REVIEW

Textural properties and quality of meat products containing fruit or vegetable products: A review

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Summary
Meat products are defined as those in which fresh meat has been improved by some processing techniques, such as curing, comminution, drying, fermentation or cooking. Fruit and vegetable in various forms (fresh, juice, powdered, puréed or extract) are excellent sources for the enrichment of meat products because of their sweet and desired taste, colour, aroma, fibres, and vitamins content. So, this manuscript reviews the effect of some fruits and vegetables such as apple, beetroot, carrot, celery, cherry, grape, lemon, mushroom, orange, spinach and tomato, on the physicochemical attributes, texture, colour parameters, sensorial and quality properties of meat products such as sausage or hamburger. The physicochemical, colour, texture and sensorial properties of meat products are affected by replacement by fruits or vegetables and addition of these products contributes to the high content of vitamins, natural colorants, minerals, polyphenols and crude fibre. Also, some vegetables, such as beetroot, celery, leek, parsley or spinach, provide naturally sourced nitrate in meat products. The meat products with natural fruits or vegetables addition have a growing share in the global market due to the high demand for goods for an improved diet, rich in phenolic compounds with antioxidant activity and positive biological properties.

Keywords
colour; fibre; hamburger; meat product; sausage; texture

New product development is a continuous challenge for both scientific and applied research. Meat products are defined as those in which fresh meat has been modified by some processing techniques, such as curing, comminution, dehydration, fermentation or cooking [1]. Sausage is one of meat products that is gaining popularity, being present in the diet of various cultures because of convenience, variety and economy. It takes little time for preparation, with some sausage types being ready to serve and others needing only to be warmed [2]. Functional improvement in meat products, modification of fatty acid and cholesterol levels in the meat, incorporation of natural extracts with antioxidant activity, limiting NaCl, addition of dietary fibres, natural gums, starch, proteins and reduction of nitrite are some of the approaches to make meat products functional foods [3].

Fibre is suitable to be contained in food products. It was previously used in emulsion food products because it has diverse functional properties such as moisture-holding capacity, gel-forming ability, viscosity, solubility, provides structural integrity, adhesiveness and shelf stability in reduced-fat products. It has a neutral flavour and causes none or limited changes in textural parameters by enhancing water-binding capabilities. It also carries significant economic advantages for both the consumers and processors [4–6]. Functionality of dietary fibres depends on their interaction with the food matrix to which they are added and on gastrointestinal conditions [7].

The present trend of using food for health purposes rather than just for nutrition, opens up whole new fields for the meat industry. Among the possible options, re-formulation by adding or substituting ingredients to change antioxidants, dietary fibre and probiotics contents or the fatty acid profile are being explored [8]. Fruit and vegetable in various forms (fresh, juice, powder, purée, pulp, fibre or extract) provide means for producers to improve the health benefits of food products [5, 6]. Fruits and vegetables contain significant amounts of natural antioxidants. In recent years, there has been increased interest in using ferment-

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ed fruits or vegetables extracts as natural antioxidants for meat products because fermentation of fruits and vegetables materials offers a promising preservation method [9]. Natural ingredients that are high in naturally occurring ascorbic acid, a very effective reducing agent, can provide this function and are permitted for use in natural and organic meat products. Excess amounts of cure accelerators remaining after curing and subsequent thermal processing can also act as reservoirs for antioxidant protection and serve as an oxygen scavenger to stabilize and protect the colour and flavour of cured meat products during storage [10]. In addition, some vegetables have an excellent potential as natural sources of nitrate and thus studies were carried out on the use of products such as beetroot, celery, leek, parsley and spinach as nitrate sources in meat products [11, 12]. The effect of some fruits and vegetables on various characteristics of meat products are presented in Tab. 1. In addition, the data listed in Tab. 2 show the physicochemical attributes of meat products containing fruits and vegetables.

Kehlet et al. [7] investigated the physicochemical and microstructural properties of meatballs and sausages containing various fibre ingredients (six recipes in total). The authors reported that the sausages had a longer chewing time and higher water content, but a lower water-holding capacity than meatballs. The microstructural properties differed between sausages and meatballs and the differences seemed to be influenced by the fibre type. In summary, fibre ingredients affected the meat quality-related properties in terms of chewing time and microstructure when added to meatballs or sausages. Effects of sugarcane dietary fibre and pre-emulsified sesame oil on low-fat meat batter physicochemical properties, texture and microstructure were studied by Zhuang et al. [13]. The authors reported that with increasing sugarcane dietary fibre level, the batters had improved physicochemical and microstructural properties of the products. The amount of sugarcane dietary fibre added did not affect the area or diameter of cavities formed by protein aggregation, but had an obvious effect on the microstructure of the gel.

Food enrichment is one of the most important processes for enhancement of the nutritional quality of meat products. Fruits and vegetables are rich sources of total phenolics, antioxidants, carotenes, minerals and dietary fibre, having a potential to enrich meat products. The present study summarizes the effects of certain fruits and vegetables on the physicochemical, colour, textural and sensorial properties and quality of meat products.

Apple

Apple represents the fourth most important horticultural crop for human nutrition in the world [14]. Addition of apple fibre could potentially have an additional effect in case of pressure treatment with regard to improvement of water-binding capacity. However, Fernández-Martín et al. [15] found that the addition of apple fibre did not cause any significant changes in weight loss in either cooked or pressure-treated pork meat batters. However, the pressure treatment decreased the weight loss when compared to non-pressure-treated samples. Apple pomace is the primary by-product of apple juice manufacturing. Apple pomace consists of pectin, which has become highly valued since it is considered as soluble dietary fibre [16, 17]. The utilization of apple pomace in foods like meat, which lack dietary fibre, can be beneficial to the consumers with respect to nutrition and cost-wise. Waste utilization of apple pomace as a source of a functional ingredient in buffalo meat sausage was investigated by Younis and Ahmad [18]. The author reported that the buffalo meat sausages incorporated with apple pomace powder showed high cooking yield and emulsion stability of 94.5 % and 74.7 %, respectively, as compared to control sausage. Additionally, the dietary fibre content got enhanced with the incorporation of apple pomace powder as expected. In another study, utilization of apple pomace powder as a fat replacer in goshtaba (a traditional meat product of Jammu and Kashmir, India) was examined by Rather et al. [19]. Sensory evaluation indicated that goshtaba products in which fat content was reduced from 20 % to 10 % and supplemented with 1 % and 3 % apple pomace powder had overall palatability similar to that of the high-fat control goshtaba (20 %).

Beetroot

There are many different types of vegetables that contain bioactive compounds, and additional features of some vegetables include uses as natural colourants and antioxidants. The use of beetroot allows for the extraction of a large number of compounds with special interest to meat products. These include colourants (betalains), antioxidants (betalains and phenolic compounds) and preservatives (nitrates), which can be applied to 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 [20]. Betalains are water-soluble nitrogen-containing pigments and consist of two subgroups, betacyanins and betaxanthins [21, 22]. Approxi-

Tab. 1. Effects of fruits and vegetables on various characteristics of meat products.

Meat product	Fruit or vegetable	Incorporated level [%]	Suggested level [%]	Result	Ref.
Beef hamburger	Carrot and lemon fibre	0, 2, 4, 6	2 (carrot fibre)	Carrot fibre and lemon fibre contribute to the nutritional and health qualities of the products.	[41]
Beef sausages	Carrot juice	0, 19.8	19.8	Sausages prepared with carrot juice and irradiated were safe and highly acceptable.	[34]
Cured pork loin	Spinach	–	–	Total viable bacterial counts in cured meats added with fermented spinach extract ranged from 0.34–1.01 log CFU·g^{-1}. *E. coli* and coliform bacteria were not observed in any of the cured meats treated with fermented spinach extracts or nitrite.	[11]
Fermented beef sausages	Beetroot powder	0, 0.12, 0.24, 0.35	0.24, 0.35	Inclusion of beetroot powder increased a^* value and resulted in protection of the desired red colour during storage.	[12]
Dry-fermented sausages	Orange fibre	0, 1, 2	1	pH, water activity, residual nitrite level and counts of *Micrococcaceae* were affected by fibre addition during dry-curing. Addition of orange fibre decreased the growth of micrococci and the amount of nitrite required to increase the microbial stability of salchichon (dry-fermented sausages)	[69]
Goshtaba	Apple pomace powder	0, 1, 3, 5	1, 3	Inclusion of apple pomace powder in low-fat treatments (10 %) resulted in higher cooking yield, redness, yellowness, protein, moisture and ash contents, as well as in lower fat content, lightness and reduction in volume than the high-fat product (20 %).	[19]
Meat emulsion	Fermented red beet extract	0, 5, 10	10	pH and L^* values of meat emulsions containing red beet extract decreased with an increase in the amount of extract added.	[26]
Pork sausages	Red beet	0, 0.5, 1.0	1.0	Red beet significantly increased the moisture content and pH, affected colour traits. a^* values dramatically increased with red beet powder addition.	[21]
Sucuk	Orange fibre	0, 2, 4	2	L^* and b^* indeces increased with the addition of fibre. Fibre addition also reduced the cooking loss.	[70]
Sausages	Apple pomace powder	0, 6	6	Less fat loss, high water activity, high cooking yield and emulsion stability was observed.	[18]
Sausages	Cherry powder	0, 0.2	0.2	Treatments with the addition of cherry powder resulted in sensory, colour, cured pigment and pigment conversion characteristics closely resembling those of the sodium nitrite-added control.	[47]
Sausages	Carrot powder	4	4	Functional carrot powder addition to sausage formulations at 4 % did not affect purge loss and resulted in sausages with higher contents of phenolic compounds and dietary fibre.	[38]
Sausages	Lemon albedo	0, 2.5, 5, 7.5, 10	2.5	Addition of albedo to dry-cured sausages represented an improvement in their nutritional properties.	[56]
Sausages	Grape seed flour	0, 0.75, 1.5, 3	3	Addition of grape seed flour did not affect pH, fat and protein values of sausage. Higher levels of grape seed flour decreased the sensory quality of the dry fermented sausages.	[52]
Sausages	Mushroom powder	0, 0.5, 1, 1.5, 2	1	Winter mushroom (*Flammulina velutipes*) powder could effectively replace phosphate in sausages and meat products.	[64]
Sucuk	Spinach powder	0, 1, 3	3	Spinach powder added to sucuk was a source of nitrite to inhibit the formation of thiobarbituric acid.	[72]

Sucuk – Turkish dry-fermented sausage.

Tab. 2. Physicochemical attributes of meat products containing fruits and vegetables.

Meat product	Fruit or vegetable	FV level [%]	pH	Moisture content [%]	Water activity a_w	Fat [%]	Protein [%]	Fibre [%]	Ash [%]	Ref.
Beef hamburger (raw)	Carrot fibre	0	5.46	58.1	–	15.9	13.6	–	2.9	[41]
		2	5.50	65.3	–	13.4	10.7	–	2.4	
		4	5.47	70.9	–	10.4	9.6	–	1.9	
		6	5.45	73.2	–	9.9	7.9	–	1.8	
Beef hamburger (raw)	Lemon fibre	0	5.46	58.1	–	15.9	13.6	–	2.9	[41]
		2	5.07	68.9	–	10.3	11.2	–	2.3	
		4	4.75	71.7	–	9.3	9.8	–	2.0	
		6	4.49	74.3	–	7.8	8.1	–	1.5	
Fermented sausages	Beetroot powder	0	–	42.9	–	33.1	20.1	–	3.4	[12]
		0.12	–	44.7	–	33.3	20.2	–	3.3	
		0.24	–	44. 6	–	30.8	20.2	–	3.2	
		0.35	–	44.3	–	30.7	20.3	–	3.4	
Fermented sausages	Carrot dietary fibre	0	5.76	30.3	0.94	–	–	–	–	[8]
		3	5.71	29.7	0.93	–	–	–	–	
		6	5.77	29.1	0.93	–	–	–	–	
		9	5.77	28.5	0.92	–	–	–	–	
		12	5.80	27.9	0.92	–	–	–	–	
Goshtaba	Apple pomace powder	0	5.59	67.5	–	11.2	17.6	–	4.0	[19]
		1	5.42	68.9	–	11.5	16.8	–	3.9	
		3	5.39	69.0	–	12.0	16.5	–	3.9	
		5	5.34	69.5	–	11.5	16.0	–	4.0	
Pork sausages	Sun mushroom powder	0	5.45	61.2	–	12.7	18.1	–	3.7	[61]
		1	5.69	58.7	–	12.3	19.0	–	3.5	
		2	5.56	58.6	–	12.7	21.2	–	3.7	
		4	5.77	57.8	–	13.9	20.7	–	3.9	
Pork sausages	Red beet powder	0	6.03	67.2	–	13.8	17. 5	–	1.6	[21]
		0.5	6.21	68.0	–	12.3	17.6	–	1.7	
		1.0	6.30	68.7	–	12.1	17.5	–	1.6	
Sucuk	Orange fibre	0	4.96	–	0.92	–	–	–	–	[70]
		2	4.83	–	0.92	–	–	–	–	
		4	4.71	–	0.92	–	–	–	–	
Sausages	Apple pomace powder	0	6.17	–	0.97	5.3	–	0.5	–	[18]
		6	6.03	–	0.99	7.5	–	3.8	–	
Sausages	Lemon dehydrated raw albedo	0	–	39.0	–	38.7	19.3	0	5.0	[57]

Tab. 2. *continued*

Meat product	Fruit or vegetable	FV level [%]	pH	Moisture content [%]	Water activity a_W	Fat [%]	Protein [%]	Fibre [%]	Ash [%]	Ref.
Sausages	Lemon dehydrated raw albedo	2.5	–	37.8	–	37.9	18.9	0.6	5.1	[57]
		5	–	38.4	–	37.9	18.1	0.7	5.1	
		7.5	–	38.4	–	37.9	18.1	0.9	5.7	
		10	–	28.0	–	39.9	23.4	1.9	5.9	
Sausages	Lemon albedo	0	5.63	38.0	–	38.7	19.3	0.0	5.0	[56]
		2.5	5.80	38.8	–	37.6	18.7	0.3	5.5	
		5	5.84	39.0	–	37.3	18.2	0.3	5.6	
		7.5	5.63	39.0	–	38.0	17.9	0.4	5.9	
		10	5.64	39.3	–	37.6	16.2	0.5	6.2	
Sausages	Carrot powder	0	6.67	67.9	–	10.5	12.2	–	3.2	[38]
		4	6.60	67.2	–	10.8	12.2	–	3.8	
	Functional carrot powder	4	6.57	67.8	–	10.2	11.8	–	3.5	
Sausages	Grape seed flour	0	4.82	42.8	–	25.7	22.8	–	–	[52]
		0.75	4.86	41.6	–	25.8	22.8	–	–	
		1.5	4.87	41.5	–	25.5	23.3	–	–	
		3	4.80	41.7	–	26.3	21.9	–	–	
Sucuk	Spinach powder	0	5.47	38.3	0.85	–	–	–	–	[72]
		1	5.38	37.2	0.86	–	–	–	–	
		3	5.33	36.5	0.85	–	–	–	–	

FV – fruits and vegetables, sucuk – Turkish dry-fermented sausage, sun mushroom – *Agaricus blazei* Murrill.

mately 62.04–118.92 mg of betalains are contained in 100 g of red beet [23].

In the L^*(lightness), a^*(redness), b^* (yellowness) space, L^* is lightness/darkness that ranges from 0 to 100, a^* isredness/greenness that ranges from –120 to 120 and b^* is yellowness/blueness that ranges from –120 to 120 [24, 25]. The objective of the study by Sucu and Turp [12] was to examine the effects of reformulation of Turkish dry fermented beef sausage (sucuk) by replacing nitrite with beetroot powder, which has high nitrate content, on some quality characteristics of the product. The authors reported that beetroot powder's inclusion increased the a^* value of sausage samples and resulted in the protection of the desired red colour during storage. Results indicated that the use of beetroot powder provided an advantage in sensory properties of fermented sausages. The overall acceptance scores of meat emulsion samples with 10 % fermented red beet [26] and emulsified pork sausage with 1% red beet powder [21] were similar to those of the control samples containing nitrite. In addition, beetroot contains bioactive phytochemicals, including phenolic compounds and, also, it is considered as a rich source of nitrate and the betalain pigments consisting of yellow betaxanthins and red-violet betacyanins. Therefore, it contains important antioxidants and natural colourants. Some studies were carried out on the use of beetroot for attaining these properties in meat products [21, 27, 28]. Effects of fermented red beet extracts on the shelf stability of low-salt frankfurters was examined by Hwang et al. [27]. The authors observed that pH, volatile basic nitrogen, lightness and yellowness of frankfurters decreased with increasing levels of fermented red beet, whereas the redness of frankfurters increased with increasing levels of fermented red beet (Tab. 3). Choi et al. [26] investigated the effects of fermented red beet extract and ascorbic acid on colour development in meat emulsions. The pH of meat emulsions containing red beet extract decreased with an increase in the amount of extract added and a^* of the treated meat emulsions was higher than that of the control with no added nitrite or fermented red beet extract. In summary, the combination of fermented red beet extract and ascorbic acid could be a viable alternative to synthetic nitrite regarding the stability of colour development in meat emulsions. Effects of red beet on quality and colour stability of low-fat sausages during refrigerated storage was studied by Jeong et al. [29]. The authors reported no effect of red beet addition on textural properties in low-fat sausage.

Red beet is regarded a good source of antioxidants and natural colourants thanks to the phenolic compounds and betalains contained in red beet. The crop has high content of betalains used as food colourants and food additives with health-promoting properties. Aykin-Dincer et al. [30] used four colourants (control, carmine, beetroot extract and beetroot extract powder) and two methods (fermentation and heat treatment) in the production of sausages. The authors reported that the moisture content, pH value, lightness, yellowness and odour values of heat-processed sausages were higher than those of fermented sausages. The addition of beetroot extract and powder to the sausages resulted in a reduction of L^* and b^* values, while a^* values were increased compared to the control. Also, the use of beetroot extract and powder had a positive effected on sensory appearance, colour, flavour and overall acceptance of sausages.

Tab. 3. Textural properties, rheological properties and colour parameters of meat products containing fruits and vegetables.

Meat product	Fruit or vegetable	FV level [%]	Hardness [N]	Cohesiveness	Chewiness [N]	Resilience	Springiness [mm]	Gumminess [N]	L^*	a^*	b^*	Ref.
Beef hamburger (raw)	Carrot fibre	0	6.11	0.38	6.20	–	2.87	2.17	41.59	9.82	16.45	[41]
		2	8.76	0.31	7.45	–	2.75	2.72	41.25	8.38	15.32	
		4	9.48	0.23	5.35	–	2.43	2.18	43.33	8.86	15.92	
		6	8.77	0.23	4.87	–	2.40	2.01	45.25	7.97	16.63	
Beef hamburger (raw)	Lemon fibre	0	6.11	0.38	6.20	–	2.87	2.17	41.59	9.82	16.45	[41]
		2	2.24	0.27	1.34	–	2.36	0.57	49.55	11.39	19.50	
		4	1.90	0.21	0.81	–	1.99	0.41	51.25	11.01	20.46	
		6	1.79	0.23	0.75	–	1.89	0.43	53.97	10.81	20.55	
Fermented sausages (sucuk)	Beetroot powder	0	8.15	0.46	1.97	0.20	–	3.71	43.70	17.54	19.74	[12]
		0.12	7.01	0.47	1.79	0.20	–	3.24	43.18	16.13	18.27	
		0.24	6.79	0.46	1.91	0.21	–	3.10	41.00	18.69	16.19	
		0.35	7.07	0.45	2.07	0.19	–	3.26	39.09	18.59	14.52	
Frankfurters	Fermented red beet	0	–	–	–	–	–	–	71.27	0.40	15.06	[27]
		1	–	–	–	–	–	–	69.91	1.14	15.12	
		3	–	–	–	–	–	–	67.53	2.61	14.06	
		5	–	–	–	–	–	–	67.51	2.82	14.01	
Goshtaba	Apple pomace powder	0	–	0.44	–	–	–	–	26.67	2.44	13.42	[19]
		1	–	0.38	–	–	–	–	33.69	0.49	14.21	
		3	–	0.40	–	–	–	–	41.83	0.60	14.17	
		5	–	0.34	–	–	–	–	35.99	1.06	26.98	
Meat emulsion	Fermented red beet extract	0	–		–	–	–	–	82.97	3.29	11.97	[26]
		5	–	–	–	–	–	–	82.26	2.48	13.02	

Tab. 3. *continued*

Meat product	Fruit or vegetable	FV level [%]	Hardness [N]	Cohesiveness	Chewiness [N]	Resilience	Springiness [mm]	Gumminess [N]	*L**	*a**	*b**	Ref.
Meat emulsion	Fermented red beet extract	10	–	–	–	–	–	–	80.78	3.27	14.48	[26]
Pork sausages	Red beet powder	0	30.38	0.57	–	–	10.09	10.02	79.10	1.80	11.10	[21]
		0.5	28.42	0.56	–	–	9.80	10.01	66.40	17.80	12.40	
		1.0	28.42	0.56	–	–	10.39	10.01	60.50	24.50	11.90	
Pork sausages	Sun mushroom powder	0	–	–	–	–	–	–	58.95	11.48	12.24	[61]
		1	–	–	–	–	–	–	55.15	10.05	16.08	
		2	–	–	–	–	–	–	50.89	9.76	16.88	
		4	–	–	–	–	–	–	44.44	8.75	17.85	
Sucuk	Orange fibre	0	–	–	–	–	–	–	42.28	17.11	11.69	[70]
		2	–	–	–	–	–	–	45.26	17.55	13.33	
		4	–	–	–	–	–	–	47.28	17.17	14.78	
Sausages	Apple pomace powder	0	48.91	0.61	–	–	0.78	29.92	33.68	12.28	10.91	[18]
		6	64.10	0.51	–	–	0.81	31.94	36.58	13.09	12.35	
Sausages	Mushroom powder	0	48.90	0.23	–	–	–	–	67.46	8.03	11.41	[64]
		0.5	40.58	0.21	–	–	–	–	68.68	7.02	12.07	
		1	37.10	0.21	–	–	–	–	69.07	7.96	11.50	
		1.5	35.84	0.20	–	–	–	–	69.46	7.99	11.50	
		2	35.51	0.20	–	–	–	–	69.21	7.79	11.83	
Sausages	Carrot powder	0	76.26	0.35	–	–	0.80	–	57.24	18.67	9.91	[38]
		4	65.65	0.31	–	–	0.69	–	56.52	17.89	22.60	
	Functional carrot powder	4	74.38	0.31	–	–	0.73	–	53.18	15.33	22.53	
Sausages	Lemon albedo	0	40.83	–	–	–	0.39	–	48.17	5.87	7.61	[56]
		2.5	41.96	–	–	–	0.32	–	46.09	8.61	7.64	
		5	55.63	–	–	–	0.33	–	46.29	8.25	7.15	
		7.5	45.26	–	–	–	0.32	–	48.95	5.79	7.00	
		10	46.69	–	–	–	0.32	–	48.87	6.08	7.24	
Sausages	Grape seed flour	0	–	–	–	–	–	–	30.27	6.91	4.73	[52]
		0.75	–	–	–	–	–	–	28.84	5.81	3.99	
		1.5	–	–	–	–	–	–	28.48	5.32	3.51	
		3	–	–	–	–	–	–	27.67	4.20	2.86	
Sucuk	Spinach powder	0	–	–	–	–	–	–	47.92	11.29	17.73	[72]
		1	–	–	–	–	–	–	42.94	9.59	18.32	
		3	–	–	–	–	–	–	44.50	7.20	19.43	

FV – fruits and vegetables, *L** – lightness; *a** – redness (+) and greenness (–); *b** – yellowness (+) and blueness (–), sucuk – Turkish dry-fermented sausage, sun mushroom – *Agaricus blazei* Murrill.

Carrot

Carrot is considered a nutraceutical crop for its high content of carotenoids, fibre and phenolic compounds [5, 31]. Dietary fibre is a necessary food component for supporting consumer's health. Several authors studied, with good results, the use of carrot as a functional and health-promoting ingredient in meat products [32, 33]. Optimization of the addition of carrot dietary fibre (at 0–12%) to a dry fermented sausage (sobrassada) was investigated, using artificial neural networks, by Eim et al. [8]. The authors observed that the obtained optimal value of added carrot dietary fibre was 4.9%. This was the highest value of added fibre that permitted the formulation of a final product similar quality characteristics to the reference product (without fibre). In another study, the antioxidant activity of carrot juice in gamma-irradiated beef sausage was investigated [34]. The carrot juice significantly reduced the oxidative processes in the samples proportionally to the juice's concentration. Also, the sausages that were formulated with carrot juice had higher sensory acceptability scores as compared with the control samples.

High-pressure processing was introduced in the food industry as a mild preservation method producing safe and less processed products, consistent with the consumer demand for minimally processed products [35]. Water-binding capacity and structure of pork sausages as affected by high-pressure processing and addition of carrot fibre were studied by Møller et al. [36]. A significant effect of addition of fibre was observed on the relaxation times of the main population (T_{23}; 68–130 ms), where samples containing carrot fibre were characterized by a significantly shorter relaxation time compared to samples without it. In another study, to investigate the synergistic cooperation between high-pressure treatment and carrot dietary fibre (2 %), two formulations of pork sausages containing various contents of carrot dietary fibre were pressurized [37]. The sensory evaluation showed that high-pressure treatment synergistically co-operated with carrot dietary fibre improving sensorial attributes like homogenity, creaminess, fattiness and firmness as detected by napping in combination with ultra-flash profile.

Use of a functional carrot powder ingredient (4 %) to produce sausages with high levels of nutraceuticals was investigated by Alvarado-Ramírez et al. [38]. In that study, a functional carrot powder ingredient was obtained by applying wounding stress to carrot (shredding and storing for 48 h at 15 °C) prior to dehydration (at 60 °C) and milling. Carrot powder formulations increased the fibre content of sausages by 72.7 % and fortified them with carotenoids, providing 30 % to 40 % of vitamin A daily requirements per portion (62.5 g). In another study, the combined effect of high-pressure processing together with carrot fibre (0.5 % and 1.5 %) and potato starch (2 % and 3.8 %) on low salt (1.2 %) pork sausages was investigated and compared with high salt (1.8 %) sausages [39]. Water-binding capacity of low-salt sausages was improved to the same level as that of high-salt sausages by high-pressure processing and addition of carrot fibre or potato starch particularly by the addition of potato starch, which produced sausages with better sensory properties than carrot fibre.

Physicochemical properties of cooked buffalo meat sausage, as influenced by incorporation of carrot powder (0–5 %) during refrigerated storage, were studied by Khan and Ahmad [40]. The carrot powder did not significantly affect the texture of the product, having a little effect on the moisture content of the product. Soncu et al. [41] determined the usability of lemon fibre (2 %, 4 % and 6 %) and carrot fibre (2 %, 4 % and 6 %) to produce low-fat beef hamburgers. Lemon fibre increased the moisture content and cooking yield due to its better water-binding properties, while carrot fibre caused higher fat and cholesterol contents owing to its higher fat absorption capacity. In summary, it is suggested that carrot fibre produces better low-fat hamburgers since up to 2% carrot fibre presented sensory and textural properties similar to those of traditional hamburgers.

Celery

Celery products, such as celery juice concentrate and celery powder, are the most widely used additives as nitrate sources in studies on cured meat products. Celery powder contains approximately 3 % nitrate [42–45]. It also contains a significant amount of naturally occurring nitrate and it will not be the best alternative source of nitrite for meat without being used in combination with nitrate-reducing bacterial cultures to produce standard cured meat products. However, the addition of celery powder to processed meat is generally limited to 0.2–0.4 % of the formulation weight because at levels higher than this, off-flavours may develop [45, 46]. The effect of pH and nitrite concentration on the antimicrobial activity of celery juice concentrate, compared with conventional sodium nitrite, on *Listeria monocytogenes* was investigated by Horsch et al. [42]. The authors reported that the celery juice concentrate increased pH of meat products, which could have implications for the antimicrobial activity of nitrite in meat products.

Cherry

Effects of various levels of cherry powder and starter culture on quality and sensory attributes of indirectly cured, emulsified cooked sausages were studied by TERNS et al. [47]. The authors observed that the overall acceptability for cured emulsified cooked sausage manufactured with cherry powder using a starter culture was not significantly different from that of their control.

Grape

Antioxidants are added to fresh and processed meat and meat products to prevent lipid oxidation, retard development of off-flavours and improve colour stability. Due to the potentially toxic effects of synthetic antioxidants, natural antioxidant sources, mostly fruits, are being preferred nowadays for use in various meat products. The majority of the antioxidant capacity of fruit is connected to the content of numerous phenolic compounds [48, 49]. Effects of two red grape pomace extracts, obtained by using different extraction systems, on meat quality (pH, microbial spoilage, lipid oxidation and colour coordinates) of pork hamburgers were investigated by GARRIDO et al. [50]. The highest colour stability and the lowest lipid oxidation values were reported in hamburgers containing Type I extract (instantaneous high-low pressure + methanolic extraction), which showed a potent antioxidant effect. In another study, impact of grape seed extract on the oxidative, colour and sensory stability of a pre-cooked, frozen, reheated beef sausage model system was studied by KULKARNI et al. [51]. The authors reported that the grape seed extract and propyl gallate-containing samples retained their fresh cooked beef odour and flavour longer than controls during storage. Rancid odour and flavour scores of grape seed extract containing samples were lower than those of controls after 4 months of storage. The $L*$ value of all samples increased during storage.

Grape seeds are waste products of the winery and grape juice industries. The grape seed flours have a potential application as an additive in some meat products. The addition of grape seed flour may affect fibre and oil contents of meat products. In addition, the grape seed flour can be used to improve technological characteristics and sensory properties of meat products [52–54]. The effects of grape seed flour (0 %, 0.75 %, 1.5 % and 3 %) on the physico-chemical characteristics, microbiological and sensory parameters of Turkish dry fermented sausage, sucuk, was investigated [52]. Grape seed flour decreased moisture content, thiobarbituric acid content, diameter loss and instrumental colour (a^* and b^*) indeces and sensory analysis scores during the ripening period. It also reduced thiobarbituric acid content, instrumental colour indeces (L^*, a^*, and b^*), total aerobic mesophilic and lactic acid bacteria counts during the storage period. The effect of natural (grape seed and chestnut extract) and synthetic antioxidants (buthylated hydroxytoluene) on physico-chemical, lipid oxidation, microbiological and sensory characteristics of dry-fermented sausage were investigated [54]. The results indicated that grape seed is an effective antioxidant and that natural antioxidants can be more effective than synthetic antioxidants. Also, addition of natural antioxidant extracts had a significant effect on redness, leading to higher $a*$ values compared to the control group.

Lemon

Fibre is a suitable component of meat products and previously has been used in cooked meat products to increase the cooking yield due to its water- and fat-binding properties, as well as to improve texture [55, 56]. Lemon albedo demonstrated its potential to be a good source of dietary fibre in meat products. The addition of lemon albedo (raw or cooked) at 5 levels (0–10 %) in dry-cured sausages was studied by ALESON-CARBONELL et al. [56]. The authors observed that the use of 2.5 % raw lemon albedo led to sensory properties similar to traditional sausage. In another study, quality and physico-chemical properties of a non-fermented dry-cured sausage formulated with lemon albedo were reported by ALESON-CARBONELL et al. [57]. The authors reported that lemon albedo lowered the hardness value of sausages. In addition, application of lemon albedo in dry-cured sausages offers processors the opportunity to improve the nutritional and health qualities of their products, including a decrease in residual nitrite levels.

Mushrooms

Mushrooms have high levels of nutrients, namely, protein, polyphenols, minerals (calcium, potassium, magnesium, phosphorus, iron, copper, zinc and manganese), fibre and vitamins. They have several biologically beneficial properties, such as antioxidant and antitumour ones. Addition of mushrooms (fresh, sliced, dried or powdered) to the food products formulae are known to change the physico-chemical, textural properties of food products [58–63]. Application of winter mushroom (*Flammulina velutipes*) powder (0 %, 0.5 %, 1 %, 1.5 % and 2 %, w/w) as an alternative to phosphates in emulsion-type sausages was examined by CHOE et al. [64]. The mushroom additions above 1.0 % increased the pH of meat batter and efficiently inhibited exudation of fat from the sausages. Lipid oxidation in sausages was inhibited by the addition of mushrooms. No adverse effects were observed concerning colour and sensory properties of the sausages containing mushrooms, except for that containing 2.0% mushroom powder (Tab. 4). In another study, oxidative and microbiological stability of fresh pork sausage with added sun mushroom (*Agaricus blazei* Murrill) powder was investigated by STEFANELLO et al. [61]. The colour of the products was characterized by decreased redness at the end of the storage period, on the 35th day. It was concluded that sun mushroom was effective in terms of increasing the oxidative stability of pork sausage when added in powdered form at levels of 1 %, 2 % and 4 %. OLONTA [65] determined the contribution of oyster mushroom *Pleurotus* sajor-caju (0 %, 20 %, 40 % and 60 %) on physicochemical, nutritional and sensory properties of hamburgers. The inclusion of mushroom caused a general decrease in the protein, fat, moisture, ash, mineral element, vitamin as well as soluble protein and an increase in the carbohydrate contents of hamburgers. The pH and water activity (a_w) of the hamburgers was 5.40–5.65 and 0.84–0.96, respectively. The use of straw mushrooms (*Volvariella volvacea*) for the enhancement of physicochemical, textural, nutritional and sensory profiles of Cantonese sausages was studied by WANG et al. [66]. The straw mushrooms improved the content of amino acids and volatile compounds in Cantonese sausage, the sausage containing 2 % of the mushroom scored best for total acceptability. Also, addition of straw mushrooms caused protein network relaxation with some pores and sponge-like structures appearing. It could be assumed that a compact and partially spongy structure was formed due to the interaction between endogenous enzymes of straw mushrooms and meat proteins during sausage processing. Also, the microstructural changes were consistent with the related texture properties.

Orange

The food industry has shown an increased interest in manufacturing healthier, high quality, minimally processed and "more natural" food products [67]. Various types of citrus by-products were successfully used to produce fresh meat products, cooked meat products and non-fermented dry-cured meat products [68]. FERNÁNDEZ-LÓPEZ et al. [69] reported that the addition of 1 % orange fibre had beneficial effects upon dry-fermented sausages (salchichon) safety and quality. These included a decrease in residual nitrite level, which could prevent nitrosamine and nitrosamide formation, and the favoured effect on growth rate of micrococci that could have a protective effect upon rancidity development and stabilize the typical cured colour. YALINKILIC et al. [70] reported that the addition of orange fibre (at 4 %) in sucuk (Turkish dry-fermented sausage) affected bacterial growth, on the one hand, it favoured the growth of lactic acid bacteria and, on the other, the *Micrococcus* and *Staphylococcus* counts decreased. *Enterobacteriaceae* counts were below the detectable level ($< 10^2$ CFU·g^{-1}). Also, there was no statistically significant difference between samples containing 0 % and 2 % orange fibre regarding texture, colour, odour, taste and total acceptability.

Spinach

Since the consumers' demand for "organic" or "natural" meat products has increased due to concerns of health risk of synthetic additives, the meat industry is currently focusing on the development of nitrite alternatives. Green vegetables such as spinach and celery are known as major sources of nitrate and nitrite in human diet [9, 11, 71]. Effects of fermented spinach as a source of pre-converted nitrite on colour development of cured pork loin was examined by KIM et al. [11]. The L^* and b^* values of raw cured meats formulated with fermented spinach extract were higher than those of the control groups (both positive and negative controls). In addition, the a^* values of cooked cured meats were increased with increasing fermented spinach extract levels, whereas the b^* values of cooked cured meats were reduced with increasing levels of fermented spinach extract. The effects of spinach powder addition (at 0 %, 1 % and 3 %) on lipid oxidation, colour and sensory properties of traditional fermented meat products (sucuk) were studied [72]. L^* and a^* values of the control group were significantly higher than treatment groups, but b^* values of 3% spinach powder-added group were significantly higher than the others. No significant difference was found between the sucuk samples at the end of storage. When the sensory properties were analysed, colour, taste, texture and general acceptability scores of spinach powder-added sucuk samples were found to be significantly lower than the control group.

Tomato

Tomatoes and tomato-derived products are used as additives in functional meat products because of the high content of lycopene [67, 73]. CANDOGAN [74] and DEDA et al. [75] studied effects of tomato paste on quality of beef patties and frankfurters, respectively. CANDOGAN [74] reported that the patties formulated with tomato

Tab. 4. Results of sensory evaluation of meat products enriched with fruits and vegetables.

Meat product	Fruit or vegetable	FV level [%]	Appearance	Colour	Hardness	Flavour	Odour	Taste	Texture	Overall acceptability	Ref.
Dry-fermented sausages	Orange fibre	0	4.40	4.20	3.80		4.30	4.52	–	4.75	[69]
		1	4.42	3.95	3.40		4.10	4.50	–	4.59	
		2	2.80	2.80	2.40		4.05	3.90	–	2.80	
Frankfurters	Fermented red beet	0	6.68	6.17	–	5.23	–	–	–	5.81	[27]
		1	6.43	6.21	–	5.03	–	–	–	6.02	
		3	6.17	5.63	–	5.02	–	–	–	5.24	
		5	6.08	6.25	–	5.01	–	–	–	4.22	
Goshtaba	Apple pomace powder	0	–	–	7.80	6.40	–	–	–	6.70	[19]
		1	–	–	7.60	7.00	–	–	–	7.48	
		3	–	–	7.30	6.60	–	–	–	7.14	
		5	–	–	6.70	5.60	–	–	–	6.44	
Meat emulsion	Fermented red beet extract	0	–	8.29	–	7.57	–	–	–	7.71	[26]
		5	–	6.43	–	6.43	–	–	–	7.01	
		10	–	7.43	–	7.14	–	–	–	7.34	
Sucuk	Orange fibre	0	–	7.78	–		7.47	7.42	6.93	7.45	[70]
		2	–	7.18	–		7.22	7.44	7.27	7.50	
		4	–	6.39	–		7.02	7.12	6.96	7.11	
Sausages	Carrot powder	0	7.84		–	7.52			7.61	7.66	[38]
		4	6.08		–	6.42			6.10	6.44	
	Functional carrot powder	4	5.91		–	6.53			6.37	6.62	
Sausages	Mushroom powder	0	–	6.45	–	4.27		4.64	4.36	4.55	[64]
		0.5	–	5.64	–	4.27		4.00	3.73	4.00	
		1	–	6.18	–	5.64		5.55	4.64	5.46	
		1.5	–	5.91	–	4.73		5.10	4.45	4.91	
		2	–	5.64	–	3.55		3.55	2.82	3.36	
Sausage	Grape seed flour	0	7.39	7.39	–	7.08	7.27	–	–	7.50	[52]
		0.75	7.15	7.04	–	6.93	7.08	–	–	7.27	
		1.5	7.47	7.39	–	7.04	7.00	–	–	7.39	
		3	6.58	6.35	–	6.54	6.89	–	–	6.85	
Sucuk	Spinach powder	0	6.50	5.22	–	–	7.11	7.22	6.67	7.06	[72]
		1	5.72	3.89	–	–	6.72	5.39	4.78	5.56	
		3	5.33	3.00	–	–	5.94	5.00	4.67	5.11	

FV – fruit and vegetable, sucuk – Turkish dry-fermented sausage.

paste had higher a^* and b^* indeces and lower L^* indeces than control patties. Calvo et al. [76] and Luisa García et al. [77] examined the influence of dried tomato peel on properties of dry fermented sausages and beef hamburgers, respectively. Calvo et al. [76] reported no significant differences in the texture properties of the sausages produced with and without dry tomato peel (at 0 %, 0.6 %, 0.9 % and 1.2 %). The sensory attributes and total acceptability of all sausages were good, indicating that tomato peel could be added to dry fermented sausages to produce meat products enriched in lycopene. Luisa García et al. [77] noted that higher than 6% dry tomato peel negatively affected texture scores. The addition of dry tomato peel to 4.5 % resulted in hamburgers with good overall acceptability and lycopene content of 49 mg·kg^{-1} of cooked hamburgers. Also, addition of dry tomato peel increased a^* and b^* of raw and cooked hamburgers, and modified all textural properties probably because of the presence of fibre.

Yilmaz et al. [78] used tomato juice in low-fat (5.9–10.3 %) cooked sausages and Østerlie and Lerfall [79] used sun-dried tomatoes, tomato paste and crystalline lycopene in minced meat. The latter authors reported that adding lycopene from tomato products to minced meat could lead to meat products with increased storage stability, different taste, better colour and with a well documented health benefit. Ghafouri-Oskuei et al. [80] investigated the chemical and quality characteristics of beef sausage containing flaxseed (0 %, 3 % and 6 %) and tomato powder at three levels (0 %, 1.5 % and 3 %). The addition of tomato powder and flaxseed powder reduced L^* values, pH, residual nitrite and moisture contents and increased b^* value, protein, carbohydrate, ash, fibre content and total energy values. Generally, adding tomato and flaxseed powders up to 3 % did not affect the sensory evaluation parameters of cooked and fried sausages. Based on the reported results, it is possible to produce sausages incorporated with tomato and flaxseed powders.

In another study, Eyiler and Oztan [81] reported that addition of tomato powder to frankfurters increased their acceptability. Also, addition of 2 % of tomato powder reduced the level of oxidation. However, 4 % of tomato powder caused a slight increase in the oxidation level when compared to the samples which did not contain tomato powder. Modzelewska-Kapituła [73] investigated the influence of commercially available tomato powder on production yield, cooking loss, acidity, colour, lipid oxidation and sensory properties of meatloaf. The addition of tomato powder did not affect L^* of products but it increased a^*, b^*, hue and saturation indeces. Based on the factors most important to the meat processors (pH value, production yield, sensory quality), the recommended level of tomato powder addition was 0.4–0.8 %.

CONCLUSION

There are many types of fruits and vegetables that contain vitamins, crude fibre and biologically active compounds. Additional features of some of them facilitate their use as natural colourants and antioxidants. Improvement of composition of meat products regarding vitamins, antioxidants, fibres and polyphenols may be achieved through integration of fruits and vegetables in them. In addition, some researchers demonstrated the possibility of changing the image of meat products from the traditional one to an image of health-promoting products thanks to the addition of various fruits and vegetables. Also, considerable amounts of nitrates are present in some vegetables such as celery, spinach, radish or lettuce, which can be used as sources of nitrite. The health perception associated with "natural" and "organic" food products has led to a significant increase in their production because of the consumers' demand. Fortification of meat products with fruits and vegetables could help to provide functional products with a high nutritional value and acceptability.

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