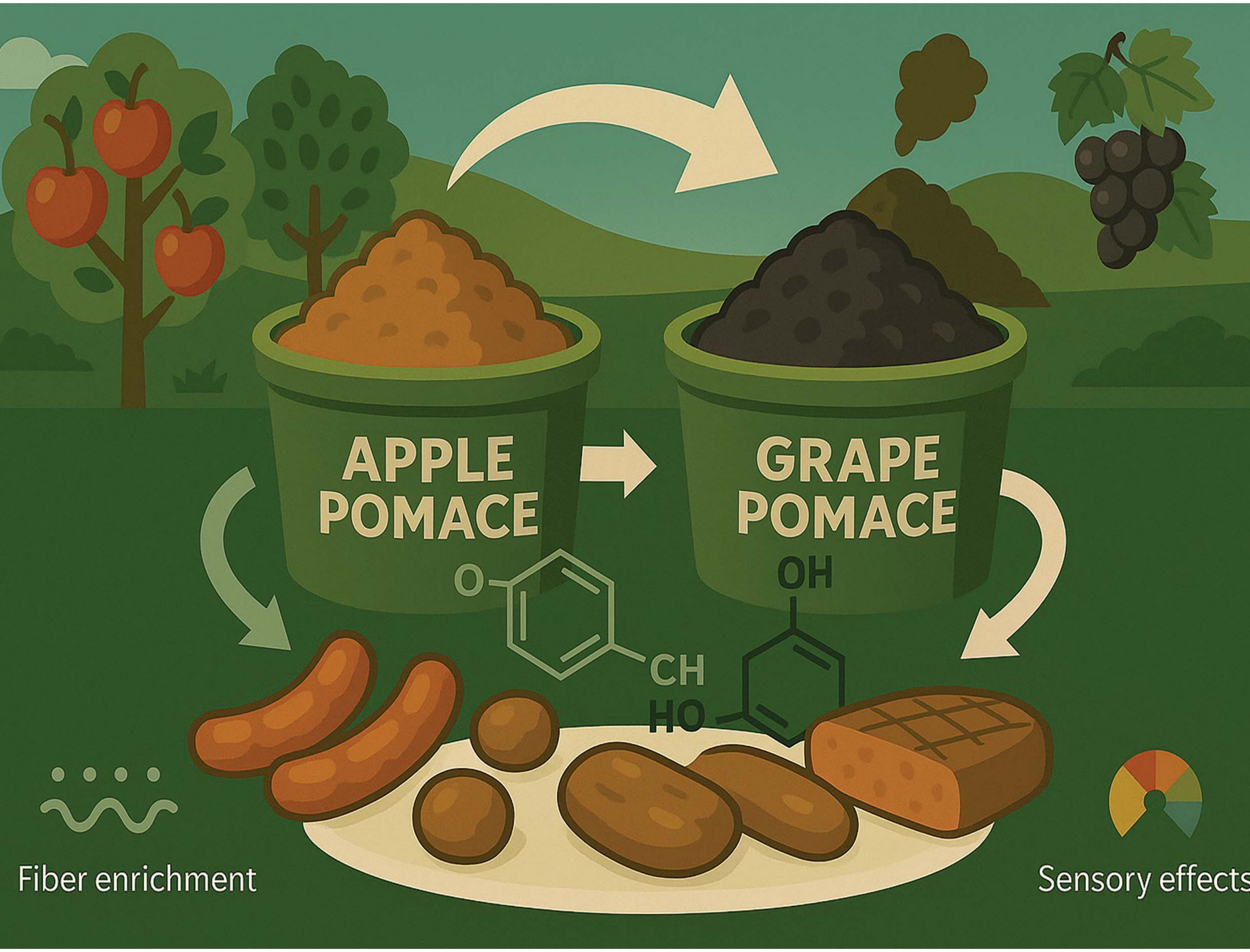
Volume 3
Number 4
July 2025
Pages 849–1236

Sustainable Food Technology

rsc.li/susfoodtech



ISSN 2753-8095

ROYAL SOCIETY OF CHEMISTRY

REVIEW ARTICLE

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Cite this: *Sustainable Food Technol.*, 2025, **3**, 861

Apple and grape pomace: emerging upcycled functional ingredients in processed meat products, designed to increase polyphenol and fiber contents†

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Received 4th February 2025
Accepted 8th June 2025

DOI: 10.1039/d5fb00040h

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Apple and grape pomace, byproducts of juice, cider, and wine production, are typically sent to landfills or used as animal feed. At landfills, they release greenhouse gases like methane and carbon dioxide during anaerobic digestion. These pomaces are rich in fiber (31.79–61.71%) and polyphenols, which are lacking in the western diet, particularly in widely consumed meat-based food products. This review aims to explore the current literature that discusses the effects of incorporating apple and grape pomace into meat, focusing on fiber enrichment, prevention of lipid oxidation, and sensory characteristics like color, flavor, and texture. This narrative review consolidates findings from research databases to provide a structured synthesis of current knowledge on the topic. The polyphenols in pomace are as effective as synthetic antioxidants in reducing lipid oxidation. However, high pomace levels can increase meat hardness. Including pomace in meat products could reduce waste, minimize landfill contributions, and enhance meat's nutritional and functional properties.

Sustainability spotlight

This paper advances the sustainable development goals set out by the United Nations. Specifically goal 12.3 that aims to halve per capita global food waste at the retail and consumer levels, and reduce the food losses along production, and supply chains, including post-harvest losses. This research focuses on apple and grape pomace as a loss at the production level of juice and wine processing, respectively. It is wasted by mostly being discarded in landfills, after the pressing step. To address goal 12.3 this research works to demonstrate the benefits of apple/grape pomace a potential ingredient in food and shows the by-product as a valuable commodity. This in turn could influence producers to invest capital to save the by-product from wastage.

Introduction

Pomace originating from apples or grapes is a beneficial resource that is currently being undervalued by going to landfill or animal feed.[1,2] Grape pomace is produced in significant quantities from the wine and grape juicing industry, being left over after the pressing process.[3] Similarly, apple pomace is another byproduct of apple pressing when making apple juice, hard and soft cider.[4] With the process being similar for the pressing of both fruits, the composition of the pomace can have skin, pulp, seeds and stems. Apple processing leaves 25% of the fruit for pomace and if a third of apples produced go for processing then according to stats by Protzman[5] at the USDA, then there are approximately seven million metric tons of apple pomace that are produced globally per month.[6,7] In relation to grape pomace, a very similar amount of the fruit is leftover after processing (approximately 20–25%).[8] According to García-Lomillo and González-SanJosé,[9] globally, over 50 million tons of grapes were processed into wine in 2017, with over 12.5 million tons of grape pomace produced. These pomaces going to landfill or to animal feed is a concern in the context of sustainability as the pomace in these environments if left untreated can cause anaerobic digestion. This produces methane and carbon dioxide, greenhouse gases that contribute to climate change.[10] Some studies have suggested the use of biorefineries to extract bioactive compounds, organic acids and phenolic compounds to create a circular economy.[11,12] However, grape and apple pomace has also been cited in literature as potential functional ingredients to improve the nutritional profile of foods. Apple and grape pomace can enhance foods as they have a considerable fiber content as well as polyphenolic compounds.[6,13]

Pomace from grape and apple sources have been shown to have polyphenolic compounds present.[3,6,13,14] Polyphenolic compounds are secondary metabolites found in plants that are extremely varied except that they have in common at least one phenol group.[15] The phenol groups allow for the reduction of

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† Electronic supplementary information (ESI) available. See DOI: https://doi.org/10.1039/d5fb00040h

reactive oxygen species, and this allows polyphenols to be effective anti-oxidants when tested *in vitro*.[16] Polyphenols have also been associated with anti-inflammatory, antimicrobial, anticancer, and anti-aging effects, however, the knowledge regarding these mechanisms is still unclear.[17,18] The main polyphenolic compounds that have been associated with grape pomace include, anthocyanins, flavanols, stilbenes and flavan-3-ols.[19] Apple pomace has been associated with polyphenols like, flavan-3-ols, flavanols, and hydroxycinnamic acids.[20,21] What gives grapes and to a lesser extent apples its red pigments is the flavonoid anthocyanin, that was shown to have positive vascular effects, as the polyphenol is metabolized by the host and the microbiome to produce beneficial metabolites.[21,22] D-Catechin, epicatechin, and -epicatechin gallate are all types of flavan-3-ols that have been found to be present in both grape and apple pomace.[1,21] Flavan-3-ols as compounds have been linked to inhibiting NF-kB to limit the activation of inflammatory pathways.[23,24] The stilbenes that are commonly present in grape pomace have been associated with improving cardiovascular health.[25] This association is specific to stilbenes that were demonstrated to enhance endothelial function decreasing LDL cholesterol and reduces blood pressure.[26] These nutritional benefits by the variety of polyphenols found in apple and grape pomace, further demonstrate the potential for these industry byproducts to be up-cycled as functional food ingredients, not only to alleviate the environmental burden, but also to improve human nutrition, and overall health.

It was established that dietary fiber is lacking in the western diet, specifically in the US, only 4% of the US adult population meets the adequate intake for dietary fiber.[27] This presents an issue that has been labelled a public health concern, as all-cause mortality can be reduced by 15–16% in individuals who consume higher levels of dietary fiber, compared to those who consume less fiber.[28,29] Dietary fiber (soluble and insoluble) presents multiple nutritional benefits. Dietary fiber is integral for the mechanism of digestion with soluble fiber being able to absorb water in the gut to allow stool to be softer, whereas insoluble fiber works to increase stool bulk and increase transit time.[30] Further, dietary fiber has an important role in supporting the gut microbiota, as it is fermented by probiotic populations. Promoting the proliferation of beneficial bacteria, and increased production of short chain fatty acids (SCFA).[31] These SCFAs include acetate, propionate and butyrate, and are linked to health promoting functions.[31] The beneficial functions that have been associated with SCFA include butyrate as being an energy source for colonocytes to allow the cells to produce more mucus to act as a barrier, provide an environment for the gut microbiome and prevent excessive permeability.[32] There has also been a link between the reduction of metabolic diseases and the consumption of fiber, as it is theorized that as the gut microbiome changes with increased diversity, this increases the SCFA production reducing the risk of metabolic syndrome.[33] These benefits of fiber add to the evidence suggesting to include more fiber in western diets to offset chronic diseases as coronary heart disease, stroke, hypertension and diabetes.[34]

With meat consumption increasing worldwide there needs to be solutions to the decreased fiber intake and how to extend shelf life without synthetic antioxidants.[35,36] Meat from any source (including white and red meats) are rich in protein, fatty acids, and minerals, that are essential in the human diet.[37] However, a concern with meat is that it does not contain dietary fiber. A nutrient already lacking in western diets.[38,39] Meat has also seen a trend with consumers negative association with synthetic antioxidants, due to health concerns of these free radical scavengers being added to meat.[40] One of the solutions to these challenges is the use of pomaces either from grape or apple production to be included in meat-based food products to fortify it with fiber but also provide natural antioxidants to reduce lipid oxidation without synthetic antioxidants.

The purpose of this narrative review is to examine the incorporation of apple and grape pomace into meat-based food products, with a specific focus on their effects on fiber content, lipid oxidation, and sensory characteristics. With increasing interest in sustainable food production and the valorization of agri-food by-products, understanding how these fruit pomaces influence the nutritional and sensory quality of meat-based products, and other animal-based foods is timely and relevant. This review aims to consolidate current findings and identify potential benefits and drawbacks to support both meat-based food products innovation, and environmental sustainability.

Materials and methods

The databases that were used for the search were PubMed and Scopus. The search within Scopus had a ten-year date restriction and PubMed had no date restrictions. The following search terms were used to search the databases: (“apple pomace” OR “grape pomace”) AND (meat OR “meat products” OR fiber) AND (inclusion OR incorporation OR addition). From the initial search of the two databases 297 articles were found and this was reduced by excluding paper based on titles abstracts and full reads to fifteen research articles, outlined in Fig. 1. Of these fifteen articles seven had apple pomace as the focus of the research and eight focused on grape pomace. Although this review follows a narrative format, the literature search was conducted systematically to ensure comprehensive coverage of relevant studies. Each selected article was critically reviewed by the authors to synthesize key findings. The review does not include a formal systematic review protocol, meta-analysis, or risk of bias assessment, but aims to provide a transparent and thorough narrative synthesis of current research. Each article used in this paper was critically reviewed by the authors.

Results and discussion

Pomace as a fiber rich functional ingredient

The seeds, stems and skin that are the constituents of apple and grape pomace contain high amounts of fiber.[41] Grape seeds have been reported to have 35% fiber and dried grape pomace levels ranged from 31.79% to 52.3%.[42–44] The current review includes research that reported on the fiber content of the apple pomace with levels that ranged between 40.19% to 60.48%.[45–47] Further, Jung, Cavender[3] tested the fiber in apple pomace, and

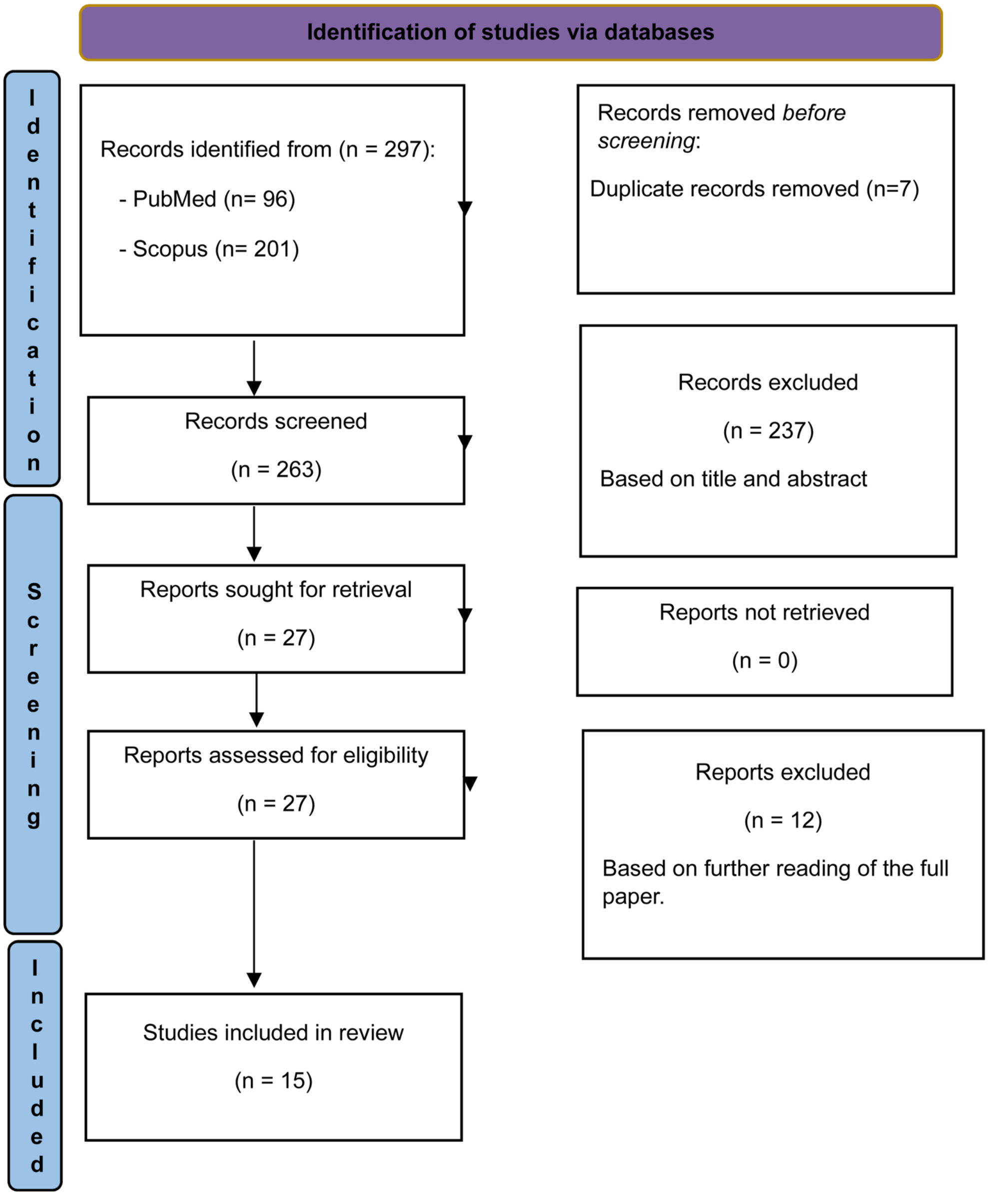

Fig. 1 PRISMA diagram of the exclusion of papers based on the scope of the narrative review.

found that the majority is insoluble at levels 59.92% out of 61.71% of the total dietary fiber. These ranges can be due to the change in processing of the pomace, the different types of processing of the pomace in this review can be seen in ESI Table 1.† Pectin is a water soluble fiber that is also present within apple pomace and is used throughout the food industry as it is essential for the gelation process as well as stabilizing acidic dairy drinks.[48] Dietary fiber present in both grape and apple pomace causes changes in the meat matrix it is added to, and effects the emulsification capacity. Emulsification capacity is a critical functional property of meat, as it influences the stability of fat and water within the meat matrix. This, in turn, impacts water-holding capacity and cooking yield, ultimately affecting the texture, overall quality, and consumer acceptance of meat-based food products.[49] Previous study[45] discusses how the 2% inclusion of apple pomace fiber had significantly less weight loss due to cooking, compared to the control ($P < 0.05$). This is due to the fiber increasing the water binding capacity between the protein and the water which has been recognized in food systems.[50] Research conducted by Solari-Godiño, Pérez-Jiménez[51] with grape pomace in anchovy mince, showed that water holding capacity increased as dietary fiber from grape pomace increased. However, fiber did not have a linear effect on cooking loss. The amount and type of fiber will influence the emulsion capacity, water holding capacity and the cooking yield. It will also depend on the type of meat that the pomace is incorporated into. Similarly with any other food product ingredient, trial and error and product development are vital to ensure the meat emulsion will still function.

Pectin found in apple pomace has a function in lipid metabolism with the capacity to bind not only cholesterol but bile acids as well to limit the effects of cardiovascular disease.[52] Health benefits have also been associated with the prebiotic effect of dietary fiber. Promoting the growth and the diversification of the gut microbiome has been associated with relieving irritable bowel syndrome symptoms and reducing weight gain.[53] The water binding of the dietary fiber is beneficial within the gastrointestinal tract as it increases stool bulk and facilitates regular bowel movements.[54] There was a slight increase in the dietary fiber content of the salmon burgers from control with 4.6 g/100 g to the Grape pomace flour treatment of 2% with 5.2 g/100 g in the study conducted by Cilli, Contini.[43] This small increase in fiber can be beneficial to consumers as there is a distinct lack of fiber in western diets.[55]

Pomace processing

The processing methods used for both apple and grape pomace varied across the studies included in this review. ESI Table 1† includes a column titled form of the by-product, which outlines the specific treatments applied to the pomace in each relevant study. Notably, several papers did not report the source or processing method of the pomace used,[56–58] which limits reproducibility and comparability. Oven drying was the most consistently used process throughout the studies.[44,46,51,59–62] Oven drying accelerates moisture removal using heat, contributing to the preservation and shelf stability of fruit and vegetable by-products.[63] Other reported processing methods included freeze-drying, high hydrostatic pressure, air drying, and high–low instantaneous pressure treatments.[43,45,47,64,65]

This inconsistency in pomace processing represents a limitation within the reviewed literature. Establishing a widely accepted standard for pomace processing would enhance comparability between studies, particularly given the inherent variability in raw material composition. Furthermore, a standardized approach would benefit industry stakeholders by offering clearer guidance on how processed pomace can be used effectively as a functional ingredient in meat-based food products (Table 1).

Polyphenols and lipid oxidation

Rancidity of meat has many factors associated with it, for example microorganisms, chemical reactions and physical factors.[66] Meat producers try to control these factors to extend shelf life. Microbial growth is controlled by refrigeration of the meat throughout processing as well as moisture and contamination controls.[66] Physical factors for contamination try to be avoided by proper handling as to not damage the product, the pH must also be maintained with minimal variations throughout shelf life.[67] There are also methods to reduce the chemical reactions that cause rancidity like oxidation and enzymatic breakdown. These methods include adding artificial anti-oxidants to prevent the oxidation of the fats and lipids in the meat as well as temperature control minimizing the activation energy of the enzymes within the meat.[68]

The process of lipid oxidation can be broken down into three stages; (1) initiation, (2) propagation, and (3) termination.[69] The initiation stage is started by reactive oxygen species or free radicals that are present in the meat. The unsaturated fatty acids in the meat have a methylene group in which the free radical compounds can remove a hydrogen atom and become a lipid radical. The next stage causes the lipid radical to react with the oxygen that was present in the environment, to form a peroxyl radical. This peroxyl radical can cleave more hydrogen from the methylene group of another unsaturated fatty acid to produce a highly unstable product of lipid hydroperoxide and a secondary byproduct of malondialdehyde (MDA). A compound measured through the TBARS test. The termination stage is when two free radicals combine to stop the chain reaction by becoming a non-radical species.[70,71] Antioxidants can work to scavenge the free radicals at the start of the process by donating an electron before the initiation phase or they can chelate metals that catalyze the oxidation process.[72]

There were seven studies that used the TBARS test to evaluate the lipid oxidation of the meat-based food products over the course of the shelf-life period.[43,44,57,59,62,64,65] These studies either used apple or grape pomace to see if the natural antioxidants present in pomace like anthocyanins and flavanols can provide similar lipid oxidation results to synthetic antioxidants.[21,22]

Grape pomace and lipid oxidation

Carpes, Pereira[62] used microencapsulated and non-microencapsulated grape pomace extract, in chicken pate with a positive control of sodium erythorbate. The authors used the TBARS test every week over the course of 42 days to determine the amount of lipid oxidation. The results indicated that the non-microencapsulated grape pomace caused the least amount of oxidation throughout the testing process except at 35 days. This was against the authors hypothesis that the microencapsulation would allow for the polyphenols in the grape pomace to be released slower, causing less oxidation over the course of the shelf life testing. Consistently the grape pomace treated chicken pate groups were lower in lipid oxidation levels compared to the positive control. Carrapiso, Martín-Mateos[65] also used grape pomace as an inclusion ingredient for dry cured pork sausages using the TBARS test to measure MDA. There was no significant ($p > 0.05$) difference for the positive control (sodium nitrate and ascorbic acid) and the grape pomace inclusion groups, even with the control having significantly ($p < 0.05$) more lipid oxidation. Further, there were no significant differences between the two groups of pomaces. The lower concentration of 0.5% grape pomace inclusion, showed the same benefits to preventing lipid oxidation as the 3% concentration of grape pomace used. In another study by Riazi, Zeynali,[44] grape pomace was used in beef sausages. As a difference this study used sodium nitrate in combination with grape pomace to assess the effect that this had on the lipid oxidation of the beef sausages. There were no significant differences between the groups in this study ($p > 0.05$), however, authors concluded that the level of oxidation is not dependent on the level of grape pomace that was included in the beef sausage. From the three

Table 1 Effects of the by-products used in each study on lipid oxidation and/or sensory aspects of the meat analyzed

By-product	Meat analyzed	Groups of meat products	Results	Author
Grape pomace	Chicken pate	T1 was the negative control with nothing added to the base pate formulation T2 was the positive control with sodium erythorbate T3 was the freeze dried grape pomace added to the original recipe T4 had the microencapsulated form of the pomace added	T3 = least amount of lipid oxidation T3 + T4: both had lower lipid oxidation than the controls	Carpes, 2020
White grape pomace	Dry-cured pork sausages	Group 1 was the control plain formulation Group 2 NITRASC is the positive control with sodium nitrate Group 3 0.5% pomace was w/w Group 4 3% pomace w/w	No differences in lipid oxidation between G3 and G4 compared to G2 G4 in sensory only had lower scores for defective textures	Carrapiso, 2024
Apple pomace fiber	Reduced fat chicken sausages	Chicken breast meat-CBM, pork back fat-PBF, ice water-IW, apple pomace fiber-APF Control = 50%-CBM, 30%-PBF, 20%-IW T1 = 50%-CBM, 25%-PBF, 25%-IW T2 = 50%-CBM, 25%-PBF, 24%-IW, 1% APF T3 = 50%-CBM, 25%-PBF, 23%-IW, 2% APF T4 = 50%-CBM, 20%-PBF, 30%-IW T5 = 50%-CBM, 20%-PBF, 29%-IW, APF-1% T6 = 50%-CBM, 20%-PBF, 28%-IW, 2% APF	Caloric input was decreased with the fiber inclusion compared to the control sausages The hardness, cohesiveness, gumminess increased with the addition of fiber	Choi, 2016
Grape pomace flour	Salmon burger	Control had base burger recipe BHT group had synthetic antioxidants added GPF 1%, grape pomace flour GPF 2%, grape pomace flour	Dietary fiber increased with increase of grape pomace fiber inclusion The GP delayed the increase in TBARS during frozen storage and was just as effective as synthetic antioxidants The treated burgers decreased significantly the scores of liking, appearance, color, and overall quality Fish flavor was masked in the GP flour samples No sig dif. in the odor scores	Cilli, 2019
Grape skin (inulin and beta glucan)	Pork sausages (non-castrated male pork)	Three groups were created for two different types of sausage Group 1 had a base recipe of 25% fat for frankfurter and 30% fat for the Spanish sausage with the rest made up by lean ham Group 2 for the frankfurter fat was reduced to 12.5% and 6% inulin, with 0.5% beta glucan, the Spanish sausage was 20% fat with 3% inulin, 0.5% beta glucan Group 3 was for the frankfurter 3% inulin, 1% beta glucan, 0.5% GPE. The Spanish sausage was 6% inulin, 1% beta glucan and 0.5% GPE	G3 frankfurter had higher hardness and chewiness scores in sensory testing The boar taint in odor and flavor were reduced by the treatment groups	Egea, 2020
Red grape pomace	Pork burgers	Control: base burger recipe GP1 high–low instantaneous pressure and then methanolic extraction added at 0.06 g/100 g GP2 methanolic extraction added at 0.06 g/100 g	GP1 reduced lipid oxidation the most after 3 days GP1 patties were much darker than control	Garrido, 2011
Apple pomace	Italian salami	Control: standard salami recipe 7% AP group 14% AP group	Both 7% and 14% AP had higher sensory scores for rancid and bitter flavor For texture scores the 14% AP salami was lower than the other groups for the juiciness and the chewiness scores with 14% AP scoring high in hardness scores	Grispoldi, 2022

Table 1 (*Contd.*)

By-product	Meat analyzed	Groups of meat products	Results	Author
			Overall acceptability scores were in order of control, 7% AP and then 14% AP salami	
		Sampling was done at day 0 of ripening and days, 5,11,19, 25		
Apple pomace powder (APP)	Buffalo meat emulsion	Control base buffalo meat recipe T4-2% APP T5-4% APP T6-6% APP	T6 had sig. lower scores in texture compared to the control	Kumar, 2024
Apple pomace	Irish breakfast sausage	18 treatment runs all together The most inclusion into sausage was 1% This was split between one two or three inclusions of either sodium triphosphate, apple pomace or coffee silver skin	The treatments with more apple pomace had higher levels of fiber AP affected the hardness, chewiness, gumminess and springiness values of the sausages compared to the STPP control Lipid oxidation was slightly increased with the addition of AP	Palanisamy, 2022
Apple pomace	Beef burger	Control: 0% base burger 4% AP 8% AP	There were significant differences in all of the groups in the triangle tests 8% AP inclusion had the highest color intensity, elasticity and cohesiveness scores. This made the overall acceptability lower	Pollini, 2022
Grape pomace	Beef sausage	Control with beef sausage formulation and sodium nitrate 120 mg kg^{-1} T1 had 60 mg per kg of sodium nitrate and then 1% grape pomace T2 had 30 mg per kg sodium nitrate and then 1% grape pomace T3 had 60 mg per kg sodium nitrate and 2% grape pomace T4 had 30 mg per kg sodium nitrate and 2% grape pomace	For lipid oxidation there was no significant differences between the batches in the TBARS test The grape pomace samples reduced the lipid oxidation over the course of storage The grape pomace enhanced the flavor profile of the beef sausages and texture was also improved Overall acceptability was lowered by grape pomace inclusion over 1%	Riazi, 2016
Grape pomace	Anchovy mince	Control: 0% 2% w/w GP 3% w/w 4% w/w	Fortified samples had no changes in color or flavors The control had the lowest general acceptability score compared with the fortified samples	Solari-Godiño, 2017
Ultrasound-treated apple pomace	Irish breakfast sausage	STPP: sodium tripolyphosphate, AP: apple pomace, CSS: coffee silver skins Formulation 1: 0.2% STPP+ 0.22% AP + 0.58% CSS Formulation 2: 0.2% STPP + 0.00% AP + 0.80% CSS Formulation 3: 0.06% STPP + 0.94% AP + 0.0% CSS All formulations are tested with ultrasound and non-ultrasound treated AP and CSS	For lipid oxidation there were no changes between formulations until day 9 Formulation 3 had higher TBARS scores for the ultrasound treated formulations	Thangavelu, 2022
Grape extract	Chicken nuggets	There were 10 different formulations designed Mechanically deboned meat (MDM) content, amount of grape pomace extract included 0 g/100 g, 120 mg kg^{-1} 15 g/100 g, 60 mg kg^{-1} 4 g/100 g, 162 mg kg^{-1} 26 g/100 g, 78 mg kg^{-1} 4 g/100 g, 78 mg kg^{-1}	The 15 g MDM and the 60 mg AP was rated the best formulation The higher inclusion of the MDM and the GPE the comments were that the nuggets were dark and off color	Tournour, 2017

Table 1 (*Contd.*)

By-product	Meat analyzed	Groups of meat products	Results	Author
		15 g/100 g, 120 mg kg^{-1}		
		26 g/100 g, 162 mg kg^{-1}		
		30 g/100 g, 120 mg kg^{-1}		
		15 g/100 g, 180 mg kg^{-1}		
		15 g/100 g, 120 mg kg^{-1}		
Apple pomace powder	Buffalo meat patties	Control: 0% w/w base patties formula	The color change was significant for the 8% inclusion in the buffalo meat patties	Younis, 2018
		2% w/w	Acceptance was highest in the 6% patties inclusion	
		4% w/w		
		6% w/w		
		8% w/w		

manuscripts that were previously discussed, three different types of meat were used, specifically, chicken, pork and beef. These studies also sourced grape pomace from various wineries and had separate varieties of grapes that were processed into powder. However, the consistent polyphenol content that is present in grape pomace allows it to be comparable in preventing lipid oxidation as commercial antioxidants already used in the meat industry, such as sodium nitrate, and sodium erythorbate.[65,73] An observation that is important to make is that lipid oxidation varies across meat for human consumption. This variation relates to the composition of fats within the meat itself. The ratio of saturated to unsaturated fatty acids directly influences the rate of lipid oxidation in meat.[71] Specifically, the increased unsaturated fatty acids that are present in the meat, will result in increased susceptibility to meat lipid oxidation, as the carbon–carbon double bonds are more accessible for free radical breakdown.[71] Chicken has the highest rate of unsaturated fatty acids relative to pork and beef.[74] The results from Carpes, Pereira[62] demonstrated that the grape pomace treated groups significantly reduced lipid oxidation in chicken pate. This is very positive as they reduce lipid oxidation despite the additional mechanical processing of the pate, which accelerates lipid oxidation, and higher content of unsaturated fatty acids in the chicken.

Apple pomace and lipid oxidation

Out of the seven studies that analyzed lipid oxidation of meat through a TBARS test,[43,44,57,59,62,64,65] the studies either did not mention how the meat was stored before testing or they were stored at refrigeration temperature. Refrigeration of the meat can reduce the level of lipid oxidation as it can minimize the movement of molecules and so limiting the ability of free radicals to begin the lipid oxidation process. Two studies analyzed different formulations of Irish breakfast sausages supplemented with apple pomace and coffee silverskin powders.[57,59] One study evaluated eighteen different combinations of sodium tripolyphosphate, apple pomace, and coffee silverskin to identify optimal formulations for phosphate replacement, adopting a broad screening approach to determine the most effective inclusion levels.[57] Phosphates can chelate metals that catalyze the lipid oxidation reaction although phosphates are not considered antioxidants.[75] For the study by Palanisamy Thangavelu, Tiwari[57] the results showed that the effect on lipid oxidation was minimal. Authors suggested that the apple pomace worked with coffee silverskin as antioxidants to maintain the reduction in lipid oxidation provided by the sodium tripolyphosphate. However, it must be noted that the higher concentration of apple pomace treatments did cause a higher level of MDA when the meat was stored in refrigeration conditions for nine days.[57] These levels of MDA were still within the safety threshold of 5 mg MDA/kg and no off flavors or odors were observed.[76] This manuscript led to the determination of the three formulations in the following manuscript by Thangavelu, Tiwari,[59] where ultrasound treated apple pomace and coffee silverskin was utilized to determine this method's effect on breakfast sausages. The formulations for the breakfast sausages that used the most coffee skins was formulation 2 (0.2% STPP + 0% AP + 0.8% CSS) and formulation 3 had the most apple pomace (0.06% STPP + 0.94% AP + 0.00% CSS). In terms of TBARS analysis the values were similar across formulations for days 0, 3, and 6, this indicates that during the assessed storage time, the apple pomace and coffee silverskin were effective in reducing the production of MDA. However, between day 6 and 9 the third formulation with higher levels of apple pomace had increased levels of MDA. This might be an indicator that the apple pomace antioxidants are degraded more rapidly relative to sodium tripolyphosphate, and the coffee silverskin antioxidants. This might occur over time in the third formulation, as there are constant oxidation reactions occurring within the meat, that degrade the antioxidants.[69]

The literature in the current review suggests that grape pomace is effective in prevention of lipid oxidation, as efficiently as synthetic antioxidants that are commonly used in the meat processing industry. This is consistent across multiple types of meat-based food products, like chicken, pork and beef.[44,62,65] The apple pomace still maintained levels of MDA that would not cause rancid flavors or aromas in the pork sausage as seen in the research conducted by Palanisamy Thangavelu, Tiwari[57] as well as Thangavelu, Tiwari.[59] The refrigerated storage of the meats minimizes the amount of lipid oxidation that can occur. However, the comparisons of the treatments with the negative control shows that the apple pomace and grape pomace can be more effective than no treatment at all even with refrigeration. The grape pomace and apple pomace have been demonstrated to be effective preventers of lipid oxidation in meat, this observation is key evidence to further explore apple and grape pomace as up cycled ingredients for human consumption.

Sensory evaluation

Sensory analysis completed by human participants can provide evidence as to what sensory aspects of a product are effected when ingredient profiles, or preparation techniques, are changed.[77] There are multiple ways to test participants in a sensory analysis, for example, the quantitative descriptive analysis. This uses hedonic scales to assess certain aspects of the food product.[78] These descriptors are usually associated with taste, color or texture, but the questions can be tailored to the food product or to what the researchers would like to determine specifically. The type of assessor for new product tests are usually sensory assessors that are naïve (haven't been trained) or an initiated assessor (some training on the product involved) and the assessor chosen can have an impact on the results obtained.[79] When trained on the food product that they are consuming participants can become very analytical and assess flavor and texture in a more critical manner. The quantitative descriptive analysis benefits from trained panelists who can be asked to identify a descriptor and give accurate values if a difference is detected.[80] Understanding the most appropriate way to assess certain products such as meat is vital to understand the effects of product changes in ingredients, and if these changes are acceptable to consumers.[81]

Effect of apple and grape pomace inclusion on meat texture

In the current review there were ten research manuscripts that used sensory analysis to determine textural, taste and color differences in the meat formulations. As sensory analysis can be very subjective per participant, the subjectivity must be limited by reducing the factors that cause variation. The factors that must be controlled have been outlined by the Declaration of Helsinki of 1975 which includes factors such as the recruitment, training, preparation and location of analysis.[82]

Carrapiso, Martín-Mateos[65] used twelve assessors to assess the dry cured pork sausages that had a stabilized but wet form of white grape pomace incorporated in four different groups of dry-cured sausages (control, synthetic additives, 0.5% grape pomace, or 3% grape pomace). Each participant received 1 sausage from each group to consume for five sessions of sensory analysis. The authors trained the assessors over two training sessions, focusing on how to measure intensity of smells, colors, and flavors. The results from the analysis indicated that the 3% grape pomace inclusion had a significantly higher ($p < 0.05$) score for defective texture with slightly higher scores ($p < 0.05$) for hardness and lower ($p < 0.05$) scores for juiciness. Similar observations for texture were observed in the research conducted by Egea, Álvarez.[56] The researchers analyzed fat reduced frankfurters and Spanish sausage with inulin, beta glucan, and grape skin. Egea, Álvarez[56] used 8 assessors in their sensory study who were trained on quantitative descriptive analysis, and tasted three samples from each treatment (control, R1 fat reduced with inulin + β-glucan, R2 fat reduced with inulin β-glucan + grape skin) and each sausage type. The 0.5% grape pomace extract (R2) included in the frankfurter resulted in significantly ($p < 0.05$) higher hardness and chewiness scores compared to the other groups. Texture scores were also affected when grape pomace (skin and seeds) flour was added to a salmon burger in research conducted by Cilli, Contini.[43] The decrease in texture scores was significant ($p < 0.05$) between the normal and positive control. Overall, these results indicate that the grape pomace once formulated with different meat emulsions and cooked, can increase hardness and chewiness of the meat. The insoluble fibers that are within the grape pomace such as lignin that can cause these changes in texture by supporting the binding factors, and structure of the meat. This is substantiated by the results demonstrating that the increased grape pomace will lead to increased fiber content.[83,84] In the research conducted by Riazi, Zeynali,[44] the authors used 20 trained assessors with 5-point hedonic scales to analyze the sensory aspects of beef sausages with varying levels of sodium nitrate, and grape pomace that was dried with a counter current dryer. There were no significant differences in texture of the beef sausage groups. The grape pomace in this instance was 52.3% fiber and could have increased the hardness and chewiness of the sausages, but for this meat format this was not a negative for assessors, therefore, scores remained constant.[44] Grape pomace was also added to anchovy mince by Solari-Godiño, Pérez-Jiménez.[51] The associated sensory analysis included 10 trained panelists, that analyzed general acceptance. The effect on the anchovy meat was similar as to previous research discussed prior, the fibers have an ability to bind with water and cause certain structural changes within the meat formulation.[43,56,83] The effect in this case was a lumpiness texture that was identified by the assessors but did not affect the overall product acceptability. Overall, it appears that the high fiber content in grape pomace, caused changes in the texture of the meat formulations that increased hardness in sensory tests and impacted acceptability scores, this is an aspect of the ingredient that must be considered prior to inclusion in meat.

Apple pomace was also analyzed in meat products through sensory analysis in 4 separate manuscripts that are included in the current review. The manuscript by Grispoldi, Ianni,[46] used 16 trained panelists to assess the characteristics of the Italian salami with additions of dried apple pomace at inclusion levels of 0%, 7% and 14% of product (w/w). These assessors utilized seven-point hedonic scales to give quantitative data to the observations they were making, specifically on the product's texture. These values indicated that for the 14% apple pomace inclusion group the texture was not juicy nor chewy, and the salami was harder than other assessed samples. This trend in reduced texture scores continued in the research conducted by Kumar, Yadav.[61] The authors used apple pomace powder in a buffalo meat emulsion at inclusion levels of 2%, 4% and 6% of product (w/w). Experienced assessors analyzed the meat emulsion on 8 point hedonic scales for multiple characteristics of the cooked meat emulsion. The texture, juiciness and tenderness scores were significantly lower ($p < 0.05$) for the 6% inclusion of apple pomace powder relative to the 2% inclusion. The authors claimed that the high fiber content in the apple pomace powder caused the product's hardness, and therefore, decreased texture scores, with overall effect on product's acceptability. Further, Pollini, Blasi[47] used triangle testing for sensory analysis of beef burger supplemented with freeze-dried apple pomace at inclusion levels of 0%, 4%, and 8% (w/w). Triangle testing gives the assessor three samples to try. Two of the samples are the same and one is different. It is the assessors job to identify the sample they feel is different from the other two.[85] If different assessors on a consistent basis are able to recognize the product that is different, then the new product has changes that are significant enough for consumers to recognize.[85] The triangle tests completed by Pollini, Blasi[47] indicated that there were differences between all apple pomace inclusion groups, as all trained assessors could detect noticeable differences to identify the sample that was the odd one out. The higher inclusion of apple pomace in the beef burger at 8% had the lowest scores for elasticity, juiciness and cohesiveness, bringing down the texture scores. Overall, it appears that the inclusion of apple pomace within meat-based product caused increased levels of hardness, and lowered overall acceptability. It should be noted however that for most of the experiments it was the treatment group with the highest apple pomace inclusion, that incurred the higher negative texture sensory scores. The hard texture in apple pomace and the negative sensory scores in grape pomace meat-based food products are both attributed to their high fiber content. This extra fiber increases the water holding capacity of the formulation of the matrix, for example, in dairy, the apple pomace reduces syneresis and aids in yogurt holding its texture.[86] The dietary fiber in apple pomace can be very useful in foods that do not have any fiber. Meat products fall into this category, and by adding pomace in correct amounts it can increase fiber consumption by consumers, also increasing the product's nutritional benefits. However, this additional fiber can cause the textural characteristics to change, which in return might be unacceptable to the consumer. Apple pomace, as a food product ingredient, should include sensory tests aimed at identifying the ideal pomace inclusion level in the assessed food product, and to assure it has minimal impact on the texture of the meat emulsion, and/or product.

Effect of apple and grape pomace inclusion on meat color

Color of meat is an important sensory factor that is considered by the consumers to be significant prior to the procurement or consumption of a meat-based food product.[87] Researchers can measure the difference in color of foodstuffs in two main ways, (1) the Hunter lab system with a chroma meter[88] or (2) sensory analysis test with participants that are familiar with the tested product.[89] Wet stabilized grape pomace in dry cured sausages at treatment levels of 0.5% and 3% (w/w) had lower scores for lean color compared to the positive control (synthetic additives).[65] Color sensory scores were also affected by the inclusion of grape pomace flour in salmon burgers during the sensory testing conducted by Cilli, Contini.[43] The grape pomace flour burgers were significantly ($p < 0.05$) different in color scores, and this is since these burgers had a higher level of red color in the cooked samples, therefore, making them appear undercooked, this appearance affected the product acceptability by the assessor panel. In the anchovy mince example of grape pomace inclusion, the assessors did not report on any color effects.[51] This could be due to the fact that the mince is already dark, and therefore, the grape pomace had minimal effect on the final color of the cooked product.[90] Grape pomace extract was used in the fortification of chicken nuggets in research conducted by Tournour, Cunha.[60] The researchers used 10 different formulations with varying levels of mechanically deboned chicken meat and grape pomace extract. The researchers conducted sensory analysis and there were seventy-nine untrained assessors that were asked to rate chicken nuggets acceptability on a nine-point hedonic scale and provide their comments. The effect on color with the two treatments was that as the level of mechanically deboned meat and grape pomace increased, the internal whiteness of the chicken nugget decreased. Specifically, the grape pomace caused a darker red color. This decreased whiteness internally, negatively affected the sensory color scores of the chicken nuggets evaluation during sensory testing. There is a consistent trend in the literature, regarding the inclusion of grape pomace in processed meat-based animal products, as these products appeared to be darker with higher levels of grape pomace inclusion, and therefore, this inclusion negatively impacted the sensory testing outcomes, in both trained and untrained participants.[43,60] The increased darkness in the product can be attributed to the high anthocyanins content in grape pomace. These are flavonoid compounds that are found in grape skins.[91] The anthocyanins have health effects as they are polyphenols that can work as antioxidants, and present antiviral activity.[91,92]

Apple pomace as a powder affected the color of the Italian salami in the research conducted by Grispoldi, Ianni.[46] The color intensity and uniformity of the Italian salami samples decreased as apple pomace inclusion increased according to the sixteen trained assessors. The off color was associated with the yellowness that originates from the apple pomace. There was no difference in the color for the addition of apple pomace powder in a meat emulsion.[61] Further, in a study conducted by Pollini, Blasi,[47] it was found that the color uniformity in the control patties (no apple pomace) had the most acceptability by the panelists assessing the burgers. However, for color intensity of the beef burgers the highest inclusion at 8% apple pomace (w/w) had the highest scores from the assessors. The buffalo meat patties in research conducted by Younis and Ahmad[58] had 0, 2, 4, 6, 8% inclusion of apple pomace in the patties (w/w). The 8% inclusion of the apple pomace was found to be unacceptable to the participants of the study, compared to the control (no pomace added). The color from the apple pomace originates from carotenoids that are natural pigments that provide yellow, orange and red hues to fruits and vegetables.[93] As well as this chlorophyll degradation occurs in apples during processing, hence might shift colors to a yellow or brown color in the product.[94] This color of the apple pomace can cause shifts in the color palette of the meat if the apple pomace is added in large volume to the product. This is especially apparent when meats like salami in the research conducted by Grispoldi, Ianni[46] has a clear consumer requirement for a red color. However, in the research presented there was some acceptance for the color changes if the inclusions were not in excess.[46,47,58,61]

Effect of apple and grape pomace inclusion on meat flavor

The most important factor to consumer acceptance is flavor, this aspect of food influences return buying, and keeps the pomace from reaching landfill while incorporated into meat-based food products.[95] Flavor as an aspect of sensory analysis needs to be incorporated as well to gauge the effect that the pomaces have on the meat matrix, compared to the control. The white grape pomace that was used in the analysis conducted by Carrapiso, Martín-Mateos[65] had minimal effect on the flavor compared to the control. This result of minimal effect on flavor was repeated in multiple studies in the current literature review.[51,60] The specific flavor traits that were assessed were flavor intensity, and off-flavor, and these had no significant differences ($p > 0.05$) between the treatment and control groups. The sensory analysis completed by Cilli, Contini[43] used grape pomace flour in a salmon burger. The results demonstrated that when 2% grape pomace flour (w/w) was used, there was a significant ($p < 0.05$) negative effect on flavor scores. However, there were comments made by the assessors that the burgers with more grape pomace flour, had more of the fish flavor masked. This result could be more appealing to some consumers. This ability to mask flavors was also found when grape pomace was added to sausages that can have a boar taint associated with them based on the type of animal used. The treatment groups with grape pomace, inulin and beta glucan reduced the odor and the flavor taint for both the frankfurter and the Spanish sausage.[56] Further, there were improvements in the flavor of the beef sausages that were assessed by Riazi, Zeynali.[44] Therefore, there is clear evidence that the inclusion of grape pomace can mask certain flavors, like fish and taints, but can also potentially enhance flavors. This ability of the grape pomace to flavor mask, and flavor enhance when added in certain meat-based food products is due to the phenolic compounds that are still present in the pomace, even after processing.[1] The phenolic compounds that influence color and produce antioxidant properties can also influence flavor, specifically anthocyanins, flavan-3-ols and flavones.[96] Overall, these results demonstrate that grape pomace has minimal effect on the flavor of certain meat-based food products. Grape pomace can be considered to be included in meat-based animal products if the other sensory aspects of the meat like texture and color are minimally affected as well.

Apple pomace and its effect on flavor in certain food products was also tested *via* sensory analysis. Grispoldi, Ianni[46] investigated the inclusion of oven dried apple pomace in Italian salami, *via* sensory evaluation. The sixteen trained panelists noted minimal changes in flavor between control (no pomace) and the 7% (w/w) inclusion of the apple pomace in the salami. The negatives they noticed for the 14% inclusion (w/w) were limited to slightly higher scores in the rancid, and bitter flavor. The research conducted by Kumar, Yadav[61] used less apple pomace included in a beef meat emulsion only reaching an inclusion group of 6% (w/w). However, similar results to Grispoldi, Ianni[46] were found. The inclusion of 2% AP powder and 4% AP powder were not significantly different for flavor scores, however, for the 6% treatment group the flavor scores were significantly different from the control and the 2% AP powder ($p < 0.05$). In contrast, the triangle tests completed by Pollini, Blasi[47] found that there were significant differences ($p < 0.05$) between each of the three freeze-dried apple pomace inclusion groups in beef patties, at inclusion levels of 0%, 4%, and 8% (w/w). The twenty trained assessors were able to identify differences in flavor between the control and the 8%, with the 8% having higher scores for acid, and sweet flavors. Younis and Ahmad[58] found, that there were no differences until 6% and 8% inclusion level of tray dried apple pomace in buffalo meat patties, specifically, in terms of taste characteristics. The taste scores of the patties did decrease with the inclusion of apple pomace in the buffalo meat patties, however it should be noted that the sweetness scores decreased as apple pomace increased. Similar to grape pomace, apple pomace has polyphenols that can influence flavor, as well as, natural sugars.[3] The rancid and bitter flavor that was found in the salami from Grispoldi, Ianni,[46] had score changes that were minimal, probably due to interactions between the meat-based food products and the apple pomace. These changes could be due to the processing and ripening of the salami, as this might lead to a bitter and rancid flavors that were minimally detected by the assessors.[97] Other studies that used 8% or less (w/w) dried apple pomace inclusions in their meat emulsions, had more of an acceptable flavor, hence, this limit may be set by food manufacturers who wish to use apple pomace in the future.

Next steps for pomace inclusion

There are many challenges that face the incorporation of these ingredients in food products for the public. One of the challenges around incorporating apple and grape pomace into the food system is the use of pesticides for these crops. Pesticides can accumulate in the human body if certain crops are eaten in large quantities and can then cause chronic diseases in humans.[98] These are challenges that can be overcome however, with the appropriate testing of pesticides in the ingredient and safeguards put in place. Another challenge is trying to achieve an appropriate cost model for the safe processing and transport of the ingredient from juice and winery production lines. If however, the monetary value that is clearly present in these up cycled ingredients could be realized by the industry then the investment could be made to overcome the cost model challenges.

The optimal inclusion level of grape or apple pomace in meat-based food products is highly variable and depends on several factors, including the type of meat, the processing method used for the pomace, and the intended functional benefit (*e.g.*, fiber enrichment, antioxidant effect, or phosphate replacement). Crucially, flavor remains the most important factor influencing repeat consumer purchases.[99] Studies suggest that grape pomace can be included at 2–3% w/w with minimal impact on flavor,[43,44] while apple pomace may be tolerated at slightly higher levels—around 4–6%—without significantly affecting sensory attributes.[46,47] Ultimately, acceptable inclusion levels will vary by product and must be guided by both functional goals and sensory evaluation.

In summary, there are numerous studies that provide evidence that the grape and apple pomace produced through wine and cider processing may have nutritional, shelf life, and sensory benefits to meat-based food products if added in a systematic and tested manner. The prevention of lipid oxidation in both grape and apple pomace can be effective even in small doses within the meat. In conjunction with this the sensory impact on the meat can be minimal if smaller doses of pomace are added to the meat. These small but effective doses of pomace within meat matrices can limit lipid oxidation compared to no additional inhibitors, while also minimally affecting the sensory aspects of the product.

Conclusions

Pomace from grapes or apples is a great source of fiber and polyphenols. These ingredients included in meat-based food products with no fiber could be beneficial even at small inclusion levels. This review presented that not only will the pomaces provide fiber but they will also reduce the need for synthetic antioxidants in meat as the polyphenols in the grape and apple pomace can limit lipid oxidation as well as providing polyphenolic compounds to the consumer. The inclusion of grape and apple pomace in meat must be controlled however as it is clear that the increase in the weight of pomace added can affect sensory characteristics like flavor, texture and color. This can be controlled and measured by the use of sensory analysis to create the best product with the most inclusion of the pomace to provide the nutrients it is rich in like fiber and phenolic compounds.

Data availability

No primary research results, software or code have been included and no new data were generated or analysed as part of this review.

Author contributions

Conception and design: P. R. G., E. T.; analysis and interpretation of the data: P. R. G., E. T.; drafting of the paper: P. R. G.; revising it critically for intellectual content: P. R. G., E. T.; final approval for the version to be published: E. T.; all authors agree to be accountable for all aspects of the work.

Conflicts of interest

The authors have no conflicts of interest to declare.

Acknowledgements

The authors thank the UK Fulbright Association for providing scholarship support.

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