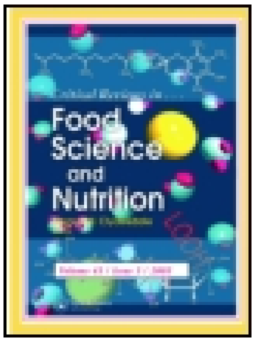

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Implications of domestic food practices for the presence of bioactive components in meats with special reference to meat-based functional foods

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Abstract

Although an essential component of the diet, the consumption of meat is in question. Meat is a major source of beneficial compounds but it also contains other substances with negative health implications. Functional foods, which are leading trends in the food industry, constitute an excellent opportunity for the meat sector to improve healthier meat options. Most studies on meat-based functional foods have focused mainly on the application of different strategies (animal production practices and meat transformation systems) to improve (increase/reduce) the presence of bioactive (healthy/unhealthy) compounds; these have led to the development of numerous products, many of them by the meat industry. However, like other foods, after purchase meats undergo certain processes before they are consumed, and these affect their composition. Although domestic handling practices can significantly alter the make-up of the marketed product in terms of healthy/unhealthy compounds, there are very few studies on their consequences. This paper provides an overview of the influence of different domestic practices (from shopping to eating) habitually followed by consumers on the presence of, and consequently on the levels of exposure to, (healthy and unhealthy) food components associated with the consumption of meats, with special reference to meat-based functional foods.

Keywords

meat-functional food, bioactive compounds, domestic practises, storage cooking, eating.

1. Introduction

Meat is a food group that supplies many of the nutrients required to meet the needs of the organism and normal growth. Meat and meat products are a major source of beneficial compounds (protein, conjugated linoleic acid-CLA, minerals such as iron, zinc and selenium, histidyl dipeptides, creatine, etc.), but it also contains other substances both endogenous and exogenous (fat, saturated fatty acids-SFA, cholesterol, sodium, nitrite, lipid oxidation products, etc.) which, depending on a variety of factors and in certain circumstances, can be harmful to health (Olmedilla-Alonso et al., 2013). Among other factors, negative implications of this kind have helped project the unfavourable image perceived by many sectors of society. However, the high level of acceptability and consumption of meat, the variety of possible presentations, the possibility of reformulation, etc., make it an exceptionally suitable food group for delivery of bioactive compounds (according to dietary recommendations and functional food approaches) without requiring changes in consumer habits. All this opens up promising avenues for the exploration of healthier meat options, including the development of functional foods, which help to improve the relationship between meat and consumer health and well-being (Jiménez-Colmenero et al., 2015). The strategies pursued for the development of meat-based functional foods have been widely reviewed (Arihara, 2006; Jiménez-Colmenero et al., 2001; Olmedilla-Alonso et al., 2013; Weiss et al., 2010; among others). A number of strategies have been proposed, based essentially on animal production practices (genetic and nutritional) and meat transformation systems (reformulation processes), to limit the presence of unhealthy compounds and promote other healthy ones (Fig. 1). This would mean increasing, adding, eliminating, reducing and/or replacing specific endogenous and exogenous bioactive components (lipids,

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minerals, vitamins, antioxidants, prebiotics, probiotics, etc.). At all events any changes need to take into account the desired nutritional or physiological effect, which must follow the ingestion of a reasonable amount. It is therefore essential that there be significant concentrations of bioactive compounds in the final product (or any unhealthy compounds be absent or present in smaller amounts), and also that these can be assimilated (or not) by the organism (Olmedilla-Alonso et al., 2013; Reglament 1924/2006). Among the criteria required to assess the scientific support for claims on foods is information on levels of exposure of food components, so that these can be linked quantitatively to the claimed effect (Agget et al., 2005). However, such requirements cannot be properly met only by considering the composition of the food as marketed. Generally speaking, a variety of processes have to be followed for consumption of the products, among others those associated with the conditions in which they are handled and consumed in the home. These practices can also significantly affect the concentrations of healthy/unhealthy compounds in foods, altering their potential health benefits (Jiménez-Colmenero 2007; Bongoni et al., 2013) (Fig. 1 and 2).

As in the case of most foods, the domestic preparation of meat and meat products induces significant changes in their physical and chemical properties and consequently in their sensory and health attributes. Handling practices during the domestic preparation of foods by consumers (storage, thawing, cooking, etc.) are mainly controlled by perceivable quality attributes (regarded as sensory attributes) such as colour, texture, etc., since the amount of bioactive components (with potential health implications) cannot be directly perceived. While in domestic preparation the texture, colour and flavour are improved to meet the consumer's preferences, the composition of products, which are sensitive to most processing conditions, largely changes

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upon preparation, although some components can become more bioaccessible (Bongoni et al., 2013).

It therefore seems clear that the domestic preparation process must be considered not only in order to obtain a product with the desired sensory preferences (e.g. texture, colour, and taste), but also to produce maximum health benefits upon consumption (appropriate presence of bioactive compounds). It is most important to have information on real concentrations of bioactive compounds after foods have been prepared for consumption in the normal ways if we are to understand the role of meat in a healthy diet as well as a functional food. This is also relevant for purposes of design and development of such foods. A number of studies have been conducted to analyse the influence of domestic food practices on food safety (microbial risk assessment) (Gilbert et al., 2007, van Asselts et al., 2009, among others), but as far as the authors are aware none have been published offering an overview of the ways in which these practices can affect the concentrations/bioavailability of bioactive compounds in meats and their impact on the role of meat and meat products as functional foods. The objectives of this paper are to provide an overview of the influence of the various habitual consumer domestic practices (from shopping to eating) on the presence (healthy and unhealthy) and/or bioavailability of bioactive compounds in meats, with special reference to meat-functional foods. This overview is not intended to provide an exhaustive analysis of all meat bioactive compounds, including those considered in the development of meat-based functional foods. The authors only propose to deal with compounds in marketed products that may be directly affected by domestic practices. And again, the depth of such analysis is determined by the compromise between aspects such as the diversity of compounds considered, the large number of phenomena involved, the degree of

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complexity and the factors affecting them, the existence of specific reviews dealing with some of the aspects covered, plus the need to adopt a comprehensive approach. This will help to more fully explore the possibilities of optimizing the consumer handling steps and thus maintain/promote the healthy properties of meats, as well as to understand their true role as functional foods.

2. Domestic handling practices: effects on healthy/unhealthy aspects of meat and meat products

Food handling practices in the home generally include everything from shopping to eating, which means that depending on factors like the type of product and the form in which the food is eaten, certain processes are involved, for instance storage, culinary preparation, cooking treatments, and finally the actual process of eating. Each of these steps can influence the amount and bioavailability of healthy/unhealthy components in meat and meat-based functional foods (Fig. 1 and 2).

2.1 Domestic storage conditions

Meat (fresh) should be refrigerated as soon as possible after purchase to avoid a substantial risk of temperature abuse. Whereas dry and fermented products (consumed uncooked) can be kept in mild (less strict) storage conditions, other products that are generally marketed under different retail conditions, including fresh and pre-cooked products, need stricter chilling storage conditions. Also, cooked meat can be kept in a refrigerated display, exposed to the oxidizing action of air, for many hours. Depending on the type of product (degree of structural breakdown, pH, Aw, contaminant levels, additives, packaging, etc.) and conditions in home refrigerators (refrigeration temperatures and storage times), products can undergo changes associated with microbial growth (with potential effects on probiotics and formation of biogenic amines) and oxidative processes which affect their healthy properties (Fig. 2). Such changes are furthered by the difficulties most domestic refrigerators (with static cooling systems) have in keeping a constant and uniform temperature distribution due to the conditions of use (temperature setting, frequency of door openings, heat sources and built-in). In this regard, it has been reported that in countries such as the UK or France the mean temperature range inside a refrigerator varied between 3 and 6.6 °C, whereas the maximum observed temperature difference was over 10 °C (Laguerre et al., 2002; Marklinder et al., 2004). A detailed survey of food temperatures of products stored in Swedish consumers' fridges found that 22% of minced meat samples and 44% of ham samples were stored above 8 °C (Marklinder et al., 2004). At present, domestic storage of chilled foods would appear to be the weakest link in the entire chill-chain (James et al., 2008), a situation that is aggravated by consumers' lack of knowledge about adequate refrigeration practices (Marklinder et al., 2004).

Consumers also handle frozen products in the home, either because the meat is purchased frozen in the marketplace or because it is frozen at home when it is perceived as liable to spoil rapidly at chilling temperatures. In these cases, products are stored (for varying lengths of time, generally short) then first thawed and cooked, or else they may be cooked while still frozen. In this connection, oxidation during storage and loss of water-soluble compounds through drip loss (thawing) are the main changes relating to the presence of healthy/unhealthy compounds.

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2.1.1. Microbiological consequences

Consumer handling produces significant variations in the temperature of the food, and this is a decisive factor in microbial growth, affecting both product quality and safety. The refrigeration process (temperature and time in storage) is particularly important in that respect. Aside from the question of food safety, in the context of this review these concerns are essentially the survival of probiotics and the formation of biogenic amines (Fig. 1 and 2).

Probiotics

Probiotic functional foods are among those most in consumer demand. The most notable advances in meat products have been achieved in fermented meats, as these offer environmental characteristics (no heat treatment) conducive to the viability of probiotic bacteria. An in-depth discussion of them is not considered here since there have been numerous reviews of these aspects (Ammor and Mayo, 2007; Arihara, 2006; Ruidi et al., 2013, among others); these cite the need to ensure the continued high viability of microorganisms during meat processing, storage, preparation and consumption (including domestic conditions), and go so far as to propose resistance to storage (e.g. refrigeration and duration) as a selection criterion for probiotics.

Storage can produce a variety of effects on the viability of probiotics depending on various factors (temperature, microorganism, meat product, probiotic delivery systems, packaging, etc.), but a number of studies have shown that the viability of probiotics in fermented sausages remained constant or even increased during storage (Ruidi et al., 2013). No particular studies have been reported to assess the effects of specific domestic storage conditions on probiotic cell viability. However, since the viability of spoilage bacteria is inversely related to storage temperature, probiotic food products should preferably be stored at 4–5 °C (Tripathi and Giri, 2014), avoiding temperature abuses. In any case, recent studies have shown that inactivated probiotic microorganisms (known as ghost probiotics, postbiotics or paraprobiotics) can also confer health benefits on their hosts, and as such they have been proposed as useful alternatives for specific cases in which probiotics are injured and do not survive during processing and/or storage (de Almada et al., 2016).

Biogenic amines (BAs)

BAs are low-molecular-weight nitrogenous compounds found in a wide range of foods including meat and meat products. Small amounts of BAs do not constitute a risk for healthy consumers; however, if ingested in large amounts, BAs in foods can be toxic for certain consumers. BAs are mainly produced by microbial decarboxylation of certain free amino acids, and therefore microbiological aspects (bacterial growth, bacterial species and strain, etc.) related to meat products, including during domestic storage, can affect the formation of BAs. In this regard, the ability of microorganisms to produce BAs has been considered as a criterion when selecting probiotic strains since they have potential for different biogenic amine formations (Ammor and Mayo, 2007).

The development of meat-based functional foods is generally accompanied by changes of composition intended to improve the balance of healthy/unhealthy compounds, and this entails changes that may potentially affect BA formation (in quantitative and qualitative terms) during storage. In this connection it has been reported that fat reduction strategies and/or the incorporation of certain ingredients as fat replacers and/or sources of bioactive compounds produce a variety of effects on BA production, depending among other things on the type of ingredient used, the conditions of use and the type of meat product (Ruiz-Capillas et al., 2012; Triki et al., 2013). BA levels have generally been found to increase with storage and seem unlikely to pose any health risk to consumers; nonetheless, it is well to assess the impact of domestic storage.

2.1.2. Lipid oxidation.

Lipid oxidation occurs during handling, processing and storage of meat and meat products. Lipid oxidation does not only produce sensory changes in the food but also, in response to various types of factors, it detracts from the food's technological properties and can even cause the production of unhealthy substances (free radicals and reactive aldehydes, among others). The rate and extent of this phenomenon is closely linked to the level of unsaturation of the lipids, which is greater in healthier-lipid meat-based functional foods (Fig. 1). This is because making products more in line with health recommendations generally requires a reduction of saturated fatty acid and trans fatty acid contents and an increase of monounsaturated (MUFAs and n-3 polyunsaturated (n-3 PUFAs, especially long-chain) fatty acids or CLA, which further make for better n-6/n-3 PUFA and PUFA/SFA ratios (Jiménez-Colmenero, 2007). Generally, increased levels of unsaturation, in addition to some specific meat processing conditions, render the system more susceptible to lipid oxidation, which means that this may occur even in relatively short storage periods, including up to the several days that foods are regularly kept) in domestic refrigerators.

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Lipid oxidation has been widely evaluated in different healthier-lipid meat-based functional foods (as part of developing strategies) over chilling and frozen storage. In most cases, in addition to increasing the unsaturation level, researchers have tested different approaches (generally antioxidants) to avoid or minimize oxidation on the reformulated meat matrices. This could explain why although some increase has occasionally been observed in oxidation levels, in general no specific problems have been reported in connection with oxidative stability during processing and simulated commercial storage conditions (considering temperature, packaging, time in storage, etc.) of fresh, cooked and fermented products formulated with healthier lipid profiles (Jiménez-Colmenero, 2007; Delgado-Pando et al., 2011; Bernardi et al., 2016; Muguerza et al., 2004). Therefore, although no specific studies have been reported, it seems unlikely that lipid oxidation could attain levels such as to compromise the healthy properties of meat products in domestic procedures. Nevertheless, this being so it is important to take into account oxidation levels at the point of sale and the storage conditions involved. Both factors may influence the effect of subsequent procedures (i.e. cooking, reheating) on the oxidative stability of the meat matrix.

2.1.3. Loss of water-soluble compounds

Purge or thawing losses remove water-soluble compounds such as nitrogenous material (sarcoplasmic protein, peptides, etc.), vitamins and minerals, some of them with health implications. During chilling storage of fresh marketed products there is some purge accumulation, which gives the product an unpleasant appearance and also promotes microbial growth, thus limiting shelf life. Then preparatory procedures like thawing produce some weight loss (components). For example, thawing loss in reduced–fat and PUFA-enriched pork patties ranged between 3 and 8% (Salcedo-Sandoval et al., 2014), while in the case of restructured beef steak containing walnut it was lower than 1% (Serrano et al., 2007).

2.2 Cooking practices

Most meat and meat-based products are cooked before being eaten. The cooking process destroys microorganisms, producing structural and compositional changes which contribute to the development of specific sensory properties (texture, flavour, and colour), rendering products more palatable and appetizing for the consumers. However, cooking also has a considerable effect on the balance of bioactive (healthy/unhealthy) compounds (Fig. 2) as affected by factors associated with the nature of meat products (type, size and form, composition, etc.) and with cooking techniques (roasting, grilling, frying, boiling, and microwaving) and conditions (time, temperature, heating rate, doneness, etc.), or even re-heating processes. Such effects with potential health implications can be grouped as: a) Changes in concentration of different components (lipids, proteins and water-soluble compounds) generally associated with cooking loss; b) Loss of heat-sensitive components; c) Changes in bioaccessibility/digestibility; and d) Formation of healthy (cis-linoleic acid, CLA, some Maillard reaction products –MRPs-) and unhealthy compounds (protein and lipid oxidation products, heterocyclic aromatic amines –HAAs- or polycyclic aromatic hydrocarbons –PAHs-).

The impact of such changes is difficult to evaluate in real conditions since consumers proceed in many different ways. However, this should be borne in mind when making a more approximate evaluation of the effects of cooking on real bioactive compound intake/exposure.

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2.2.1 Lipids changes

Fat and fatty acids contents

The original fat content of a food is not necessarily the same as the consumer intake; fat intake can vary considerably depending on a number of factors associated with some domestic practices (preparation and consumption, especially cooking). This is an important point that needs to be taken into account by consumers themselves (especially the health-conscious) and for meat production especially where healthy-lipid reformulated meat products are concerned. Cooking produces a widely varying (as much as >50%) loss of matter (mainly water, and to a lesser extent fat) with potential effects on fatty acid contents, including MUFAs or n-3 PUFAs (Tables 1 and 2). The magnitude of the changes that take place is closely related to factors determined by the nature of the product (i.e. composition, surface/volume ratio, shape, degree of structural disintegration, ingredients/additives, etc.), and also by the cooking techniques used (e.g. heating rate, final cooking temperature, heating medium, etc.). All these determine changes of composition produced by the mass transfer processes (evaporation and drip) occurring during thermal treatment. This multifactorial dependence explains the considerable variability in the literature data for lipid retention after cooking (Table 1). Generally, fat retention tends to decrease with cooking time and temperature (Gerber et al., 2009; Lee et al., 2006). Also, the proportion of fat loss is directly related to fat content (low fat meats lose far less fat than their fattier counterparts) and with greater structural disintegration where fat can be easily removed. The variability has also been related to the presence of variable levels of subcutaneous/intermuscular fat, since this can affect the loss to drip or to the cooking medium in different ways (Badiani et al., 2002).

Fatty acid (FA) concentrations in cooked meat are affected by product type and composition, as well the cooking method (Table 2). Meat fatty acids melt between about 25 and 50 °C, with SFAs melting at higher and PUFAs at lower temperatures. As with most nutrients, FA concentrations increase as a consequence of moisture loss through cooking, the more so the higher the moisture and the lower the fat losses. Increased FA concentrations induced by cooking have been reported in a number of meat products, including products with healthier lipid content, although this effect has been reported to vary depending on the type of product and cooking technique (Librelotto et al., 2008; López-López et al., 2011; Rodríguez-Carpena et al., 2011; Salcedo-Sandoval, et al., 2014). For example, household cooking methods (boiling, microwaving and grilling) seem to increase the percentages of SFAs and MUFAs, and reduce the relative proportions of PUFAs in beef intramuscular fat (Alfaia et al., 2010). Frying has been reported to increase SFA, MUFA and n-6 PUFA contents of low-fat restructured beef steaks (Libreloto et al., 2008). However, with respect to absolute values, total SFAs, MUFAs and PUFAs generally decrease because of the melting of fat during cooking (Gerber et al., 2009). This clearly indicates a connection with fat loss, and hence with the factors influencing it—cooking procedure and meat system characteristics (Table 2). In this regard, while no substantial variations in FA contents (Table 2) were found in completely trimmed beef muscle (Badiani et al., 2002) or in separable lean from lamb rib-loins (Maranesi et al., 2005), substantial losses have been reported in different meat products with relatively low levels of fatty acid retention (Table 2). For example, fatty acid retention in PUFA-enriched pork patties ranged between 55-108% for SFAs, 69-147% for MUFAs and 71-115% for PUFAs as affected by composition and cooking methods (electric grill and pan-frying) (Salcedo-Sandoval et al., 2014). Similarly, after pan-frying of restructured low-fat beef-steak or beef-steak with added walnut, fatty acid retention values ranged between 49-53% for SFAs, 37-52% for MUFAs and 25-91% for PUFAs (Librelotto et al., 2008). The cooking retention of DHA (C22:6n3) in fortified ground turkey patties and pork sausages ranged between 65-75% (Lee et al., 2006). In addition to the loss of fat, some changes in the concentration of fatty acids (mainly decreased PUFAs) can occur during cooking due to their low oxidative stability (Lee et al., 2006; Ganhão et al., 2013). Some particular aspects need to be considered in order to understand the impact of pan-frying on the fat content of cooked products. In this case the role played by the fat or oil is twofold. On the one hand it acts as a heat transfer medium, and on the other hand it penetrates the food (accompanied by loss of water) and becomes part of its composition (Serrano et al., 2007; Sheard et al., 1998a), so that the fatty acid profile of the meat product tends to resemble that of the frying medium used

Meat and meat products, especially from ruminants, represent a major source of natural CLA isomers in the human diet, and this fatty acid has been shown to be stable under cooking and storage conditions. However, thermal processes (as affected by different factors such as cooking method, final temperature or degree of doneness) have been found to influence the concentration of dietary CLA since the fat content and the amount of edible portion were reduced (Schmid et al., 2006). Again, it has been reported that CLA in beef may be formed by thermal oxidation of C18:2 or destroyed by high cooking temperatures and oxidative reactions during subsequent storage (Dhiman et al., 2005). As an anticarcinogenic fatty acid, the formation

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of CLA in cooked products is particularly useful for limiting the effects of some of the unhealthy compounds that have been identified in cooked meats (Hasler, 1998).

PUFA/SFA ratios have been found to be higher in oven-cooked low-salt, low-fat beef patties with added wakame/olive oil (Lopez-Lopez et al., 2011) or in various cooked (grilled, boiled or steamed) meat cuts (Gerber et al., 2009; Scheeder et al., 2001) than in raw samples. These findings have been associated with the specific locations of the different types of fatty acids. For instance, because unsaturated FAs, particularly PUFAs, are more strongly bound to the membrane structures than SFAs, they undergo less pronounced changes during heat treatment. However, the PUFA/SFA ratio has also been found to be higher in raw beef patties (with added flaxseed flour) than in grilled samples (Bilek and Turhan, 2009), or there may be no change, as in (boiled, broiled, oven roasting and microwaved) beef muscle (Badiani et al., 2002). On the other hand, it has been found that the n-6/n-3 ratio increased in restructured steaks with added walnut pan-fried in olive oil (Librelotto et al., 2008) and after electric grilling or pan-frying of PUFA-enriched pork patties (Salcedo-Sandoval et al., 2014). Different effects (increasing and decreasing) on n6/n3 ratios have been observed depending on the type of product (beef or pork) and the cooking method (grilling or boiling) (Gerber et al., 2009). However, no difference in the n-6/n-3 ratio between the raw and cooked products were observed in improved-lipid beef burgers as a result of adding olive, corn or deodorized fish oils (Martinez et al., 2012). Cooking has been found to reduce the atherogenicity and thrombogenicity indexes in electric grilling or pan-frying of reduced-fat PUFA-enriched pork patties (Salcedo-Sandoval et al., 2014), in pan-fried restructured beef steak (Librelotto et al., 2008) and in oven-cooked beef patty (López-López et al., 2011). However, Dal Bosco et al. (2001) reported an increase in the

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thrombogenic index as cooking (boiled, frying and roasting) of rabbit meat reduced n-3 fatty acids.

Cholesterol is also lost in cooking of meats since it is present in drip loss. Cooking cholesterol retention has been reported as ranging between 96% to 74% for ground beef with 9.5% and 28.5% fat content respectively (Kregel et al., 1998). These authors reported that cooked low fat product had higher cholesterol values because cooking of these products did not reduce cholesterol as much in the samples containing higher fat levels. Relative to the proportion of subcutaneous/intramuscular fat in different pork and beef meat cuts, cholesterol retention values ranged between 97-122%, (Badiani et al., 2002), while in ostrich meat retention was 105% (Sales et al., 1996), and in meat products (meatballs, hamburgers or sausages) it varied between 85-99% (Baggio and Bragagnolo, 2006). Chizzolini et al. (1999) reported that cooking did not generally produce changes in cholesterol concentration in dry matter. The increase in the cholesterol level, expressed per 100 g of product, is mainly a consequence of water loss and hence is concentrated on a wet tissue basis.

Depending on different factors, then, household cooking can significantly affect the lipid material, with significant consequences for the healthy properties of meat-based functional foods.

Lipid oxidation

In order to better understand the influence of household cooking on lipid oxidation levels in meat and its impact when eating, it is important to consider both the effect induced during the

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actual cooking process and the consequences of this in subsequent storage (chilled or frozen), or even when reheating cooked meat.

It is well known that heating accelerates lipid oxidation in meats, provoking the rapid development of off-flavours (known as warmed-over flavours—WOFs) and formation of compounds potentially hazardous (as reported previously) for human health. The lipid oxidation (in terms of both rate and magnitude) undergone by meat and meat products depends on factors relating both to the nature of the meat matrix (composition: fat content, degree of unsaturation, antioxidants, etc.; structural disintegration, processing, etc.) and to the kind of thermal treatment applied in the preparation (cooking techniques, final temperature, etc.). Cooking effects are manifested in deterioration of the cellular organization and protein denaturation, all of which contribute to loss of antioxidant enzyme activity and release of iron (protein-bound) (Decker and Xu, 1998). The relative impact of such processes associated with the antioxidant effect of MRPs means that oxidation tends to be less when the meat is subjected to high-temperature and/or prolonged cooking than when subjected to low-temperature/shorter-term cooking. In this regard, it has been reported that the presence of MRPs increases with temperature and that the most suitable conditions for the release of non-haem iron occur at 70 ° C (Cross et al., 1987).

The effect of cooking on lipid oxidation has been studied in various different meat-based functional foods. Cooking of PUFA-enriched patties promotes lipid oxidation (Dzudie et al., 2004; Martinez et al., 2012; Poyato et al., 2015). Also, moderate promotion of lipid oxidation has been reported in restructured beef steaks containing walnuts irrespective of the cooking method (conventional oven, microwave oven, electric grill and pan-frying) (Serrano et al., 2007) or oven

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pork patties (Rodrıguez-Carpena et al., 2011; Ganhão et al. 2013). This effect was reduced by using berry extracts as antioxidants (Ganhão et al. 2013) or by partial back-fat replacement (50%) with avocado, sunflower, and olive oils, attributed to the presence of some antioxidant components (Rodrıguez-Carpena et al., 2011). Numerous oxidized lipid compounds from pan-fried and sous-vide thermally processed beef have been detected, although the quantity and quality of oxidized lipid molecules was not affected by the cooking or processing technique (Noura et al., 2015).

As compared with fresh meat, cooked meat is more prone to lipid oxidation during chilling and frozen storage (Bastida et al., 2009; Ganhão et al., 2013; Lee et al., 2006; Rodríguez-Carpena et al., 2011). Botsoglou et al. (2014) reported that lipid oxidation of cooked pork patties enriched with n-3 fatty acids increased during chilling storage. The acceleration of lipid oxidation during storage may be caused by a number of factors including the physicochemical changes occurring during cooking, which enhances the susceptibility of meat to oxidative reactions. Antioxidant strategies may be based on a dietary approach (Perez et al., 2010) or a reformulation process, for example the use of berries (Ganhão et al., 2013), olive leaf (Botsoglou et al., 2014) or carob fruit (Bastida et al., 2009) extracts; this effect has been used to limit the intense oxidative reactions occurring during chilling storage of cooked meats for muscle foods retailed as refrigerated pre-cooked meats.

Some studies have evaluated the formation of cholesterol oxides induced by heat treatment in meat and processed meat products, suggesting that time and temperature are determining factors in this process. Cholesterol oxides (oxysterols among others) are considered

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more harmful than cholesterol itself in the formation of arteriosclerotic plaque and as mutagenic, carcinogenic and cytotoxic agents (Baggio and Bragagnolo, 2006). The latter authors detected no formation of cholesterol oxides as affected by cooking of meat products, but Perez et al. (2010) reported that cooking induced cholesterol oxidation resulting in the formation of oxysterols in PUFA-enriched chicken meat, and also that roasting generated a greater increase in oxysterol formation than boiling or pan-frying.

2.2.2. Changes in protein and other nitrogen-based compounds

Protein

Since protein is not susceptible to migration as a result of coagulation/denaturation, cooking generally has little effect on protein loss. Dal Bosco et al. (2001) reported protein retention ranging between 93% and 97% for boiled and roasted rabbit meat, while frying had no impact on protein loss. Protein retention levels around 100% were reported by López-López et al. (2011) in oven-cooked low-salt/low-fat patties with added Wakame and partial or total replacement of pork backfat with olive oil-in-water emulsion. Protein retention levels around 90% were found in electric grilled and pan fried PUFA-enriched pork patties (Salcedo-Sandoval, et al., 2014). Oven-roasting, microwave cooking, boiling or steaming (chicken and lamb chops) had no effect on protein loss, with retention of 99–103% (Kumar and Aalbersberg, 2006).

On the other hand, the quality of proteins may be compromised if there are modifications to essential amino acids when meat is cooked. Free radicals produced during meat cooking reduce bioavailability of amino acids such as cysteine and tyrosine through the formation of crosslinks, reducing food digestibility and nutritional quality (Deb-Choudhury et al., 2014).

Loss of other nitrogen-based bioactive substances

Meat and meat products contain a number of protein-based bioactive substances, such as carnosine, anserine, L-carnitine, glutathione, taurine and creatine, with promising physiological properties. Although these compounds attain nutritionally significant levels in meat (in some cases they are the main dietary source), their concentrations vary with thermal treatment ~~(Fig. 2)~~. Household cooking practices have a considerable impact on final concentrations and ingested levels since it has been established that cooking of meat leads to significant reductions in taurine, carnosine, and creatine contents. These reductions are due to temperature-lability, as in the case of creatine (conversion to creatinine) or water-soluble compounds (taurine, carnosine and creatine) lost in cooking juices (Purchas et al., 2004a; Mora et al., 2008). Cooking can cause a reduction of up to 50% of carnosine in beef products, depending on the cooking procedure (Peiretti et al., 2012; Purchas et al., 2004a). While cooking methods have been found to reduce the L-carnitine content of red meat (higher with longer cooking durations), they increased “in vitro” L-carnitine bioaccessibility (Gokhisar and Nehir-El, 2015).

Protein oxidation

Meat products are subjected to a number of processes both industrially and in the home, many of which can trigger processes such as protein oxidation (Estevez, 2011). Protein oxidation is a complex phenomenon which causes chemical modifications related to specific amino acid side chains and/or to the peptide backbone. Oxidation of meat proteins causes amino acid destruction (including essential amino acids), loss of enzymatic activity, formation of carbonyl derivatives, etc. Protein oxidation has not only been associated with negative effects on technological and sensory properties; it may also have significant adverse health implications in human consumers (Estevez, 2011) In a recent article Soladoye et al. (2015) reviewed the impact of various processing technologies (including emerging technologies) on protein oxidation status in processed meat and their potential implications for nutritional value and human health. Some of those techniques (such as chilling/freezing treatments or cooking processes) are in common household use. In this regard, these authors reported that protein oxidation can occur in the meat matrix during frozen storage, particularly over long-time storage at conventional industrial and household temperatures. Consequently, and depending on various factors, two possible main effects in meat: increased free radical generation and deterioration of antioxidant protection systems, both issues contributing to protein oxidation.

2.2.3. Mineral changes

Thermal treatments cause drip and leaching losses of variable amounts of minerals depending on the type of meat ~~(Fig. 2)~~ and the cooking method used. Calcium, sodium, potassium, magnesium and phosphorus decrease during cooking in different beef cuts, while iron and zinc have been found to increase. While the losses were attributed to the leaching of minerals into the broth, the increase has been related to exposure to the cooking utensil (Gerber et al., 2009). However, Lombardi-Boccia et al. (2005), using oven and iron-free pan cooking (methods which require no water), detected iron losses ranging between 74-88%, zinc losses between 76-87% and copper losses between 71-79% in cuts from beef, veal, lamb, chicken, turkey and rabbit. The cooking process, besides affecting total iron, also causes changes in the haem/non-haem iron ratio. Increases in the final cooking temperature are accompanied by

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diminishing levels of soluble haem iron, more so at the surface of the meat than in cooler zones (interior) (Lombardi-Boccia et al., 2002, Purchas et al., 2004b, Purchas et al., 2006). Changes in the form of iron are important in that they affect bioavailability (most likely in the soluble haem form).

2.2.4 Loss of vitamins and chemically similar compounds

Meat and meat products are generally recognized as foods that provide valuable amounts of vitamins (mainly from the B complex, which are major sources of B12). However, as well as being susceptible to drip and leaching loss, some vitamins are unstable to heat exposure, so domestic cooking practices can produce considerable vitamin losses depending on the cooking conditions (time, temperature and method) and meat product characteristics (size of the cut, fat content, etc.), with significant effects on the contribution of meat to daily intake of these micronutrients.

In this regard, cooking can cause up to almost 100% loss of thiamine, as the most heat-labile of the B-vitamins (Gerber et al., 2009; Lombardi-Boccia et al., 2005), depending on the type of meat and the cooking method (boiling>braising>grilling). Riboflavin and nicotinic acid, which are relatively less susceptible to thermal degradation, undergo smaller losses than thiamine. Riboflavin retention values in domestically-cooked meat have been reported at 17-51% (Gerber et al., 2009), 20-58% (Lombardi-Boccia et al., 2005), or 16-97% (Kumar and Aalbersberg, 2006), and niacin retention values of 35-60% (Gerber et al., 2009), 30-51% (Lombardi-Boccia et al., 2005) or 68-77% (Kumar and Aalbersberg, 2006). Also, vitamin B12 is reduced (5-25%) during cooking (Ortigues-Marty et al., 2006). Riccio et al., (2006) reported a

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51% reduction of vitamin B12 by cooking, with the loss increasing to 85% under more severe conditions (120 °C/20 min). In response to different health recommendations on fortified daily-consumed foods, folic acid (vitamin B9) has been incorporated in ready-to-eat meat products. In these products, cooking has been found to reduce the bioaccessibility of this bioactive compound (Galan et al., 2014). B vitamin loss can generally be reduced with short-duration mild thermal treatments using cooking methods that limit loss through leaching into the drippings or diffusion in the cooking water.

As compared with water-soluble vitamins, fat-soluble vitamins (such as retinol and alpha-tocopherol) are more stable to heat treatment, although they can be destroyed at high temperatures and in the presence of oxygen (Lund, 1973). Geber et al. (2009) reported vitamin losses during cooking ranging between 15 and 34% for retinol and 10 and 20% for alpha-tocopherol. Kumar and Aalbersberg (2006) reported retinol retention values between 20 and 91%, suggesting that the loss could be associated partially with loss into the melted fat leaching into the drip, combined with the duration of processing and the heat level. Then again, in processed meat products (beef patties and pork breakfast sausages) fortified with CoQ10 (a molecule chemically similar to liposoluble vitamins such as E and K and with significant antioxidant activity), retention of CoQ10 in cooking can be as much as 79 %, with a digestibility level of around 94% (Tobin et al., 2014).

In any case, although variable amounts of different components do leach into the exudate, the final implications of these are difficult to evaluate if the drip from meat is consumed (Gerber et al., 2009).

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2.2.5. Formation of compounds during cooking

Heating meats produces the formation of different MRPs associated with the formation of specific colour and aromas. Also, MRPs have both healthy (i.e. melanoidins) and unhealthy effects (Fig. 2). Other substances with potential mutagenicity/carcinogenicity effects, like HAAs and PAHs, may be formed during cooking. However, cooking has a limited effect on other major carcinogens such as environmental pollutants (substances which are already present in raw or unprocessed meat), since the concentrations of these depend more on the contaminants present in specific food items before cooking than a particular cooking process (Domingo and Nadal, 2016). As most of these environmental contaminants are organic, cooking procedures that promote fat loss should tend to reduce their concentrations in the cooked meat (Domingo and Nadal, 2016).

Heterocyclic aromatic amines in meat.

HAAs are compounds which form naturally (in trace amounts) in meat when heated. Because of their carcinogenic and/or mutagenic properties, they have been associated with a high risk of cancer (colon, prostate, lung, skin, breast, liver and gastrointestinal tract tumours). They tend to form when meat is heated at temperatures over 200 °C (or even at lower temperatures if cooking is longer) in the presence of precursors such as creatine/creatinine, amino acids and sugars, via Maillard reactions. The concentration and type of HAAs that are formed in each case depends on the type of meat, the temperature and cooking time, the final degree of browning (charring and blackening), and also the cooking method. In this regard, cooking techniques such

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as grilling, frying, barbecuing, broiling and roasting promote the formation of large amounts of HAAs in meat (Rahman et al., 2014; Szterk and Jesionkowska, 2015).

There is a general lack of knowledge concerning HAA content in home-cooked meat; however, in order to understand the actual exposure of consumers to HAAs, several recent studies have focused on both home-cooked and restaurant-cooked meats, (Salmon et al., 2005). This information should help to minimize the impact on consumers and will therefore be extremely useful from a public health standpoint. Also, it could influence the practices of people involved in meat preparation, who have been strongly advised to try and reduce HAAs (Demeyer et al., 2016). Some specific domestic cooking practices can be used for that purpose, including for example avoiding direct contact of meat surfaces with flame and overcooking (well done meat), or through pre-treatments such as microwaving or marinating. Some specific ingredients have been proposed in healthy meat product formulation to reduce HAA generation during heating processes (e.g. spices, herbs, vegetable and fruit extracts with antioxidant activity) or to reduce HAA bioaccessibility, for example fibre to absorb HAAs and so limit the fraction released from the food matrix (Meurillon and Engel, 2016). Additionally, time in chilling storage (including consumer fridges) can be optimized to achieve low HAA concentrations (Demeyer et al., 2016; Rahman et al., 2014; Szterk and Jesionkowska, 2015).

Polycyclic aromatic hydrocarbons

PAHs are ubiquitous environmental toxicants produced by incomplete combustion of organic compounds. Some have been categorized by the International Agency for Research on Cancer as probable/possible human carcinogens (Demeyer et al., 2016). PAHs may be formed

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during heating of food by barbecuing, roasting, grilling or smoking. In meat products (like other foods) the formation of PAHs generally varies in response to factors determined by the meat matrix (composition/fat, type of meat, etc.), and also by the cooking technique and the way it is applied (temperature, heat source, proximity to the heat source and release of fat (Oz and Yuzer, 2016) For example, when meat is grilled (an increasingly popular cooking method in the home) directly over the burner, the fat and other components of the meat drip straight onto the flame and burn, causing the formation of PAHs which can adhere to the surface of the product (Demeyer et al., 2016).

One of the possible strategies for reducing PHA formation is to change the cooking conditions. Such an approach might for example include searching for alternatives to limit direct contact between meat and flame, or the redesign of grilling systems to stop the melted fat from dripping onto the heat source; thus, the absence of fat pyrolysis would prevent the formation of this group of carcinogens (Lijinsky and Ross, 1967). It is important to note that the way the meat is cooked—e.g. “exposure to a naked flame”—rather than the meat per se, contributes to the formation of PAHs and the increased risk of colorectal cancer (Demeyer et al., 2016). Moreover, natural products such as spices (onion, garlic or red wine pomace seasoning) that can act as radical scavengers have been proposed to limit the formation of PAHs (García-Lomillo et al., 2017). As well as PAH formation, consideration should be devoted to other aspects relating to potential mutagenicity, which could be reduced by accompanying eating cooked meats with a high intake of fruits, vegetables and cereals (Ferguson, 2010).

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Nitrosamines

When nitrates and nitrites are used in the manufacture of cured meat products, N-nitrosamines (NAs) are formed by nitrosation of amines, amides and other nitrogenated compounds. NAs are a large group of compounds (about 300), many of them toxic, mutagenic or carcinogenic (AESAN, 2007), and their adverse health effects are more pronounced in processed meat than in meat in general (Herrmann et al., 2015). NAs can be produced by endogenous synthesis (in the organism, chiefly saliva and stomach) or by exogenous formation in the product depending on various factors, mainly as effects of the cooking procedure—frying, roasting, etc. (AESAN, 2007). Concentrations generally increase after heat treatment as heating accelerates the processes involved in the synthesis of these compounds. A study was recently conducted to mimic preparation procedures in the home or in e.g. the fast food industry (Herrmann et al., 2015). These authors reported that the level of specific NAs depended on the type of product (bacon, ham, pepperoni, chorizo) and/or the heat treatment (frying, oven baking). Reformulation strategies for development of meat-based functional foods (reduction of nitrate and nitrite levels or incorporation of ascorbic and/or erythorbate acids, plant polyphenols) and technological approaches (selecting cooking technique) have been suggested as possible alternatives to attenuate the potential risk of NA formation (AESAN, 2007).

2.3 Eating

In addition to the home practices discussed previously, there is yet another way in which consumers can influence the dietary intake of some meat components with health implications, namely manual separation of some parts of the meat on the plate ~~(Fig 2)~~. In this regard, the mechanical removal of some material (charred or blackened) from the surface of broiled meat (household cooking) can be an efficient method of reducing consumers' exposure to PAH and HAA (Demeyer et al., 2016). Similarly, the trimming of visible fatty tissue from cooked product can considerably reduce fat levels, reportedly by 56-79% (Leeds et al., 1997) and 24-59% (Gerber et al., 2009). Gerber et al. (2009) found that the sum of trimming fat loss and cooking loss brought overall fat reductions (cooking + trimming) of 50-78%. Given that the trimming of visible fatty tissue can result in a major reduction of fat consumption from meat, trimming off fat might be more effective advice in terms of reducing fat consumption than reducing meat consumption (Gerber et al., 2009).

3 Final considerations and conclusions

Consumer perception and interest in meat and meat products is a critical issue for the meat industry as it directly impacts on profitability. This is particularly important in the area of health (nutrition) and in the development of meat-based functional foods. Many valuable scientific contributions have served to improve the composition of meat and meat products, particularly in terms of optimizing the healthy/unhealthy balance using strategies based on meat production (genetic and nutritional) and meat transformation (mainly reformulation). However, products are not generally exactly as marketed; from point of purchase to moment of consumption, meats, like other foods, undergo certain treatments (storage, preparation, cooking, eating) with important consequences for safety, quality, stability, overall palatability and composition.

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A major concern in the development of meat-based functional foods is the changes occurring in specific components during various steps prior to eating, since some can limit their potential health benefits. Particular attention needs to be paid to domestic handling practices since these significantly influence specific meat components, with important consequences for the presence of healthy/unhealthy compounds. In addition to their potential health implications, the consequences of those practices should be taken into account ~~when nutrient~~ when the contributions of meat and meat products to the dietary intake of nutrients (fat, FAs, minerals, vitamins, etc.) ~~from meat~~ are estimated. In this regard it has been suggested that the consumption of fat from some meat is almost certainly overestimated, especially for strongly marbled cuts (Gerber et al., 2009; Sheard et al., 1998b). In any case, while acknowledging the importance of such changes, since most domestic practices depend on individual preferences, it is very difficult to gauge their real impact. Nonetheless, it is essential to carry studies of this kind forward to lend scientific support to health claims, since it is necessary to certify levels of exposure to a specific component (**P**rocess for the **A**ssessment of **S**cientific **S**upport for **Claim**s on Foods. PASSCLAIM. Agget et al., 2005). To that end the food or food component for which the claim is made needs to be characterized, and such characterization must necessarily address ~~the~~ issues related to how it is consumed ~~of consumption~~ (Agget et al., 2005). Hence, in addition to research to gain a better understanding of the role of meat consumption in human health, the design and development of products so as to optimize the presence of bioactive compounds requires further investigation into how domestic handling affects levels of exposure to them.

The information analysed in this review highlights the impact of domestic consumer practises on the presence of different components with potential implications for human health.

A better understanding of this would help to determine the most suitable domestic handling conditions for meat, including meat-based functional foods, to maximize health benefits.

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References

AESAN (2007). Report of the Scientific Committee of Spanish Agency For Food Safety and Nutrition (AESAN) about a question of the Executive Direction of AESAN, in relation to the risk of the possible presence of N-nitrosamines in marinated fresh meat products when they are subjected to culinary treatments of frying or roasting. *Rev.Com.Científ*. **8**:9-39.

Aggett, P. J., Antoine, J. M., Asp, N. G., Bellisle, F., Contor, L., Cummings, J. H., Howlett, J., Müller, D. J. G., Persin, C., Pijls, L. T. J., Rechkemmer, G., Tuijtelaars, S. and Verhagen, H. (2005). PASSCLAIM. Process for the Assessment of Scientific Support for Claims on Foods. *Eur. J. Nutri*. **44**:I/1–I/2.

Alfaia, C. M., Alves, S. P., Lopes, A. F., Fernandes, M. J., Costa, A. S., Fontes, C. M., Castro, M. L., Bessa, R. J. and Prates, J. A. (2010). Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. *Meat Sci.* **84**:769–777.

Ammor, M. S. and Mayo, B. (2007). Selection criteria for lactic acid bacteria to be used as functional starter cultures in dry sausage production: An update. *Meat Sci*. **76**:138–146.

Arhiara, K. (2006). Strategies for designing novel functional meat products. *Meat Sci*. **74**:219-229.

Badiani, A., Stipa, S., Bitossi, F., Gatta, P. P., Vignola, G. and Chizzolinili, R. (2002). Lipid composition, retention and oxidation in fresh and completely trimmed beef muscle as affected by common culinary practices. *Meat Sci*. **60**:169-186.

Baggio, S. R. and Bragagnolo, N. (2006). The effect of heat treatment on the cholesterol oxides, cholesterol, total lipid and fatty acid contents of processed meat products. *Food Chem.* **95**:611-619.

Bastida, S., Sánchez-Muniz, F., Olivero, R., Pérez-Olleros, L., Ruiz-Roso, B. and Jiménez-Colmenero, F. (2009). Antioxidant activity of carob fruit extracts in cooked pork meat systems during chilled and frozen storage. *Food Chem.* **116**:748-754.

Bernardi D. M., Bertol, T. M., Pflanzer, S. B., Sgarbieri, V. C. and Rodrigues Pollonio, M. A. (2016). ω-3 in meat products: benefits and effects on lipid oxidative stability. *J. Sci. Food Agric.* **96**:2620–2634.

Bilek, A. E. and Turhan, S. (2009). Enhancement of the nutritional status of beef patties by adding flaxseed flour. *Meat Sci.* **82**:472–477.

Bongoni, R., Steenbekkers, L. P. A., Verkerk, R., van Boekel, M. A. J. S. and Dekker, M. (2013). Studying consumer behaviour related to the quality of food: A case on vegetable preparation affecting sensory and health attributes. *Trends Food Sci. Technol.* **33**:139-145.

Botsoglou, E., Govaris, A., Ambrosiadis, I., Fletouris, D. and Papageorgiou, G. (2014). Effect of olive leaf (*Olea europea* L.) extracts on protein and lipid oxidation in cooked pork meat patties enriched with n-3 fatty acids. *J. Sci. Food Agric.* **94:**227–234.

Chizzolini, R., Zanardi, E., Dorigoni, V. and Ghidini, S. (1999). Calorific value and cholesterol content of normal and low-fat meat and meat products. *Trends Food Sci. Technol.* **10**:119-28.

Cross, H. R., Leu, R. and Miller, M. F. (1987). Scope of warmed-over-flavor and its importance to the meat industry. In: Warmer-over-flavor of meat, pp. 1-18. St. Angelo, A. J. and Bailey, M. E. Eds. Academic Press, Orlando.

Dal Bosco, A., Castellani, C. Bernardini, M. (2001). Nutritional quality of rabbit meat as affected by cooking procedure and dietary vitamin E. *J. Food Sci.* **66**:1047-51.

de Almada, C. N., Almada, C. N., Martinez, R. C. R. and Sant'Ana, A. S. (2016). Paraprobiotics: Evidences on their ability to modify biological responses, inactivation methods and perspectives on their application in foods. *Trends Food Sci. Technol.* **58**:96-114.

Deb-Choudhury, S., Haines, S., Harland, D., Clerens, S., van Koten, C. and Dyer, J., (2014). Effect of cooking on meat proteins: mapping hydrothermal protein modification as a potential indicator of bioavailability. *J. Agric. Food Chem.* **62:**8187−8196.

Decker, E. A. and Xu, Z. (1998). Minimizing rancidity in muscle foods. *Food Technol.* **52**:54-59.

Delgado-Pando, G., Cofrades, S., Ruiz-Capillas, C., Solas, M. T., Triki, M. and Jiménez-Colmenero, F. (2011). Low-fat frankfurters formulated with a healthier lipid combination as functional ingredient: Microstructure, lipid oxidation, nitrite content, microbiological changes and biogenic amine formation. *Meat Sci.* **89**:65-71.

Demeyer, D., Mertens, B., de Smet, S. and Ulens, M. (2016). Mechanisms linking colorectal cancer to the consumption of (processed) red meat: a review. *Crit. Rev. Food Sci. Nutr.* **56**:747–2766.

Dhiman, T. R., Nam, S. H. and Ure, A. L. (2005). Factors affecting conjugated linoleic acid content in milk and meat. *Crit. Rev. Food Sci. Nutr.* **45**:463–482.

Domingo, J. L. and Nadal, M. (2016). Carcinogenicity of consumption of red and processed meat: What about environmentalcontaminants? *Environm. Res.* **145**:109–115

Dzudie, T., Kouebou, C. P., Essia-Ngang, J. J. and Mbofung, C. M. F. (2004). Lipid sources and essential oils effects on quality and stability of beef patties. *J. Food Eng.* **65**:67-72.

Estevez, M. (2011). Protein carbonyls in meat systems: a review. *Meat Sci.* **89**:259–279.

Ferguson, L. R. (2010). Meat and cancer. *Meat Sci.* **84**:308–313.

Galán, I., García, M. L., Selgas, M. D. and Havenaard, R. (2014). Effect of E-beam treatment on the bioaccessibility of folic acid incorporated to ready to eat meat products. *LWT-Food Sci. Technol.* **59**:547-552.

Ganhão, R., Estévez, M., Armenteros, M. and Morcuende, D. (2013). Mediterranean berries as inhibitors of lipid oxidation in porcine burger patties subjected to cooking and chilled storage. *J. Integr. Agric.* **12**:1982-1992.

García-Lomillo, J., Viegas, O., Gonzalez-SanJose, M. L. and Ferreira, I. M. P. L. V. O. (2017). Influence of red wine pomace seasoning and high-oxygen atmosphere storage on carcinogens formation in barbecued beef patties. *Meat Sci.* **125**:10–15.

Gerber, N., Scheeder, M. R. L. and Wenk, C. (2009). The influence of cooking and fat trimming on the actual nutrient intake from meat. *Meat Sci.* **81**:148–154.

Gokhisar, O. K. and Nehir-El, S. (2015). Impacts of different cooking and storage methods on the retention and in vitro bioaccessibility of l-carnitine in veal muscle (*M. longissimus dorsi*). *Eur. Food Res. Technol.* **240**:311–318.

Hasler, C. M. (1998). Functional foods: Their role in disease prevention and health promotion. *Food Technol.* **52**:63-70.

Herrmann, S. S., Duedahl-Olesen, L. and Granby, K. (2015). Occurrence of volatile and non-volatile N-nitrosamines in processed meat products and the role of heat treatment. *Food Control*, **48**:163-169.

James, S. J., Evans, J. James, C. (2008). A review of the performance of domestic refrigerators. *J. Food Eng.* **87**:2–10

Jiménez-Colmenero, F. (2007). Healthier lipid formulation approaches in meat based functional foods. Technological options for replacement of meat fats by non-meat fats. *Trends Food Sci. Technol.* **18**:567-578.

Jiménez-Colmenero, F., Carballo, J. and Cofrades, S. (2001). Healthier meat and meat products: Their role as functional foods. *Meat Sci.***59**:5-13.

Jiménez-Colmenero, F., Salcedo-Sandoval, L., Bou, R., Cofrades, S., Herrero, A. M. and Ruiz-Capillas, C. (2015). Novel applications of oil-structuring methods as a strategy to improve the fat content of meat products. *Trends Food Sci. Technol.* **44**:177-188.

Kregel, K. K., Prusa, K. J. and Hughes, K. V. (1998). Cholesterol content and sensory analysis of ground beef as influenced by fat level, heating and storage. *J. Food Sci.* **51**:1162-1165.

Kumar, S. and Aalbersberg, B. (2006). Nutrient retention in foods after earth-oven cooking compared to other forms of domestic cooking. 1. Proximates, carbohydrates and dietary fibre. *J. Food Comp. Anal.* **19**:302–310.

Laguerre, O., Derens, E. and Palagos, B. (2002). Study of domestic refrigerator temperature and analysis of factors affecting temperature: a French survey. *Inter. J. Refrig.* **25**: 653–659.

Lee, S., Hernández, P., Djordjevic, D., Faraji, H., Hollender, R., Faustman, C. and Decker, E. D. (2006). Effect of antioxidants and cooking on stability of n-3 fatty acids in fortified meat products. *J. Food Sci.* **71***:*C233- C238.

Leeds, A. R., Randle, A. and Matthews, K. R. (1997). A study into the practice of the trimming fat from meat at the table, and the development of new study methods. *J. Human Nutr. Dietet.* **10**:245-251.

Librelotto, J., Bastida, S., Serrano, A., Cofrades, S., Jiménez-Colmenero, F. and Sánchez-Muniz, F.J. (2008). Changes in fatty acids and polar material of restructured low-fat or walnut-added steaks pan-fried in olive oil. *Meat Sci.* **80**:431-441.

Lijinsky, W., & Ross, A. E. (1967). Production of carcinogenic polynuclear hydrocarbons in the cooking of food. *Food Cosmetic Toxicol.* **6**:343–347.

Lombardi-Boccia, G., Lanzi, S. and Aguzzi, A. (2005). Aspects of meat quality: trace elements and B vitamins in raw and cooked meats. *J. Food Comp. Anal.* **18***:*39–46.

 ACCEPTED MANUSCRIPT

López-López, I., Cofrades, S., Cañeque, V., Díaz, M. T., López, O. and Jiménez-Colmenero, F. (2011). Effect of cooking on the chemical composition of low-salt, low-fat wakame/olive oil added beef patties with special reference to fatty acid content. *Meat Sci.* **89**:27-34.

Lund, D. B. (1973). Effects of heat processing. *Food Technol.* **27**:16–18.

Maranesi, M., Bochicchio, D., Montellato, L., Zaghini, A., Pagliuca, G. and Badiani, A. (2005). Effect of microwave cooking or broiling on selected nutrient contents, fatty acid patterns and true retention values in separable lean from lamb rib-loins, with emphasis on conjugated linoleic acid. *Food Chem.* **90**:207–218.

Marklinder, I. M., Lindblad, M., Eriksson, L. M., Finnson, A. M. and Lindqvist, R. (2004). Home storage temperatures and consumer handling of refrigerated foods in Sweden. *J. Food Prot.* **67**:2570–2577.

Martínez, B., Miranda, J. M., Vázquez, B. I., Fente, C. A., Franco, C. M., Rodríguez, J. L. and Cepeda, A. (2012). Development of a hamburger patty with healthier lipid formulation and study of its nutritional, sensory, and stability properties. *Food Bioproc. Technol.* **5**:200–208.

Meurillon, M., & Engel, E. (2016). Mitigation strategies to reduce the impact of heterocyclic aromatic amines in proteinaceous foods. *Trends Food Sci. Technol.* **50**:70-84.

Mora, L., Sentandreu, M. A. and Toldrá , F. (2008). Effect of cooking conditions on creatinine formation in cooked ham. *J. Agric. Food Chem.* **56**:11279–11284.

Muguerza, E., Gimeno, O., Ansorena, D. and Astiasarán, I. (2004). New formulations for healthier dry fermented sausages: a review. *Trends Food Sci. Technol.* **15**:452-457.

ACCEPTED MANUSCRIPT

Noura, A., Chiang, V. S. C., Milan, A. M., Tarvainen, M., Pundir, S., Quek, S. Y., Smith, G. C., Markworth, J. F., Ahotupa, M., Cameron-Smith, D. and Linderborg, K. M. (2015). The impact of beef steak thermal processing on lipid oxidation and postprandial inflammation related responses. *Food Chem.* **184**:57–64.

Olmedilla-Alonso, B., Jiménez-Colmenero, F. and Sánchez-Muniz, F. (2013). Development and assessment of healthy properties of meat and meat products designed as functional foods. *Meat Sci.* **95**:919-930.

Ortigues-Marty, I., Thomas, E., Prèvèraud, D. P., Girard C. L., Bauchart, D., Durand, D. and Peyron, A. (2006). Influence of maturation and cooking treatments on the nutritional value of bovine meats: Water losses and vitamin B12. *Meat Sci.* **73**:451–458.

Oz, F. & Yuzer, M. O. (2016). The effects of cooking on wire and stone barbecue at different cooking levels on the formation of heterocyclic aromatic amines and polycyclic aromatic hydrocarbons in beef steak. *Food Chem.* **203**:59–66.

Peiretti, P. G., Medana, C., Visentin, S., Dal Bello, F. and Meineri, G. (2012). Effect of cooking method on carnosine and its homologues, pentosidine and thiobarbituric acid-reactive substance contents in beef and turkey meat. *Food Chem.* **132**:80−85.

Perez, T. I., Zuidhof, M. J., Renema, R. A., Curtis, J. M., Ren, Y. and Betti, M. (2010). Effects of vitamin E and organic selenium on oxidative stability of ω-3 enriched dark chicken meat during cooking. *J. Food Sci.* **75**:T25- T34.

Poyato, C., Astiasaran, I., Barriuso, B. and Ansorena, D. (2015). A new polyunsaturated gelled emulsion as replacer of pork back-fat in burger patties: Effect on lipid composition, oxidative stability and sensory acceptability. *LWT - Food Sci. Technol.* **62**:1069-1075.

Purchas, R. W., Busboom, J. R. and Wilkinson, B. H. P. (2006). Changes in the forms of iron and in concentrations of taurine, carnosine, coenzyme Q10, and creatine in beef longissimus muscle with cooking and simulated stomach and duodenal digestion. *Meat Sci.* **74**:443–449.

Purchas, R. W., Rutherfurd, S. M., Pearce, P. D., Vather, R. and Wilkinson, B. H. P. (2004b). Cooking temperature effects on the forms of iron and levels of several other compounds in beef semitendinosus muscle. *Meat Sci.* **68**:201–207.

Purchas, R., Rutherfurd, S., Pearce, P., Vather, R. and Wilkinson, B. H. (2004a). Concentrations in beef and lamb of taurine, carnosine, coenzyme Q10, and creatine. *Meat Sci.* **66**:629–37.

Rahman, U., Sahar, A., Khan, M. I. and Nadeem, M. (2014). Production of heterocyclic aromatic amines in meat: Chemistry, health risks and inhibition. A review. *LWT - Food Sci. Technol.* **59:**229-233.

Reglament EU 1924/2006 of the European parliament and of the council of 20 december on nutrition and health claims made on foods. (2006) *Official J. Europ.Union,* **L 404**:9-25.

Riccio, F., Mennella, C., & Fogliano, V. (2006). Effect of cooking on the concentration of vitamins B in fortified meat products. *J. Pharmac. Biomed. Anal.* **41**:1592–1595.

Rodrıguez-Carpena, J. G., Morcuende, D., & Estevez, M. (2011). Partial replacement of pork back-fat by vegetable oils in burger patties: effect on oxidative stability and texture and color changes during cooking and chilled storage. *J. Food Sci.* **76**:7, C1025-C1031.

Ruidi, M., Sohrabvandi, S. and Mortazavian, A. M. (2013). Probiotic fermented sausage: viability of probiotic microorganisms and sensory characteristics. *Crit. Rev. Food Sci. Nutr.* **53**:331–348.

Ruiz-Capillas, C., Triki, M., Herrero, A. and Jiménez-Colmenero, F. (2012). Biogenic amines in low- and reduced-fat dry fermented sausages formulated with konjac gel. *J. Agric. Food Chem.* **60**:9242-9248.

Salcedo-Sandoval, L., Cofrades, S., Ruiz-Capillas, C. and Jiménez-Colmenero, F. (2014). Effect of cooking method on the fatty acid content of reduced-fat and PUFA-enriched pork patties formulated with a konjac-based oil bulking system. *Meat Sci.* **98**:795-803.

Sales, J., Marais, D. and Kruger, M. (1996). Fat content, caloric value, cholesterol content, and fatty acid composition of raw and cooked ostrich meat. *J. Food Comp. Anal.* **9**:85–89.

Salmon, C. P., Knize, M. G., Felton, J. S., Zhao, B. and Seow, A. (2006). Heterocyclic aromatic amines in domestically prepared chicken and fish from Singapore Chinese households. *Food Chem. Toxic.* **44**:484–492.

Scheeder, M. R. L., Casutt, M. M., Roulin, M., Escher, F., Dufey, P. A. and Kreuzer, M. (2001). Fatty acid composition, cooking loss and texture of beef patties from meat of bulls fed different fats. *Meat Sci.* **58**:321-328.

Schimd, A., M. Collomb, R. Sieber, and Bee, G. (2006). Conjugated linoleic acid in meat and meat products: A review. *Meat Sci*. **73**:29-41

Serrano, A., Librelotto, J., Cofrades, S. Sánchez-Muniz, F. and Jiménez-Colmenero, F. (2007). Composition and physicochemical characteristics of restructured beef steaks containing walnuts as affected by cooking method. *Meat Sci.* **77:**304-313.

Sheard, P. R., Nute, G. R. and Chappell, A. G. (1998a). The effect of cooking on the chemical composition of meat products with special reference to fat loss. *Meat Sci.* **49**:175-191.

Sheard, P. R., Wood, J. D., Nute, G. R. and Ball, R. C. (1998b). Effects of grilling to 80 °C on the chemical composition of pork loin chops and some observations on the UK National Food Survey estimate of fat consumption. *Meat Sci.* **49**:193–204.

Szterk, A. and Jesionkowska, K. (2015). Influence of the cold storage time of raw beef meat and grilling parameters on sensory quality and content of heterocyclic aromatic amines. *LWT - Food Sci. Technol.* **61**:299-308.

Tobin, B. D., O’Sullivan, M. G., Hamill, R. and Kerry, J. P. (2014). Effect of cooking and in vitro digestion on the stability of co-enzyme Q10 in processed meat products. *Food Chem.* **150**:187–192.

Triki, M., Herrero, A. M, Rodríguez-Salas, L., Jiménez-Colmenero, F. and Ruiz-Capillas, C. (2013). Chilled storage characteristics of low-fat, n-3 PUFA-enriched dry fermented sausage reformulated with a healthy oil combination stabilized in a konjac matrix. *Food Control*, **31**:158-165.

Tripathi, M. K. and Giri S.K. (2014). Probiotic functional foods: Survival of probiotics during processing and storage. *J. Funct. Foods,* **9**:225–241.

Weiss, J., Gibis, M., Schuh, V. and Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Sci*. **86**:196-213.

Table 1. Examples of the effect of cooking on fat retention of meat products, including meat-based functional foods

Meat product	Cooking method/% of fat retention	Reference
Pork chop	Grilled/66	Sheard et al., (1998b)
Lamb rib-loins	Microwave/102, Broiled/96	Maranesi et al., (2005)
Beef cuts	Boiling (94), Broiling/101, Oven roasting/100, Microwaving/100	Badiani et al., (2002)
Veal chop	Grilled/82	Gerber et al., (2009)
Veal rolled breast	Steamed/56	Gerber et al., (2009)
Minced beef	Fried/boiled/36-70	Sheard et al., (1998a)
Restructured steaks	Grilled/60-95, Conventional oven/70-92	
Restructured beef steak (2% fat)	Conventional oven/71, microwave/62, electric grill/64, pan-frying/153	Serrano et al., (2007)
Restructured beef steak (13% fat/walnut added)	Conventional oven/103, microwave/99, electric grill/91, pan-frying/106	
Low fat beef burger	Grilled/94	Sheard et al., (1998a)
	Fried/150	
Beef patties (11% fat content)	Air oven/61	López-López et al., 2011
Beef patties (9% fat/wakame and olive oil added)	Air oven/110	

Pork patties (3% fat)	Electric grill/96	Salcedo-Sandoval et al., (2014)
Pork patties (10% fat/PUFA enriched)	Pan-frying in olive oil/120	
	Electric grill/81	
	Pan-frying in olive oil/106	

Table 2. Examples of the effect of cooking on fatty acids retention of different meat products, including meat-based functional foods

Meat product	Cooking method	SFA retention (%)	MUFA retention (%)	PUFA retention (%)	Reference
Beef cuts	Boiling	97	102	95	Badiani et al., 2002
	Broiling	97	101	102	
	Oven roasting	103	102	91	
	Microwaving	96	104	99	
Lamb rib-loins	Microwaving	108	106	100	Maranesi et al., 2005
	Broiling	98	96	89	
Pork neck steak	Grilled	75	75	83	Gerber et al., 2009
Pork belly	Grilled	84	82	87	
Restructured beef steak (2% fat)	Pan-fried	56	37	25	Librelotto et al., 2008
Restructured beef steak (13%)	Pan-fried	53	52	44	
Restructured beef steak (13% fat/with added walnut)	Pan-fried	49	42	91	
Beef patties patties (11% fat content)	Air oven	65	67	64	López-López et al., 2011

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Beef patties (9% fat/wakame and olive oil added)	Air oven	101	109	117	
Pork patties (15% fat)	Electric grill	55	70	71	Salcedo-Sandoval et., al 2014
Pork patties (3% fat)	Electric grill	104	99	81	
Pork patties (10% fat/PUFA enriched)	Electric grill	77	80	91	
Pork patties (15% fat)	Pan-frying	83	104	92	
Pork patties (3% fat)	Pan-frying	108	94	101	
Pork patties (10% fat/PUFA enriched)	Pan-frying	101	111	113	

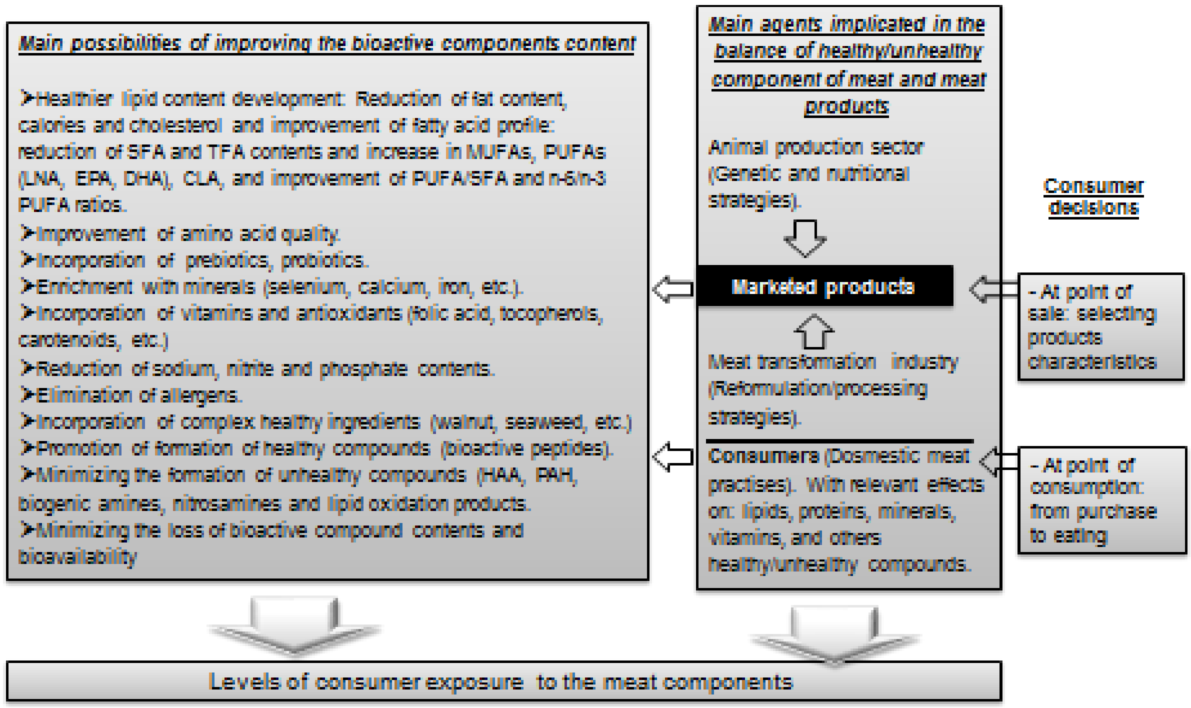

Fig 1. Main opportunities and agents which affect the final (eating) balance of physiologically active (healthy/unhealthy) compounds content in meat and meat products (Adapted from Olmedilla et al., 2013). LNA, α-linolenic acid; CLA, conjugated linoleic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; SFAs, saturated fatty acids; HAAs, heterocyclic aromatic amines; PAHs, polycyclic aromatic hydrocarbons.

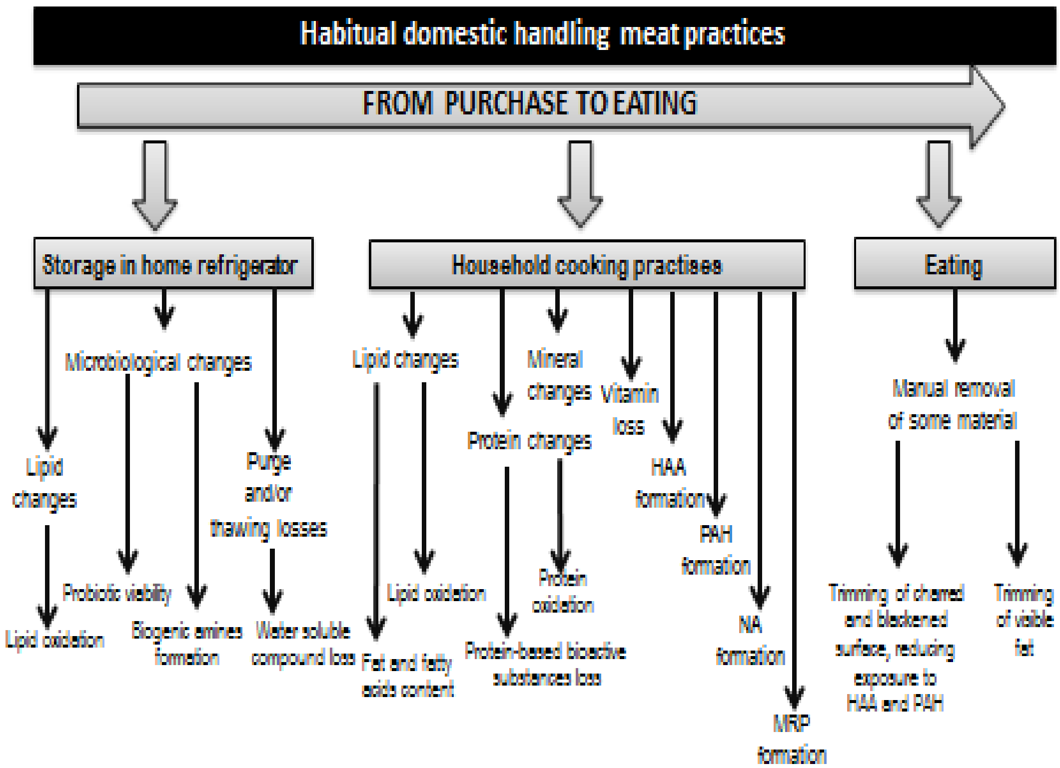

Fig 2. Overview of potential consequences of consumer behaviour related to bioactive components of meat and meat products. HAAs, heterocyclic aromatic amines; PAHs, polycyclic aromatic hydrocarbons; NAs, nitrosamines, MRPs, Maillard reactions products

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