

Review

Red Beetroot. A Potential Source of Natural Additives for the Meat Industry

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Featured Application: This review aims to conduct an exhaustive search on the main bioactive compounds present in beetroot, with a primary focus on the implications of their consumption on human health as well as highlighting research that has utilized beetroot (or their products) for the reformulation of meat products. Despite the fact that some studies presented very promising results, the number of researchers that have investigated the use of beetroot in meat or meat products is very limited. Therefore, in addition to exposing the main achievements and observations, this review comprehensively discusses the potential that this vegetable has for the meat industry.

Abstract: Currently, the food industry is looking for alternatives to synthetic additives in processed food products, so research investigating new sources of compounds with high biological activity is worthwhile and becoming more common. There are many different types of vegetables that contain bioactive compounds, and additional features of some vegetables include uses as natural colorants and antioxidants. In this sense, and due to the special composition of beetroot, the use of this vegetable allows for the extraction of a large number of compounds with special interest to the meat industry. This includes colorants (betalains), antioxidants (betalains and phenolic compounds), and preservatives (nitrates), which can be applied for the reformulation of meat products, thus limiting the number and quantity of synthetic additives added to these foods and, at the same time, increase their shelf-life. Despite all these benefits, the application of beetroot or its products (extracts, juice, powder, etc.) in the meat industry is very limited, and the body of available research on beetroot as an ingredient is scarce. Therefore, in this review, the main biologically active compounds present in beetroot, the implications and benefits that their consumption has for human health, as well as studies investigating the use beetroot in the reformulation of meat and meat products are presented in a comprehensible manner.

Keywords: *Beta vulgaris* L.; betalains; betanin; natural colorant; natural antioxidant; synthetic additives replacers; healthy meat products; lipid oxidation

1. Introduction

The food industry, and more specifically the meat industry, is of vital importance both from a social and economic point of view. However, microbial degradation and oxidative phenomenon are the two main factors of food spoilage [1]. These processes generate important economic losses to the industry and can be a major problem for consumer health. Therefore, the use of synthetic additives and preservatives to ensure the safety and quality of food is widely implemented worldwide. Among these additives, the meat industry uses multiple colorants and antioxidants to limit oxidative processes as well as the deterioration of the color of meat and meat products derived from these reactions [2,3]. It is well known that color is the main attribute that influences consumer acceptability and purchase intention, so it is a very important factor that should be controlled by the manufacturer [4]. In this regard, processed meats are expected to have a characteristic color profile; for example most beef products have a cherry red color [5].

The use of synthetic nitrate and nitrite ingredients is very frequent in this industry, since these ingredients ensure color stability and the correct flavor development in meat products [2,6], in addition to serving as powerful antimicrobial agents against pathogenic organisms such as *Clostridium botulinum*, the outgrowth of its spores, as well as growth of other bacteria [7,8]. However, nitrite and nitrate cause the formation of carcinogenic nitroso-compounds [9]. Therefore, despite not being able to totally dispense with these compounds in the meat industry, their use tends to be reduced or substituted by other additives or alternatives [2,7].

With this in mind, nowadays, consumers demand more natural products, which limits the meat industry in the use of synthetic additives, leaving manufacturers with few other options [1]. Moreover, there is a global tendency for the increased consumption of functional foods due to consumers who are looking for a safer way to improve their health [10], which has a strong influence on the meat processing industry's practices. To this regard, during the last several decades, the replacement of synthetic additives with natural bioactive compounds was a significant endeavor studied by the scientific community and also the industry [4,11,12]. Consequently, there exists a continuing interest in identifying new sources of valuable and natural additives to increase food stability and safety [13–15].

On the other hand, agricultural practices tend to be modernized in order to exert less impact on the environment and optimize resources such as land and water [16,17]. However, wastes and by-products, in the form of pods, peel, pulp, and seeds, generated during processing of fruits and vegetables is of major concern to the agricultural industry. These wastes cause considerable environmental impact and economic losses [18]. However, it is well known that residues from vegetable processing normally still contain a large amount of bioactive compounds, which offers an inexpensive source of high-value compounds for the food and meat industry [4,13,19]. In this regard, red beetroot (*Beta vulgaris* ssp.), beetroot products (juices, powder, extracts, etc.), and other residues generated during processing can be considered an excellent source of raw materials that can serve as functional ingredients (antioxidants and/or colorants) [8]. The beetroot is a vegetable grown throughout the Americas, Europe, and Asia [20]. The world production in 2017 was 301 million tons, where Western Europe is the largest producer with about 70% of the total production (200 million tons) [21,22]. Most beetroot is consumed as a vegetable, although it is also consumed as juice and can be processed into a powder for use as a food coloring agent [22]. Due to the high content of betalains (pigments with deep and powerful purplish-red color, and antioxidant activity), phenolic compounds (antioxidants), and inorganic nitrate, the use of both juices and beetroot powder offer an excellent opportunity to increase the shelf life of meat and meat products while also limiting the use of (and potentially replacing) synthetic additives [9,18,23]. Moreover, beetroot extracts have antibacterial activity against a wide range of bacteria, while no inhibitory activity has been found against fungi and yeasts [24]. Finally, the exceptional composition of beetroot (high content of vitamins, antioxidants, and other biologically active compounds), their consumption, and/or their application as functional ingredient in meat products can exert important health-promoting properties [21].

Nevertheless, the direct use of beetroot juice or powder can have a negative effect on the sensory characteristics of meat products. This is due to the presence of geosmin in the beetroot, which impart a significant and undesirable earthy flavor. In order to limit this drawback, some authors have proposed the use of the extracted bioactive compounds, instead of the direct addition of juice or powder [24].

Despite the potential that raw materials obtained from beetroot offers for the meat industry, it should be noted that most of the studies to-date focus on the extraction and purification processes of compounds, such as betalains or phenolic compounds. However, there are a limited number of researchers that have applied beetroot and its extracts in the reformulation of meat products [8].

Therefore, this article aims to generate an extensive and comprehensive review of the compounds obtained from beetroot that are of great interest to the meat industry, the implications that the intake of these compounds has on human health, as well as review the studies that have applied beetroot or extracted compounds from beetroot to increase the stability and safety of meat products.

2. Phytochemicals Present in Beetroot

Beetroot has a nutritive composition, with high amounts of dietary fiber [25] and high content of several biologically active compounds (Figure 1), including betalains (betacyanins and betaxanthins), carotenoids (β -Carotene, lycopene, and lutein), alkaloids (calystegine B1, calystegine B2, calystegine C1, calystegine B3, ipomine), glycosides, phenolic acids (ferulic acid, caffeic acid, syringic acid, p-coumaric acid, vanillic acid), flavonoids (rutin, rhamnetin, astragaline, rhamnocitrin, kaempferol), terpenoids (triterpenes and sesquiterpenoids), coumarins, saponins (oleanic acid and several betavulgarosides), vitamins (A, E, K, C, B₁-thiamine, B₂-riboflavin, B₃-niacin, B₅-pantothenic acid, B₆-pyridoxine, B₉-folates, and B₁₂-cyanocobalamin), phytosterols, minerals (iron, phosphorous, potassium, calcium, manganese, magnesium, and selenium), and inorganic nitrate [10,21,26–28].

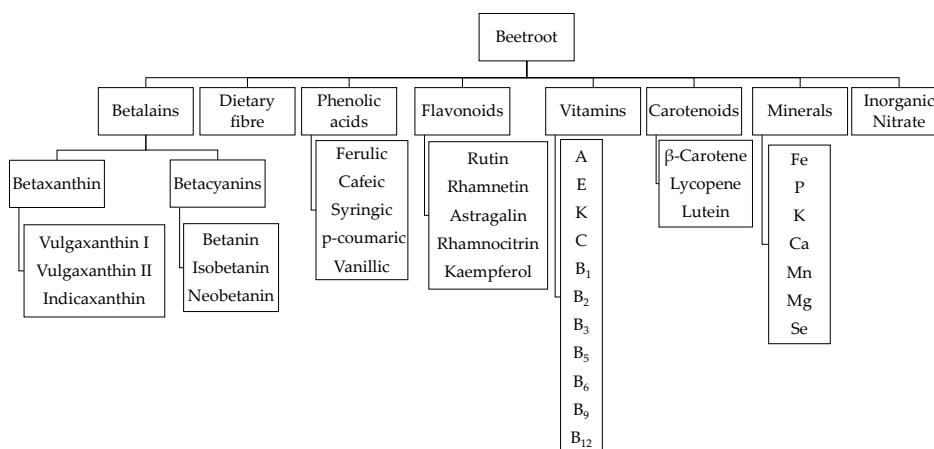


Figure 1. Scheme of the main bioactive compounds present in beetroot.

Despite the high content of compounds that are of great interest to the meat industry, it must be borne in mind that the chemical and nutritional composition, as well as the content of bioactive compounds, depends on multiple factors [24]. These include the harvesting conditions, the beetroot variety, maturation stage, or the soil and climatic conditions. In addition, it is also important to point out that the amount of beetroot compounds depends on the anatomical part of the plant (leaf, stem, root, peel) [10]. All these aspects are vital when utilizing beetroot as a source for extracting active compounds for food application [24].

Even though the multiple compounds mentioned above are noteworthy for the food industry, the subsequent section will focus on those that are of special interest to the meat industry, which is the subject of this review.

2.1. Betalains

It is well known that betalains are the most important compounds present in beetroot. They are plant secondary metabolites with similar chemical properties, biological functions, and color spectrums as anthocyanins. However, anthocyanins and betalains never coexist together in plants [20]. Betalains are hydrophilic nitrogenous pigments, which could be subdivided into two main groups according to their chemical structure and color [26]. Betacyanins present a red-violet color, while the betaxanthins are yellow pigments (Table 1). Thus, these compounds had an extreme potential for their use in meat products as natural colorants. In the literature, there are discrepancies regarding the proportions between betacyanins and betaxanthins in beetroot, although it seems clear that the content of betacyanins in beetroot is much higher than that of betaxanthins. Some authors reported that the betacyanins represented about 80–90% of total betalains [28,29], while others found that the concentration of betacyanins was between 50–70% of total betalains [20,30]. The variation in these proportions determines the coloration of the root, and the higher content of betacyanins confers its typical red-purple pigmentation [3].

More than 90 different betalains (60 betacyanins and 33 betaxanthins) have been found in nature [9]. Despite the large number of compounds referred to by the term betalains, the betacyanins that are found in the highest concentration in beetroot are, in decreasing order, betanin, isobetanin, neobetanin, and probetanin (Figure 2). In the case of the betaxanthins present in beetroot, also in descending order, they are vulgaxanthin I, vulgaxanthin II, indicaxanthin, miraxanthin, and portulaxanthin (Figure 3) [3,5,24,31].

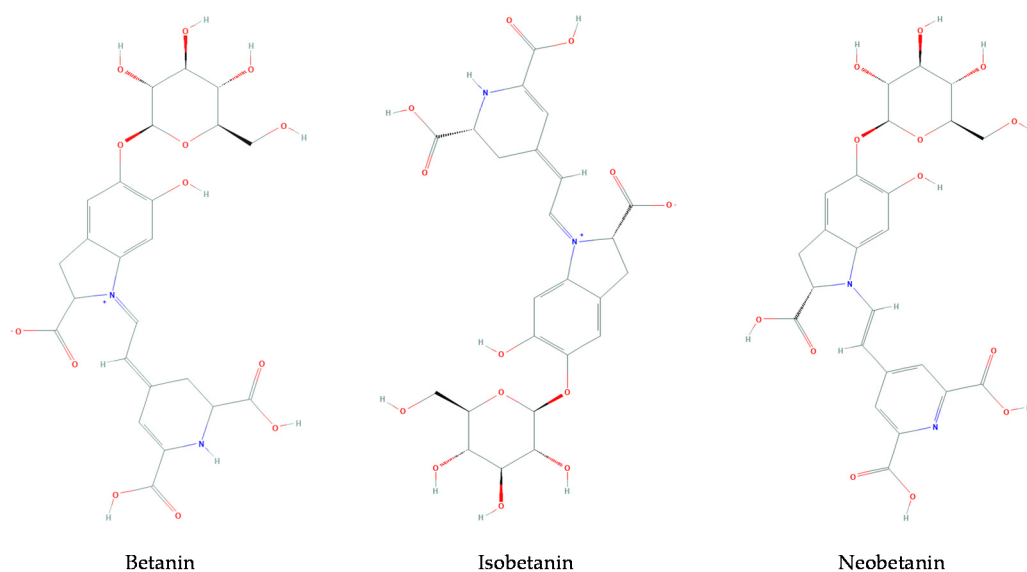


Figure 2. Chemical structure of the three main beetroot betacyanins.

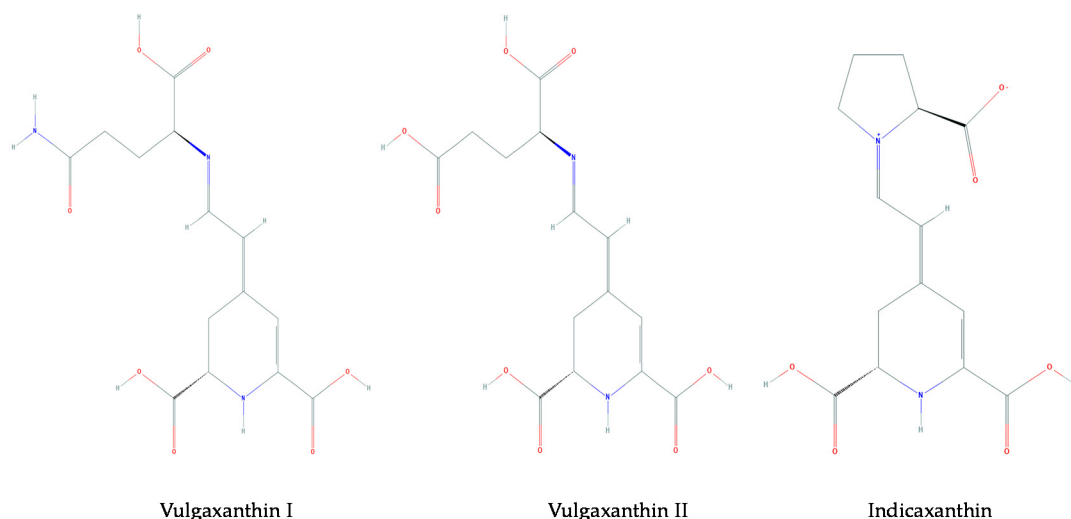


Figure 3. Chemical structure of the three main beetroot betaxanthins.

Despite this, different studies have observed a large number of betalains in beetroot. In a previous study, the authors detected a total of 20 betacyanins and 11 betaxanthins in dried extracts from beetroot [30]. In addition to the betalains discussed above, important contents of 17-decarboxy-isobetanin, 15-decarboxy-betanin, betanidin and 17-decarboxy-neobetanin (betacyanins) and γ -aminobutyric acid-betaxanthin, isoleucine-betaxanthin, and isovulgaxanthin IV (betaxanthins) were detected. Similarly, in more recent research, other authors have identified 18 betacyanins and 12 betaxanthins in different beetroot varieties [32]. In addition to the majority of betalains, this research also observed high amounts of other betacyanins (2,17-bidecarboxy-betanin/isobetanin, 2,17-bidecarboxy-neobetanin, 17-decarboxy-neobetanin, 17-decarboxy-betanidin/isobetanidin, 17-decarboxy-betanin), and betaxanthins (valine-betaxanthin, vulgaxanthin IV, 3-methoxytyramine-betaxanthin, γ -aminobutyric-acid-betaxanthin, and vulgaxanthin III). In the same way, fermented grated beetroot and juiced beetroot were described with a total of 32 betalains, including 24 betacyanins and 8 betaxanthins [28].

On the other hand, although betalains are chromoalkaloids, they have no toxic effects [33] and are a potential natural alternative to replace synthetic colorants in the food industry [21]. Due to this fact, betanin was approved for use as a natural food coloring, both in Europe (additive E-162) and the United States (Food and Drug Administration, Title 1 of Code of Federal Regulations, 21 DFR 73, 40) [3,21]. However, its application as a food colorant agent is conditioned by its sensitivity to degradation to different processes in the industry [21].

According to their stability, it should be noted that betalains maintain their structure through a wide pH range (between pH 3 and 7) [33,34]. This makes these pigments suitable for use in both low-acid and pH-neutral foods [35]. This is an advantage compared to other natural compounds such as anthocyanins, as the color is stable over wider pH and temperature ranges [18]. In addition, it is important to highlight that betalains also had other advantages, since they are more water-soluble, presented higher coloring strength and greater free radical ability than anthocyanins [23,26]. Moreover, betalains have a higher molar extinction coefficient than synthetic dyes, which gives them a very high coloring power [9].

Although betalains are stable in a wide pH range, they are susceptible to light, enzymatic activity, metal ions, oxidation, and heat during food processing and storage [21]. To this regard, the thermostability of betalains is the greatest between pH 4 and 5 [10], and different studies concluded that betacyanins are more thermostable than betaxanthins [10,26]. In contrast to this, other authors reported that betacyanins decreased whereas betaxanthins increased when the drying temperature rose from 50 to 120 °C [18].

The specific conditions of each processing technique result in a different degradation of betalains. These losses mainly depend on the temperature and time of the process [9]. The application of

non-conventional technologies, such as microwave retained can even increase the content of betalains, in contrast to the significant losses obtained with the traditional boiling or roasting techniques [36]. The degradation processes include isomerization, decarboxylation, and/or cleavage of betalains during processing, by heat and/or acid methods. This could explain that thermal processes applied during beetroot processing increase isobetanin concentrations as a consequence of the epimerization of betanin to isobetanin [37]. However, it is also important to note that the application of intermediate heat treatments would protect betalains since they would inactivate the autochthonous enzymes responsible for the degradation of these pigments [36]. The main sign of deterioration of betalains is a loss of color since their pigment properties are modified [27].

Table 1. Content of total betalains, betacyanins, and betaxanthins in different beetroot sources.

Beetroot Material	Pigments			Ref.
	Betacyanins	Betaxanthins	Total Betalains	
Beetroot extract	300 mg/L	261 mg/L	562 mg/L	Aykln-Dinçer et al. [9]
	16.3–20.7 mg/g	19.0–30.78 mg/g	39.7–47.1 mg/g	Georgiev et al. [38]
	221–337 mg/L	122–182 mg/L	-	Raikos et al. [36]
	3.46–4.20 mg/g	2.59–2.80 mg/g	-	Righi Pessoa da Silva et al. [39]
	55.17 mg/100 g DM	0.71 mg/100 g DM	-	Vulić et al. [40]
Beetroot pulp	-	-	370 mg/100g	Chhikara et al. [41]
Beetroot flour	-	-	68–81 mg/g DM	Costa et al. [18]
Grated beetroot	38–116 mg/kg	13–19 mg/kg	-	Czyżowska et al. [28]
Beetroot juice	24–69 mg/L	6–19 mg/L	-	
	2.81 mg/g DM	1.27 mg/g DM	-	Desseva et al. [20]

DM: Dry matter.

Nevertheless, not only the processing conditions affect the stability of betalains, but proper storage conditions are also critical to limit their degradation. A recent study concludes that raw and cooked beetroot juice clearly show degradation of betalains during storage, both in dark and under lighted conditions [23]. These authors found that the cooking process (probably due to enzyme inactivation) and refrigeration storage increase the stability of juice pigments. The same authors also reported that the stability of betalains was independent of changes in pH. Similarly, the storage of beetroot juice at -80°C during 32 days did not show changes, while samples stored at room temperature showed significant degradation of betacyanins [27]. The storage of fermented beetroot and beetroot juice at 5°C during 7–10 months resulted in about 3-fold decrease of red pigments [28].

In addition to the coloring properties and in comparison with other compounds, the use of betalains as bioactive agents has not been extensively explored, despite the fact that many studies indicate that they have high antioxidant power (Table 2). In fact, beetroot belong to the group of 10 vegetables with the highest antioxidant potential [20]. This is related to the antioxidant potential of betanin, which is about 2-fold more active than anthocyanins [26], 10-fold higher than tocopherol, and 3-fold higher than catechin [10]. Moreover, beetroot is well known for high antioxidant and free radical scavenging activities of betalains, which are comparable to the synthetic antioxidant butylated hydroxytoluene (BHT) [42]. However, as discussed regarding the color stability of beetroot, different processing and storage conditions have an important impact on antioxidant potential [37]. Some authors reported that the antioxidant properties of beetroot powder (DPPH scavenging activity) were improved with a temperature increase from 60 to 70°C . However, with higher temperatures (80°C), the same authors observed a significant reduction of the antioxidant activity [18]. The application and use of moderate temperatures during processing of beetroot increased the content of betalains and improved the antioxidant activity of beetroot powder. This could be related to facilitating the breakdown of cellular organelles and the release of these compounds. However, several studies

reported contradictory effects of processing/extraction temperatures on the content of betalains. In this regard, it is well known that beetroot has several endogenous enzymes such as β -glucosidases, polyphenoloxidases, and peroxidases [43,44], which have an important role in the degradation of betalains. Therefore, the application of moderate-high temperatures that effectively inactivate these enzymes ensures greater stability of the beetroot products (juice, powder, extract, etc.), both during processing and storage. Nevertheless, it must be taken into account that the high temperatures also cause degradation of several bioactive compounds.

However, more factors than just the use of moderate-high temperatures affect the amount of bioactive compounds, since other processes actively influence their content. In a recent research study, authors observed that vacuum treatment during processing favors the extractability of betalains from beetroot tissues [43]. These compounds are highly sensitive to oxidation, so therefore it seems clear that the application of high temperatures in vacuum-treated samples has a different effect on the degradation of betalains than the application of the same temperature in samples processed/stored in an atmosphere containing oxygen. Simply, low oxygen levels favor the pigment to be partially recovered after degradation [43]. Other authors reported that the application of a chlorination process to beetroot reduced the content of betalains and antioxidant activity when they are dehydrated at 80 °C, while this process did not affect the content of betalains at lower temperatures [18]. So, despite the fact that temperature plays a very important role in the degradation of betalains, other factors and treatments during processing also influence their degradation, and consequently, their antioxidant activity. In fact, a high correlation between the antioxidant activity of beetroots and content of betalains were reported by several authors [20,33]. Additionally, it is important to note that this correlation is stronger with betacyanins than with betaxanthins, which indicates that the red pigments had greater antioxidant properties than yellow pigments [26]. The free radical scavenging activity is exceptionally high at a pH higher than 4 [44].

However, it is important to take into account that although betalains (especially betacyanins) have strong antioxidant power, the high antioxidant capacity of beetroot cannot only be attributed to these compounds but must be due to both betalains and phenolic compounds found in this vegetable [18,20,40].

2.2. Phenolic Acids and Flavonoids

Beetroot are recognized as an important source of dietary phenolic compounds, including both phenolic acids and flavonoids [24]. This characteristic composition, together with the aforementioned content of betalains, results in a vegetable with an exceptionally high antioxidant and radical scavenging capacity [10]. However, once again, the total phenolic and flavonoid contents reported in different studies presented high variation (Table 3). As discussed for betalains, phenolic content also varies among different parts of the plant [24]. In this regard, it was observed that beetroot peel presented the highest total phenolic content, followed by crown and flesh [48]. Similarly, the processing steps in the industry also has an important influence on the amount and quality of phenolic content [24]. However, although the application of heat treatments is usually linked to the reduction of these compounds, this is not always the case. In fact, some authors reported that heat application protects the phenolic and flavonoid content, which enhanced the total antioxidant capacity [37]. Moreover, storage conditions are a crucial factor for maintaining the amount of phenolic compounds and antioxidant activity. In a recent study, authors observed that total phenolic content decreased in grated beetroot (from 920 to 570 mg/kg) and beetroot juice (from 810 to 540 mg/L) during three months of storage under refrigeration (5 °C) [28].

Table 2. Antioxidant activity in different beetroot sources.

Beetroot Material	Antioxidant Activity					Ref.
	DPPH	ABTS	FRAP	ORAC	CUPRAC	
Beetroot pulp	70 (%) inhibition)	-	-	-	-	Chhikara et al. [41]
Beetroot leaves	-	-	-	200.3 μ mol TE/g DM	-	Ninfali and Angelino [45]
Beetroot powder	65 (%) inhibition)	-	-	-	-	Costa et al. [18]
	7140 mg TE/g	429 mg AA/100 g	1275 μ mol FE + 2/100g	-	-	Ozaki et al. [46]
Fresh beetroot	-	-	-	18.21 μ mol TE/g DM	-	Ninfali and Angelino [45]
	137 mg TE/100 g	190 mg TE/100 g	181 mg TE/100 g	-	3889 mg TE/100 g	
Boiled beetroot	131 mg TE/100 g	158 mg TE/100 g	126 mg TE/100 g	-	3376 mg TE/100 g	
Dried beetroot	143 mg TE/100 g	188 mg TE/100 g	170 mg TE/100 g	-	3567 mg TE/100 g	
Pickled beetroot	114 mg TE/100 g	122 mg TE/100 g	66 mg TE/100 g	-	2413 mg TE/100 g	Guldiken et al. [37]
Beetroot jam	127 mg TE/100 g	160 mg TE/100 g	126 mg TE/100 g	-	2931 mg TE/100 g	
Beetroot puree	139 mg TE/100 g	186 mg TE/100 g	148 mg TE/100 g	-	3529 mg TE/100 g	
Beetroot juice	110 mg TE/100 g	126 mg TE/100 g	112 mg TE/100 g	-	2397 mg TE/100 g	
	56.7 μ mol TE/g DM	95 μ mol TE/g DM	184.7 μ mol TE/g DM	-	222.8 μ mol TE/g DM	Desseva et al. [20]
	315 (IC ₅₀ μ g/mL)	515 (IC ₅₀ μ g/mL)	-	-	-	Edziri et al. [47]
Beetroot extract	-	-	-	33.9 μ mol TE/L	-	Aykln-Dinçer et al. [9]
	254 (IC ₅₀ μ g/mL)	359 (IC ₅₀ μ g/mL)	-	-	-	Edziri et al. [47]
	14.2–90 (%) inhibition)	-	-	1250–4100 μ M TE/L	-	Georgiev et al. [38]
	-	-	4.8–6.9 mol/L	-	-	Raikos et al. [36]
	0.32–0.57 mg TE/g	-	4.10–4.74 mg TE/g	-	-	Righi Pessoa da Silva et al. [39]

DM: Dry matter; TE: Trolox equivalent; AA: Ascorbic acid.

Table 3. Total phenolic and total flavonoid contents in different beetroot sources.

Beetroot Material	Phenolic Compounds		Ref.
	Total Phenolic	Total Flavonoid	
Beetroot pulp	245 mg/100 g	0.88 mg/100 g	Chhikara et al. [41]
Beetroot leaves	12.76 mg/g DM	11.64 mg/g DM	Ninfali and Angelino [45]
Beetroot powder	292 mg/100 g	-	Ozaki et al. [46]
Fresh beetroot	1.77 mg/g DM	1.44 mg/g DM	Ninfali and Angelino [45]
	255 mg GAE/g	260 mg RE/g	Guldiken et al. [37]
Grated beetroot	570–920 mg GAE/kg	-	Czyżowska et al. [28]
Boiled beetroot	238 mg GAE/g	261 mg RE/g	Edziri et al. [47]
Dried beetroot	347 mg GAE/g	230 mg RE/g	
Pickled beetroot	192 mg GAE/g	173 mg RE/g	
Beetroot jam	231 mg GAE/g	143 mg RE/g	
Beetroot puree	236 mg GAE/g	290 mg RE/g	
Beetroot juice	225 mg GAE/g	126 mg RE/g	
	540–810 mg GAE/L	-	Czyżowska et al. [28]
	30.8 mg GAE/g DM	6.72 mg QE/g DM	Desseva et al. [20]
	0.978 mg GAE/g	1.42 mg CE/g	Edziri et al. [47]
Beetroot extract	20.73 mg GAE/g	39.75 mg CE/g	Aykın-Dinçer et al. [9]
	27.2 mg GAE/mL	-	
	279–399 mg/L	-	
	53–65 mg GAE/g	-	Righi Pessoa da Silva et al. [39]

DM: Dry matter; GAE: Gallic acid equivalent; QE: Quercetin equivalent; CE: Catechin equivalent; RE: Rutin equivalent.

Based on previous research studies, the most important phenolic compounds in beetroot extracts were 4-hydroxybenzoic acid, benzoic acid, ferulic acid, vanillic acid, protocatechuic acid, chlorogenic acid, caffeic acid (phenolic acids), vanillin, catechin, catechin hydrate, epicatechin, and rutin (flavonoids) [13,38,40].

In a recent study, Płatosz et al. [49] observed that isoferulic acid, protocatechuic acid (phenolic acids), epicatechin, and apigenin (flavonoids) were predominately found in beetroot products (fresh, fermented, and juice). However, the same authors detected a total of 20 phenolic compounds, including 10 other phenolic acids (m-hydroxybenzoic acid, chlorogenic acid, caffeic acid, syringic acid, sinapic acid, ferulic acid, p-coumaric acid, p-hydroxybenzoic acid, 3,4-dihydroxyphenylacetic acid, and trans-cinnamic acid) and 6 flavonoids (vitexin, rutin, luteolin, quercetin, kaempferol, and orientin). These compounds are in agreement with those reported in beetroot juice [20]. Płatosz et al. [49] also reported that total phenolic acids and flavonoids were different among the beetroot products. Raw beetroot presented the highest amounts of both phenolic and flavonoids content (32.21 and 33.02 µg/g DM, respectively) when compared with fermented beetroot (17.51 and 18.10 µg/g DM, respectively) and commercial beetroot juice (3.19 and 4.0 µg/mL, respectively). This confirmed, although the content of some individual compounds was higher, that the fermentation process decreased the concentration of phenolic acids (45.6% reduction) and flavonoids (27.2% reduction). This reduction could be partially attributed to the activity of phenolic acid decarboxylases and reductases [49].

In addition to those phenolic compounds reported by the aforementioned studies, other authors also identified other phenolic acids, such as p-coumaroylquinic acid, 2-O-(3,4-dihydroxybenzyl)-2,4,6-trihydroxyphenylacetic acid, and theogallin acid, and flavonoids such as quercetin-glucoside, A-type dimer of (epi)catechin-(epi)catechin, betagarin, rhamnetin, rhamnocitrin, and astragalin, in beetroot or its products [28,42]. In general, despite all the phenolic compounds detected, it should be noted that beetroot presents a significant content of rutin [24], which agrees

with other authors who concluded that the primary flavonoids in red beetroot are rutin, kaempferol, rhamnetin, rhamnocitrin, and astragalin [42].

Therefore, the results discovered in this review confirm the high phenolic and flavonoid amounts in beetroot and beetroot products. This has a direct impact on the antioxidant and free radical scavenging activity of these products. In this regard, several authors observed a strong correlation between beetroot phenolic content and antioxidant activity [10,21,24,38]. However, as reported in the betalains section, it should be mentioned that betalains exert a synergistic effect with phenolic acids and flavonoids to further enhance antioxidant properties. Finally, other compounds such as carotenoids and ascorbic acid, also contribute to the total antioxidant capacity of beetroot [20]. However, their low content relative to betalains and phenolic compounds make their effect on the antioxidant properties of beetroot comparatively much less.

2.3. Nitrates and Nitrites

The use of nitrates and nitrites in the meat industry has been related to their antioxidant, color protective, and preservative effects. Regarding color stability, nitric oxide reacts with myoglobin in meat and forms nitrosomyoglobin, which presents a dark red color. This pigment could be converted into nitrosohemochrome (pink color) during thermal processing, which presents the characteristic color of thermally processed cured meat products. Finally, in addition to the color stability, the use of these compounds also increases the oxidative stability of lipids and proteins [50].

However, the use of synthetic nitrates and nitrites (i.e., sodium nitrate and sodium nitrite) in meat products is controversial, and their application in the meat industry are trending towards reduced use [9]. Therefore, the use of natural extracts rich in nitrate and/or nitrite has been proposed to accomplish both technological requirements and meet consumer demands/expectations [50].

In this regard, beetroot is an important source of inorganic nitrates. However, the nitrate amounts vary based on multiple factors. In fact, it is reported to vary 10-fold between single varieties [51]. In a previous study, the authors reported that nitrate levels in beetroot ranged from 644 to 1800 mg/kg [52]. However, in a more recent research study, authors found higher nitrate amounts in beetroot. For example, beetroot juice had 4965 mg/L of nitrate [27], raw beetroot presented 4420 mg/kg, but this amount dramatically increased to 42,415 mg/kg after a dehydration process [53]. Similarly, 14,037 mg/kg of nitrate was observed in beetroot powder [46]. These high values confirm that beetroot is a promising source of “naturally occurring” nitrate. In addition, fermenting beetroot juices and extracts would allow us to pre-convert nitrates into nitrites [15,21], which would increase the protective effects, since it would be added to the meat product in the form of nitrite [6,54].

With this in mind, it seems clear that natural beetroot extracts are proposed as a very interesting alternative to synthetic nitrites and nitrates for the meat industry, thus limiting the use of these synthetic additives in meat products.

3. Potential Use of Beetroot for the Development of Functional Meat Products: Health Implications

Nowadays, consumers, aware of the implications that diet has on health and well-being, demand nutritious and safe products that have a benefit to their health [55]. The use of bioactive compounds for the reformulation of traditional food products allows for the transformation of these products into functional foods. These offer the consumer the possibility of consuming health-promoting compounds, without having to make changes in their eating habits. In this regard, the development of functional meat products is one of the most studied research themes in recent years. This is related to the fact that processed meat products are manufactured with several ingredients, which facilitates the inclusion of bioactive compounds in their formulation. Multiple studies have been conducted examining foods to observe their protective effects against several chronic diseases [37]. With this in mind, over the last decade, there was great interest in the biological activities of beetroot due to its composition of bioactive compounds and its possible effects in the prevention of multiple chronic

diseases [10,25]. In fact, the consumption of beetroot or its products (juice, powder, etc.) has been demonstrated to exert anti-anemic, anti-ischemic, anti-inflammatory, antioxidant, hepato-protective, antidiabetic, cholesterol-lowering, and anti-carcinogenic effects [41]. Moreover, beetroot also improves gastrointestinal health, optimizes lipid metabolism, has lipid peroxidation and oxidative stress inhibitory effects [21,26], and has antibacterial, antiviral, cardio-protective [49], and renal protective [47] effects. Moreover, beetroot consumption reduced the incidence of several tumors (skin, breast, lung, liver, colon, and esophagus) and contributed to protection from age-related diseases [10,26]. All of these beneficial health effects could be attributed to the biologically active compounds found in beetroot, most notably betalains, phenolic, dietary fiber, pectin, and inorganic nitrate [21]. In general, the protective effect of these compounds is related to the stimulation of hematopoietic and immune systems, and the protection of the kidney, liver, gastric mucosa, and gut from toxic compounds [45].

The administration of betalains in drinking water of mice showed significant inhibition of liver, skin, and lung tumor [42]. This demonstrated the effective cancer chemoprevention of these compounds at low doses, which confirm that betalains had an important antioxidant, anti-inflammatory, and anti-tumoral activities [10,40]. Betalains were also reported as important compounds that protect cells from oxidative stress processes and DNA damage due to their hydroxyl and amine groups, which confer with a strong antioxidative properties [56]. The anti-tumoral mechanism proposed was the interruption in the exchange of metabolites between tumor cells and surrounding tissues, which would hinder the ability of tumor cells to disperse into other tissues [45]. Moreover, another study reported that betalains modulate the expression of adhesive molecules in endothelial cells, which in combination with their antioxidant properties, exert protective effects in atherosclerosis, atherotrombosis, and ischemia [57]. The hepato-protective and cardio-protective effects of betalains (donor of methyl groups) include the modulation of hepatic protein metabolism, that reduces blood homocysteine and regulates the hepatic fat metabolism, preventing steatosis and plasma dyslipidemia that contribute to various cardiovascular diseases [26]. Finally, the anti-inflammatory effects could be related to the fact that betalains inhibit the cyclooxygenase [45].

Similarly, the phenolic compounds found in the beetroot had a chemopreventive effect against oxidative stress and free-radical compounds [42]. With this in mind, and taking into account that the carcinogenesis process is the event whereby a cell is transformed into neoplastic form due to the oxidative stress, the phenolic compounds could be considered as potential anti-carcinogenic agents [42]. The combination of phenolic compounds and oligosaccharides, polysaccharides, pectin, and fiber found in beetroot have an important positive effect on gastrointestinal health because they modulate the gut microbiota and promote the growth of probiotic bacteria (bifidogenic effects) [21]. Additionally, these compounds stimulated the intestinal excretion of cholesterol and cholesterol metabolites, which result in a hypocholesterolemic effect, improving blood pressure with a clear antihypertensive effect [26]. The anticoagulant properties of beetroot also were related to the high content of both phenolic acids and flavonoids in this vegetable [47]. Finally, blood glucose effect of beetroot could be linked to the flavonoid content. These compounds inhibit the α -amylase and α -glucosidase activities, which delay the digestion and absorption of carbohydrates and suppress postprandial hyperglycemia [45]. It has also been proposed that glucose-lowering effects may be due to the inhibition of glucose transporters by flavonoids, or may be due to the inhibition of gluconeogenesis and glycogenolysis by saponins [45]. Therefore, the mechanism is not yet completely clear, so it should be further investigated. Moreover, in a recent study, beetroot juice was found to effectively lessen the impact of insulin resistance in a similar way that diabetic pharmaceutical products would [51].

On the other hand, consumption of high levels of nitrate may be a potential health risk. This is related with the endogenous formation of N-nitroso compounds, which are recognized as carcinogenic, and may also induce several other adverse effects [58]. However, some may consider the nitrates found in beetroot as an important nutrient from the health point of view [26]. Dietary nitrate is bioconverted into nitric oxide, which increases in vivo nitric oxide availability [26]. This compound is related to cardio-protective effects, and it is responsible for lowering blood pressure and providing

vasoprotection that prevents some diseases such as hypertension and endothelial function [10,51]. In fact, a recent study in humans demonstrated that the ingestion of beetroot juice significantly decreased blood pressure proportionally to the increase of plasma nitrite [59]. At the present time, the cardio-protective effects of beetroot are basically linked to the increase in nitrate intake and the subsequent increase in nitric oxide in blood [51]. However, after conducting a study directed toward this phenomenon, authors have pointed out that the protective effect against hypertension is not due exclusively to nitrates [60]. These authors demonstrate the blood pressure-lowering effects of beetroot juice and highlight its potential nitrate-independent effects. Even so, beetroot and its biological active compounds are potentially safe and cost-effective nutritional products for managing several diseases such as hypertension and preventing undesirable cardiovascular outcomes [60].

Taking into account the data available in the literature, it seems clear that the compounds (mainly betalains, phenolic compounds, and nitrate [56]) present in beetroot and their products could be used for the treatment of various metabolic disorders and diseases [51]. Therefore, it is important to note that the use of these beetroot products as an ingredient in the reformulation of meat products imparts these health benefits, which allows the development of multiple functional products [5].

4. Application of Beetroot in Meat Products

As discussed above, beetroot, as well as the extracts obtained from beetroot, have several bioactive compounds with high industrial value due to their antioxidant (betalains, phenolic acids, and flavonoids), coloring (betalains), and stabilizing (nitrate/nitrite) activity. In addition to these positive attributes, the benefits to human health should be included. However, despite this great potential for the substitution of synthetic additives, when conducting an exhaustive literature search, it was found that the application of beetroot and its product by the meat industry is very limited. Even so, it seems that in the last 5 year-interest from the scientific community on beetroot, its application for the reformulation of meat products is growing.

When observing the results obtained in various research studies, it is evident that there is difficulty in comparing the main effects that the addition of beetroot exerts on meat products (Table 4). This is mainly due to the fact that studies use multiple meat products with different manufacture processes (raw, cooked/heat treatment, and fermented). In addition, the strategies for adding beetroot are also very different, since there are studies that incorporate beetroot as a powder, in extract (liquid or dehydrated; fermented or non-fermented), in the form of juice, or in the form of purified pigments. There are also studies that investigated a combination of beetroot inclusion and a decrease in sodium nitrite, while others completely rely on the addition of sodium nitrite. There was even a study that compared the effect of encapsulation of a beetroot extract.

Table 4. Application of beetroot in the reformulation of meat products.

Beetroot Material	Meat Product	Amount	Main Effects		Ref.
			Nutritional and Technological Quality	Sensory Quality	
Beetroot extract	Beef sausages	5% (liquid extract) and 2% (powder extract)	↓ Lipid oxidation ↑ Redness and ↓ lightness and yellowness ↓ pH	↑ Color, flavor, and appearance scores ↑ Overall acceptability	Aykln-dinçer et al. [9]
	Cooked ham	0.4, 0.88, and 4.55 g/kg (non-encapsulated) and 7.29 g/kg (encapsulated)	↑ Redness and yellowness; = lightness	-	
	Meat model system	50, 100, and 200 ppm of GAE	↓ Lipid oxidation	-	Burri et al. [61]
	Cooked pork patties	100 and 500 mg/kg	↓ Lipid oxidation (TBARs) (in dose-dependent manner) ↓ Hexanal (in dose-dependent manner)	-	Rey et al. [62]
	Sausages	0.02% (with or without cyclodextrine and chitosan)	No affect color parameters ↓ pH ↓ Residual nitrite	-	
Beetroot pigments (purified)	Ground pork loin	2%	↓ Lipid oxidation	-	Vieira Teixeira da Silva et al. [3]
Fermented beetroot extract	Raw and cooked meat emulsion system	5 and 10% (with or without addition of ascorbic acid)	↓ Lipid oxidation (than samples formulated without nitrite and similar values than samples formulated with commercial nitrite) ↑ Yellowness and = redness (than samples formulated with nitrite) ↓ pH ↓ Residual nitrite	↑ Color and odor scores (than samples formulated without nitrites) ↑ Overall acceptability	Choi et al. [15]

Table 4. Cont.

	Pork frankfurters	1, 3, 5%	↓ Lipid oxidation	No affect sensory acceptability	Hwang et al. [54]
			↓ Microbial contents		
			↑ Redness and ↓ lightness and had low effect on yellowness		
	Pork sausages	3%	↑ Yellowness and ↓ redness and no affect lightness	-	Hwang et al. [6]
			↓ pH		
			No affect lipid oxidation (in comparison with control samples without nitrite) and ↑ lipid oxidation (in comparison with control samples with nitrite)		
			↓ Microbial contents		
			↓ Residual nitrite		
Beetroot juice	Fresh pork sausages	0.5 and 1 mg/kg	↑ Redness and ↓ lightness and had low effect on yellowness	↑ Consumer acceptability ↓ Sausages discoloration	Martínez et al. [64]
Beetroot powder	Turkey patties	6%	↑ TPC, vitamin C, lutein, α-, and β-carotene and tocopherol	-	Duthie et al. [13]
			↑ Oxidation stability		
	Emulsion-type pork sausages	0.25 and 0.5% (with or without addition of 0.005% NaNO ₂)	↑ Redness (except 0.25% without NaNO ₂) and yellowness and ↓ lightness	-	Ha et al. [65]
			↓ pH		
			↓ Residual nitrite		
	Boiled sausages	0.5% (with 0.0075% NaNO ₂) and 1% (without NaNO ₂)	↑ Redness and yellowness and ↓ lightness	-	Jeong et al. [66]
			No affect pH values		
	Emulsified pork sausage	0.5 and 1% (with and without 0.0075 NaNO ₂)	↑ pH	↑ Color score	Jin et al. [8]
		↓ Residual nitrite (in samples without the addition of NaNO ₂)			
		↑ Redness and ↓ lightness and had low effect on yellowness	No affect overall acceptability		
			No affect or ↑ lipid oxidation		
			↓ pH (1% of beetroot powder)		
			↑ Redness and ↓ lightness and yellowness	-	
	Dry-fermented sausages	0.5 and 1%	↓ Residual nitrate and nitrite (except for nitrite in 1% beetroot samples)		Ozaki et al. [46]
			↓ Lipid oxidation		
			No affect microbial contents		

Table 4. Cont.

Beef sausages (Sucuk)	0.12, 0.24, and 0.35% (with 0.1%, 0.05% and without curing mixture containing nitrite, respectively)	Not affect or increase residual nitrite (after ripening period)	↑ Inner color scores (the first 14 storage days)	Sucu and Turp [53]
		↑ Lactic acid bacteria		
		↑ Lipid oxidation (low TBARS values in all samples)	↑ Overall acceptability scores	
		Maintain redness in sausage inside surface (during storage)		
Chicken sausage	-	↑ Water holding capacity	↑ Color scores	Swastike et al. [67]
		No affect pH values	↓ Flavor scores	
			No affect overall acceptability	
Sausages	2, 4, 6%	↓ pH	-	Turp et al. [68]
		↑ Redness and ↓ lightness and yellowness		
		↓ Lipid oxidation		

In a recent study, the use of both liquid beetroot extract and freeze-dried beetroot extract in the reformulation of fermented beef sausages and heat processed beef sausages showed very promising results [9]. The addition of beetroot extract decreased the pH, which conferred with higher stability to the sausages. This was related to the use of citric acid in the extraction procedure. Another strategy for including bioactive beetroot compounds in meat products is the use of fermented extracts. Various authors have fermented beetroot extracts, mainly with the aim of pre-converting nitrates into nitrites and testing the influence of fermented beetroot extract (5% and 10%) in raw and cooked meat emulsion systems [15], and in the reformulation of pork frankfurters (1%, 3%, and 5% fermented extract) [54] and pork sausages (3% fermented extract) [6]. Two of these research studies observed a significant reduction of pH values with the inclusion of fermented extracts in the meat products [6,15]. These findings are due to pre-converted nitrite extracts with low pH values. Moreover, the inclusion of beetroot powder [8,46,61–65] and fermented extract [6,15] produces a significant reduction in the residual nitrite. The fermented extracts also lowered microbial contents [6,54] of reformulated products. In contrast, the effect of the use of dehydrated beetroot showed contradictory results for pH values. The influence of the direct addition of beetroot powder was studied in emulsified sausages [8,65,66], fermented sausages [46,68], and boiled sausages [66,67]. The use of 0.25–0.5% [65], 0.5–1% [46], and 2–6% [68] of beetroot powder decreased pH, while the use of 0.5–1% of powdered beetroot did not affect [66,67] or increase [8] the pH values of sausages.

Regarding lipid oxidation, beetroot extract had an important protective effect against lipid oxidation, since both extracts (powder and liquid) reduce the thiobarbituric acid reactive substances (TBARs) values of beef sausages [9]. However, this reduction was only significant with the use of beetroot extract powder [9]. Similarly, the use of beetroot leaf extract reduced the lipid oxidation of a meat model system in a dose-dependent manner [61]. In this study, the authors observed that the extract inhibited oxidation down to 16.6% in comparison with the control sample. These results agree with those obtained by Rey et al. [62] in cooked pork patties. In this case, the use of 100 and 500 mg/kg of beetroot extract produced a dose-dependent inhibition of lipid oxidation. This was proven with the determination of the TBARs index and confirmed with the hexanal content (the main volatile aldehyde derived from the lipid oxidation). The values obtained showed that the addition of 500 mg/kg of extract produced 2.0-fold lower TBARs values and 8.0-fold lower hexanal content than the use of 100 mg/kg of extract. The results of all these research studies confirm that the use of beetroot extract exerts a strong antioxidant effect in meat products [62].

In the same way, the application of purified betanin (2%) in ground pork meat presented significant antioxidant activity [3]. The authors observed that 2% betanin had similar inhibition power to that of synthetic antioxidants (BHA and BHT) during storage (6 days). They concluded that the use of purified betanin is a potential substitute for synthetic additives in the preservation of refrigerated meat.

Regarding the use of fermented extracts, they produced a significant reduction in lipid oxidation in meat emulsion systems [15] and pork frankfurters [54], while fermented extracts did not affect (in comparison with control samples formulated without nitrite) or increase (in comparison with control samples formulated with nitrite) TBARs values in pork sausages [6]. Likewise, the use of beetroot powder also presented contradictory effects on lipid oxidation. In emulsified pork sausages [8] and Sucuk sausages [53], authors reported that the use of beetroot powder did not prevent lipid oxidation. In contrast, the beetroot powder caused a significant inhibition of lipid oxidation in sausages [46,68], and the inclusion of 6% of commercial dried beetroot powder in turkey patties increased the amount of bioactive compounds (phenolic compounds, vitamin C, lutein, carotenes, and tocopherols) and oxidation stability [13].

On the other hand, the addition of beetroot extract to beef sausages [9] and cooked ham [5] had a significant influence on their color properties. In both products, an increase in instrumental redness was observed, which show that beetroot extract is effective in providing a desired red color in the meat products, probably due to the characteristic red color of betalains and also the nitrate content [9]. This extract showed high color stability even when it was subjected to pH and temperature

variations [5], confirming that it could be used in different processed meat products. Instrumental lightness and instrumental yellowness presented different trends between both studies. In the case of beef sausages [9], both parameters decreased, while in the cooked ham [5], instrumental yellowness increased and instrumental lightness did not show a clear trend with the inclusion of beetroot extract.

Other authors have tested the efficacy of purified betalains extracted from beetroot in ground pork loin [3] and sausages [63]. In the case of sausages, the use of beetroot pigments (at 0.02%) showed very low influence on color parameters [63]. In fact, instrumental redness was not significantly different between control and reformulated samples. This could be related to the very low content of pigments added to the sausages (0.02%), which may not have been enough to change the color of the product. Moreover, as expected, the partial replacement of commercial nitrite with the beetroot pigment produced a significant decrease in residual nitrite found in the meat product.

The addition of fermented extracts produced an increase in instrumental redness and a decrease in instrumental yellowness for pork frankfurter [54], while pork sausages had decreased levels of instrumental redness and increased levels of instrumental yellowness [6] and meat emulsion systems were unaffected for instrumental redness values but had increased levels of instrumental yellowness [15].

There is only one study in which the beetroot juice (0.5% and 1%) was used in the reformulation of fresh pork sausages [64]. In this case, the use of beetroot juice resulted in samples with higher instrumental redness and lower instrumental lightness than control. Similar to these findings, several studies that used beetroot powder observed a significant increase in instrumental redness and a significant decrease in instrumental lightness in reformulated sausages [8,65,66]. In the same way, a significant increase in instrumental redness and a decrease in instrumental yellowness and instrumental lightness was observed when beetroot powder was incorporated in dry-fermented sausages (0.5–1%) [46] or in other sausages (2%, 4%, and 6%) [68]. Instrumental redness was also maintained on the inside surface of Sucuk (beef sausage) during storage [53].

Finally, the scores obtained during sensory evaluation of reformulated beef sausages [9] are in line with the aforementioned results for product quality (less oxidation and improved instrumental color). These authors [9] observed that the incorporation of beetroot extract improved color, flavor, and appearance scores. This resulted in the reformulated sausages receiving higher overall acceptability scores. In line with these results, the incorporation of fermented beetroot extract in meat emulsion systems improved color and odor scores in comparison with control samples formulated without synthetic nitrite, which resulted in higher overall acceptability scores than samples formulated without synthetic nitrite [15]. These authors [15] also found that samples formulated with 10% fermented beetroot extract had a similar score for overall acceptability when compared with samples formulated with synthetic nitrite. Contrary, after evaluating the sensory implications of the use of fermented beetroot extract in pork frankfurters [54] and meat emulsion systems [15], the results showed that the overall acceptability scores for pork sausages decreased with increasing the inclusion level of the fermented beetroot extract, but this result was not statistically different [54].

The effect of the direct addition of beetroot (juice or powder) on sensory quality for meat products has also been evaluated. Fresh pork sausages formulated with beetroot juice [64] had lower discoloration values (sensorial evaluation) during storage (2 °C) in comparison with samples without beetroot ingredients. This translated to high consumer acceptability when pork sausages were formulated with beetroot juice [64]. Moreover, according to the responses of consumers, the addition of beetroot juice caused a significant increase in the purchase intention after 12 days of storage, which confirmed that shelf-life of reformulated sausages increased by 4 days with respect to control samples. Similarly, the use of beetroot powder increased color scores but did not influence the overall acceptability of sausages [8]. The results presented in this study [8] agreed with those reported by other authors, who reported that chicken sausages reformulated with beetroot powder resulted in a higher color (due to the highest red color) and lower flavor scores (due to the earthy taste of beetroot powder) than control samples, while the inclusion of beetroot powder did not affect the overall acceptability [67].

In the Sucuk samples, the incorporation of beetroot powder increased both visual color and overall acceptability scores [53].

With these results in mind, it seems clear that the use and application of beetroot in the meat industry should be the subject of additional research studies and potentially wide-spread industrial utilization.

5. Conclusions and Future Trends

Beetroot is an exceptional source of biologically active compounds of great nutritional, health, and technological value. These compounds include betalains, phenolic compounds (flavonoids and phenolic acids), and inorganic nitrate, which are of special interest for the meat industry due to their functional and technological properties, such as colorants, antioxidants, and preservatives. Despite this, the number of studies carried out on the reformulation of processed meat products using beetroot is very limited, and the results obtained vary in their effectiveness. This is mainly due to the low number of studies, together with the different strategies of beetroot inclusion in meat products [i.e., direct addition as powder or juice, addition as an extract (fermented or unfermented), or addition of the purified pigments], which affect its effectiveness against degradation reactions and influence both technological and sensory characteristics. Even so, in general, the results obtained by the available research studies show a strong antioxidant and coloring activity, which limits lipid oxidation processes and discoloration during storage, and therefore increases the shelf-life and overall acceptability by the consumer. Moreover, the phytochemical profile of beetroot presents positive effects on human health, which would also allow the development of functional and innovative foods.

Main points to consider, and those that should be investigated in greater depth would include the following:

Use of beetroot extracts—The use of extracts instead of the direct application of dehydrated beetroot or beetroot juice has several advantages, including the concentration of bioactive compounds. Therefore, a greater coloring and antioxidant power is expected when beetroot extracts are used as opposed to the direct addition of beetroot ingredients. Additionally, the major drawback that limits the direct application of beetroot in meat products is the presence of geosmin, which imparts an undesirable earthy flavor, which could be solved by using extracts instead of direct addition of beetroot ingredients.

Extraction conditions during ingredient isolation—The extraction conditions of the bioactive compounds from the beetroot must be optimized according to the meat (or food) product application. It must be taken into account that the bioactive compounds of the raw material (beetroot) can vary depending on multiple factors during the isolation of the ingredient. Furthermore, the processing conditions of beetroot can also degrade multiple compounds, so the quantity and properties of these compounds must be carefully evaluated.

Meat product applications—Finally, the effects of the addition of beetroot (or beetroot extracts) in the reformulation of meat products should be extensively studied. This would allow for partial or full replacement of synthetic additives for multiple meat products.

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