# Feeding Strategies to Produce High Quality Pork* - Review -

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**ABSTRACT** : The cost of production of high quality pork is compensated by high returns, but constraints by the market are increasing. A few opportunities to maintain and improve pork quality by dietary means are presented. The healthy value of pork is a prerequisite. A careful control of suppliers and preservation of feeds are essential to protect pork against presence of contaminants from the feed. The feeding level and some dietary components modify the partition of the dietary energy into different pig tissues and chemical components of pork, affecting the hygienic and nutritional value, tenderness and taste. It is difficult to transfer a nutrient from the diet to pork, if the requirements for growth are satisfied. Fatty acids and Vitamin E are the most studied exceptions. There is some evidence that iron and selenium contents can be affected too. Varying the content of a nutrient frequently changes sensorial and technological properties of pork. The addition of oils improves the acidic profile of depot fats, but the effect on phospholipid composition is not well studied and negative effects on oxidability and consistency of meat products are observed. Vitamin E can improve many healthy and sensorial characteristics, but its effect is clearer when the meat is stressed or manipulated. *(Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 2 : 271-281)*

**Key Words** : High Quality Pork, Dietary Means, Feeding Level, Dietary Components, Nutrient

## INTRODUCTION

With the introduction of systems of more and more intensive breeding, the pig production could have stayed competitive and reduce the price of pork for the consumer. A second strategy has been to produce high quality pork for some specialized markets. In this cases the specialty of the products has guaranteed better revenue for the carcasses. Generally this production has been obtained by maintaining a traditional extensive system, as in Spain for the Iberico ham, or in connection with an increasing intensivation of the production. In the last case, to obtain high quality products, the pigs are frequently slaughtered at high or very high weights, as it is in Italy for the Parma ham and San Daniele ham or in France and Germany. Other areas of specialized products, obtained from whole cuts or from minced meat and/or other ingredients, are present all over the world. However this second strategy could not still be sufficient to guarantee enough returns to compensate the increasing costs of specialty and the coming out of new requirements from the markets.

In many countries the consumer concern about the way of pig production, the healthy value of pork and the environmental effects of its production is sensibly increased. Thus, the consumer, being the final utilizer, determines the qualitative requisites of pork with his demands. According to this, the concept of a high healthy and psycho-sociological value of pork can be included within the strategy for high quality productions.

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Furthermore the requirements of retailers, transformers and big supermarket chains are more economically restrictive, demanding products that satisfy particular standard condition, even for products for a niche market. This includes the dimension of the portions and their suitability for a long displaying period. Then, before the consumer and the detailers, all the operators of the chain of transformation from the live animal into products of meat have of their own demands that contribute to the general evaluation of the subjects from slaughterhouse. It is resulting therefore that the concept of quality of the meats, also maintaining the healthy as common denominator, could vary greatly according to the eating habits and the type of final product. The managerial capacity of the producer or the production organization will lead in the choice of the most correct goal and production tools. The feeding, together with the genetic improvement and the management, is fundamental to adapt pig production to the market. However, whereas the nutrient requirements that can allow to maximize most classical productive characters of economical relevance are quite stabilized, the relative importance of each nutritive factor and feeding technical for any qualitative parameter of pork has not yet definitively established.

## MAIN TEXT

Table 1 resumes the qualitative characteristics of the pig meats. The further presentation concerning feeding effects on pork quality will refer to this ideal partition of parameters.

## EFFECTS ON HYGIENIC AND SANITARY CHARACTERISTICS

The most important healthy qualities relate to factors

**Table 1.** Qualitative characteristics of pork (Russo, 1989, modified)

| Healthy | Nutritional | Sensorial | Technological | Psycho-sociological |
|---|---|---|---|---|
| | | *Detectable at purchasing* | | |
| - pathogen and total microbes<br>- residual of pesticides additives pharmaceuticals hormones heavy metals mycotoxins radionuclides<br>- poly-/mono-/saturated f.a.<br>- cholesterol | - proteins<br>- vitamins<br>- minerals<br>- essential fatty acids<br>- energy value | - color<br>- juice loss from cut surfaces<br>- texture<br>- marbling<br>*Detectable at meal*<br>- tenderness<br>- juiciness<br>- flavor<br>- fragrance<br>- off-flavor | - pH<br>- resistance to oxidability<br>- water holding capacity<br>- salt absorbing capacity<br>- cooking losses<br>- fat iodine number<br>- fat melting point | -symbol value<br>- animal welfare<br>- ecological production |

not strictly endogenous (pathogens living organisms, residuals) and have to be considered as a pre-requisite factor for a high quality product.

The feed can be a vector of many spores and fecal bacteria (concentrates badly treated). The spores are frequently high in whole corn silage's, frequently used in Italy for pig feeding; anyway, with the modern practical of slaughtering it is not probable a contamination of the meat.

The presence of toxins and their metabolites, residuals from pesticides, heavy metals, radionuclides in meat partly depends on: overall pollution, modern way of producing with the use and abuse of drugs, preservation methods. As concerns the three former causes, the only one feeding strategy of the farmer is a careful choice of dietary raw materials, water included, for what is within his chance. The receipt of certificates of analysis for the new materials either prior or at the time of purchase should become a standard practice in the feed manufacturing industry. The agreement with raw materials providers and the adoption of a quality system can help. For pesticides a passport system involving documentation accompanying the cereal which lists what, if any, pesticides have been used to treat the grain (Vernon and Ross, 1994). The preservation methods of feeds produced within the farm and or purchased, are important to reduce the risk of mycotoxins. For antibiotics the risk of consumer health is minimized by the specified withdrawal period. Furthermore the lists of permitted molecules were compiled using older rules and a revision is in progress in the EC. Some antibiotics are only permitted at relatively low levels in diets.

The healthy value of pig meat and pig products can be affected by changing its fat composition. According to UK recommendation the human diet has to contain about 35% of dietary energy from fat and 10% of energy from saturated fatty acids (Department of Health, 1994). In many high quality products from swine, backfat is an important component (like salami, embutidos and saucissons). The possibility of manipulating the fatty acid composition of backfat by dietary means is well established for the light pig (Madsen et al., 1992; Morgan et al., 1992). Also for the pigs reared up to heavy slaughter weight (150 - 160 kg and more) research data are available demonstrating that backfat composition can be modified (Mordenti et al., 1994, Bosi et al., 1996). However effects on firmness and oxidability of fats can reduce the practical utility of this manipulation. Furthermore the choice of partially hydrogenated dietary sources of fat, to reduce fat softness, has been shown to increase the content of *trans* fatty acid C18:1 in backfat from heavy pigs, from negligible values to 2.5% (Della Casa et al., 1996). This is with some concern for the consumer, even if a final demonstration of a direct correlation between *trans* fatty acid and health problems is still lacking (Entressangles, 1995).

Concerning the fats inside the lean cuts, compared to standard diets or diets with tallow, the use of sources rich in oleic acid (high oleate sunflower oil, canola oil, acorns) increases the percentage of this acid in intramuscular fat of pork from light pigs (Rhee et al., 1988; Miller et al., 1990; Klingenberg et al., 1995) and in its triglyceride fraction from heavy pigs (Bosi et al., 1996; Cava et al., 1997). The increase of monounsaturated fatty acids is usually accompanied by a decrease of saturated fatty acids and an increase of polyunsaturated (Bosi et al., 1996; Cava et al., 1997). The reduction of saturated fatty acids is usually less pronounced than in the backfat (Warnants et al., 1996) and was explained by Wood (1984) by the slower growth of intramuscular fat than backfat.

In the polar fraction the increase of monounsaturated fatty acids stimulated by the diet is often counter-balanced by a reduction of linoleic and other polyunsaturated ones (18 :3 ; 22 :5 ; 22 :6) (Bosi et al., 1996; Cava et al., 1997). The decrease of 18 :2 could be explained considering that the lipid fraction has an important role for cellular membrane integrity, so this trend can be to maintain the standard degree of desaturation. This hypothesis can be accepted for the data from Bosi et al. (1996), where arachidonic acid was found constant, but not for Cava et al. (1997). The same difference between polar and neutral fraction was observed in broiler meat, when oil addition was compared with coconut addition (Lin et al., 1989).

The effect of addition of n-3 and n-6 fatty acids on intramuscular fat is reviewed by Warnants et al. (1996). Again it is observed that intramuscular fat is less affected than backfat. In the polar fraction, the most represented fatty acid in the dietary fat (linoleic, linolenic, arachidonic acid or others) is the most increased usually (Warnants et al., 1996).

In some cases the levels of longer fatty acids of the same series are increased too, with an overall increase of unsaturated acids (Ahn et al., 1996) or a decrease of other important fatty acids (c22:5; c:22:6 with high linoleate in the diet, Enser et al., 1990).

## EFFECTS ON NUTRITIONAL CHARACTERISTICS

The nutrients that pigs draw from their feed limit more or less their growth and their productivity. So the possible deficiency, also when not revealed by clinical symptoms, reduce the growth and the production of muscular masses. But, for most of these nutrients, the concentration in the muscle, and in the meat, is scarcely influenced.

The most relevant exception concerns the qualitative characteristics connected somehow to the feeding level of the pig and its use of the energy. Therefore, if any dietary factor influences the quantity of available energy for the deposition of fat, the characteristics of the meat will be influenced too. Particularly the caloric value, the relationship between proteins and fat, the characteristics of acidic composition of fat and its technological performance are affected. In the case of reduced energetic availability, the swine in fact directs more energy to maintain protein deposition, uses saturated and monounsaturated fatty acids sources for energetic purposes and deposits the more unsaturated ones, contributing to make the fats softer (Woods, 1984).

Other exceptions are those nutrients being normally stored in the muscular fibre. It is well demonstrated the possibility of increase the content of vitamin E in pork with dietary doses higher than those that maximise the growth, the deposition being higher in muscle with a greater membranal tissue, as *psoas maior*, than in *longissimus dorsi* (Jensen et al., 1997). In the heavy pig for high quality products the $\alpha$-tocopherol content of loin muscle was increased from control values of 1.4 mg/kg to values of 4.6 mg/kg with the addition of 200 mg/kg Vitamin E and high oleate sunflower oil from 35 to 160 kg (Zanardi et al., 1997) or from 5.4 mg/kg to 8.4 mg/kg with a 300 mg addition in the last 60 fattening days (Pastorelli et al, 1995). In such a way the nutritive and hygienic value of meat can be improved as this vitamin is protective for many pathologies of man.

Scant demonstration of the chance of increase the contents of other vitamins in the muscle is available. Values of Vitamin $B_1$ in muscles from pigs receiving higher doses of this vitamin in the diet were higher than the ones observed for lower doses (Aitken and Duncan, 1960).

Pork is also an important source of minerals and supplies, between the others, higher quantity of selenium and chromium than other meats (Turns et al., 1988; Oster et al., 1994). Unfortunately, it is in general shown that the swine, beyond the quota needed for maintenance and growth, does not absorb more and increases the excretion of minerals. When, beyond a certain dose in the diet, an accumulation in the organism is verified, the liver is usually the place of deposit. When liver is used for special products, the level of minerals in such preparation can exceed the toxicity level. Iron is frequently present in Italian feed compounds at very high levels. Two observations of an increase of iron in the muscle with doses about 5-10 times the requirement exist (Miller et al., 1994; Bosi et al., unpublished). But unfavorable effects on meat oxidability have been observed in those cases. An increase of selenium in *longissimus dorsi* muscle (+23%, Groce et al., 1971) or in the carcass (+50%, Nielsen and Rasmussen, 1979) was observed with dietary doses of selenium about 3 fold higher than the requirements. For chromium, with a 300 $\mu$g/kg addition in the diet as chromium picolinate, increased levels of this metal were observed in kidney and liver, but not in the muscle (Anderson et al., 1997). On the whole the research data are scarce on this topic and usually not oriented toward the assessment of the effects on the quality of the meats. In practical terms the possibility of increase the content of micronutrients that can be deficient in human diets needs more demonstrations.

Copper is frequently considered for its supposed effect on the quality of pig carcasses, mainly for its effect on the lipidic fraction. In the Sixties the growth promoting effect of this metal has been frequently demonstrated with elevated doses in the diet (200/250 mg/kg) and then a negative effet on the consistence of lard was observed, due to the greater unsaturation of fat. Now the European Union, to protect the environment, restricts for growing-fattening pigs the copper dietary levels to 35 - 100 mg/kg, according to live weights and to pig density in each Country. However, in other Countries copper is not restricted and also in the UE, if economically convenient, other copper sources with biological activity higher than the copper sulfate could be used, fitting the doses within permitted limits.

Figure 1 presents the variation observed for the acidic composition of backfat from light and heavy pigs according to the dietary doses of copper from mineral origin. The entity of the effect is not constant and the fatty acids interested by the variations are not always the same. The numerical data concerning the most large study (Castell et al., 1975; about 600 swines), the one from Myer et al. (1992) with different levels of canola oil addition, and the one from Bosi et al. (1996), with measures repeated at different weights on the same subjects (85, 135 and 160 kg), show that the differences are in the range of one point. The tendency is always toward the decrease of degree of saturation. For the practical situation the differences observed are smaller than those which can be predicted when current adjustments in cereal inclusions are done in a formula.

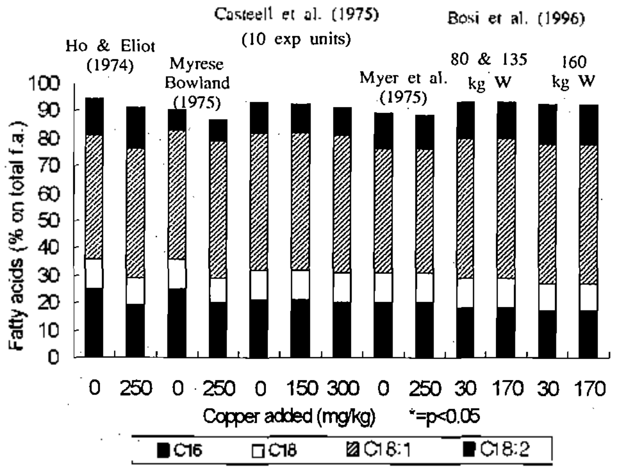


**Figure 1**. Effect of copper dietary addition on backfat composition of light and heavy pigs

Concerning the lipids of muscle, the contents of oleic and arachidonic acid were slightly increased in the phospholipid fraction from *Longissimus dorsi* m. of pigs fed high copper dietary doses, but not for both live weight considered (135 and 160 kg) (Bosi et al., 1996). No effect of copper was detected for the neutral fraction.

## EFFECTS ON ORGANOLEPTIC AND TECHNOLOGICAL CHARACTERISTICS

Most of technological and organoleptic characteristics depends more or less strictly on how the cellular membranes and the muscular myofibrils lose integrity or functionality after the death and during the maturation.

The breakup of the integrity of the myofibrils affects meat tenderness mainly. The possibility of an effect of the diet on pork tenderness seems to be function of the feeding level, allowing to modify the age and the maturity of the subjects for slaughter. High feeding planes or regimen are frequently connected with lipid concentration in meat and with tenderness, and juiciness. Warkup and Kempster (1991) in a large set from Meat and Livestock Commission (UK) observed that the combination of both high growth and high lipid content in meat was beneficial for eating quality. When only one trait was present, the quality was lower. The independent effect of high growth could result from reduced collagen maturity in muscle and increased post-mortem proteolysis. However Ellis et al. (1996), observing a direct effect of feeding level on tenderness of meat and other taste panel variables, did not find a significant independent effect of fatness or live-weight gain as covariates. In cattle, high-energy diets can improve tenderness (Aberle et al., 1981) and increase the percentage of soluble collagen (Miller et al., 1983). Dietary factors that reduce protein growth would be expected to be associated with a reduced proteolytic activity, as it is for the activity of lysosomal proteases during protein deficiency (Tawa and Goldberg, 1994). The reduced activity of these enzymes can impair the process of meat tenderization (Etherington, 1984), whereas a poor meat texture of cured raw hams has been correlated with abnormal levels of cathepsin B enzymatic activity in freshly slaughtered thigh meat (Schivazappa et al., 1992). However, Goerl et al. (1995) observed in pigs that increasing dietary protein contents from 10% to 22%, the shear values of loin muscle increased of 23%, with the fat contents reduced to one third. Conversely, Wood et al. (1996) found a tendency, although not significant, for the meat to be tender at a feeding level permitting a 14% increase of growth, compared to the control. On the whole, whereas the prevailing theory is in favor of a positive effect of growth on tenderness, it is difficult to separate in practical the specific effects of age, growth, and dietary factors. Our understanding on the impact of dietary growth factors on eating quality need to be improved.

The loss of functionality of the cellular membranes has an effect on other organoleptic traits and on liquid losses, strongly influenced by the phenomenon's of oxidation that develop in the meat, catalysed by myoglobin, haemoglobin, cytocromes and non-haeme iron (Morrissey et al., 1994). The processes of oxidation raise initially from the phospholipid fraction present in the subcellular membranes, which have a high degree of insaturation of the lipids. Then the oxidation involves the myoglobin, with the formation of metamyoglobin and loss of color, and the browning of the meats; at the same time the cellular membranes lose their own integrity with the increased endocellular juice release. Besides, the possible accumulation of products of oxidation contributes to the formation of the typical off-flavors.

This phenomenon can be reduced with the addition of additives. The food industry olds some metal chelating agents, nitrates and antioxidants. But to control directly in the carcass the oxidative risk, only those antioxidants that are deposited in tissues or that act in the live muscle, can be taken in consideration. In this list vitamins E, C, carotenes and carnosine are included.

### Vitamin E

The generic term of vitamin E refers to four tocopherols and four tocotrienols, $\alpha$-tocopherol being the most biologically active. The first hypothesis of the antioxidant function of the Vitamin E was from the observation of Olcott in the years 30, that the autoxidation of lard was prevented by an oil from the lettuce and that this effect was due to the presence of vitamin E in it (Burton, 1994). Currently vitamin E is the natural antioxidant more considered for the protection of the membranes from oxidative damages. The particular localization of the vitamin in biological membranes, close to polyunsaturated fatty acids, explains its protection of meats when supplied in the diet of slaughtering subjects.

The effectiveness of vitamin E for different qualitative parameters of pork, as preservability, taste and aroma, drip loss, color, is function of the degree of preservation and processing.

*i) Effects on qualitative parameters measurable at slaughterhouse and on fresh pork*

The quick parameters at slaughterhouse (pH, color) in general are moderately influenced by dietary vitamin E additions and the quality of the meats for the fresh consumption is not always improved. Cannon et al. (1996) considered different chilling times of the cuts (up to 56 days) and different exposition times. As overall means, muscle pHs, microbial counts and organoleptic characteristics were not affected by vitamin E levels (control and 100 mg/kg addition), except for the global acceptability and the state of oxidation, evaluated on the base of malonildialdehyde contents (TBARS) (table 2).

slaughtering. In the two first cases an improvement of drip losses and TBARS with vitamin supplementation was observed, at least as a tendency, whereas in the third no effect was observed. In the heavy Iberico pig, a 100 mg/kg vitamin E supplementation reduced TBARS values of meat chilled for 3, 6 or 9 days, and iron-induced oxidation of loin muscle homogenates and of its microsomial fraction (C. Lopez-Bote, EU project Dietox, personal communication).

*ii) Effects on cooked meat*

In the heavy pig diet, 200 mg/kg vitamin E were not sufficient to reduce fatty acids oxidative stability, cholesterol oxides and aldehydes content of cooked pork chops (Zanardi et al., 1997).

*iii) Effects on the quality of the frozen meat and products*

The effectiveness of vitamin E supplementation is particularly expressed when the meats have been subjected to long periods of freezing. In this case drip losses and red color losses are reduced (figure 2). The oxidative stability is improved particularly when, after the thawing, the meats are preserved as slices or as ground (figure 3).

**Table 2**. Effects of Vitamin E (100 mg/kg feed) on some quality traits of fresh loin chops, as overall means of different chilling times at 2°C of 10 cm sections (0, 14, 28, 24, 56 days) and displaying time of slices (1, 3, 5 days) (Cannon et al., 1996)

| | | |
|---|---|---|
| Positive effect | | |
| Lipid oxidation (TBARS) | - Panel test (*) : Overall palatability | |
| No effect | | |
| - pH | - color uniformity | Panel test (*): |
| - color L, a, b | - percentage discoloration | - juiciness |
| - total bacteria counts | | - tenderness |
| - drip loss * | - color of lean | - pork-flavor intensity |
| - cooking loss * | - overall appearance | - off-flavor intensity |

* = only at the 1[st] day of exposure.

Some data are coming available also for the pigs reared up to very heavy weight for typical productions. In table 3 the effects of high supplementations of integration of vitamin E in the diet, on fresh meat quality of heavy Italian pigs are summarized. In general no effects are observed for measures within 24 h after

**Table 3**. Effects of dietary Vitamin E addition on quality of fresh meat from heavy Italian pigs

| | Lo Fiego et al. (1995) | | | Pastorelli et al. (1995) | | | Bosi et al. (1996) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vitamin E addition (mg/kg) | | | | | | | | |
| | 0 | 200 (65 d) | 200 (95 d) | 0 | 75 | 275 | 0 | 100 | 200 |
| N. subjects | 15[a] | 15[a] | 15[a] | 9 | 9 | 9 | 24 | 24 | 24 |
| **Overall means of LD, SM and BF** | | | | | | | | | |
| - $pH_{45}$ | - | - | - | - | - | - | 6.34 | 6.36 | 6.29 |
| - $pH_{24h}$ | 5.69 | 5.71 | 5.66 | 5.54[b] | 5.51[b] | 5.47[b] | 5.56 | 5.53 | 5.63 |
| - Color *L* | 52.5 | 49.9 | 51.2 | 49.3[b] | 50.8[b] | 52.3[b] | 46.2 | 45.8 | 45.9 |
| *a* | - | - | - | 14.0[b] | 11.50[b] | 14.2[b] | 8.7 | 9.2 | 9.5 |
| *b* | - | - | - | 8.1[b] | 7.2[b] | 9.1[b] | 4.6 | 4.7 | 4.6 |
| ***Long.dorsi* m.** | | | | | | | | | |
| -drip losses (%) (days 1-6) | 4.99 | 3.98 | 3.89 | 7.3[c] | 6.5[c] | 5.9[c] | 5.1 | 5.7 | 5.1 |
| - TBARS, 6[th] day (moles MDA/kg tissue) | 87 | 76 | 75 | 235 [d] | 220 [d] | 175 [d] | 110 | 106 | 112 |

- LD = *Longissimus dorsi* m.; SM = *Semimembranosus* m.; BF = *Biceps femori* m.
- a : N=10 for drip losses and TBARS.
- b : only on *Biceps femoris*.
- c : measured from 0 to 7 days, not group "0" but group "+25 mg Vit. E".
- d : average of days 6[th] and 8[th].

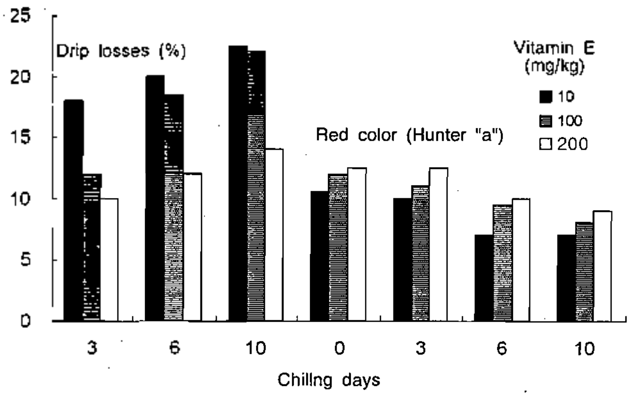


**Figure 2.** Effect of dietary vitamin E on drip losses and red color (Hunter "a") of pork chops freezed and then chilled at 4℃ under fluorescent light (Ashgar et al., 1991)

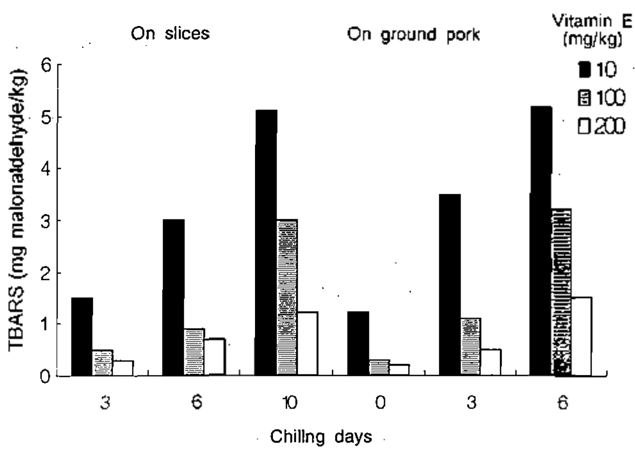


**Figure 3.** Effect of dietary Vitamin E on oxidative stability of pork chops freezed and then chilled at 4℃ under fluorescent light (Ashgar et al., 1991)

The preparation of precooked pig products can be an additional cause of lipid oxidation, off-flavor production and formation of dangerous products as cholesterol oxides. In some cases it is not during the cooking that the products of oxidation increase, but when the cooling phase is longer (Mills and Fishell, 1995). In this case, for pork crumbles the utility of a 200 mg/kg Vitamin E dietary addition to control lipid oxidation has been demonstrated by Mills and Fishell (1995), the most convenient addition starting from 4 weeks before slaughtering. In the production of precooked chops and roasts, the addition of 100 mg/kg in the pig diet could reduce the TBARS values during the period of 56 days of storage at 2° C under vacuum (Cannon et al., 1995). However the sensory properties and total plate count of chops stored from 7 to 56 d were not improved, whereas tenderness, off-flavor score and total plate count of roasts were favorably affected.

As concerns some typical fresh minced and dry-cured products, some data will be available when all the results of a EC projects called DIETOX will be published. For the dry-cured Parma ham, the dietary addition of vitamin E could maintain a more intensive red color of the lean and reduce slightly the TBARS, without affecting the overall yield during the aging (Bosi et al., not published).

**Other factors that can modify the response to Vitamin E addition**

According to Duthie et al. (1989) the pigs genetically stress-sensitive, compared to not sensitive, can be considered as subjects lacking for vitamin E, as emphasized by the higher release of enzymes from the muscle to the plasma and from the greater concentrations of TBARS and conjugated dienes in the plasma. This could explain the reduction of indicators of the oxidative status like TBARS in meats of stress-sensitive subjects fed with 200mg/ kg of vitamin E, opposed to the meat from subjects not sensitive (figure 4a). Today it is possible to recognize the eterozygote subjects for the sensibility to the halothane (CRC gene) and verify the differences between these and the dominant homozygote subjects, not sensitive. Elevated doses of vitamin E in the diet (500 mg/kg), compared to the negative control, decreased drip losses in the more sensitive *Longissimus dorsi* m. in both genotypes (Cheah et al., 1994). Instead in the masseter, a red muscle, Vitamin E addition did not produce an effect on drip losses, that were reduced for both genotypes, compared to the former muscle (figure 4b).

Between the dietary factors undoubtedly the quality and the quantity of fat in the diet of the swine could modify the oxidative risk of pork. Monahan et al. (1992) observed that the addition of 200 mg/kg in feed compounds containing or tallow or soybean oil reduced the iron-induced oxidation of meat. However the reduction was higher for the meats containing more linoleic acid in the cellular membranes, originating from subjects fed soybean oil, that is more oxidable.

Also the degree of preservation of the fats used in the diet could modify the effect of dietary Vitamin E additions. In the case of meats obtained from subjects fed fresh or oxidized corn, elevated doses of vitamin could reduce the loss of red color after some days of chilling only in the case of diet with fresh oil. The protection against the loss of color was instead more effective and wide for both diets when the meats were also freezed for 4 months(Monahan et al., 1994) (figure 5a). Another factor to consider is the exposure of the meats (figure 5b). In fact, after 5 days of normal refrigeration, with an ulterior chilling of 8 days, pork preserved in the dark presents a reduced loss of the red color and no effect of the supplementation with vitamin is observed (Lanari et al., 1995). Instead, the stability of red color is improved by the addition of elevated doses of vitamin to the diet when the meats are preserved in illuminated environment, independently of the type of packaging (aerobic envelope or in modified atmosphere). For heavy pigs supplemented with Vitamin E, Zanardi et al. (1997) observed a higher stability of the color of meat packed under modified atmosphere, but not for meat in oxygen permeable film.

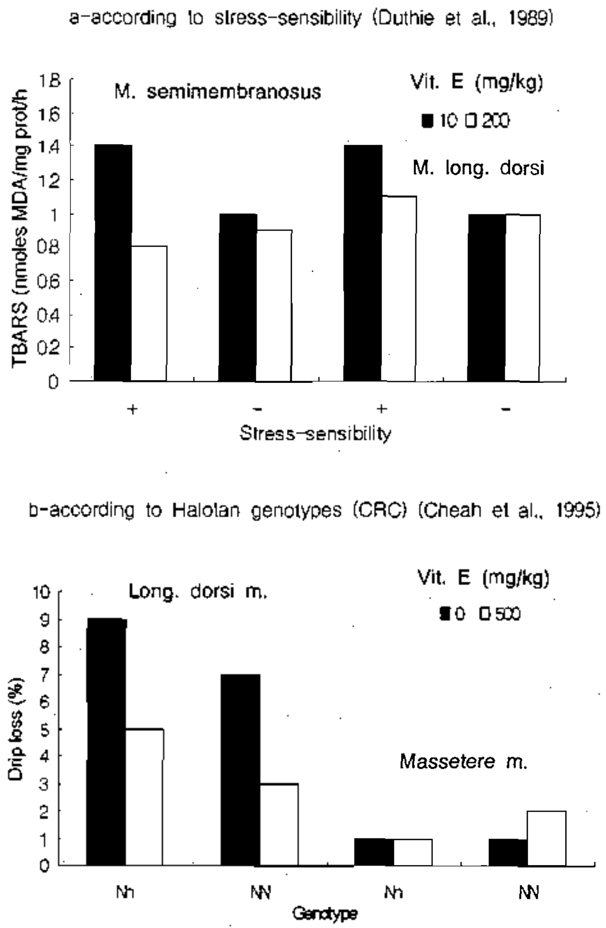


**Figure 4**. Vitamin E in the diet and pig strain

## Other antioxidants

The hypothesis of use of other antioxidants is restricted only to the additives that can be effective at muscular level, when supplied in the diet directly or in a precursor form. Till now, only the effects of the addition of C vitamin and carnosine have been tested.

It is well known that vitamin C can reduce the stress of the animals and for these reasons it has been proposed to reduce the stress of chicken at the slaughterhouse. In crossed pigs Large White×Pietrain, a reduction of the level of haematic cortisol was observed with high doses of vitamin C in the diet (Mourot et al., 1992). In the same genotypes, with the addition of 250 mg/kg of vitamin the authors have observed an improvement of pH values at 45 minutes up to values not indicative of PSE.

After the genotype effect, they observed a positive reduction of the acidification of meat at 24 hours and of the index of brightness and a better yield of pork cooked ham measured with the "Napole" method (figure 6). For a positive result, it would sufficient the supplementation during the last month before slaughtering.

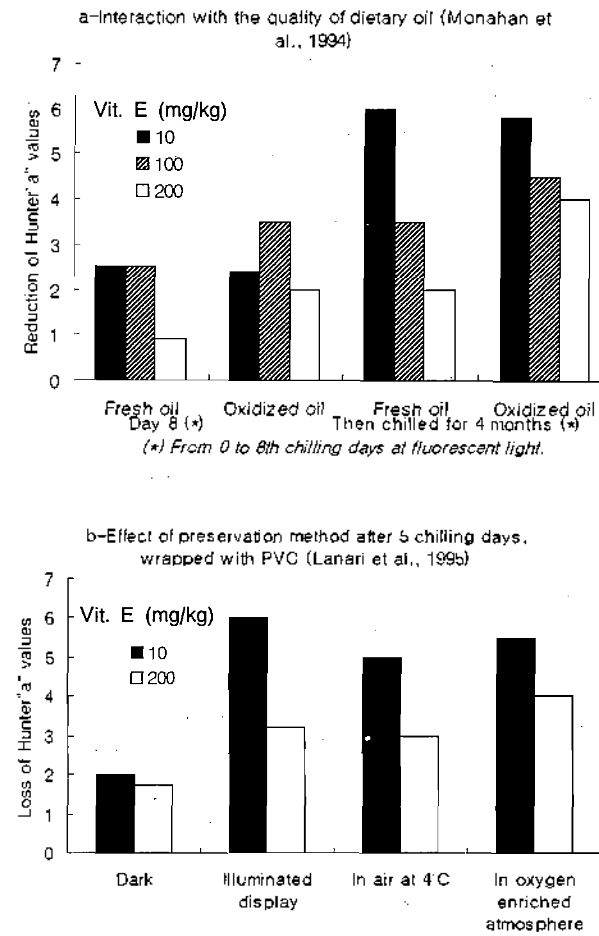


**Figure 5**. Effect of vitamin E dietary supplementation on red color loss of pork chops chilled at 4℃ for 8 days

Other positive outcomes with vitamin C addition were improved pH and color of fresh meat (Sevkovic et al., 1976; Rajic et al., 1976), the best results being obtained with 75 mg/kg for the fattening period. Furthermore ascorbate has the capacity of sustaining antioxidant activity of vitamin E, by recycling the $\alpha$-tocopherol radical in membranes (Bisby and Parker, 1995). The positive observed results are not related to the antioxidants properties of ascorbate, as the vitamin C in the meats does not seem to be influenceable (Biting, 1996; Mordenti and Marchetti, 1996). Furthermore its low preservability in feed compounds is well known.

Recently the antioxidant properties of some natural carotenoids in the presence of tocopherols have been demonstrated in vitro, according to the ability to scavenge various reactive oxygen species like peroxyl radicals (Thurnham, 1994; Haila et al., 1996; Mortensen and Skybsted, 1997). The carotenoids are transported with the blood and could develop their function in the circle and be deposited in the tissues, mainly in the fat fraction. But the addition of such pigments in the diet of livestock (mainly $\beta$-carotene) has been tested for its effect on hens, sows and dairy cows production and reproduction, not for its efficacy on the products quality. In broilers, according to IRTA (E) research (Garcia, personal communication), the addition of $\beta$-carotene in diets containing Vitamin E was pro-oxidant at 50 mg/kg and antioxidant at 15 mg/kg. In model systems, compared to $\beta$-carotene, other pigments, as lutein, lycopene and criptoxantine, showed a stronger antioxidant efficacy (Thurnham, 1994; Mortensen and Skybsted, 1997).

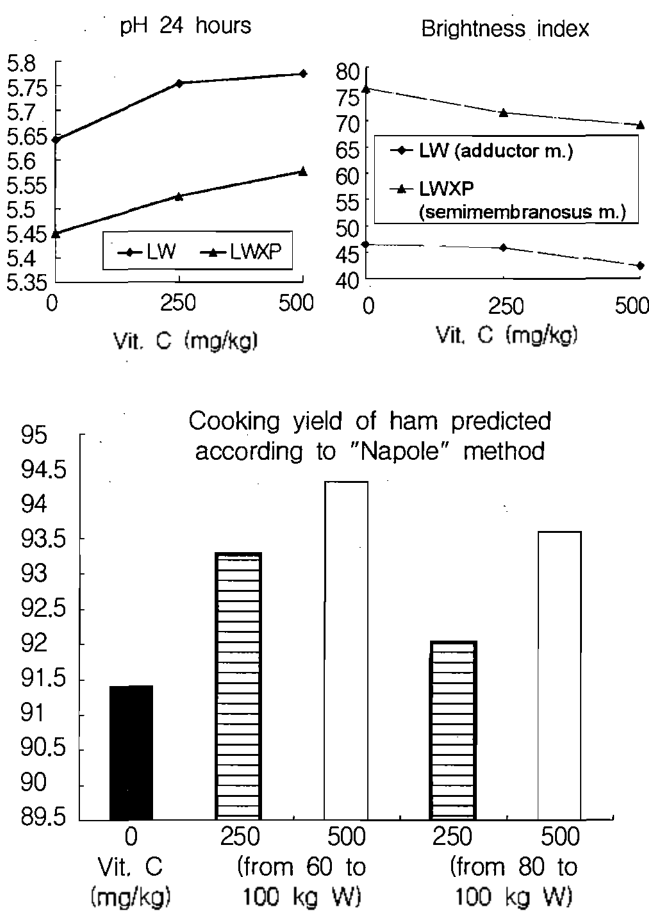


**Figure 6.** Dietary vitamin C addition and some pork quality characteristics (Mourot et al., 1992)

Carnosine is a dipeptide composed of $\beta$-alanine and histidine and it is normally present in the muscle of pig at 60-535 mg/100 g of muscle. Recent researches have shown that the addition of 0.9 g/kg feed increased the oxidative stability of the skeletal muscle and that the effect was synergic with the one of vitamin E (Decker et al., 1994). But the high cost of this substance makes almost prohibitive its use in pig production. Since however this dipeptide is synthesized in the animal from the two amino acids, a higher presence of these amino acids in the diet could have the same effect. Decker and Cromwell (1995) verified the effects of the addition of 0.18% of $\beta$-alanine and of 0.32% of istidine separately or together in the diet of pigs from 50 to 110 kg. The double integration of the diet allowed a moderate improvement of the stability of the color and inhibition of the oxidation of the lipids of salted, ground and frozen pork. The concentration of carnosine in the muscle was not affected and therefore the moderate observed effect could be related to different vitamin E contents in the muscle. Practical applications of this double supplementation will be advisable only after a better elucidation of the mechanism of action of the carnosine in the muscle.

**Micro elements and oxidative risk**

Due to the oxidizing properties of transition metals, such as iron and copper, a high supplementation of these elements in the diet can be considered dangerous for fat and pork susceptibility to oxidation. With high copper levels Taylor and Thomke (1964), Astrup and Matre (1987) and Masakazu (1990) did not find an effect on fat peroxidation, while Amer and Elliot (1973) observed that the lard oxidized more quickly. For the meat, Castell et al. (1975) did not observe any effect of the level of copper. The experimental data from the EU "Dietox" tend to confirm this observation. For the heavy Italian pig no adverse effect on meat characteristics was found with a 140 mg/kg supplementation higher than that currently allowed for the heavy pig finishing diets (Bosi et al., 1996) (figure 4). That result obviously is not a support to overcome the legal values in the diet; in our trial, high copper addition from 35 kg live weight to 160 kg slaughter weight did not improve growth performance.

Concerning iron, it is normally considered that the organism regulates its homeostasis and its content in the muscle. But the observations of Miller et al, (1994) and Bosi et al. (not published) seem to show that it doesn't happen beyond some levels of iron intake. The two groups in fact observed that moving from a medium to a high level (209 mg/kg and 420 mg/kg, for standard and heavy pig rsp), iron in meats was increased, mainly in the non-heme fraction, and lipid peroxidation of fresh and ground-cooked meat was increased too (figure 7). The high TBARS did not correlate with off-flavor presence, that was unaffected by the iron dietary level (Miller et al., 1994). In turkey, the removal of the iron supplement from the diet fed 3 to 7 wk prior to slaughter reduced lipid oxidation in dark muscle (Kanner et al., 1990), however in following trials, iron additions from 0 to 500 mg/kg did not affected negatively TBARS value of tight muscles (Bartov and Kanner, 1996). In Italy, the formulas for fattening pigs frequently contain more than 250 - 300 mg/kg; in these cases it is not advisable to supplement, with iron, considering some risk for the oxidative properties of meats.

Selenium *in vivo* is necessary to cooperate with the activity of other antioxidant factors, being the co-factor of glutathione peroxidase. However, after the requirements of the live pigs are satisfied, no further positive effect of additional doses has been signaled. Considering that for selenium the toxic dose is not so higher than the requirements, no further supplementation over the one required to maintain growth performance is advisable.

Finally it is interesting to consider the trace element recently more studied for the effect that it would have on growth and on reproduction as an enhancer of insulin: chromium. No effect on pork quality seems to be predictable with chromium addition to diets, except those connected with a different energy partition of the diet. Boleman et al. (1995) did not find negative effects on the sensorial characteristics of loin, with the exception of the meats of those subjects that had received an integration with chromium for all the trial. In this case pork was less tender than the one of the subjects that had received chromium only in finishing. The acidic composition of intramuscular fat from *Longissimus dorsi* m. was modified by chromium supplementation, while the area of loin muscle and its fat content were increased (Wenk et al., 1995).

**Other feeding factors**

Some factors can induce an inadequate post mortem acidification of the muscular fibre: genetic factors, stress from transport to abattoir and differences between muscles. A reduced availability of energy from glycogen reserves, does not allow a correct evolution of the anaerobic glycolysis in the muscle.

The glycerol participates to the gluconeogenesis and to the lipogenesis and has been proposed as a fuel of quick use to reduce the quota of glycogen from which the animal obtains energy in the hours before the slaughtering. In the figure 8 the effects of a 5% inclusion of glycerol in the diet on the quality of pork are summarized (Mourot et al., 1993; Cerneau et al., 1994). While effects on the pH at 45 minutes and after 24 hours and on the index of color were not observed, glycerol in the diet reduced drip losses from *Longissumus dorsi* m. and *Semimembranosus* m., cooking losses from the latter and cooking yield of ham.

An increased content of glycogen in muscle was observed with the dietary addition of 75- 150 mg/ kg of nicotinic acid (Piva et al., 1992); also in this case a direct effect on pH's and color of pork was not demonstrated, while a tendency to a small improvement of yield during the Parma ham seasoning was detected (Piva et al., 1995).

**Dietary fats and sensorial qualities**

The introduction of sources of unsaturated fatty acids in pig diets to modify its hygienic and nutritional value could affect pork sensorial qualities too. Cameron and Enser (1991) in Landrace and Duroc pig found positive correlations between flavor and mono- and saturated fatty acids, except for stearic acid, whereas poly- were negatively related, except for linolenic acid.

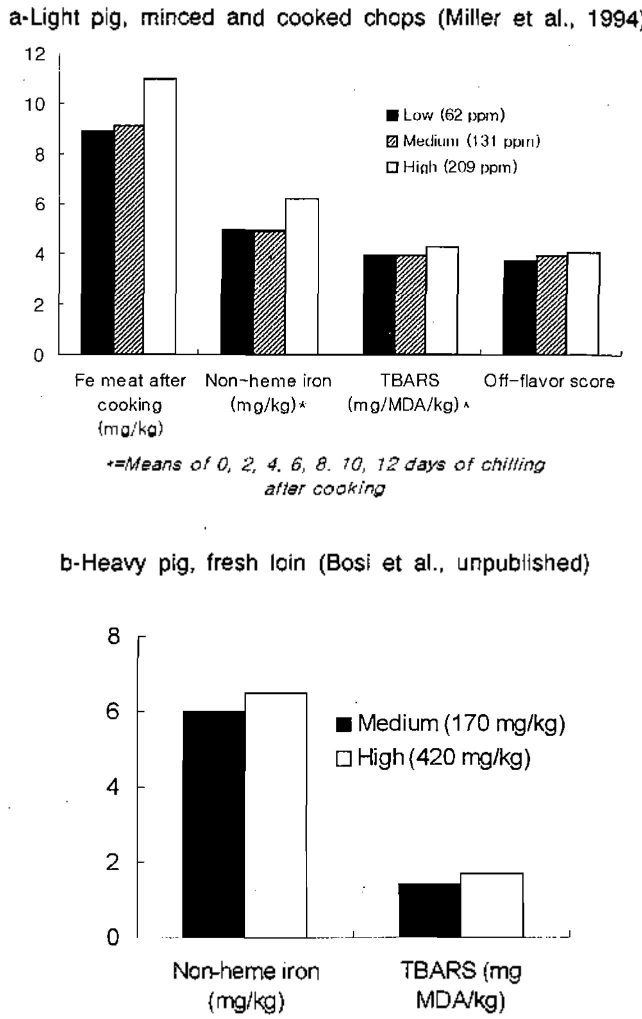


**Figure 7.** Effect of dietary iron on characteristics of pork

**Fat firmness and high quality products**

Since early works in the 20's (Ellis et al., 1926), the negative effects on physical properties of backfat have been frequently reported according to the degree of unsaturation of dietary fats and the level of inclusion. Fat firmness is very important for the production of high quality dry-cured products and for minced dry-cured products. The subcutaneous fat of the fresh ham to be processed to Parma ham need to have an iodine number lower than 70 and less than 15% of linoleic acid. To meet these requirements it is well documented that the dietary content of polyunsaturated fatty acids in the finishing diets must be reduced (Mordenti et al., 1994; Della Casa et al., 1996). However unsaturated fat sources can be a cheep energy source in pig feeding and a positive factor for the hygienic value of the meat. The addition of high oleate sunflower oil to heavy pig diets permitted to produce a subcutaneous fat within the limits for linoleic acid, with normal firmness of the fresh fat (Bosi et al., not published), but with a iodine number off the limits (Zanardi et al., 1997). Furthermore, after the seasoning, the Parma hams were judged excessively tender for this typical product (Bosi et al., not published).

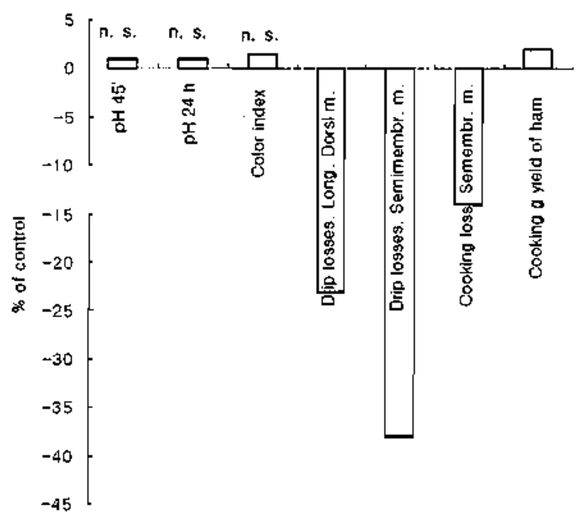


**Figure 8**. Effect of glycerol in the diet on some pork characteristics (Mourot et al., 1993)

## CONCLUSIONS

With the present review some dietary tools to maintain and improve the qualitative characteristics of pork by dietary means were presented. However the practical opportunities of manipulating pork are reduced by the ambivalent effects shown by some feeding strategies.

For the lipid fraction, the knowledge about dietary effects on subcutaneous fat needs to be extended more to the effects on muscular lipids.

Concerning some nutrients, particularly minerals and vitamins, more research is needed to exclude the possibility to increase its contents in pork, the research being generally oriented to test requirements for growth and not for pork quality.

Vitamin E seems to be an important tool to control effects of oxidations on sensorial and hygienic value of pork, but the opportunity of its addition can be evaluated according to each predicted destination of the meat.

On the whole, any variation from the least-cost feeding need to be compensated by a higher return from the consumer.

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