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RABBIT MEAT PROCESSING: HISTORICAL PERSPECTIVE TO FUTURE DIRECTIONS[1]

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Abstract: In past centuries, because rabbits are relatively small, animals slaughtered for consumption were generally eaten immediately. However, since a single rabbit would offer little more product than could be consumed at one sitting, little effort was devoted to developing preserved rabbit products (such as salted or dried meat, sausages, etc.). For this reason, although there is a rich history of recipes using rabbit meat in the Mediterranean area, there are few traditional further-processed products. Nowadays, even though the processing industry is pushing more and more towards the introduction of more attractive products (i.e. ready meals, ready-to-cook, etc.) for consumers with little time for meal preparation, most rabbit meat worldwide is still sold as whole carcass or cut-up parts. This review analyses the main strength and weakness factors regarding the use of rabbit meat to manufacture further processed products. Bearing in mind these considerations, it then describes the more promising processing technologies for raw meat materials to obtain added-value products (marinated, formed, emulsified, coated, etc.) by exploiting rabbit meat's intrinsic characteristics, such as high protein/low fat content coupled with a balanced n-6 to n-3 PUFA ratio, low cholesterol and heme-iron content. Major trends in meat product formulation (modulation of lipid content and composition, use of novel antioxidants and salt reduction) are also discussed by highlighting strategies to provide healthier meat products meeting current nutritional needs. Finally, major packaging solutions for rabbit meat and meat products (ordinary and modified atmosphere, vacuum) are considered.

Key Words: rabbit, meat, processing, product formulation, packaging.

INTRODUCTION

Nutritional and technological properties of rabbit meat and its relationship with *ante-mortem* and *post-mortem* factors have been extensively investigated and many exhaustive review articles have been published over the last 10 yr (Dalle Zotte, 2002; Cavani and Petracci, 2004; Hernández, 2008; Dalle Zotte and Szendrő, 2011). Rabbit meat is still currently sold worldwide as whole carcass or at least as cut-up parts, while very low quantities are marketed as processed products (i.e. ready-to-cook, ready-to-eat meals, etc.). In consequence, few food scientists have researched this area and published studies are fairly scarce. However, in societies where people tend to live and work in urban areas, taking most meals away from home and spending less and less time on home meal preparation, together with increasing culinary ignorance (Swatland, 2010), rabbit meat consumption can only be boosted by introducing rabbit meat as an ingredient in processed food products (i.e. ready meals, ready-to-cook, etc.). Otherwise, consumption is bound to become even more marginal, even in major rabbit meat consuming countries. So, setting out from the historical evolution of rabbit meat consumption, this review goes on to deal with more promising technological, formulation and packaging solutions that are potentially suitable to exploit rabbit meat characteristics.

EVOLUTION OF RABBIT MEAT CONSUMPTION

Numerous hare- and rabbit-based food products have traditionally been prepared and consumed ever since the main ancient civilisations that arose and flourished around the Mediterranean basin (Lebas *et al.*, 1997). As rabbits are relatively small, animals slaughtered for consumption were generally eaten immediately. However, since a single

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rabbit would offer little more product than could be consumed at one sitting, scant effort was devoted to developing preserved rabbit products (such as salted or dried meat, sausages, etc.). For this reason, despite the rich history of recipes using rabbit meat in Mediterranean area, there are few traditional further-processed products. Red meat and fish often demanded some form of further processing to preserve excess quantities arising from the size of the animal (beef and pork) or because of a large fish harvest (Fletcher, 2004).

In rural societies, many families kept at least a few rabbits for meat production, to be used for occasional feasts. Even today, rabbit meat is often associated with special festival meals in many Mediterranean countries. Farmers may then have taken rabbits to a traditional market or sold them directly to a processor, who slaughtered and prepared the rabbits for sale to consumers (Lebas *et al.*, 1997). As industrial cities began to grow, the production of many foodstuffs became more concentrated, with the sole purpose of supplying high-population centres with food. The shift from primarily agrarian to industrial societies depended on the intensification of food production, whereby farms began to look more to the production of specific foods as opposed to being self-contained units. The processor would have sold directly to the public or to wholesalers, who then sent the carcasses to a number of small meat markets, meat shops or restaurants in towns and cities (Fletcher, 2004). In the early 1970s, rabbit farming became intensive in the main European producer countries such as Italy, Spain and France, with the application of intensive breeding programmes, better nutrition, disease control, management improvements and vertical integration. A major consequence of this intensification was the increase in size of rabbit companies and the concomitant decrease in the number of rabbit producers (Lebas *et al.*, 1997). With the advent of large scale retailing following the concentration of population in urban centres, rabbit meat began to be sold as pre-packed, still mainly in the form of whole carcasses, although main cut-ups (i.e. loin and hind legs) also became available. However, even today the majority of rabbit meat is sold as whole carcass and cut-up, strictly remaining a commodity in which almost all consumption is based on home preparation. In contrast, the market share of processed poultry meat products has seen a tremendous increase in recent decades (Cavani *et al.*, 2009) (Figure 1). As consumers were still not used to buying poultry meat in the form of processed products (i.e. sausages, salami, ham, etc.), it took many years for these products to gain consumer acceptance. Only when "white meat" (i.e. poultry and rabbit) as opposite to "red meat" (i.e. beef, pork and mutton) began to be perceived as healthy (i.e. high protein/low fat content coupled with a balanced n-6 to n-3 polyunsaturated fatty acids (PUFA) ratio, low cholesterol and heme-iron content) (Table 1) did the development of marketing further processed products made from white poultry meat come about (Fletcher, 2004). This trend has long been exploited by the poultry industry, which made significant investments in the processing area. In addition to its dietary and nutritional properties, the huge worldwide success of further processed products from poultry meat is due to relatively low and competitive prices compared to red meats, the absence of cultural or religious obstacles and suitability for processed product development due to the bland flavour and soft texture, which enables producers to impart desired flavour profiles (e.g. spicy *vs.* mild flavour) and textures according to market/marketing needs and consumer targeting (e.g. adult *vs.* children) (Dalle Zotte, 2004; Petracci *et al.*, 2013). In recent years, rabbit industries have increasingly tried to push towards the introduction of more attractive products for consumers with little time for meal preparation (Cavani *et al.*, 2009). Further processed products are currently demanded due to their convenience, but also to high food safety and quality standards which can be more effectively guaranteed through proper traceability systems

Table 1: Composition and nutritional value of different chicken and rabbit meats (adapted from Barroeta, 2007 and Combes, 2004).

	Chicken		Rabbit	
	Whole	Breast	Whole	Loin
Water (%)	70.3	75.4	70.3	75.0
Protein (%)	20.0	21.8	19.6	22.4
Fat (%)	9.7	2.8	8.8	1.4
Energy (kcal/100 g)	167	112	196	145
Cholesterol (mg/100 g)	110	69	59	50
Iron (mg/100 g)	1.1	1.0	1.4	1.1
Sodium (mg/100 g)	64	81	49	37
Selenium (µg/100 g)	6	7	77	22
Saturated fatty acids (%)	29.5	29.5	38.8	37.5
Monounsaturated fatty acids (%)	51.1	50.4	27.8	26.5
Polyunsaturated fatty acids (%)	20.4	20.1	33.4	36.0

within vertically integrated production chains (Cavani and Petracci, 2006; Hernández, 2008). This market change would also involve demands from the rabbit sector for some degree of extended shelf-life and product diversification to allow reasonable time for distribution and marketing of more consumer-oriented foods, as opposed to mass quantities of basic commodities. There are few studies focusing on the shelf-life of pre-packaged rabbit meat (Hernández, 2008). Nevertheless, in order to favour the development of processed meat products, improvements are needed in slaughtering practises to reduce carcass contamination and in carcass chilling to reduce subsequent microbial growth (Cavani and Petracci, 2004). There are no real technical limitations to manufacturing processed products using rabbit meat, but technical ability has always taken second place to the realities of marketing and economic viability. Today, only very few processed meat products manufactured with rabbit meat are marketed, such as hamburgers, stuffed rolls and baby foods. This is because even though rabbit meat presents a nutritional profile which is similar to poultry, there are crucial limits impeding the spread of processed rabbit products (Table 2). First of all, rabbit meat cost/price is not competitive compared to poultry, owing to much higher production costs. In poultry processing, there is also a huge supply of very inexpensive raw material such as mechanically deboned meat (MDM), which is very attractive for incorporation into further-processed products, while MDM production from rabbit carcasses is very difficult because the skeleton is prone to leaving bone fragments. Moreover, in many countries there are barriers to its human consumption because rabbits are considered as pets (González-Redondo and Contreras-Chacón, 2012). On the other hand, it should be noted that no religious obstacles for rabbit meat consumption exist as for pork and beef, and for this reason rabbit meat is popular in some North African countries, as well as other countries like Indonesia (Raharjo, 2008).

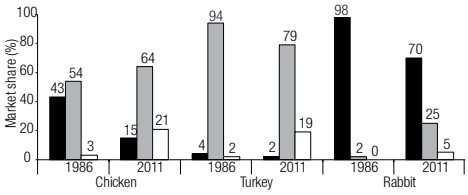

Figure 1: Evolution of poultry product distribution (UNA, 2013) and rabbit meat (our estimation from unofficial data) in the Italian market. ■ Whole carcass; ■ Cut-up; □ Processed products.

Despite these limiting factors, the only sure way to increase or at least maintain current levels of rabbit meat consumption is to develop rabbit meat-based processed foods tailored to customer needs at various levels (i.e. retailing, catering, final consumer). This allows us to exploit the positive nutritional aspects of rabbit meat, in line with the current consumer demand for low-fat meat with a high unsaturation degree of fatty acids and low sodium, cholesterol and heme-iron levels (Dalle Zotte and Szendrő, 2011), by contributing to a ''balanced diet'' with possible preventive effects on chronic non-deficiency diseases (e.g. obesity, type 2 diabetes, cancer and cardiovascular diseases) (Demeyer, 2010; Corpet, 2011). Moreover, consumption of rabbit meat in the form of processed foods will also limit the ethical implications of using animals for food consumption, particularly relevant for rabbits, which are largely considered pets in many countries. Moreover, the use of common flavouring agents used in the meat industry can mask the typical wild flavour of rabbit meat, which can negatively affect the attitudes of young and unfamiliar consumers.

MAIN PROCESSING TECHNOLOGIES TO MANUFACTURE RABBIT MEAT PRODUCTS

The first steps in modern processing are slaughtering, evisceration and chilling of carcasses (Cavani and Petracci, 2004). Further processing can be referred to as the operations ranging from cutting of the carcass into parts, packaging of raw consumer products, deboning and portioning to formulation of specific products (shaping, marinating, coating, etc.), cooking and packaging (Figure 2). However, it should be noted that these definitions are arbitrary, can change

Table 2: Main strengths and weaknesses of rabbit meat for inclusion in processed products.

Strengths	Weaknesses
Nutritional profile	Higher price compared to pork and poultry
Good health image	Poor vertical integration of production chain
Culinary tradition in Mediterranean countries	Quite hard to process (i.e. lack of automated systems for cut-up, deboning, meat recovery, etc.)
	Typical wild flavour, marked fibrosity, minimal juiciness
	Image as pet animal

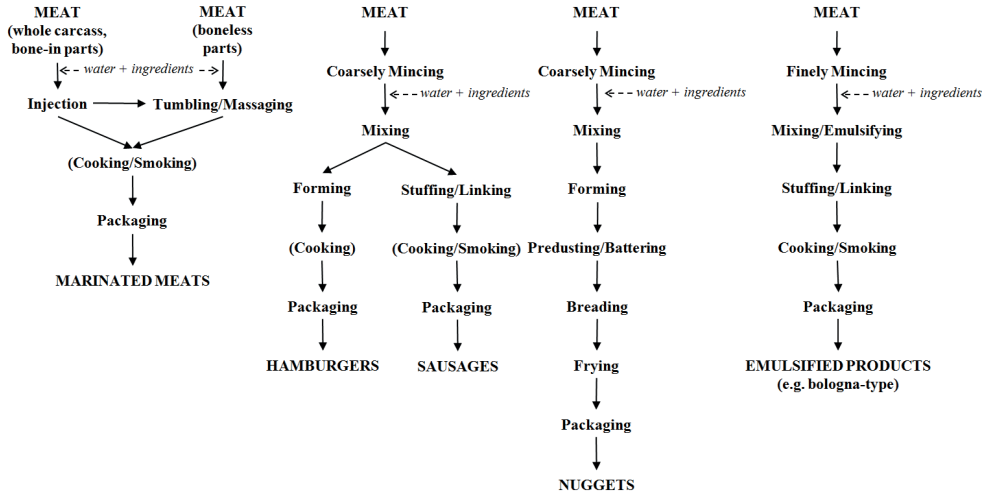

Figure 2: Main steps in marinated, formed, coated and emulsified meat product manufacturing.

over time and may be used differently by different companies and in different countries. It is also important to underline that processing refers to an industrial and centralised approach to the creation of "pre-prepared" products, rather than an item prepared for immediate food consumption (Fletcher, 2004). More promising technologies to be adopted in rabbit meat further processing are described below.

Cutting, deboning and portioning

The majority of processed rabbit meat is still sold as cut-up for direct consumer sale or use in restaurants or institutional markets. Both of them require a highly uniform rabbit size and specialised cutting operations for portion control. Uniformity of size is critical for cooking protocols, inventory control and consumer expectations. Due to the highly specialised nature of the cuts involved, many of these processors still rely on manual cutting. Consumers often prefer to buy only whole carcass or one specific cut (i.e. loin, hind leg) and this demand is not as specific as that of larger food chain customers, so generic cutting is acceptable and more appropriate for automated cut-up systems. These machines have been available for many years, but are still subject to research and development. Due to the relatively small volume of rabbit meat sold as cut-up, there are few specialised and integrated in-line machines designed for specific cuts, but more frequently a cut-up separation of entire carcass is performed in a single step (i.e. hind legs, loin region, half front and head). Diner and restaurant customers often demand specific and highly uniform products in relation to size, shape and weight.

If cut-up parts are hand deboned, edible tissues may be recovered from bones and skeletal frames by using belt-and-drum deboners and this meat is classified as "mechanically deboned meat" (McNitt *et al.*, 2003; Negatu *et al.*, 2006). MDM from poultry is widely used to manufacture sausages (bologna, salami, and frankfurters) and nuggets; it has the texture of a fine paste and is high in fat and heme pigments from the bone marrow, which give the product a pink/red colour. MDM must comply with requirements concerning residual bone particles and calcium, muscle destructuration, protein and fat content (Froning and McKee, 2010). Some studies conducted in the United States have shown that mechanically deboned rabbit meat can satisfy the requirements for calcium, protein and fat, although there were too many large bone fragments (McNitt *et al.*, 2003; Negatu *et al.*, 2006). This issue originated because rabbit bones tended to produce fragments more easily compared with pork and beef, but also with poultry, and this greatly limits the production and utilisation of MDM in the rabbit industry. Some previous studied have evidenced that *in vivo* bone resistance to fracture has occasionally been related to genotype and housing conditions (Martrenchar *et al.*, 2001; Gondret *et al.*, 2005; Dalle Zotte *et al.*, 2009; Combes *et al.*, 2010; Buijs *et al.*, 2012), so it is possible that bone fragmentation during meat recovery could be ameliorated by improving bone strength.

Marination

Marination, the addition of liquids to meat before cooking, is an old process, used in preparing meat either for immediate consumption or as a preliminary step in preservation. Soaking in vinegar, oils, or both, in combination with spices, improved meat flavour and extended shelf-life (or at least masked off-flavours). More recently, marination has been proven to provide additional advantages including functionality of product use and improved yield for the processor (Smith and Acton, 2010). Marinades are primarily a mixture of salt, organic acids, nitrates and spices in solution in which the meat is soaked, or with which it is injected prior to smoking and/or curing. Whole carcasses and parts can be injected with a flavoured salt or phosphate solution prior to manufacture of roasted products. The marinade produces a more tender product, with more flavour, lower cooking losses and increased juiciness. Boneless meat can be marinated in a tumbler, operated in a static, vacuum or high pressure environment to improve marinade absorption and uniformity. These products can be sold directly to the consumer as pre-marinated, ready-to-cook meat, or else frozen for distribution to canteens or restaurants (Fletcher, 2004). Rabbit meat is generally lean and so presents the minimal juiciness and marked fibrousness that represent the main sensory defects of rabbit meat (Dalle Zotte, 2002). Many traditional recipes include a pre-treatment with vinegar, wine or lemon juice, salt and spices for rabbit meat before cooking to improve its juiciness and tenderness. Like poultry and pork, rabbit meats are also very suitable for the application of modern marinating techniques (injection and tumbling). Injection can accommodate a wide variety of product shapes and sizes, leaving bone intact. It is ideal for whole carcass, halves and large and small cut-up parts. These products can be used for oven-cooked, smoked and roasted rabbit products. Moreover, tumbling, or mechanical massaging, is more suitable for whole meat such as deboned loin or leg meat. Recently, Petracci *et al.* (2012) showed that rabbit meat's ability to retain water during processing and tenderness can be improved by marination. These authors also proposed the use of sodium bicarbonate as an alternative to phosphates in order to address natural and clean labelling trends.

Emulsified and formed products

In rabbit, formed products basically include meat patties (such as pre-formed hamburger patties), which are prepared with coarsely ground meat obtained from fore and hind leg. To reduce the cost of raw materials, meat from culled rabbit does is also often used to prepare formed products. Both hamburger and fresh coarse-ground sausages manufactured with rabbit meat have gained some interest in the marketplace only during the last few years as healthier alternative to the traditional ones manufactured using beef or pork, especially for children and elderly consumers.

On the other hand, to produce modern emulsified products, such as hot dogs and bologna, raw meats are finely ground and the meat's fibrous structure disappears. Overall, rabbit emulsified products are lacking, with the exception of baby foods, which are nevertheless a niche product. On the other hand, in pork and poultry, since most consumers prefer the fibrous nature of whole-muscle meat, these products, although very popular, are often viewed as having less prestige than whole-muscle products (Fletcher, 2004). The majority of poultry emulsified products are manufactured using MDM, which allows a radical reduction in formulation costs (Froning and McKee, 2004). As previously described, the technical difficulties in producing rabbit MDM dramatically limit the potential development of emulsified products made with rabbit meat, as the cost would not be competitive compared to currently marketed products.

Coating

The coating of meat products can potentially vary from minimal seasoning with salt and pepper through sophisticated sauces to completely battered and breaded (enrobed) products. Coating is often used as basic preparation technique to add flavour, seal the product so that moisture and juiciness are retained during cooking and improve product appearance. Potential rabbit meat products could be those in which carcass parts, patties or preformed products are pre-dusted, battered, breaded (or some combination thereof) and "flash fried" merely to partially cook or "set" the coating. The products can then be cooked in other types of oven, such as forced-air convection or steam ovens, without drying the product or compromising the textural quality of the coating. The products can be frozen and ready to "heat and eat". The industry is currently under pressure to lower the fat content of products used by institutions or sold

directly to consumers. Coating mixes have been developed to coat meat products that can be cooked in conventional ovens to simulate fried foods, but without the added fat (Fletcher, 2004). Today, rabbit coated meat products are scarcely marketed because of the reasons described before (e.g. non-competitive cost, scarce consumer habit, etc.). Nevertheless, it should not be forgotten that coated products are very popular for children and young people, so coated products manufactured with rabbit meat can be viewed as extending the range of existing product lines made with other types of meat, as recently done by some companies.

TRENDS IN INGREDIENTS INCORPORATED IN MEAT PRODUCTS

Several ingredients and additives can be applied during the manufacture of meat products to increase, restore or enhance attributes such as taste, colour, texture, firmness and shelf life. Major trends to be adopted in rabbit meat product formulation are summarised as follows.

Modulation of lipid content and composition in meat products

Rabbit meat is leaner compared with other kinds of meat (Dalle Zotte and Szendrő, 2011); in consequence, when it is used to manufacture emulsified and coarsely ground sausages, other kind of meats (pork, poultry meat) and/or fats (i.e. pork lard) are usually added, which may increase lipid content up to 30%. This should be avoided in order to preserve the current healthy image of rabbit meat. As alternatives, fat from plants rather than animal resources and other ingredients such as fat replacers can modulate fat levels and its composition (i.e. low cholesterol content, high PUFA level). Manufacturing finely ground meat products such as emulsified, boiled sausages (frankfurter style) is extremely challenging and poses difficulties in term of appearance, flavour, water holding capacity (lower ability to retain liquid during cooking) and texture (i.e. increase of firmness) (Weiss *et al.*, 2010). For this reason, a number of hydrocolloid systems with water-holding capacity that are able to promote the formation of gels have been examined for their ability to replace fat. Main possibilities are alginate, carrageenan, xanthan gum, cellulose derivatives, starches and pectins. The use of these non-meat ingredients can significantly lower costs for processors, which in turn can help increase the competitiveness of rabbit meat. However, to address natural and clean label trends and maintain the current good image of rabbit meat, heavy use of non-meat ingredients should be avoided. Product formulation should be performed with a view to reinforcing the good healthy profile of rabbit meat, for example by incorporating functional ingredients such as vegetable fibres. In fact, due to their technological functionality and nutritional benefits, fibres can be used for enrichment, either alone or in combination with other ingredients, as sources of prebiotic fibre to cut down on fat, salt or phosphates and enable the use of plant oils rich in PUFA n-3 (Arihara, 2006; Decker and Park, 2010; Weiss *et al.*, 2010; Zhang *et al.*, 2010). On the other hand, fat composition can be also manipulated by dietary means, as proven by many studies (Hernández and Gondret, 2006). A considerable amount of work has been done to enhance the n-3 PUFA content of rabbit meat by inclusion in the diet of raw materials rich in n-3 PUFA, as reviewed by Petracci *et al.* (2009) and Dalle Zotte and Szendrő (2011).

Decreased oxidation by the use of novel antioxidants

Oxidation of lipids in meat products is a key problem that reduces shelf life of frozen and fermented processed meat, but also of precooked meats. In the latter, lipid oxidation leads to formation of "warmed-over flavours", which refers to the development of off-flavours in cooked product when reheated after refrigerated storage (Weiss *et al.*, 2010). The formation of lipid oxidation products from unsaturated fats is initiated by singlet oxygen converted from triplet oxygen, or a catalyst and triplet oxygen. Further reactions yield hydroperoxides that act as strong oxidising agents (Kubow, 1992). Metal catalysts such as iron and copper are key elements involved in the breakdown of these compounds. From a sensory point of view, a large number of low molecular weight degradation products that are often volatile are formed. These compounds are ultimately responsible for the development of a rancid off-flavour, which is stronger when starting from PUFA n-3 rather than PUFA n-6 (Enser, 1999). In addition, some of these oxidation products have shown to possess mutagenic and carcinogenic potential, making extensive oxidation of meat and meat products a health problem (Weiss *et al.*, 2010). Rabbit meat has quite a high content of polyunsaturated fatty acids (Dalle Zotte and Szendrő, 2011), which makes it somewhat susceptible to lipid oxidation and the subsequent off-flavour (and off-aroma) characteristic of warmed-over flavours (Bianchi *et al.*, 2006). There are several compounds

with antioxidant potential which may be used as food ingredients (butylated hydroxyanisole, butylated hydroxytoluene, sodium nitrate, tocopherols, selenium, ascorbic acid, etc.) (Decker and Park, 2010; Weiss *et al.*, 2010; Zhang *et al.*, 2010) and/or dietary supplementation (tocopherols, ascorbic acid, etc.) (Abdel-Khalek, 2010; Dalle Zotte and Szendrő, 2011) in order to prevent or al least reduce meat oxidation processes. It is widely known that tocopherols are also most effective antioxidants in rabbit meat and their content can easily be increased both by dietary fortification (López-Bote *et al.*, 1997; Castellini *et al.*, 1999) and its use as an ingredient with beneficial effects on lipid oxidation during frozen storage (Castellini *et al.*, 1999; Lo Fiego *et al.*, 2004) and cooking (Dal Bosco *et al.*, 2001), colour stability (Corino *et al.*, 1999; Dalle Zotte *et al.*, 2000) and some technological properties (Castellini *et al.*, 1998). In recent years, interest in the use of natural antioxidants has increased both in animal nutrition and the food industry. There are highly active essential oil compounds in rosemary, oregano, thyme and sage and their use is allowed both as dietary compounds and meat additives (Decker and Park, 2010; Weiss *et al.*, 2010; Zhang *et al.*, 2010). The influence of dietary supplementation with oregano essential oil has been also studied in rabbits by Botsosglu *et al.* (2004) and Soultos *et al.* (2009), who found that a 200 mg/kg level was effective in meat protection against lipid oxidation and development of off-odours by spoilage bacteria during refrigerated storage of rabbit carcasses, respectively. More recently, dietary supplementation with chia seed (Meineri *et al.*, 2010) and tannins (Gai *et al.*, 2009; Dalle Zotte *et al.*, 2010) did not result effective in retarding lipid oxidation.

Salt and sodium reduction

Salt or sodium chloride (NaCl) is the most important ingredient in the production of meat products. In recent decades, with the increasing consumption of many different processed foods containing high sodium levels, the perception of dietary salt has evolved to a point where it is now considered by some to be a potential health threat. As these high levels of dietary sodium are associated with a high prevalence of hypertension, pre-hypertension and other possible adverse effects on health, many national and international health organisations recommend that sodium intake should be significantly reduced (Doyle and Glass, 2010). It should be mentioned that even though raw rabbit meat is often claimed to have a very low sodium content if compared with other kind of meats, the amount of sodium added during culinary preparation of raw meats or industrial food processing is nevertheless much higher (300 to 800 mg/100 g of edible product) in terms of its intrinsic content, which can vary from 37 to 47 mg/100 g, as reported by Dalle Zotte and Szendrő (2011). One of the biggest barriers to salt replacement is cost, as salt is one of the cheapest food ingredients available. Moreover, consumers have grown accustomed to salt through processed foods, so in some cases it has been difficult to remove, as previously discussed. Another issue is that although there are alternatives to salt in terms of functionality, some consumers and retailers may not be comfortable with these new ingredients on the label (Petracci *et al.*, 2013). In meat systems, besides the organoleptic factors, an important consideration when replacing NaCl with other chloride salts is the effect on the physical properties of the final product. Sodium chloride reduction by itself will result in lowered WHC of the raw meat, which, upon heating, will result in higher cooking losses, drier product and, if cooking losses are too extensive, a totally unacceptable product (Barbut, 2002).

The main strategies for sodium reduction are the use of sodium chloride substitutes, in particular potassium chloride (KCl) and flavour enhancers that enhance the perception of salt in the finished products (Petracci *et al.*, 2013). No specific studies have been conducted on processed products manufactured with rabbit meat; however, there are no difficulties in transposing the knowledge gained in other kinds of meat.

MAIN PACKAGING SOLUTIONS FOR RABBIT MEAT PRODUCTS

Evolution from whole carcass and cut-up to processed products in the rabbit sector would involve a demand for some degree of extended shelf-life, product diversification and convenience. Convenience is a very important function of modern packaging, together with containment, information and protection. For example, single serving sizes of sliced meat and microwavable packages allow for cooking/reheating and consumption of the product in a part of the package (Dawson, 2010). In modern retail, rabbit meat products are retailed for display and store branded or branded by the supplier. Stretchable and clear polyvinylchloride (PVC) film overwrap with product placed on an expanded polystyrene (foam) tray is currently the most common case-ready display package for most traditional rabbit products such as whole carcass and cut-up. An absorbent pad can be placed under the meat to absorb purge (Dawson, 2010).

Products manufactured with uncooked ground rabbit meat require different packaging, designed to enhance microbial shelf-life and colour stability. These products are usually packaged under modified atmosphere in polystyrene foam trays with a non-oxygen-permeable film overwrap. A further solution is a "lidded" tray in which high barrier films with shrink capacity are sealed to a pre-shaped barrier tray, leaving a top surface lip to provide a film-to-tray sealing area (Acton *et al.*, 2007). Different gas mixture combinations are recommended depending on the product. For example, boneless portions may use 60 to 80% oxygen for colour maintenance (oxymyoglobin), 20 to 25% carbon dioxide, and the remainder as nitrogen filler to prevent packaging collapse (McMullin, 2008; Singh *et al.*, 2011). Several packaging formats used for processed ready-to-eat products can be the same as those for fresh rabbit meat. Barrier foam can also be used, or solid trays with barrier overwraps (but not lidded trays) and thermoformed packages using vacuum packaging or modified atmosphere packaging (Acton *et al.*, 2007). However, modified atmospheres used are not the same as for most fresh rabbit meat, consisting of 25-30% carbon dioxide and the remainder as nitrogen. Exclusion of oxygen is a major requirement for all products in these categories. Barrier systems ensure zero or minimal loss of flavours through control of lipid oxidation that leads to development of rancidity (Acton *et al.*, 2007; McMullin, 2008; Singh *et al.*, 2011).

CONCLUSIONS

Similar to poultry, rabbit meat has a nutritional profile and technological traits highly suitable for inclusion in added-value products to meet modern consumer demands for food health and convenience and industry requirements in term of flexibility. There are only a few real technical limitations in the use of rabbit meat to manufacture certain kinds of processed products, but this has always taken second place to the realities of marketing and economic viability. Indeed, the very high cost of raw rabbit raw meat for further processing compared to pork and poultry, together with cultural constrains, severely limits its use in the formulation of processed products. The development of further processed products can allow improvements in the appearance and sensory traits of rabbit meat products, while reducing the cultural and ethical implications of using rabbits as food consumption. Main promising approaches to developing rabbit further processed products involve industrialising traditional rabbit meat dishes and culinary practices (i.e. stuffed rolls, marinated meat) and extending the range of existing product lines made with other kinds of meat (i.e. nuggets, sausages, frankfurters). Product formulation should be performed by reinforcing the good healthy profile of rabbit meat and maintaining low amounts of fat, saturated fatty acids, cholesterol, sodium, etc. and including beneficial compounds such as n-3 PUFA, natural plant extracts, vegetable fibres and iodised salts, etc. Failure to successfully market such processed products could seriously risk hampering the future development of industrial-scale rabbit production. In this situation, rabbit meat sales through modern retail and catering channels could even decline and rabbit meat might become just an important niche in both traditional (i.e. local and ethnic markets, typical restaurants, etc.) and rich and diverse food supply (i.e. high class restaurants, specialised meat shops, etc.).

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