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MAIN FACTORS INFLUENCING THE RABBIT CARCASS AND MEAT QUALITY

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After a brief definition of rabbit carcass and meat quality, this review has been divided in two sections. The first section is devoted to analyse the evolution of the meat quality concept *sensu lato*, the contribution of the rabbit meat researchers up to now and to investigate on what the researcher can do to satisfy the consumer's changing definition of quality in relation to rabbit meat. The second section, more technical, describes the main factors which can affect rabbit carcass and meat quality.

SECTION I

Definition of rabbit carcass and meat quality

As for other livestock, even rabbit meat products could be evaluated according to the carcass quality and to the meat quality.

Carcass quality has to satisfy economic objectives, such as saleable meat yield, aspect and attractiveness to consumer. On rabbit, carcass quality mainly concerns carcass weight (it varies from 1.0 to 1.8 kg, according to the various European countries or regions considered; Colin, 1999), slaughter yield, referred as whole carcass (55 to 60% of liveweight) or retail cuts yield (loin joint: 23 to 28%; hind legs: 27 to 29% of chilled carcass), meatiness, referred as meat to bone ratio of the reference carcass (7.0 to 8.0) or that of hind leg (5.5 to 6.0), fatness, expressed as percentage of dissectible fat (3 to 6% of reference carcass; Blasco and Ouhayoun, 1996) and chilling losses (2.4 to 4% of carcass). Generally speaking, livestock carcass composition research is increasing in importance because the consumer demands more and more lean carcasses, attractive and, implicitly, wholesome. Fortunately, commercially rabbit carcass is quite lean and does not present serious qualitative problems linked to anomaly of the muscle biology or to the pre- and post-slaughter handling, if compared with that of other species (Ouhayoun, 1992a).

Meat quality concerns a very wide definition, depending on to who it is addressed: the processor, the distributor or the consumer but, as the latter is the final ring of the chain, his conception of meat quality is the most important. Consumer's definition of meat quality has been conditioned by changing attitudes in society, often amplified by the media. Meat quality not only includes nutritional properties such as appropriate proportions of bioactive compounds, proteins, lipids and their essential sub-constituents, sensory characteristics such as tenderness, flavour and colour, healthiness such as fat and saturated fatty acids (FA), technological factors such as aptitude to be processed, but also views or perceptions about the conditions of animal production in relation to animal welfare, the impact of animal production on the environment and, of course, food safety. Rabbit meat is notoriously appreciated for its high nutritional and dietetic properties: it is lean and lipids are highly unsaturated (60% of total FA), it is rich in proteins (20-21%) and its aminoacids are of high biological value, it is poor in cholesterol and sodium and rich in potassium, phosphorus and magnesium (Parigi Bini *et al*., 1992b).

Evolution of the meat quality concept

During the second half of the past century the meat consumer demands in developed countries was firstly focused on income, availability, price and, of course, nutritive value. More recently, it was influenced by a whole range of market factors including visual appeal, fitness for purpose, the choice of alternative foods available and the eating satisfaction experienced.

Nowadays, many developed countries are experiencing fundamental changes in lifestyle as social structures change, as affluence increases, as families fragment and as individuals achieve more leisure time. This leads to major changes in meal patterns and the time available for preparation and consumption, so increasing the demand for such convenience foods.

Evolution of the researchers concerns

The quality traits taken into account by researchers varied with time, as scientific progress was made and as market requirements manifested themselves. Traditionally, understanding the mechanisms underlying rabbit meat quality has been a major concern of meat scientists (Barany *et al*., 1965; Nougues *et al*., 1974; Vigneron *et al*., 1976). Muscle fibre composition, fibre areas and capillary density of the muscles are important factors influencing many of the *pre-* and *post-mortem* biochemical processes and, therefore, meat quality (Alasnier *et al.*, 1996; Dalle Zotte and Ouhayoun, 1998; Gondret and Bonneau, 1998). Histochemical and biochemical characterisation and classification of muscle fibres are closely related to colour stability and tenderness, as well as water holding capacity (WHC), eating quality (Aquaron and Serratrice, 1972; Ouhayoun and Dalle Zotte, 1993; Dalle Zotte and Ouhayoun, 1995; Dalle Zotte *et al*., 1996) and lipid oxidation (Alasnier *et al.*, 1996).

During the last decade studies on rabbit meat quality were mostly focused on meat chemical composition, pH and colour (Blasco and Piles, 1990; Xiccato *et al*., 1990; Castellini and Battaglini, 1992; Parigi Bini *et al*., 1992b, 1994; Cabanes-Roiron and Ouhayoun, 1994; Haddad *et al.*, 1994; Cobos *et al.*, 1995; Dalle Zotte *et al.*, 1995, 1997, 1998; Oliver *et al*., 1997; Dalle Zotte and Ouhayoun, 1998). In order to understanding clearly the linkage between these traits and the organoleptic variables, researchers were also interested to investigate forward on the several aspects of the meat WHC, *i.e*. drip loss, chilling loss, cooking loss, thawing loss and the meat tenderness measurements (Bernardini Battaglini *et al.,* 1994; Dalle Zotte *et al.*, 1995; Pla and Cervera, 1997).

As in developed countries people tend to exercise control over their fat intake and fat composition of foods, one of the main aims of meat researchers is now to produce dietetic and healthy meat reducing the saturated FA and increasing the unsaturated FA in fat deposits. As regards the fat content, rabbit meat is characterised by lower fat (0.8 to 3.6 g/100g fresh meat), calories (6.0 to 6.8 MJ/kg) and cholesterol contents (45 to 55 mg/100g fresh meat), if compared with other meats (Lukefahr *et al*., 1989; Parigi Bini *et al*., 1992b). According to fat composition, rabbit meat could be a very useful food in human dietetics. In fact, it possesses a relatively high content of polyunsaturated FA – PUFA - (Romans *et al*., 1974; Ouhayoun *et* *al*., 1985; Ouhayoun *et al*., 1987; Alasnier and Gandemer, 1998) and a low FA-n6/FA-n3 ratio (Castellini *et al.*, 1999). However, increasing the degree of unsaturation of animal tissues by dietary manipulation accelerates oxidative deterioration during meat processing and storage. Since rabbit meat is commonly rich in highly PUFA (HUFA), its further increase may limit the shelf-life of cooked meat (Lee and Ahn, 1977; Fernàndez-Esplà and O'Neill, 1993; Lopez-Bote *et al.*, 1997).

The link between lipid oxidation and human health is an important issue in meat research, too. Lipid oxidation is one of the main mechanisms responsible for characteristic flavour development but it can also lead to warmed-over flavour development and the generation of cholesterol oxides (Gandemer, 1998). With this mind, it is important to establish the relationship between the presence of antioxidants (mainly vitamin E) and dietary fats in animal feed and meat and meat-product stability, shelf-life, sensorial properties and toxic compound generation.

Great effort has been made by researchers to evaluate and introduce new methods for meat quality evaluation, for example the use of instruments like ultrasound, electronic nose, taste sensing, NIRS, TOBEC, Video Image Analysis, Reflectance Fat Probe, NMR (Cross and Belk, 1992). However the meat industry has adopted very few of them, in large scale operations, because of their prohibited costs or they are not yet ready for on-line production. Therefore, more research is needed to objectively describe the different quality requirements of meat markets.

Research performed on rabbit carcass and meat quality occurred to a large extent with the aim to progress in knowledge than to meet the consumers demand. As the fuel driving the meat consumption is the consumer, it is fundamental to satisfy his expressed and implicit needs. At this point, all the people involved in rabbit meat chain management, together with scientists, have to ask themselves simple but important questions: what kind of meat does the consumer want today and how should it be presented?

The first step of this analysis consists in defining the main important quality traits required by rabbit meat consumer. Therefore, the analysis must focus on the main factors which are able to modify and satisfy consumer requirements. In this context, two main categories of variability factors could be defined: of moderate effect and of high effect on consumers.

Rabbit meat consumer concerns in the near future

Rabbit meat consumption like that of any other meat has been influenced by historical, economical and also by social evolution. Nevertheless, because rabbit meat production is strongly developed in Mediterranean Countries of the UE, its consumption is to a wide extent dependent on cultural, traditional and religious reasons and the changes in rabbit meat demand were, in the last 20 years, less important than those observed for meats of other species, particularly for the "red meats".

Nowadays, rabbit meat eating habits are changing, too. In fact, while the eating habits of middle-aged consumers are relatively stable, the impact on the eating habits of the young emerging generation is potentially very great, because of more sensitive criticisms of meat as a food, of the impact of production systems on animals and the environment, and of the lack of experience and publicity of rabbit meat as a food.

An important question that is nowadays continuously posed by the various "actors" of the rabbit chain management is: how to increase rabbit meat consumption? Recently, some French producers are trying to segment the market by differentiating the product, *i.e.* developing *labelled or mature rabbits* in order to increase the rabbit meat demand (Hassan and Monier-Dilhan, 1999). Nevertheless, the perspectives of development of such "higher quality" rabbit production seems to be limited until now, essentially because the traditional consumer considers the meat of standard rabbits as already of high quality, so he is not inclined to pay more for it. On the contrary, results obtained by the same market research are stressing that the modification of the traditional consumers' expectation risks having an opposite effect.

So, what are the expectances of the consumer as regards to rabbit meat? An Italian market research (De Carlo, 1998) exhibits interesting results on rabbit meat consumption habits; consumers are attracted by rabbit meat according to these criteria set in decreasing order: quality *sensu lato*, appearance, carcass weight and quality to price ratio. Nevertheless these criteria relate only to the traditional consumer (76% of the interviewed). The remaining 24% do not eat rabbit meat for these main reasons: they don't like it (60%) and the main reason of refusal is its wild taste, they do not know of it (11%) and it is more difficult and takes longer to prepare and to cook (7%).

In order to stimulate the purchase of rabbit meat by the non-consumers, efforts should be made at informative and educational levels, and by increasing the serviceability (today quite absent) and preservability of rabbit meat. "Hedonistic quality" has not to be underestimated; it could influence the younger population, as well as the middle-aged, if other alternative proposals are done.

During the last five years the rabbit meat trade in Europe is involving more and more the big distribution, with the direct effect to homogenise the production and concerns both the carcass weight and the carcass price (Colin, 1999). Nevertheless, with this kind of trade we risk loosing little by little the rich cultural patrimony of some countries, based on bio-diversity and on typicalness of products strongly related to the territory (Di Falco, 2000). As it has to satisfy both the traditional and the "modern" rabbit consumer, the supply should be diversified by assuring always the availability of the traditional product (whole and cut rabbit carcass) and also that of portioned, elaborated, ready to cook and ready to eat products.

Up to now, rabbit meat consumers have had no doubts about its healthiness. Nevertheless, healthiness represents an important pre-requisite and the consumer is prompt to change meat eating habits as confidence in this sense fails. According to these recent results, the main criteria considered by the rabbit meat consumer seem to be: healthiness, sensory properties, hedonistic quality (variability on visual appeal), cooking facility and swiftness and, implied, price.

<u>Healthiness</u>

The consumer demand is more and more influenced by growing concerns about the *healthiness* of meat and about modern methods of production and their impact. Other two concerns that are most widespread in the developed world relate to *residues* and *contaminants*. The fear that substances administered to animals to promote growth or to prevent or treat disease, pesticides used in plants that are used to feed animals and "additives" in some processed meat products will leave residues in the meat which are harmful to the health of the consumer is common in the developed world.

The wholesomeness of rabbit meat derives from the absence or sporadic presence of zoonosis and drug residues (Facchin *et al.*, 1996). Nevertheless, the frequency of multi-factorial pathologies in rabbit breeding farms promoted an excessive and uncorrect use of antibiotics, with the possible presence of residues in meats at dangerous levels (Facchin *et al.*, 1998). Rabbit meat contamination could also appear during the processing procedures, if a hygienic programme is not correctly adopted (Zanon *et al.*, 1998). Moreover, the food scandals such as those that have erupted over recent decades, in particular those related to the human safety (Clenbuterol, BSE and Creutzfeldt Jakob disease) affected also the consumer confidence in rabbit meat.

As wholesomeness of rabbit meat is becoming an indispensable requirement for the consumer, and he must not be deceived, rabbit meat chain management "actors" must be more and more orientated to certify their product (Vannucci, 2000). Certification means in particular the limitation of antibiotic treatments and the meat traceability from farm to consumer.

The effect of chain management components on meat quality are additives, so, the high quality of the meat produced with the contribution of the production components could be compromised by erroneous treatments made by only one of these components. In an attempt to guarantee the safety of meat products the meat industry is adopting Quality Assurance (QA) schemes. Up to now hazard analysis and critical control point (HACCP) and ISO 9000 principles have been applied in order to maintain hygiene in a large amount of food processing. In the rabbit chain management the QA scheme has not yet reached great approval, however, it is recently introducing a sort of certification which could represent an opportunity to evaluate the quality traits of food products: the voluntary product certification (Biguzzi, 2000). New market requirements and scientific evidence will, undoubtedly, lead to an improvement in the standards of food safety, animal welfare and meat quality.

Sensory properties

Meat sensory properties are crucial for the consumer's choice. The most significant variables include the appearance (colour and consistency of the raw meat), texture (tenderness and juiciness) and flavour (taste, smell and aroma). Rabbit meat may change appearance with storage time: it can become darker and drier or wet according to packaging systems, with consequences on its acceptability by the consumer. In fact, the consumer associates freshness and quality with a good colour of lean meat. For these reasons, storage conditions should be accurately taken into account and various packaging methods should be evaluated, also in the rabbit meat production.

Rabbit meat is considered by the traditional consumer to have positive sensory properties: it is tender, lean and flavoured. Nevertheless, the main cause of refusal is its typical taste of wild game meat sometimes perceived by the consumer (De Carlo, 1998) and partially due to the meat fat content and its FA composition. Researchers should then investigate further on the various possibilities to reduce the wild taste in rabbit meats with the aim to satisfy this particular consumer category.

Hedonistic quality

It differs from standard aspect and concerns the various means of meat presentation. Together with the standard aspect, the hedonistic quality represents one of the main reasons which can influence the consumer's preference.

Consumers, and in particular the younger ones, are being more and more attracted in the way a product is presented. Rabbit meat is commonly sold as whole carcass or as part of it and, often, it is not so attractive. Rabbit meat could gain commercial acceptance if sold fresh as retail packs, if differently cured as for "country-style" popular in France and if packaging systems are competitive with that of other species.

Cooking easiness and swiftness

Today, the limited time available for meal preparation is increasing the demand for foods easy and swift to use. Consumers are more and more orientated towards meats ready to cook or ready to eat. Hence, for rabbit meat too, the future will be the product diversification in order to better fit in to the real consumer's needs.

Price

All these factors are very important for the consumer's demand but the cost factor plays an unegligible role. The cost of any process, and subsequently any standards which have to be maintained during the process, must be such that the final product remains an economically viable and marketable item. The result of a failure to meet this requirement is quite obvious: no sale, no profit, no further production. From this point of view, rabbit meat production in developed countries is not well placed, if compared with that of other meat species, mainly due to the difficulty of reducing the rabbit feeding costs. In fact, the rabbit production costs are twice as high as for broilers and 20-30% higher than in pigs. A possibility to reduce the amount of feed/unit of meat production consists in improving rabbit feed efficiency (Maertens, 1999).

Today, the lack of enlarging meat consumption in developed countries lead a very strong concurrence between several meats. In this sense, as rabbit meat tends to be more expensive than other "white meats", its consumption risks remaining "traditional", if it continues to be sold as an entire carcass. Fortunately, the rabbit carcass sold in cuts or pre-cooked is increasing, notwithstanding the price increases, too, stressing that consumers are favourable to pay for the service included in elaborated rabbit meat (Hassan and Monier-Dilhan, 1999).

SECTION II

Factors affecting rabbit carcass and meat quality

The present paper does not intend to describe in detail all rabbit carcass and meat variability factors, other reviews were devoted to this, but would stress mainly those giving a significant effect for the consumer. According to their importance, the description will be divided into two parts: 1- Factors of moderate effect on rabbit carcass and meat quality, 2- Factors of high effect on rabbit carcass and meat quality, as required by the consumer.

Factors of moderate effect on rabbit carcass and meat quality

Environmental effects

They involve mostly the environmental temperature and the season, in which temperature plays a major role on productive and slaughtering performance. As occurs for all livestock, even for rabbits the increase of environmental temperature over the thermoneutrality value reduces the feed intake and, consequently, the growth rate resulting in lower slaughter weight, at commercially slaughter age, and, sometimes, better slaughter yield because of the lower proportion of skin, empty gut and offals (Lebas and Ouhayoun, 1987; Chiericato *et al*., 1993, 1996b). Similarly, temperature under the thermoneutrality value affects growth rate, because of the existing thermostatic mechanism of intake regulation and the higher energy requirement for thermoregulation (Prud'hon, 1976). By consequence, seasonal effects are economically unfavourable for producers and processors, in particular if consumers prefer heavy carcasses. Nevertheless, if environmental temperature can be controlled around the thermoneutrality range, seasonal effect on growth performance can be strongly reduced (Rouvier, 1970). In order to improve growth performance at high environmental temperatures, it seems opportune to increase the energy density of the diets, by adding fats (Cervera *et al.*, 1997).

Meat quality characteristics seem to be influenced by the thermal conditions to a less extent. Chiericato *et al*. (1996a) observed that rabbits reared at high temperature, if compared with those reared in thermoneutral conditions, exhibit paler meat and its lipids have higher saturated FA proportion. High saturated FA intake have been demonstrated to be dangerous for human health, but, as they are less oxidable so meat shelf-life and lipid stability are favoured, this kind of production could be in a some way advantageous for the summer production.

Rearing techniques

Recently, with the aim to improve the animal welfare and to differentiate rabbit meat production, rabbit researchers revealed an interest into studying a more extensive type of housing. Van Der Horst *et al.* (1999) comparing two types of housing (classical fattening wire mesh cages with 16 rabbits/m^2 *vs* pens with 8 rabbits/m^2) demonstrated that animals raised in pens exhibit lower growth rate, worse dressing percentage and lesser perirenal fat percentage, mainly due to the increased physical activity. Animals reared in pens also resulted less mature and needed to be slaughtered later. Same results were obtained comparing the classic cages (2 rabbits/cage) with mobile cages (6 rabbits/cage), the latter were moved daily and rabbits consumed grass in addition to commercial pellet (Margarit *et al.*, 1999). However, sensory test did not appreciate significant differences among treatments.

Another recent study (Xiccato *et al*., 1999) postulated that the effect of the increase of stocking density (from 12 to 16 rabbits/m^2) is negligible on carcass and meat quality, as well as the type of cage (1 vs 3 rabbits/cage) which slightly favour the collective rearing, giving lower transport losses and higher meat lightness and fracture resistance of the tibia bone. Behaviour test done in the same trial showed that collective rearing improved animal transport stress resistance, because of their best environmental adaptation. According to stocking density, significant reduction of food intake has been observed only over a density of 17-20 rabbits/m^2, related to the decreased animal comfort (Maertens and De Groote, 1984; Morisse and Maurice, 1996).

<u>Feeding effects</u>

As clearly explained by Ouhayoun in a recent review contribution (1998), all factors which can influence growth potential, by changing the relative growth of tissues and organs, lead to modifications of the carcass and meat quality. With this mind, even the feeding factor can play an important role.

Numerous research has been conducted on rabbit nutrition and feeding, most of them took into account the effect of feeding level by introducing variations in the quantity of ingested feed or in energy concentration of the diet. This topic has recently been reviewed by Maertens (1998, 1999) and Xiccato (1999). These researches lead to state that, in the rabbit, efficient chemiostatic mechanism of appetite regulation maintains quite constant the daily energy intake, thus the rabbit adjusts its voluntary feed intake in response to changes in dietary energy concentration, but it occurs only over 9.2 MJ DE/kg (Lebas, 1975; Maertens *et al*., 1988; Partridge *et al*., 1989). Best performance and meat production are obtained by feeding rabbits *ad libitum* and with DE concentration higher than 10.45 MJ/kg (INRA, 1989; Lebas, 1991). However, rabbit requires a certain fibre quantity (130-140g crude fibre/kg) which limits high DE intake. Fortunately, energy intake can be increased by adding fat to the fibrous rabbit diet.

Studies on the effect of the feeding level showed that, as rabbits ingest less than 85% of the *ad libitum*, growth, feed efficiency, slaughter yield, carcass adiposity and lipid content are seriously compromised, thus, under this intake level meat production is not profitable (Ferreira and Carregal, 1996; Perrier, 1998; Jérôme *et al.*, 1998; Gondret *et al*., 1999).

Up to or near this level, the effect of **<u>feed restriction</u>** on carcass and meat quality depends on how it is implemented. Perrier and Ouhayoun (1996), comparing three feed restrictions (but with the same overall degree of restriction, equal to 80% of *ad libitum*, control group: 80-80) observed that a period of severe feed restriction (70% of *ad libitum*) followed by a light restriction (90% of *ad libitum;* 70-90 group) is more favourable to growth, feed efficiency, carcass weight, hindleg meat to bone ratio and ultimate pH, than the reverse. Similar trend was obtained comparing 70-90 group with control group (80-80). These results are due to the compensatory growth of early restricted rabbits, which favours late-maturing tissues, in this case muscle and fat. Nevertheless, more recently Perrier (1998) observed that, when rabbits are restricted to 70% of *ad libitum* from 35 to 56 days, then fed *ad libitum* until 11 weeks of age, compensatory growth does not completely compensate the slow growth of rabbits, if compared with those fed *ad libitum* for the whole period.

Nowadays, with the aim to produce *labelled* rabbit, characterised by low growth and so higher slaughter age, some producers are trying to feed rabbits with moderate restriction, by giving less food or food energetically less dense, or by limiting the feed access. Research on this topic resulted in poorer live performance, carcass weight, yield and adiposity (Ouhayoun *et al.*, 1986a; Jérôme *et al.*, 1998), less intramuscular fat content and proportion of oxidative fibres in *Longissimus lumborum* muscle (Gondret *et al.*, 1999) when rabbits food intake was restricted, even if 3 weeks older than the *ad libitum* ones when slaughtered.

A commercial pelleted diet is normally formulated for covering the energy, protein, mineral and vitamin requirements for body maintenance and growth. Since these requirements change with the rabbit's age, some **feeding plans** are being developed. Thus, for obtaining better carcass shape and intermuscular fat inclusion, during fattening the diets must be more concentrated in energy than those formulated for post-weaning period, to the detriment of protein level.

The influence of feeding plans on carcass and meat quality has never been demonstrated to be of great effect. In detail, when changing the dietary energy content during post-weaning period, followed by diets with high energy content during fattening, the growth, the feed intake and the carcass yield were not significantly affected, but feed conversion index was lower and dissectable fat was increased in rabbits fed with high-energy diets from post-weaning to slaughter (Lebas *et al*., 1982; Xiccato *et al*., 1993, 1998; Dalle Zotte *et al*., 1997). With regard to meat quality, the same authors did not observe noticeable variations on meat composition or on meat lightness, when changing the feeding plan. Significant decrease of ultimate pH and increase of aldolase activity were found in the *Longissimus dorsi* muscle of rabbits fed with high-energy diets during the whole period (Dalle Zotte *et al*., 1996).

It has to be stressed that a diet which perfectly fulfils the animal's requirements, besides expressing the best growth potentiality, also significantly reduces both the feeding costs and the nitrogen and mineral excretion. The latter topic is of fundamental importance in areas with a high density of animal production (Maertens, 1999). Thus, as material and energetic requirements of rabbits in the finishing period are different to those of post-weaned ones, phase feeding is advisable.

The effect of the nature of the **diet components** on carcass and meat quality has been a matter of some investigation. In order to find less expensive raw materials, alternative to cereal grains, sugar beet pulp was tested at different levels of inclusion. When the animals were fed from weaning to commercial slaughter weight diets containing sugar beet pulps at substitution levels ranging from 15 to 50%, the lowest level of inclusion showed no effects or little positive effects on growth performance, dressing percentage, meat chemical composition and on FA composition, meanwhile the highest level of inclusion significantly impaired carcass and meat quality traits (Garcia *et al*., 1993; Cobos *et al*., 1995). When the animals received 15% of sugar beet pulp in substitution of barley or alfalfa meal during post-weaning period, their dissectible fat percentage and meat to bone ratio of hindleg increased (Trocino *et al.*, 1999).

The effect of the **dietary protein content** on live performance, carcass and meat quality has been studied either by modifying the dietary protein concentration (in iso-energetic diets) or by varying simultaneously the protein and the energy content. The first approach causes difficulty in the extrapolation of the real protein effect because the digestible protein to digestible energy ratio (DP/DE) changes reveal different protein intake. As the optimum level of protein with a balanced EAA composition increases with the energy level of the diet (Lebas, 1983), the second method is more useful for the appreciation of dietary protein effect.

Low DP/DE ratio, under the optimum value of 10.5-11.0 g/MJ, is not sufficient enough to cover the daily protein requirement, therefore growth rate could be negatively affected because muscular protein accretion is sub-optimal; in this case animals could exhibit either low dissectable fat deposit, due to the delay in the development of this tissue (Chiericato *et al*., 1983; Lebas and Ouhayoun, 1987), or high intracellular lipid accumulation, due to the high energy level (Lanari *et al.*, 1972; Fraga *et al*., 1983; Ouhayoun and Cheriet, 1983; Maertens *et al*., 1997). However, the decrease in growth rate in this way obtained, seems to enhance meat quality by limiting the development of the muscle glycolytic metabolism and leading to less lean meat and with a better WHC (Ouhayoun and Dalle Zotte, 1993).

When DP/DE ratio is over the optimum value of 10.5-11.0 g/MJ, the effects on carcass and meat quality are not yet precisely established. Some authors did not observe any variation on live performance and on carcass and meat quality (Raimondi *et al.*, 1973; Xiccato *et al*., 1993), meanwhile others found significant reduction of dissectible fat deposit, but only at very high DP/DE ratio (>12 g/MJ) (Maertens *et al.*, 1988), together with worse live performance and meatiness when the ratio exceed 14 g/MJ (Kiær and Jensen, 1997).

Recent results of Maertens *et al.* (1997, 1998) seem to indicate that only extreme variations in DP/DE are able to modify carcass and meat quality. In fact, when DP/DE range 10.5 to 12.5 g/MJ, as protein intake permits the maximum expression of muscular protein synthesis, growth performance is high and remains constant in the range, meanwhile meat water and nitrogen content tend to increase to the detriment of the fat content. Other meat qualities are not affected by the dietary DP/DE ratio when increasing towards the highest value of the above range.

The impact of quite small differences in PD/ED ratio (11.5 *vs* 12.5) on nitrogen output was recently stressed (Maertens *et al.*, 1998). Between this range of PD/ED ratios, if EAA (lysine, sulphur AA and threonine) cover the requirements, a dilution of the dietary protein content seems to be possible, obtaining the same zootechnical performance.

<u>Preslaughter conditions</u>

The effect of *ante mortem* treatments in rabbits has not been fully investigated. Some research evaluated the effect of feed or water fasting in pre-slaughter period. The main effect consisted in an expected significant reduction of the weight of the transported rabbits and of the offals volume, so this practice seems advantageous for the slaughterhouse (Lebas, 1969). In fact, from the meat quality point of view, no significant difference was found: only the muscular ultimate pH (pHu) was increased and brightness was reduced by fasting (Ouhayoun and Lebas, 1994). Otherwise, Masoero *et al.* (1992) observed a favourable decrease of pHu in fasted rabbits.

Preslaughter handling and transport may increase body weight loss during transport (Masoero *et al*., 1992), ranging from 1.4 to 4.6% with increasing the transport duration from 1 to 7 hours (Luzi *et al*., 1994). The meat from a transported rabbits has more commonly higher pHu and, by consequence, higher WHC, it appears darker and less colourful, and results in being more tender, evaluated instrumentally or sensorially (Ouhayoun and Lebas, 1994; Dalle Zotte *et al*., 1995). These results suggest that preslaughter treatments do not lead to important modifications of meat properties or anomalies such as PSE or DFD syndromes. On the contrary, a short term transportation may improve the sensory qualities of rabbit meat, by making it more tender and juicy.

Stunning conditions

Whatever stunning methods are employed they always determine an extremely violent stress demonstrated by the release of catecholamins, associated to the depletion of energy reserves and to the reduction of the extent of acidification (Hulot and Ouhayoun, 1999). The stun with electroanaesthesia at high frequency (4000 Hz), if compared with the electroshock (270 V, 50 Hz), may increase the adrenaline discharge accelerating the *rigor mortis* development, but without modifying the pHu. However, the first method as well as being too dangerous to the operators it is also painful to the rabbits and causes subsequent muscular contractions which may provoke bone fractures, therefore it is not used in practical conditions (Makaev *et al.*, 1976). Today, the more common legal rabbit stunning method is the electroshock (up to 320 V, 50 Hz), followed by the cutting of the jugular vein and the carotid artery. If compared with the stunning by the neck or the neck dislocation practices, the electroshocks favours the impoverishment of the muscular energy reserves (ATP, PC and glycogen) and provokes a sarcomere shortening but it does not seem to have a great effect on pHu, on ageing process or on rabbit meat tenderness (Ouhayoun, 1988).

Factors of high effect on rabbit carcass and meat quality

Genetic effects

In rabbits, the genetic variability between pure-bred is very high (a giant rabbit is 5 times heavier than a dwarf one, at adult weight) and adult weight has been demonstrated to have great importance in determining the growth rate, the precocity degree and, finally, the rabbit's body composition (Ouhayoun and Rouvier, 1973; de Rochambeau, 1997). However, as rabbits reared for meat are, in practical conditions, commercial hybrids derived from selection programmes based on a three-way cross in which breeds have adult weights usually ranged between 4 and 5 kg, their slaughter weight at commercial slaughter ages (from 11 to 13 weeks) is not so different among final products (Ouhayoun, 1998). According to recent results (Lambertini *et al*., 1996; Hernàndez *et al.* 1998b) the differences between lines in terms of meat quality are weak and seems to be a certain constancy in rabbit meat quality.

In the last decade, breeding strategies considerably increased the growth capacity of rabbits (de Rochambeau, 1997). In fact, current selection programmes are selecting the fast growth rates using terminal sires of large size, with the aim to improve feed efficiency and shortening the rearing time. If these rabbits are slaughtered at light commercial weights, as defined for example by the Spanish market, this often leads to a less mature animal with some undesirable consequences as reduction of carcass yield, mainly due to the higher proportion of the digestive tract, and lowering carcass quality, principally by modifying the fat deposition (Pla *et al*., 1996; Dalle Zotte and Ouhayoun, 1998). Selection for fast growth might also favour a glycolytic energy metabolism in muscle tissue and consequently spoils meat quality: tenderness, by reducing the WHC and the ultimate pH (Ristic and Zimmermann, 1992; Hernàndez *et al.*, 1998a; Piles *et al.*, 2000), flavour and juiciness, by lack of intramuscular lipids (Ouhayoun and Dalle Zotte, 1993).

In order to reduce these negative selection effects two ways can be pursued: 1- increase the commercial carcass size, 2- alternatively include in selection programmes carcass traits (Rouvier, 1970) or meat traits, *i.e.* pHu, which present with growth parameters a moderately high and negative genetic correlation (Ouhayoun *et al*., 1974). In this way, heavy fast growing hybrids can be used when carcasses are appointed to the retail cut market.

<u>Biological factors: age and weight</u>

Animal body weight increases as a function of age and this fact makes it difficult to attribute an effect as dependent only on rabbit weight or on its age. Moreover, it is also difficult to compare research results on on this topic because of the use of strain at different degrees of maturity and because of the majority of the research considered the effect of age by varying also the slaughter weight (Rudolph and Fischer, 1979; Ouhayoun *et al*., 1986b; Poujardieu *et al*., 1986; Parigi Bini *et al*., 1992a and 1992b; Xiccato *et al*., 1993; Bernardini Battaglini *et al.*, 1994; Dalle Zotte *et al*., 1995; Dalle Zotte and Ouhayoun, 1995; Dalle Zotte *et al*., 1996; Preziuso *et al*., 1996; Gondret *et al*., 1998b; Juin *et al*., 1998; Russo *et al*., 1998; Jehl and Juin, 1999) or the effect of weight by varying the slaughter age (Fraga *et al*., 1983; Deltoro and Lopez 1986, 1987; Szendrö *et al*., 1996a and 1996b). Only few studies separated the effect of age (Cabanes and Ouhayoun, 1994) from that of weight (Varewyck and Bouquet, 1982; Lambertini *et al*., 1990; Grashorn *et al*., 1996; Petracci *et al*., 1999) and only one evaluated the effect of both, distinctly (Roiron *et al*., 1992).

During **<u>growth</u>** the different body components develop at different rates - allometry of growth - and the changement of the allometric coefficients of organs and tissues occurs at different body weights. Cantier *et al.* (1969) firstly studied the relative growth of organs and tissues in the rabbit of adult weight of 4.5 kg. This study demonstrated that, with the exception of the adipose tissue and the skin, the allometric coefficients of the other organs and tissues usually decrease with growth. This explains the increase in slaughter yield as a fuction of slaughter weight, but explains also the increase in the cost of feeding associated with the rapid increase of the relative growth rate of the adipose tissue over 2.1 kg of empty body weight.

The carcass and the meat quality changes markedly with the animal's age or weight at slaughter. Due to the changement of the allometric coefficients, the carcass yield seems to increase until 91 days (Parigi Bini *et al*., 1992a; Dalle Zotte and Ouhayoun, 1995; Dalle Zotte *et al*., 1995) or 98 days of age (Jehl and Juin, 1999). A study of Szendrö *et al*. (1996a) which considered 7 slaughter weights (from 2.2 to 3.5 kg) ranged into classes in graduations of 200 g, showed that the better dressing percentage and meatiness were obtained from rabbits weighed in the range of 3.2-3.4 kg.

Increasing the slaughter age, the chilling losses are reduced and the carcass meatiness is improved (Xiccato *et al*., 1993; Bernardini *et al.*, 1995). Postponing the slaughter age permits a better exploitation of growth potentiality, but, the parallel increase of the carcass fat content, and then the worsening of the feed conversion index, reduce the economic interest to rear rabbits older than a determined age, the latest dependent on the precocity of the strain used.

The overall meat quality improves as growth increases. The meat increases its lipid content to the detriment of the water content (Parigi Bini *et al.*, 1992b; Bernardini Battaglini *et al.*, 1994; Preziuso *et al*., 1996; Gondret *et al.*, 1998a) and the meat flavour or smell result sometimes more developed (Jehl and Juin, 1999). In a recent study of Juin *et al.* (1998) the defer of the rabbit slaughter age to 18 weeks, exhibited more tender and less fibrous meat than that from 11 weeks rabbits, but no significant differences were observed on juiciness and flavour.

On the contrary, some physicochemical meat properties could worsen with age. In some cases (Hulot and Ouhayoun, 1999) was observed that as the age increased, the glycolytic energy metabolism also increased (Dalle Zotte *et al*., 1996) and, correlatively, the oxidative metabolism, the myoglobin level (Ouhayoun *et al*., 1983) and the pHu decreased (Dalle Zotte and Ouhayoun, 1995; Perrier and Ouhayoun, 1996). The lowering of pHu corresponded to a lowering of WHC in the raw rabbit meat (Ristic, 1986). These results are however conflicting with those of Parigi Bini *et al*. (1992a) and Bernardini Battaglini *et al*. (1994) which did not observe any lowering of pHu during growth (from 9 to 13 weeks) in five muscles sites of the carcass. These contradictory findings could result from differences in rearing conditions, in the various muscles analysed and, above all, in breeds used by the several authors. The interaction of these parameters make the interpretation of the results and their comparison with other studies difficult.

From the nutritional and dietetic point of view the consumption of more mature rabbit meat is indicated for older people and for people with cardiovascular diseases, because of its reduction in cholesterol and Na contents, as age increases (Parigi Bini *et al*., 1992b). However, considered the higher production costs derived from longer rearing period, performed with the aim to obtain heavy carcasses, the defer of the slaughter age over 13 weeks could be conceivable only if carcasses are submitted to further transformations, with high added value.

Intra-age weight effect has seen to be significant on dissectible fat content (Petracci *et al*., 1999; Varewyck and Bouquet, 1982; Lambertini *et al*., 1990) and on muscle lipid content (Ouhayoun, 1998), both higher in the heaviest rabbits, meanwhile the other carcass traits, *i.e*. the ratio of the cuts and the muscle, bone and fat percentage, were not influenced by the slaughter weight. The heavier the rabbits were(from 2.2 to 2.6 kg), the lower the average pHu of their muscles resulted, whether their weight was attained at 70 or 77 days (Roiron *et al*., 1992), but none of the above cited authors found relevant differences in meat quality. Grashorn *et al.* (1996) recently observed that if the animals were slaughtered at older age (112 days), the pHu and the corresponding qualitative meat traits were not influenced by the slaughter weight (2.8 *vs* 3.3 kg). Results with opposite trend were obtained by Roiron *et al*. (1992). The latest autors, studying both the effect of slaughter age (70 and 77 days) and slaughter weight (2.2, 2.4 and 2.6 kg) stressed that the weight effect plays a major role on carcass traits (carcass yield, meatiness and adiposity), meanwhile the age effect is negligible.

This disagreement on results is mainly dependent on the short range of the chosen independent variable, or by the various degree of maturity of the rabbits used.

When comparing rabbits slaughtered at the **same weight** but at **different ages**, their carcass and meat quality depended on how quickly they have reached that weight. Cabanes-Roiron and Ouhayoun (1994) observed that the rabbits which reached earlier (62 *vs* 73 days) the prefixed weight (2.45 kg) exhibited better growing performance, but their carcass qualities (slaughter yield and meatiness) were worsened. This result indicate that when the rabbits are characterised by more rapid growth weight they possess an inadequate degree of maturity and so their carcass traits are not yet completely expressed. Even if the sensory properties of the meat were not affected by the growth rate, the study of the above mentioned authors suggests that when rabbits of rapid growth rate are used, they have to be slaughtered at an older age.

Feeding factors

Meat is often considered as rich in saturated FA and several epidemiological studies signaled an evidence of relationship between saturated FA intake and cardiovascular diseases. Consequently, most physicians recommend lowering its consumption. However, fat content of muscles is rather low and FA are not all saturated. In the rabbit meat the unsaturated FA represent the 57-59% of the total FA and the amount of PUFA, which represents more than the 25% of the total FA, is much higher than that found in other meats, poultry included. Moreover, rabbit meat PUFA are well equilibrated between the 2 series, (n-6) and (n-3) and some HUFA are present. Thus, rabbit meat plays a very important role in human nutrition. On the other hand, high PUFA content in rabbit meat may affect its suitability for processing and storage, because more susceptible to oxidation.

In this chapter will be took into account the use of dietary fats of various origin with the aim to reduce the feeding costs and to settle by a compromise the dietetic properties and the shelf-life of rabbit meat.

Since rabbits digest pure fats and oils or fat-rich feedstuffs in a way comparable to other monogastric animals, lipids represent an interesting possibility in increasing the dietary energy content of the fibrous rabbit diets. Consequently, the increased DE intake favours feed efficiency but leads, in most cases, comparable growth rates (Lebas *et al*., 1988; Fernàndez and Fraga, 1996). Sometimes, there have been observed either an improvement of the growth rate and final live weight (Parigi Bini *et al*., 1974; Richard *et al*., 1982; Beynen, 1988) or a decrease of the same parameters (Falcão e Cunha *et al*., 1996). These heterogeneous results could be due to differences in the range and the total level of added fat investigated. Thus, the undoubted positive result of the use of fat-added diets seems to be its optimisation of feed efficiency and so its usefulness in the intensive rabbit meat production system, but it shows also some potentiality in improving performance when rabbits are reared at high environmental temperatures (Cervera *et al*., 1997).

Dietary fat inclusion level and source play different roles on carcass and meat quality. The effects of **dietary fat inclusion levels** are in most cases limited to the carcass quality. Thus, inclusion of dietary fat content until moderate concentrations (3 to 6%) can improve carcass yield (Raimondi *et al*., 1974; Beynen *et al*., 1990; Pla and Cervera, 1997), but the greatest effect concerns the increase of the carcass adiposity, in terms of incidence of perirenal fat (Lanari *et al*., 1972; Lebas *et al*., 1988; Fernàndez and Fraga, 1996; Christ *et al*., 1996; Oliver *et al*., 1997) or total dissectible fat (Pla and Cervera, 1997).

With increasing the dietary fat supplement over these values fat deposition increases further (Lebas *et al*., 1988; Oliver *et al*., 1997; Christ *et al*., 1996) meanwhile carcass yield could be impaired (Raimondi *et al*., 1974), rendering unprofitable the fat enrichment. However, it must be stressed that, under practical feeding conditions the fat inclusion is limited to 3% because of technological problems, such as the reduced hardness of pellets.

Considering now the influence that dietary added fat has on meat composition, could have important consequences. Rabbit meat is regarded as a low-fat meat. Between individual muscles, concentration of ether-extractable lipid vary typically from 1-2% in the *Longissimus dorsi* muscle to 3-4% in the hindleg. When moderate added fat levels are used, the meat lipid content does not vary significantly, both on *Longissimus dorsi* muscle (Raimondi *et al*., 1974) or on empty body (Fernandez and Fraga, 1996) or on whole carcass meat (Cobos *et al*., 1993), but when higher fat inclusions are carried out, the fat content of the meat increases (Lanari *et* *al.*, 1972; Christ *et al*., 1996), meanwhile water and protein contents decreases (Lanari *et al.*, 1972; Pla and Cervera, 1997).

The lack of juiciness in rabbit meat, particularly in loin joint, is sometimes associated with low lipid levels. As above mentioned, there is a large amount of published information on the effects of the dietary fat inclusion on fat content of the carcass and, to a lesser extent of the tissues, but few of them relate the meat lipid content to the sensory properties, such as tenderness, juiciness, flavour, and the overall appeal of cooked rabbit meat, all of which are aspects of the quality of the meat fundamental to consumers. Lebas *et al.* (1988) brought to evidence that there was no difference in the organoleptic evaluation by using increased levels of hempseed meal. On the contrary, Oliver *et al.* (1997) reported higher juiciness in loins in abbits fed on added fat diets (of vegetable or animal origin), if compared with the control diet. Unfortunately, these authors did not analyse the fat content of the meat.

Christ *et al*. (1996), performed both fat content and sensory analysis on rabbit hindleg meat; even if meat fat content significantly increases from 4.9 to 7.4 to 7.9%, with increasing the rapeseed oil addition from 0 to 4.5 to 9.0%, no sensorial difference was appreciated among treatments. More recently, Gondret *et al*. (1998b) did not find any relationship between lipid content of *Longissimus dorsi* muscle and juiciness, but observed a positive correlation with sensory tenderness.

The effect of the **dietary fat source**, animal *vs* vegetable origin, does not seem to significantly affect either the growth performance (Raimondi *et al.*, 1974; Maertens *et al*., 1998), or the main carcass traits (Fernandez and Fraga, 1996; Pla and Cervera, 1997) and the carcass and meat lipid content (Fernandez and Fraga, 1996; Pla and Cervera, 1997; Maertens *et al*., 1998). The same parameters were not affected not even by comparing different vegetable fat sources (coconut, palm and sunflower oil), with the exception of lipid content of *Longissimus lumborum* muscle, which was significantly lower with the coconut diet, if compared with the other two diets (Gondret *et al.*, 1998c).

Particular attention has to be drawn to the fact that the composition of the dietary fat, as the result of the use of various fat sources, can considerably modify the FA composition of the rabbit fat tissues (Raimondi *et al.*, 1975b; Ouhayoun *et al.*, 1987; Cobos *et al.*, 1993; Cavani *et al*., 1996). In fact, as in other monogastric animals, linoleic (C18:2 n-6) and linolenic (C18:3 n-3) FA are essential FA for rabbit, thus its HUFA result from the influence of exogenous lipids, mainly linoleic acid present in cereals and oil seed meal and linolenic acid present in alfalfa grass. In this way, rabbits are able to incorporate dietary FA directly into adipose and muscle tissue lipids, making it possible to modify the FA profile of rabbits by the strategic use of unsaturated dietary fat sources. However, the FA composition of rabbit lipids does not perfectly reflect that of the dietary source of fat and the FA profile of the dissectible fat seems to be more similar to that of the diet lipids, than that of the intramuscular fat (Cobos *et al*., 1993; Gondret *et al*., 1998c; Bernardini *et al.*, 1999a).

Since the concentration of PUFA in rabbit fat is much lower than in most vegetable oils, vegetable fat-enriched diets generally increase unsaturation of depot lipids (Oliver *et al.*, 1997; Gondret *et al.*, 1998c) and reduce their (n-6)/(n-3) ratio (Dal Bosco and Castellini, 1998). Thus, an enrichment of the diet with oils derived from soybean, sunflower or rapeseed, originates rabbit meat containing higher degree of unsaturation, consisting mainly in C18:2 (n-6) and C18:3 (n-3) (Cobos *et al.*, 1993; Kessler and Pallauf, 1994; Cavani *et al.*, 1996). Gondret *et al*. (1998c), comparing the effect of the dietary enrichment with sunflower, palm and coconut oils observed that the lipids of both meat and perirenal fat contained significantly more PUFA when rabbits were fed with sunflower oils, meanwhile with coconut oil the PUFA content was the lowest.

However, not always the dietary enrichment in vegetable oils increases the unsaturation index of intramuscular lipids. Lopez-Bote *et al.* (1997) observed that the addition of olive oil or sunflower oil did not significantly change this parameter and furthermore reduced the concentration of (n-3) FA in polar lipids, if compared with rabbits fed with none enriched diets.

More certainly, a basal diet enrichment with fat of animal origin generally increases saturation of body stored tryglycerides (Raimondi *et al.*, 1975b; Cobos *et al*, 1983).

According to the fat source added to the basal diet, the physical properties of dissectible fat change, too. The firmness of the fat tissue itself is determined mainly by variation in the FA composition, particularly the balance between saturated and unsaturated FA which have high and low melting points, respectively. An interesting study of Ouhayoun *et al.* (1987) evaluated the effect of one fat of animal origin (beef tallow) and six of vegetable origin (copra, cocoa, olive oil, soybean oil, linseed oil and rapeseed oil); from this study emerged that some of this fat enrichments resulted in inadequate physical characteristics of the perirenal fat, due to their influence on the melting point of FA: with copra the perirenal fat was too firm, with olive oil too liquid and with rapeseed oil too soft.

Fat addition could affect also some physical properties of rabbit meat. Raimondi *et al.* (1975a) observed an increase of ultimate pH and cooking losses in rabbit meat, when fed with supplemented fat (tallow and groundnut oil). Oliver *et al*. (1997) and Maertens *et al*. (1998) reported a similar trend for ultimate pH with the use of animal fat source, but no evidence was found as regards cooking losses (Maertens *et al*., 1998) or WHC of cooked meat (Pla and Cervera, 1997).

The meat redness tends to increase with vegetable fat source (Oliver *et al*., 1997; Maertens *et al*., 1998), meanwhile that of the perirenal fat tends to decrease both with vegetable and animal fat source, if compared with a control diet (Oliver *et al.*, 1997). Perirenal fat lightness was significantly lower when animals received diets with vegetable fat source, and this could affect the consumer’s acceptance when rabbit is sold whole, because of dissectible fat colour is perceived as an index of freshness.

In other species, the FA composition of body lipids can considerably influence the sensory properties of meat. The intramuscular fat has the greatest influence on the eating quality of lean meat (Murphy and Carlin, 1961). Among sensory attributes, the one mainly related to intramuscular lipids is flavour. Lipids contribute to the development of positive flavour but also to its deterioration, even if their contribution in the processes is not completely understood. According to recent results, it seems that the overall flavour of meat during cooking and eating arises from a subtle equilibrium between the desirable aroma compounds formed through Maillard reaction and the poor odour molecules coming from the oxidative breakdown of PUFA of phospholipids (Gandemer, 1998).

Also with the rabbit, the change of FA profile, modified by the dietary fat inclusion, may have great influence on flavour. Formerly, Raimondi *et al.* (1975a) found that the organoleptic properties of meat from rabbits fed with added groundnut oil were preferred to those of animals fed with added tallow. Successively, Ouhayoun *et al*. (1987) pointed out that the use of copra, soybean and linseed oils negatively influenced the meat flavour, resulting soapy, unpleasant and rancid, respectively. Moreover, the addition of tallow or olive oil did not modify the organoleptic quality, meanwhile rapeseed oil conferred unpleasant taste to the meat only if consumed after frozen storage. Only using cocoa butter the meat flavour was considered favourable. More recently, Oliver *et al.* (1997) observed that vegetable fat source, if compared with the animal one, resulted in a better flavoured meat (higher aniseed and grass flavour).

From these results emerged that the quantity and the quality of the dietary fat source used for the finishing of the rabbit carcass should be undertaken with great caution.

The FA profile of the rabbit lipids may have an incidence on meat technological characteristics (Bernardini *et al*., 1996; Dal Bosco *et al*., 1998). The long-chain PUFA are the main substrates for oxidation and lipid oxidation is one of the main causes of deterioration in the quality of meat during storage and processing (Gandemer, 1998). Phospholipids contain more long-chain PUFA than tryglycerides. Moreover, as phospholipids of oxidative muscles contain more long-chain PUFA than those of glycolytic ones, this is one of the reasons for the high tendency of these muscles to oxidise (Alasnier and Gandemer, 1998). Thus, when dietary oil treatments increase the polyunsaturation degree of the meat lipids and the proportion of (n-3) PUFA, they also tend to increase the susceptibility of muscle tissue towards oxidation, formation of peroxides and eventually rancidity, otherwise no difference on fat oxidation can be observed (Lopez-Bote *et al*., 1997; Castellini *et al.*, 1999). Fortunately, due to the fact that rabbit meat is poorer in iron if compared with other meats, which is a pro-oxidant of phospholipids PUFA, its lipid oxidation is less accentuated (Ouhayoun, 1992b).

The consumption of products derived from lipid oxidation may compromise human health. Prevention of lipid oxidation in muscle-based food can be achieved by the addition of natural antioxidants, such as α-tocopheryl acetate, by dietary supplement.

Numerous recent results confirm that feeding rabbits supra-nutritional levels of α-tocopheryl acetate, improves the oxidative stability of the *post-mortem* meat by increasing the amount of the lipid-soluble antioxidant incorporated into the meat (Castellini *et al.*, 1998; Corino *et al.*, 1999; Dalle Zotte *et al.*, 2000). However, Bernardini *et al*. (1996) suggested to increase the amount of α-tocopheryl acetate when diets are very rich in PUFA. In order to observe its complete protective action, thirty days are needed (Bernardini *et al.*, 1999b).

Compared to the influence on lipid oxidation, the effect of dietary α-tocopheryl acetate supplement on colour and WHC seems to be of minor practical importance. However, similarly to that reported on pigs (Asghar *et al.,* 1991; Monahan *et al.*, 1994), dietary α-tocopheryl acetate has further been found to stabilise the surface colour of both raw (Corino *et al.,* 1999) and cooked rabbit meat (Castellini *et al.*, 1998) and also that of raw rabbit hamburger, together with an improvement of its appearance, observed both on 1 day and on 7 days storage at +4°C (Dalle Zotte *et al*, 2000). The meat physicochemical characteristics (WHC, L*a*b* colour and oxidative stability) were better preserved during frozen storage for 30 days, when animals were fed 200 mg of α-tocopheryl acetate/kg diet (Dal Bosco and Castellini, 1998).

Also increasing levels of oat in rabbit diets, the oxidative stability of rabbit lipids could be significantly improved, indicating that oat could be an interesting and natural way of improving meat stability (Lopez-Bote *et al.*, 1998).

The choice of the right fat source has to be done by compromising the positive dietetic and nutritional function of the PUFA, mainly those of (n-3) series, and their high sensibility to oxidation, taking into account always the sensory parameters (Lopez-Bote *et al*., 1997; Castellini *et al.*, 1999). Thus, selection of appropriate dietary fat sources is fundamental in view of meat processing, storage and, finally, consumer acceptability.

<u>Chilling conditions</u>

The transition from muscle to meat – from life to death – is accompanied by quantitative changes in several metabolites (glycogen, lactic acid, ATP, phosphate) and physical properties (pH, ionic strength, contractility). The glycolytic process may widely vary among carcasses according to the treatment administered in the early *post-mortem* period and it is easily manipulated. Thus, the properties of meat that are of most interest to the consumer are strongly affected by carcass treatments in the first few hours *post-mortem*.

The type of chilling could moderately influence the meat WHC, the biochemical evolution of the muscle into meat, and the bacterial development, depending on how strongly it can influence the achievement of the pHu.

For higienic reasons, carcasses should be chilled rapidly. The faster the carcass chilling is (*e.g*. 2°C *vs* 12°C during the first 3 hours of chilling), the lower is the rate at which pHu is reached, resulting sometimes in higher WHC and yield of the carcasses (Ouhayoun *et al*., 1990; Hulot and Ouhayoun, 1999). However, the muscle contraction is increased, too (Ouhayoun *et al*., 1990). Fortunately, if the cooling process occurs at obove-zero air temperature, the intensity of this contraction is rarely high and then unable to affect the rabbit meat tenderness (Ouhayoun, 1992a; Haddad *et al*., 1994). On the contrary, if the carcass chilling is made at temperatures proximate to or under 0°C, the ATP depletion and the *rigor mortis* onset may be accelerated, because of an anomaly in energy metabolism of the glycolytic muscles at low temperature (Ito *et al.*, 1986).

Chilling duration has also to be taken into account. If rabbit carcasses are submitted to short chilling, muscular energy reserves are not completely depleted and the meat results exudative and with high pHu. This *status* lead to favour the development of microrganisms, compromising the hygienic quality and the shelf-life of the meat (Ouhayoun *et al*., 1989).

<u>Technological factors</u>

Combination of carcass processing treatments may have larger effects on meat “quality” than production factors including feeding systems.

The change in meat quality during the **<u>refrigerated storage</u>** are strongly affected by different factors: temperature, duration, breaks in the refrigeration chain, packaging, etc… (Hulot and Ouhayoun, 1999).

pH value represents a key role on the preservation of the meat *quality* during storage. In fact it determine environmental microbial balance. Low pHu has a bacteriostatic effect even on meats. Thus, meats with pHu values above 6 are generally considered unsuitable for storage, because of the favourable development of proteolytic microrganisms. During refrigerated storage (2°C to 4°C) which follows chilling, meat pH tends to rise because of the increase of ammoniacal nitrogen levels (Costantini and Bosi, 1968; Sunki *et al*., 1978). Exceptionally, pH continue to fall during refrigerated storage if the previous chilling has been too short and not allowed to exhaust the muscular energy reserves (Ouhayoun *et al.*, 1989). However, pH variation can also show a quadratic trend (5.81 to 5.91 up to 8 days, 5.88 at the 12th day) during 12 days storage at 2°C (Cabanes-Roiron *et al.*, 1994), explained by two contemporary mechanisms: a rise in the level of ammoniacal nitrogen, which alkalinises the meat, and the formation of free FA, which tends to acidify it.

A break in the refrigeration chain, even if it is of short duration (*e.g.* 30 minutes at 20°C), entails a rise in meat pH and enhance bacterial proliferation making the meat unfit for human consumption (Hulot and Ouhayoun, 1999).

Lipolysis in refrigerated fresh rabbit meat was studied only recently (Alasnier *et al.*, 2000). The authors evaluated lipolysis in muscles as related to the metabolic type of the fibres during 7-days-storage at 4°C. The results showed that the free FA (FFA) sharply incresed during the refrigerated storage, especially that of long chain PUFA. The metabolic type chearly affected the FFA amount of muscles and oxidative muscles contained more FFA than glycolytic ones.

Contrary to what occurred with other species, studies on packaging methods are not yet so developed. Vacuum packaging reduces lipid oxidation in rabbit meat and thus may extend its shelf-life at chill temperatures (Fernàndez-Esplà and O'Neill, 1993). However vacuum packaging darkens the meat and so it can only be carried out when retention of red colour is not important. In fact, as the consumer associates freshness and quality with a good colour of the lean meat, the latest must be apparent in packs. The need for oxygen in the pack to prolong colour retention, and of carbon dioxide to inhibit bacterial growth, has led to controlled atmosphere packaging with other kinds of meats. Whith rabbit meat, Gariepy *et al*. (1986) compared the packaging under vacuum with that at controlled atmosphere (nitrogen and carbon dioxide). After 50 days of storage the packaging at controlled atmosphere produced lower pH and bacterial growth, but WHC was reduced, the meat resulted brighter and more tough.

The **frozen storage** further extended the meat preservability. Deep-freeze (core temperature of -18°C within 2.30 h) better preserves the tissues integrity if compared with ordinary freezing methods (-12°C attained later) and then WHC results higher.

If compared with fresh meat, the frozen one has lower WHC and its colour appears less pleasant, whatever the lenght of storage (Senesi *et al.*, 1975; Cabanes *et al*., 1996). However, as the reduction in WHC is more a result of tissue lesion caused by the process of freezing and thawing than by variations in pH during storage, it could be possible to limit the extent of this phenomenon by slow the meat thawing (4°C). Nevertheless, thawing losses are fairly moderate and neither cooking losses nor meat tenderness were influenced by the frozen process (Cabanes *et al.*, 1996; Dalle Zotte *et al*., 1998).

Frozen storage does not stop the enzymatic (mainly hydrolytic) reactions entirely and so the maturation process is continuing. During freezing, pH has been shown to remain stable up to 3 months, followed by a progressive rise up to 15 months (Dalle Zotte *et al*., 1998) or to 18 months (Cabanes *et al.*, 1996). Frozen storage also worsens some chemical parameters, indicators of meat biochemical evolution. Thus, the Total Volatile Nitrogen (TVN), indicator of protein deamination, and the TBA test value, indicator of lipolysis, are higher on frozen than on fresh meats (Cabanes *et al.*, 1996).

The frozen storage length slightly (Cabanes *et al.*, 1996) or more intensively (Dalle Zotte *et al.*, 1998) increases the thawing losses, of the carcass or of its retails, respectively. Long frozen storage significantly worsens the TVN, which increases up to 15 months of storage

(Dalle Zotte *et al*., 1998), then stabilise up to 18 months (Cabanes *et al.*, 1996) and the TBA test value, which increases up to 9 months, then vary erratically up to 18 months (Cabanes *et al.*, 1996).

Sensory tests evidenced that the fresh meat is preferred to that derived from frozen storage, if evaluated raw, but none differences were found if cooked. Otherwise, the effect of frozen length on sensory appreciations was observed to be more weak than the frozen process *sensu stricto* (Cabanes *et al.*, 1996).

The studies performed until now assert that the physicochemical variations which occur during the frozen meat storage unaffect the sensory traits of cooked meat, almost up to 12 months. Afterwards, lipid and protein stability become compromised with the direct effect on sensory attributes.

CONCLUSIONS

The meat quality concept is continuosly changing and, nowadays, the consumer is very sensible to the healthiness of meat, hedonistic quality, sensory properties, cooking easiness and swiftness, and price.

During the last two decades, rabbit meat researchers focused their interests on how to increase live performance and carcass yield and rather a lot human resources were used to widely study the effect of the various biological and zootecnical factors on carcass and meat quality. On the contrary, the effect of technological factors were studied less intensively.

Among the various variability factors considered, selection programmes, slaughter age and weight, dietary fat inclusion and source, *ante* and *post mortem* factors were found to be of high effect on rabbit carcass and meat quality. However, the effect of these factors on hedonistic and sensory properties were scarcely investigated. Thus, attested that among the consumer’s concern, these two properties are of great importance, research on this topic should be pursuived.

<u>Future perspectives on rabbit meat quality research</u>

In this review an attempt has been made to identify future priorities for rabbit meat research and development. Considered that during the last 20 years a negative development in consumer perception was observed for all meats, even if to a different extent, the strategies to promote rabbit meat consumption could be summarised as follows:

1. to examine the procedure, *i.e.* to identify methods of production at point of sale, to provide greater consumer assurance about practices and controls.
2. maintain the rabbit meat production of a high quality.
3. continue to produce standard rabbits sold as whole carcass in order to satisfy the requirements of the traditional consumer.
4. produce portioned rabbit meats, ready to cook and ready to eat, with the multiple aim to make the meal preparation easier and then reduce the cooking time, to increase its preservability and to stimulate the choice and the purchase by the neo-consumers.
5. to establish strong information and educational programmes about rabbit meat as nutritious, tasty and premium food, at scholarship, medical and refreshment levels.

Finally, meat scientists must contribute by making available objective information about meat production, particularly on issues of safety, wholesomeness and welfare.

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