSO_4$	*Technological*	More pronounced hydration of meat proteins. Negative influences on the sensory and technological characteristics of the product.	[86]
Soda-Lo®	Free-flowing hollow microspheres	*Reducing the Na content by optimizing the salt form*	Hollow microspheres are significantly smaller than regular salt crystals but contribute to the intense and clean salt taste.	[88,97]
PurasalR® P *PurasalR® S* *Purasal OptiFormR®* *Ksalt®*	Sodium acetate & diacetate (E262); Sodium lactate (E325); Potassium lactate (E326); Sodium citrate (E331)	*Taste enhancer*	Bacteriostatic effect; More intense perception of saltiness; Enhances the flavor; Optimizes the brining process; Increase in firmness and in the juiciness of pork cooked; More pronounced hydration of meat proteins; Sodium lactate promotes cohesiveness better than potassium lactate. E326: Weaker cohesiveness and saltiness (40% substitution).	[90,98,99]
Potassium lactate and Sodium diacetate	0.5% NaCl + 1.5% K-lactate/Na-diacetate replacement	*Reducing the Na content; Technological and sensory*	Reduced Na levels by 40% and extended the shelf life by containing the growth of bacteria in packaged meat products. Significantly improvement of the flavor, harder and less juicy texture of the meat products (fermented sausages).	[99,100]

Table 1. *Cont.*

Trade Name®	Substitute for NaCl	*Application*	Effects	Reference
/	Sodium glutamate and derivatives Glutamic acid (E620); Monosodium glutamate (E621); Monopotassium glutamate E622; Calcium diglutamate (E623); Ammonium glutamate (E624); Magnesium diglutamate (E625).	*Taste enhancers*	Most commonly used taste enhancers worldwide. Maximum allowed amount of additives limited to 10 g/kg.	[101]
/	Guanylic acid (E626); Disodium guanylate (E627); Dipotassium guanylate (E628); Calcium guanylate (E629); Inosinic acid (E630); Disodium inosinate (E631); Dipotassium inosinate (E632), Calcium inosinate (E633); Disodium ribonucleotide (E634); Calcium ribonucleotide (E635).	*Taste enhancers*	Enhance the taste of meat products; Significantly improves ratings of sensory properties (texture, hardness and chewiness). No effect on changes in color, pH value and WBC was determined.	[102]
PansaltR ® *AlsoSaltR®*	Arginine; Taurine; Lysine, Glycine	*Taste enhancers*	Particularly significant in solving the challenge of finding substitutes for NaCl. Lysine and Arginine (Acids basic amines) contribute to a more intense perception of saltiness. Glycine—without differences in any attribute of the sensory properties compared the content of NaCl.	[71,86,103]
/	Blend of KCl/glycine and K-lactate/glycine	*Reducing the Na content*	In fermented sausage, substitution of NaCl reached 40%–70%: significant flavor and textural defects.	[99]
AscendR® *SaltWise®*	Trehalose	*Masking agent*	Masking agent without specific taste; Taste enhancer; Bitterness inhibitor.	[104]
Betrasalt®	Adenosine monophosphate (AMP)			[101]
Sub4salt®	Sodium gluconate + NaCl + KCl	*Reducing the Na content (up to 50% and 35%, resp.)*	Exibited no differences in flavor, texture, and color. Product safety and stability both showed same ability to control microbial, pH, and water activity.	[70,94]
Savoury Powder® (SP) *LactoSalt Opti Taste®*	Whey and derivatives	*Aroma*	*SP* didn't enable sufficient ionic strength optimal extraction of myofibrillar proteins.	[70,105]
Maggi®	Soy sauce and derivatives	*Taste enhancers*	Under the influence of the supplement changes of technological properties have been reported, which vary considerably depending on the meat products: decrease or increase in hardness, cohesiveness and chewiness, decrease in color (L^*, a^* or b^*)	[102]
/	Soy sauce	*Reducing the Na content*	Replace salt with brewed soy sauce up to 50%, 17%, and 29%, respectively, without significant effect on taste and delicacy.	[106]
Koji-Aji®	Yeast extracts	*Savory seasoning*	Decrease of pH values is much faster during storage; Final a_w values of the products is significantly lower.	[104]
Provesta® *Aromild®*	Yeast autolysates	*Taste enhancers*	Cover the bitter flavor of KCl and reduce NaCl content. Autolysates have a strong broth flavor, which may not be appreciated in some products. Monosodium glutamate has been connected with possible health implications: hyperactivity, sickness, and migraines.	[94,107,108]
/	Hydrolyzed vegetable protein		An additional ingredient in the product formulation.	[42]

Table 1. *Cont.*

Trade Name®	**Substitute for NaCl**	*Application*	**Effects**	**Reference**
Algysalt® *Seagreens®*	Seaweed extracts	*Algysalt®: NaCl substitutes in fresh and cooked meat product; Seagreens®: Blend of shallow water seaweeds*	(High levels of sodium glutamate). Strong influence on cooking efficiency thanks to fiber algae content (better water retention and fat in products after cooking). *Algysalt®* provided harder texture of products.	[54,109,110]
SANTE®	Tomato extracts	*Natural flavour enhancer; Reducing the Na content;*	Salt reduction by up to 30%; Meaty flavour; High levels of E620. Does not mask intrinsic flavour.	[111]
Mycoscent®	Mushroom extract, by-product of mycoprotein production, rich source of both glutamate and ribonucleotides.	*Natural taste enhancers*	High levels of E620.	[112]
Winter mushroom powder (WMP)	Winter Mushrooms (*Flammulina Velutipes*)	*Alternative to phosphates in emulsion-type sausages*	Softer texture, can inhibit the lipid oxidation.	[113–115]
Halophytes: Salt marsh plant	Seablite (*Suaeda maritima*) Glasswort (*Salicornia herbacea* L.)	*Salt replacers*	Provided salty taste and can reduce the use of salt. Dry-cured ham: reduced salt content by 50%. Providing color, texture, and sensory properties. Potential health benefits (antimicrobial and antioxidant effects).	[106,116]
Red wine pomace seasoning (RWPS)	RWPS (by-product)	*By-product of natural origin for salt replacement*	Provided the reduction of salt content in beef patties; Bacteriostatic on aerobic mesophilic and lactic bacteria.	[117]
Various seasonings	Black pepper, ginger, basil, curry, origano, rosemary, garlic, onion, cumin, coriander, chili, mustard, paprika, mint, lemon, vinegar	*Natural seasoning for salt replacement*	Additional ingredient in the formulation of product. *Rosemary* can replace about 48% salt and has a positive correlation with taste acceptability. The addition of *fresh garlic* in Brazilian frankfurters decreases the sodium content, retards lipid oxidation, and works as an antimicrobial agent. Spices ubiquitously present in Asian cuisine provide sweet, sour, bitter, salty, and umami tastes. Healthier Bologna sausages created by reduction of the Na content up to 50% when it was NaCl substituted by KCl and a blend of herbs and spices (coriander, Jamaican pepper, onion, cardamom, and white pepper) without negatively affecting safety and palatability.	[85,103,113, 118,119]
/	Carrot fiber, β-glucan	*Functional agent*	Water retention.	[42]
/	Potato starch, carrageenans		Additional ingredient in the formulation of product.	[42]
	Transglutaminases, polyphenoloxydases		Additional ingredient in the formulation of product.	[42]

Therefore, the reduction of the sodium content in meat products can be achieved by different procedures: (1) by reducing the amount of added NaCl; (2) replacing a part of NaCl with other salts [120]; (3) using flavor enhancers and masking agents [54]; (4) a combination of the mentioned procedures [121]; (5) adding herbs and spice extracts to meat products [122,123]; (6) optimization of the physical form of the salt [124], and (7) alternative processing techniques [125].

3. Reduction of Fat Content and Improvement of Fatty Acid Profile

Meat products have been developed out of the need to preserve meat as essential food for a long period. The combination of different animal tissues with early preservation techniques (drying, salting, heating, and smoking) and spices led to the emergence of different meat products.

For centuries, such products were used in nutrition as an important source of protein, energy, and other nutrients. Because of the high availability of fresh meat, over the past decades, meat products have been valued more for their sensory characteristics which depend on the protein/fat/water ratio, the use of non-meat ingredients (salt, nitrates, phosphates, etc.), preservation procedures, and their interactions [126].

As was pointed out in Section 1, fat (fatty tissue) plays a very important role in the quality of meat products. This is especially pronounced in products where fatty tissue is ground together with meat, mixed with non-meat ingredients (salt, additives, spices), and subjected to different procedures to produce:

- Dry-fermented sausages: fermented, sometimes smoked sausages dried in cold air (10–25 °C)
- Emulsified sausages (frankfurters, mortadella): heat-treated finely comminuted meat products
- Fresh, minced meat products (burgers, patties, fresh sausages) which are intended for heat treatment (e.g., grill, barbecue) before consumption.

Dry-fermented sausages have been produced for centuries with numerous national and local variants worldwide highly valued for their specific sensory characteristics [27]. They are made by simultaneously grounding and mixing meat and fatty tissue of various animals with salt, sugar and different additives and spices. Once such a mixture is obtained, it is stuffed into natural and/or artificial permeable casings of different diameters, after which it undergoes fermentation and ripening in ambient or controlled conditions for a period of several weeks or months [127].

Initially, the mixture contained between one quarter and one third fatty tissue, which increased to 40% after drying [32] or even up to 50% in some traditional variants [33,128]. Flavor, texture, mouthfeel, and juiciness are highly correlated to the amount of fatty tissue, as well as to continuous and uniform drying [129]. Moreover, fatty tissue usually contains a high amount of SFA, and during mincing and ripening it is easier to cut and more difficult to melt. This leads to better binding of meat and fat parts, and obtained products are oxidatively stable [32].

Emulsion-type sausages (frankfurters, mortadella, etc.) are prepared by comminuting and mixing meat and fatty tissue with water and other non/meat ingredients (salt, phosphates, spices, etc.) filled into casings. After cooking (70–75 °C in the thermal center), they are packed and cold-stored for several weeks. The formulation and stability of the emulsion affects the technological and sensory properties of products, as determined by the protein/fat/moisture ratio and by the content of used ingredients [64]. Fat content in the emulsion-type sausages could be up to 30% [130] and is very important for the formation and stabilization of meat emulsions, and thus for the sensory properties of emulsion-type sausages, such as color, texture, flavor, juiciness, and mouthfeel [131].

Fresh meat products, such as burgers, patties, and fresh sausages, are intended for heat treatment (e.g., grill, barbecue) before consumption. They are produced by mincing and mixing meat, fatty tissue and other non-meat ingredients. Afterward, they can be filled into natural casings (fresh sausages) or shaped (burgers), and then cold stored for several days or freeze stored for several months. Burgers and other beef patty-type products can contain from 20% to 30% of fat [132]. Fat is also significant for the sensory quality because it affects the appearance, cooking loss and deformation ratio during grilling, texture, aroma [132].

In view of the above, it appears that only a partial reduction or replacement of fatty tissue in meat products can be done. However, it poses a challenge as it necessitates the creation of a product with enhanced functional properties and the same or imperceptibly changed sensory qualities [32].

This leads into two strategies:

1. The reduction of fat content through a decrease in the amount of fatty tissue in the initial mixture and/or replacement with non-lipid replacers.
2. Partial fatty tissue replacement with oils rich in PUFA and a simultaneous reduction of the amount of fatty tissues.

Regarding the first strategy, a lower content of fatty tissue (and a higher content of meat) leads to a larger weight loss during the drying of fermented sausages, and to a firmer texture, surface wrinkling and the formation of a hard edge, which reduce acceptability [133] and lead to the introduction of special conditions during the production process to produce low-fat products with satisfactory sensory quality [130]. Moreover, low-fat burgers and similar products had lower acceptance [132]. This could be somewhat improved by the partial replacement of fatty tissue with non-lipid fat replacers, such as inulin, cereal, and fruit fibers [129]. However, this only achieves total fat content reduction, but without a change in the fatty acid profile. In that sense (regarding nutritional enhancement), the second strategy, which involves the introduction of oils rich in MUFA and PUFA (especially n-3 PUFA) into the formulation, is much more interesting. Different vegetable oils (olive, grapeseed, flaxseed, soybean, corn, canola, hazelnut, walnut, cottonseed), marine oils (fish and algae), and their combinations were used to partially replace the fatty tissue in different types of meat products.

However, this strategy introduces a new risk regarding sensory quality, i.e., oxidative stability, especially regarding dry-fermented sausages. Namely, oils rich in unsaturated fatty acids (UFA) are more prone to oxidation compared to highly saturated animal fatty tissue (e.g., pork backfat). Moreover, the earliest research indicates that the application of liquid oils in fermented sausage formulation disrupts the drying process and reduces sensory quality [134] which is confirmed in recent research [135,136]. In view of this, oils should be pre-treated (stabilized) before application to increase oxidative stability and create solid-like material which replaces solid fatty tissue [136]. Emulsions, double emulsions, gel-like matrixes, and different encapsulation techniques were used in stabilization and immobilization of oils rich with PUFA [126].

This strategy can be implemented with two principles [32]:

- First, by substituting one part of fatty tissue with an equal amount of oil treatment (e.g., emulsion, gel), which results in the reduction of total fat, given that oil content in these treatments is up to 50–55%, unlike the fatty tissue that contains 80–90% fat. The oil content in this approach was up to 5% in the initial batch [137,138].
- The second principle implies a partial substitution of fatty tissue with an equal amount of oil added as emulsion, gel or encapsulated, thus leading to a slightly altered total fat content. This principle enables almost double the amount of the oil content compared to the first principle, with the equal share of fatty tissue being replaced [32,35,133].

In early research, olive oil was mostly used while oil-in-water emulsion system with soy protein isolates (SPI) was the most commonly used immobilization technique [32]. In the last decade, other oils (flaxseed, grapeseed, fish, algae and their combinations) were immobilized and stabilized by double emulsions, structured emulsions, oil bulking, spray-drying, electrostatic extrusion, coacervation, etc. [126].

While nutritional properties depend on the fatty acid profile of oils (olive oil is rich in MUFA and flaxseed oil in n-3 PUFA), the influence on the technological and sensory properties depends on oil properties, level of oil added, immobilization technique, and type of meat product. Regarding fermented sausages, research indicated that the drying and ripening processes were not altered independently of oil properties, the level of oil added, and immobilization technique [136,137] even when higher levels of oils were added [32]. In two research studies, Stajić et al. [139] and Stajić et al. [136] replaced five parts of backfat with five parts of grapeseed and flaxseed oil, respectively, (the second principle), both stabilized within three different techniques: oil-in-water emulsion with SPI, alginate gel and encapsulated by electrostatic extrusion in calcium alginate. Because of different color parameters between grapeseed and flaxseed oil, especially in terms of b* values, treatments with flaxseed oil had higher yellowness relative to control, compared to corresponding treatments with grapeseed oil. Moreover, this difference was pronounced in treatments (with both oils) where oils were immobilized with SPI. Moreover, the use of encapsulated flaxseed oil altered the properties of texture, i.e., lower hardness and chewiness, which is perceived as less desirable in sensory evaluation. The authors attributed this to the large number of microspheres thanks to which meat pieces are prevented from binding firmly during the fermentation and ripening stage. Alejandre et al. [137] found that instrumental color properties of fermented sausages with flaxseed oil gel emulsion with carrageenan (the first principle) depend on the amount of the added oil. Moreover, the authors reported that the treatment with the highest flaxseed oil content (about 4% in the formulation) was not acceptable in terms of sensory characteristics. Research about the use of high levels of oils (>5% in the formulation) is quite rare. Stajić et al. [32] used flaxseed oil immobilized as emulsion (with SPI) and alginate gel in the amount from approximately 5% to 9% in the formulation (initial batch). An increase in the amount of flaxseed oil progressively increased yellow tones (b* and h angle values), especially in sausages with SPI emulsion, while hardness and chewiness were reduced in sausages with flaxseed oil added as an alginate gel. All sausages were oxidatively stable during the 90 days of cold storage. However, an increase in flaxseed oil content (independently of immobilization) led to lower sensory acceptance especially in terms of color and overall acceptance, and texture in sausages with flaxseed oil added as alginate gel. The most recent research explores the use of oleogels in terms to provide higher levels of oils in dry-fermented sausages because oleogels can contain up to 90% of oil compared to gelled emulsion or encapsulated oils which contain no more than 50% [140,141]. Sunflower wax and beeswax are used as organogelator for immobilization of cold-pressed flaxseed oil [140] and olive and chia oil mixture [141]. The influence on properties of dry-fermented sausages depends on the oils and organogelator used, fat level substitution (partly [141] or totally [140]) and type of sausages. However, common features of both research are: lower hardness (and other textural properties), lower sensory grades, and lower oxidative stability of modified sausages. The future studies should be conducted to overcome these effects.

Regarding emulsion-type sausages, as was the case for fermented sausages, a simple reduction of the fat content is limited and a partial replacement of fatty tissue with non-fat fractions or with immobilized oils can provide better results. Kurćubić et al. [142] replaced backfat (20% in the formulation) in Pariser sausage in the amount of 25% to 100% with pre-hydrated cellulose fiber. Instrumental colour parameters were unchanged while hardness and chewiness were lower only in sausages with totally replaced backfat. Moreover, this sausage received the lowest grades for texture and juiciness after sensory evaluation. Regarding nutritional properties, a significant reduction of energy values was observed while the fatty acid profile was not improved (as had been expected). Improvement of the fatty acid profile was achieved by Stajić et al. [35] when chicken skin emulsion was partially replaced with immobilized flaxseed oil in all-chicken frankfurters. The authors replaced 25% and 50% of chicken skin emulsion with flaxseed oil immobilized by corn fiber and alginate with the aim to provide 50% and 100% of the recommended alpha-linolenic acid daily intake per 100 g of frankfurters. The addition of flaxseed oil increased yellow tones in modified frankfurters which was not noticed in the sensory evaluation, while other technological properties were similar to control. Regarding sensory evaluation, all modified frankfurters received similar grades compared to control. The fatty acid profile was improved in modified frankfurters, i.e., lower SFA contents, higher n-3 and total PUFA contents, while PUFA/SFA and n-6/n-3 ratios were more favorable. Pumpkin seed oil encapsulated in alginate and pectin matrices (using electrostatic extrusion) was used to partly (25%) replace backfat in beef model system emulsions with phosphates and with shell powder as a phosphate substituent [131]. Backfat substitution with encapsulated pumpkin seed oil increased yellow tones in treatments with phosphates and they were higher during cold storage, indicating the lower stability of encapsulated oil in the presence of phosphates.

Beef burgers where 50% of back fat was replaced with encapsulated (by the external ionic gelation technique) flaxseed and chia oils were successfully produced by Heck et al. [132]. The substitution did not alter technological properties and hardness, while burgers with flaxseed oil received better scores in sensory evaluation compared to the ones with chia oil. Regarding nutritional properties, modified burgers had lower fat content and more favorable PUFA/SFA and n-6/n-3 ratios.

4. Plant-Based Meat Analogues—A Trend of Increasing Popularity

The consumption of meat and meat products can be related to several health issues [143], furthermore, it can also have a negative sustainability perception, as many current environmental problems, e.g., greenhouse gas emissions, phosphorus cycle disruption, and water pollution, have been linked to the production of farm animals [143–145]. Other than sustainability issues, animal welfare and health are also big drivers for some consumers to reduce meat consumption and/or completely switch to a plant-based diet [145]. Therefore, meat analogues are becoming more popular, and consumers perceive them as a healthier and environmentally friendly alternative to real meat [146,147]. This popularity is reflected in market value growth, which is projected to be close to 7.9 billion USD in 2022 and to reach 15.7 billion USD by 2027 [148].

The general classification of meat products is as follows: formed (or ground), comminuted (emulsified) and whole muscle. Likewise, meat analogues are classified into these same categories [149]. As stated earlier, they are made with a combination of different plant ingredients and can be pre-heated (e.g., pre-cooked) in a factory or raw-produced and heated by a final consumer. Pre-heated products are mainly comminuted meat analogues (e.g., cold-cuts, hams, spreads and sausages) and one part of ground type products, like pre-cooked burgers, nuggets and meatballs. The most common raw-produced products in the market include "raw" formed products, e.g., burgers and meatballs. Plant-based whole muscle products, which have a pronounced fibrous structure, are usually produced with different extrusion techniques, which include dry and high moisture extrusion and shear-cell technology [150]. Another technique for the production of whole muscle meat analogues is to produce mycoprotein by continuous fermentation of fungus in bioreactors. Innovative techniques, such as wet-spinning, electro-spinning, and freeze structuring, are also used in the production of this group of products, and their detailed overview is given in the work of Dekkers et al. [149].

At present, there are many different meat analogue products in the market, produced with different techniques and ingredients. The ingredients that contribute the most to the nutritional profile of meat analogues are proteins, lipids and polysaccharides (e.g., starches and fibers). Further ingredients include additional non-protein binding agents (e.g., methylcellulose and gums), flavor components, and coloring ingredients, which contribute mainly to the structure and sensory properties of the final product.

Proteins in meat analogues are used in the form of isolates, concentrates and flours, with a function to retain water and oil, create a stable emulsion, form a gel upon heating or simply fortify a product with a selected amino-acid profile [151,152]. These functions of plant proteins are dependent on the compositional characteristics (such as protein primary and secondary structure and amino acid profile) and processing characteristics (such as pH, temperature, pressure, and ionic strength) [151]. To achieve a coarser and fiber-like texture, proteins are very often used in a textured form, produced with a wide range of extrusion technologies [149,151]. The plant proteins used the most for the production of these products include soy, wheat gluten, and mushrooms [143]. Soy proteins have been historically the most common proteins used for the production of a wide range of plant-based meat products, e.g., burgers, nuggets, sausages, cold-cuts, and whole-muscle products [153], because they have specific traits (e.g., bland flavor and a light color in comparison to other proteins) and are available at a low cost [152]. Additionally, soybean proteins have the beneficial amino-acid profile and the PDCAAS (Protein Digestibility Corrected Amino Acid Score) of 1.0 [153], which is comparable to meat, eggs, and dairy products [154,155]. The wheat gluten is used for its specific elastic texture, which can form a three-dimensional network that has a meat-like fibrous structure [156,157]. Its characteristics make it ideal to be used both as a binder and as a texturizer [151]. Nowadays, meat alternatives are also manufactured with an addition of proteins from pea, chickpea, lentil, potato, barley, oat, rice, mung-bean, canola and other crops, each of them having the specific functional properties and nutritional profile [143,158,159]. Nutritionally, legume proteins (i.e., from pea, lentil, chickpea and mung-bean) have a PDCAAS between 0.40 and 0.70, as they are low in methionine and with lower digestibility compared to, e.g., soy [155,160]. Most recently, an edible fungi and micro-algae have been used as a protein source in these formulations [161], which have a very favorable PDCAAS of 1.0 [155,162,163]. While animal derived proteins contain each of the nine essential amino acids, with an excellent digestibility, meat analogue products are usually produced with a combination of various plant proteins to match meat protein attributes, both for nutritional and functional purposes [160,163,164]. As the environmental impact of most food products is currently based on the quantity of protein produced, it is generally considered that the production of meat has a much higher "environmental footprint" compared to plants. However, if the quality of protein was considered here, especially the amount and presence of essential amino acids and their digestibility, the overall environmental footprint of meat and meat products would be much lower than previously estimated and probably comparable to most plant foods [165].

The amount of lipids in meat analogue products on average matches their real meat counterparts [160]. Commonly used lipids include firm plant fats, that can mimic "visible" fat particles of meat products (e.g., in burgers, sausages and mortadella) and various oils, which are usually added in a liquid form or pre-emulsified [151]. Palm and coconut fat and canola, sunflower, soy, and corn oil are some of the fats and oils mostly used as an ingredient in plant-based meat products. Adding vegetable oil and fat can enhance juiciness, flavor and overall mouthfeel, which are very important sensory features of the final product [152]. From a nutrition standpoint, compared to animal derived products, fats and oils used in meat analogues generally contain a greater portion of polyunsaturated fatty acids, less saturated fatty acids and no cholesterol. The variability of fatty acid composition of plant fats and oils presents a big opportunity for food processors to tailor a desirable fatty acid profile and boost the nutritional quality of the final product [151,161].

Meat does not contain carbohydrates, although ingredients, such as starch and fibers, are commonly added to various meat products to improve their functionality, structure and nutritional profile [166]. Polysaccharides used in the production of meat analogues are usually starches, flours, and non-starch hydrocolloids, e.g., methyl-cellulose, carrageenan, xanthan, guar, and many others [143,164]. These ingredients are added to improve the texture, components binding, mouthfeel, and juiciness by retaining the water inside the product. Generally, the carbohydrates used in plant-based industry do not differ much from the ones used in the real meat industry. The possible exception is methyl-cellulose, a modified cellulose dietary fiber, which is included in many modern meat analogues, with a function as a hot-set binder, and is not a common ingredient in real meat products [160]. Although, with a current E-number free trend in the food industry, many producers are looking for alternative ingredients as replacement.

Plant-based meat analogues are not a new food category, as they are produced from ancient times, like soy-based products in China [160]. They are formulated to mimic real meat products in terms of appearance, texture, flavor and macro-nutrient specifications [143,151,163,164]. One of the most marketed advantages of meat analogues over real meat products is improved nutritional characteristic. Yet, one of the biggest drawbacks of modern meat analogues is that many of them are produced with little or no whole food ingredients and can be categorized as ultra-processed food [160]. Regarding this, current trends in this field are going in the direction of decreasing the number of ingredients in the label, using E-number free ingredients, as well as improving the nutritional profile. Plant-based meat analogues are a valuable dietary option, whose production is nowadays booming. Arguably, they are unlikely to have a big impact on the food market and significantly substitute real meat and poultry products in the recent future [150,152]. Nevertheless, with an increasing world population and a big demand for sustainable, organic, and nutrient rich food, the production of plant-based meats is going to keep evolving in terms of their formulation and nutritional specification.

5. The Utilization of Plant Extracts in Meat, Meat Products and Fodder as Natural Antioxidant and Antimicrobial Additives

Antioxidants are a frequent addition to meat products, and they can be of natural or synthetic origin. Most meat products are prepared using traditional additives with AOX properties, such as vitamin C and E, sodium erythorbate, or sodium hydrosulfite, and to a minor extent substances of natural origin (phytochemicals, other vitamins or extracts) are applied. The use of natural antioxidants in the meat industry is scarce. Although several meat products are labeled as "organic" and "natural", no natural antioxidants are used in their production. These facts indicate the lack of interest by researchers when it comes to the application of natural antioxidants in the development of meat products. Furthermore, the use of synthetic antioxidants is considered more cost-effective, safer and simpler, thus reducing the use of natural antioxidants [167,168]. However, consumers nowadays are becoming more aware of potential adverse effects of synthetic food additives [44,51] and therefore they have a positive attitude when purchasing meat products with natural additives [169,170]. Synthetic antioxidants in high doses can be carcinogenic, and there is much less substantiated evidence that indicates the harmful effects of naturally occurring antioxidants [171]. Not only are those natural antioxidants capable of neutralizing reactive oxygen species (ROS), but they also reduce the likelihood of toxin formation when high temperatures are applied in thermal processing of products [172]. Natural antioxidants utilized in the product formulation might also increase the existing antioxidant (AOX) potential, even if the meat is not subjected to extensive processing. This additional health and nutritional benefit could be a distinct advantage of natural antioxidants applied in meat processing. Thus, there is a growing interest in pursuing proper preservatives of plant origin.

Plants (herbs, fruits, and vegetables) are an endless source of BAS with strong AOX and AM activities, which can be utilized in food processing. Most of these compounds belong to the secondary metabolites that are responsible for plant protection from microorganisms and pathogens, and they also define organoleptic properties of plants. Regarding the chemical composition, secondary metabolites are phenolic compounds and include phenolic acids, flavonoids, quinones, tannins, etc.

Most studies on the shelf life of meat products enriched with natural (plant) extracts have focused on inhibiting lipid oxidation by improving their AOX power, while research on improving AM activity is limited. Oxidation is one of the main factors that causes a decrease or degradation of the quality of meat products, if we exclude the influence of microorganisms. Oxidative processes affect lipids and proteins in meat, which leads to spoilage and unacceptability of meat products by consumers [173]. Oxidative processes lead to the development of an unpleasant taste, deterioration of color and reduction of the nutritional quality of meat products, due to the breakdown of essential fatty acids and vitamins. Lipid oxidation in meat products is mainly generated through multiple factors, such as fatty acid composition, heme proteins, and metals [5]. In addition to the aforementioned degrading changes, protein oxidation leads to the deterioration of meat softness and juiciness and reduction of essential amino acid content and digestibility [174]. Moreover, it is considered that the multiple toxic compounds produced during lipid oxidation are the cause of pathological changes that lead to cancer, inflammation, atherosclerosis, Alzheimer's disease and accelerate the aging process [175,176]. Therefore, the use of antioxidants is of vital importance in the meat industry. However, the addition of antioxidants, both synthetic and natural, is usually followed by the changes in the sensory characteristics of meat products and that is a major challenge for the meat industry.

The shelf life of meat products can easily be extended by controlling the temperature conditions during their storage, using modern packaging and using preservatives [177–179]. There is a danger that consumers may not be interested in the benefits of extending the shelf life of meat products or the issues related to lipid oxidation. Certain consumers prefer meat products with a short shelf life, because they believe that such products do not contain additives or are natural.

Researchers worldwide added various plant extracts in meat in order to prevent oxidation. Thus, different fruit and herb materials and extracts were added in meat and poultry products as a potential replacement for synthetic additives [180–182]. Extracts of grape seed, green tea, rosemary, pomegranate, nettle, pine bark, cinnamon, and cloves exhibited stronger antioxidant properties than some common synthetic compounds. Nevertheless, the addition of such natural antioxidants may influence organoleptic properties of meat, mostly color, and this parameter must be taken into consideration [7]. Burri et al. [183] obtained 28 plant materials and extracts and screened their capacity for inhibition of lipid oxidation in a processed meat model system, applying from 5 to 200 ppm (based on total phenolic content). After two weeks of application of 200 ppm, summer savory freeze-dried powder, beetroot leaves ethanol extract, and olive powder polyphenols sample decreased oxidation down to 17.2%, 16.6%, and 13.5%, respectively, compared to the blank sample. Utilization of only 5 ppm of rhubarb juice during the same period of time (two weeks) resulted in a decrease in lipid oxidation for 68.3%, compared to the additive-free sample [183]. Plant biomass extracts might be utilized as natural antioxidants in meat [184].

In an interesting review, the natural antioxidants used in various meat products of pork, beef, poultry, lamb, and goat meat were listed [43]. The tables show the types of meat products, raw materials and concentrations in which they were used, active substances and factors, and references from which the presented data were taken. In most of the mentioned studies, antioxidant substances of plant origin were applied, such as: phenols, flavonoids, anthocyanin, chlorogenic acid, lycopene, quercetin, catechins, tocopherol, rutin, caffeic acid, ferulic acid, p-coumaric acid, protocatechuic acid, β- carotene, vitamin C, vitamin E, carotenoids, myricetin, caronosin, kaempferol, zeaxanthin, chrysin, chlorophyll, sesamol, rosmarinic acid, carnosic acid, carnosol, and gallic acid. The levels of AOX materials used in meat products varied from 7.8 ppm to 19.8%, with the levels depending on the characteristics of the AOX materials. Overall, the use of natural antioxidants in meat products contributed to the inhibition of the activity of various radicals, TBARS, free fatty acids, volatile basic nitrogen, and peroxide value.

The addition of individual herbs or spices to the nitrite-reduced frankfurter sausages showed a great impact on the AOX capacity during 30 days of storage. Sausages with rosemary showed the highest antioxidant activity, followed by sausages with thyme, black pepper, turmeric, and red paprika. Authors showed that AOX capacity was highly correlated with total phenolics present in these herbs and consequently in the sausages (R^2 varied from 0.944 on the day of sausage production up to 0.976 on the 30th day of storage at 4 °C) [185].

Plant extracts, raw materials, and fruit and vegetable by-products and wastes have been added into the fodder in order to improve not only the animal health and welfare performance, but also the oxidative stability and organoleptic properties of meat (Table 2). Some studies showed that essential oils of certain plants might improve the quality of meat products if added both in the fodder [186] and directly into the raw or cooked meat [187–189].

Table 2. Influence of enriched animal diet on meat quality parameters.

Supplementation	Animal	Benefits	Reference
Cistus ladanifer L. extract	Lambs	Antimicrobial activity	[190]
Rosemary extract	Lambs	Increased lipid stability	[191]
Grape pomace silage	Lambs	Increased lipid and protein stability	[192]

Table 2. *Cont.*

Supplementation	Animal	Benefits	Reference
Pomegranate by-product	Lambs	Increased concentration of vitamin E, suppressed lipid oxidation and metmyoglobin formation	[193]
Red orange and lemon extract	Lambs	Antimicrobial activity	[194]
Mimosa, chestnut and tara extracts	Lambs	Reduced "pastoral" odour of lamb meat	[195]
Artichoke, celery, beet, onion, garlic, spinach, avocado, oats and parsley extracts	Pigs	Increased quality and sensorial characteristics of meat	[196]
Grape seed extract	Pigs	Improved quality and antioxidant capacity of meat, changed, changes the fatty acid composition	[197]
Tomato processing waste	Pigs	Reduced intramuscular fat, changed fatty acids composition	[198]
Moringa oleifera and mulberry leaf	Pigs	Increased meat quality	[199]
Mango extract	Pigs	Increased lipid and antioxidant stability	[200]
Rosemary extract	Pigs	Antimicrobial activity	[201]
Grape pomace	Chickens	Increased concentration of linoleic acid, decreased lipid oxidation	[202]
Olive leaf extract	Chickens	Antimicrobial activity	[203]
Goji berries (*Lycium barbarum*)	Rabbits	Decreased lipid oxidation, improved oxidative stability	[204]
Olive oil by-products extract	Rabbits	Antimicrobial activity	[205]

Recent data indicate the existence of more than 1340 registered plants from which over 30,000 compounds have been extracted that exhibit antimicrobial effects [206]. The use of AM agents of natural origin is widely accepted by consumers, because it has the GRAS status (GRAS—Generally Recognized as Safe). Today, *Listeria monocytogenes*, *Clostridium perfringens*, *Salmonella* spp., and *Escherichia coli* are considered to be the main causes of food poisoning isolated from meat products [207–209]. Although phenolic compounds of plants contain a certain level of AM activity, such application in meat production is not widely spread. Nevertheless, certain innovative solutions in this field recently showed up. Rahnemoon et al. [210] encapsulated pomegranate peel extract into alginate nanospheres and tested the AM activity of such nanoparticles in coated boneless chicken breasts during storage at 4 °C for two weeks. The authors found that the total microbial count was quite diminished in extract-loaded nanosphere coated samples after 14 days of storage (6.5 log CFU/g) compared to the alginate containing the extract and the control sample (without pomegranate extract). It is noteworthy that the upper limit of total microbial count is 7 log CFU/g, as defined by the International Commission on Microbiological Specification for Foods. The same trend was observed regarding the yeast and mold counts and psychrophilic bacteria in these chicken breast samples. Other plant extracts were also applied in processed meat to prevent microbiological activity: Amaranthus tricolor [211], sage [212], basil, calendula, corn silk, laurel, oregano, rosemary, spearmint, thyme [213], etc. [214]. However, there are insufficient studies on the criteria for selecting natural materials with appropriate characteristics for use as natural additives and further research is needed [52].

6. Conclusions

The design and creation of "healthier" or functional meat products have yet to experience a more serious transfer from biomanufacturers to the meat industry. A big multi/trans disciplinary challenge for scientists and experts is the production of tasty and nutritious biologically high value meat and meat products, to which negligible amounts of synthetic additives (chemical by-products) potentially harmful to public health have been added. Recent research reveals that it is possible to prevent health risks and minimize the impact of potentially risky synthetic substances via the targeted application of secondary metabolites of plant origin that exhibit antimicrobial and antioxidant activities. Natural antioxidants can successfully inhibit the formation of toxic substances that arise in complex reactions, especially during the processing of meat products at high temperatures. Moreover, with the prudent use of natural functional ingredients, the taste and color of the product can be maintained and shelf life extended. Continuous research is necessary to identify the most effective natural preservatives and antioxidants from various available natural plant raw materials, making maximum use of their already described synergy, in order to achieve the strongest target effect in optimal (low) concentrations of active substances. Along with the application of plant extracts, it is valuable to apply an optimized processing process (e.g., minimal food processing procedures), in order to prevent the matrix, which is rich in proteins and fats, from reflecting negatively on the effectiveness of herbal bioactive substances, as well as to avoid a decrease in the biological value of groceries. There is already evidence that meals containing meat products fortified/enriched with natural preservatives and antioxidants can prevent infections with multi-resistant microorganisms, as well as more scarce information about the potential for strengthening antioxidant power in the human body against oxidative stress. All of the above indicates that food reformulation is a relatively new strategy aiming to develop foods with beneficial properties for human health. This will require a high level of multidisciplinary research efforts in the future, which will be promoted to consumers and the meat industry. In addition, superior results are expected from the combination of the application of supplements of plant origin and meat processing with modern green technologies, e.g., ultrasound, high-pressure processing, and pulsed electric field, as environmentally friendly processes. This kind of synergy would make it possible to obtain safe products with preserved biological value, as well as for modified products to be adequately declared as "clean label" products.

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