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Importance of vitamin E in the oxidative stability of meat: Organoleptic qualities and consequences

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SUMMARY - The principal factors determining the organoleptic quality of meat are tenderness, colour, and flavour. Storage of meat often leads to the development of abnormal odours and tastes and loss of colour. Oxidation of the lipids of meat and meat byproducts can be effectively controlled with antioxidants. This article explains how oxidation of lipids and deterioration in the organoleptic quality of meat occur and how these phenomena can be minimized by including α-tocopherol in animal diets. Dietary α-tocopherol is deposited in muscle and fat during the life of the animal and protects against meat oxidation after slaughter.

Key words: Oxidation, lipids, muscle, α-tocopherol, vitamin E, quality, cholesterol.

RESUME - *"Importance de la vitamine E dans la stabilité oxydative de la viande : qualités organoleptiques et conséquences". Les principaux facteurs qui déterminent la qualité organoleptique de la viande sont la tendreté, la couleur, et la flaveur. Le stockage de la viande mène souvent au développement d'odeurs et de goûts anormaux et à une perte de couleur. L'oxydation des lipides de la viande et produits dérivés de la viande peut être effectivement maîtrisée avec des antioxydants. Cet article explique comment ont lieu l'oxydation des lipides et la détérioration de la qualité organoleptique de la viande et comment ces phénomènes peuvent être minimisés en incorporant de l'α-tocophérol dans les régimes animaux. L'α-tocophérol alimentaire est déposé dans le muscle et le gras pendant la vie de l'animal et protège contre l'oxydation de la viande après l'abattage.*

Mots-clés : *Oxydation, lipides, muscle, α-tocophérol, vitamine E, qualité, cholestérol.*

Introduction

Meat can be defined as the product that results from the continuous changes that occur in muscle after the death of the animal (Sañudo, 1992). Meat is a highly nutritious food that contains high-quality protein, minerals, essential trace elements, and vitamins, in particular those of group B. In addition to its nutritive value, meat has other qualities, in particular its flavour, that increase its value and attractiveness.

Despite these positive attributes, consumption of meat has fallen in recent years. Consumers are demanding ever healthier and safer foods.

The principal factors determining the organoleptic quality of meat are tenderness, colour, and flavour, the latter being composed in turn of the two distinct factors taste and odor.

Though the concept of "quality of meat" is very ambiguous, high-quality meat may be defined as meat that satisfies the needs and demands of consumers, in particular those relating to *organoleptic quality, nutritional quality, hygienic quality, and suitability for processing*.

Prominent among new dietary trends is an increase in the consumption of *frozen, processed, and precooked meat*. This implies less consumption of fresh meat and favours oxidation and deterioration of meat. Recent human medical studies have confirmed the importance of certain *polyunsaturated fatty acids* in the prevention of pathologic processes (cardiovascular diseases, arthritis, inflammatory processes, etc.). There is also a trend towards modifying the fatty acid profile of meat in the sense of increasing the ratio of polyunsaturated to saturated fatty acids.

Oxidation of the lipids of meat and meat products depends on a number of factors. Prominent among these are the polyunsaturated fatty acid composition of the fat of muscle and other tissues, fatty acids (mostly unsaturated) present in the muscle membrane, the presence of prooxidants such as iron, the lipid composition of feed, and the presence of antioxidants.

Storage of meat often leads to the development of abnormal odors and tastes and loss of colour. The major challenge facing the meat production and distribution industry is how to prevent rapid oxidation and resulting loss of flavour and acceptability of fresh meat, processed meat, and precooked meat products.

The changes that occur after oxidation of meat are generally quantified by measurement of secondary degradation products. Data are expressed as TBARS (thiobarbituric acid reactive substances). The TBARS value is generally regarded as a good indicator of the degree of deterioration of the organoleptic characteristics of meat as a result of oxidation.

Oxidation of the lipids of meat and meat subproducts can be effectively controlled with antioxidants. Many recent studies have dealt with the use of synthetic antioxidants. Nevertheless, consumers are now becoming increasingly health-conscious and resistant to the use of synthetic antioxidants.

There is now considerable interest in the actions of a variety of natural antioxidants such as extracts of vegetables, fruits, grains, spices, and herbs. Vitamin E has been shown to be an effective antioxidant, especially when included in animal diets, and is accepted by consumers on the basis that it is a naturally occurring substance.

Oxidation of lipids

Oxidation of cellular membranes

Lipid oxidation is an autocatalytic process that occurs in foods and biological membranes.

Most of the oxygen utilized by cells is reduced in the mitochondria, while a small amount is used in reactions that take place in the cytosol, the nucleus, and the cell membrane. This latter oxygen generally receives four electrons after generating a number of molecules of NADH that ultimately increase energy content via ATP. Via the action of certain oxidises, however, it can receive only one electron, giving rise to the production of a superoxide anion ($O_2^{-\bullet}$) or hydrogen peroxide (H_2O_2). The $O_2^{-\bullet}$ anion is one of the principal free radicals that initiate cellular oxidation processes (Fig. 1). It can react with H_2O_2 to form the even more aggressive hydroxyl radical ($^{\bullet}OH$).

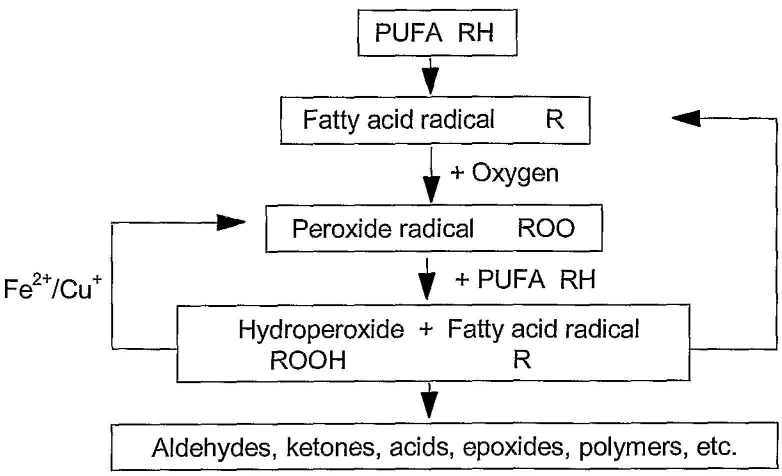


Fig. 1. Oxidation of lipids.

Free radicals can also be formed via the metabolism of neutrophils and macrophages and by the action of the lytic enzymes of these. They can also be exogenous molecules.

The presence of transition metals such as Fe^{2+} and Cu^{+} favours the formation of highly reactive free radicals.

These oxidation phenomena are favoured by the following factors, among others:

(i) Level of unsaturated fatty acids in meat.

(ii) Free radicals, myoglobin, hemoglobin, cytochromes, metals such as iron and copper and other heavy metals.

(iii) Conditions of slaughter (stress, pH, temperature of the carcass, electrical stimulation).

(iv) Rupture of the integrity of muscle membranes (mechanical deboning, grinding, processing, and cooking).

Effect on the organoleptic characteristics of meat

As a result of the peroxidation that occurs in living animals and the oxidative rancidity that starts to develop shortly after slaughter, polyunsaturated fatty acids are broken down into short-chain compounds (aldehydes, ketones, acids, epoxides, polymers, etc.). These give rise to unpleasant odors and tastes that reduce the acceptability of the meat to the consumer.

Discoloration of meat is due to oxidative processes and to reductant enzymatic systems involved in the control of metmyoglobin levels (Faustman and Cassens, 1990).

As a result of the oxidative processes oxymyoglobin is generated and the meat acquires a bright red colour and subsequently a brown-red colour as a result of formation of metmyoglobin. This gives the meat an undesirable appearance that is rejected by consumers (Fig. 2).

Globin	Globin	Globin
|	|	|
$>Fe^{+2}<$	$>Fe^{+2}<$	$>Fe^{+3}<$
|	|	|
	O_2	HOH
Deoxy-Mb Purple red	Oxy-Mb Bright red	Met-Mb Brown red

Fig. 2. Colour of meat and associated forms of myoglobin (Faustman and Cassens, 1989).

Renerre *et al.* (1996) observed that during the maturation of meat the content of metmyoglobin (met-Mb) and lipofuscin is greater in muscles with greater instability of colour.

These oxidative processes are even more pronounced in precooked meat. Precooking results in abnormal odors and tastes ("warmed-over flavour"). The same processes occur also in meat that is ground and exposed to the air.

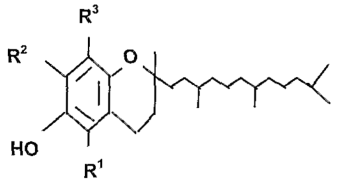
Other studies have demonstrated that as well as causing colour changes, loss of cellular integrity causes the meat to exude a greater amount of water (Monahan *et al.*, 1990).

Vitamin E

General considerations

At least eight compounds with vitamin E activity have been isolated from the oils of plants. These compounds are α, β, γ, and δ-tocopherol and α, β, γ, and δ-tocotrienol. They are all chemically different. The principal characteristic of the trienols is their unsaturated condition at carbon atoms 3, 7, and 11 of the chain, whereas in tocopherols the corresponding carbon atoms are saturated. The nomenclature α, β, γ, and δ used for tocopherols and tocotrienols indicates the number and position of the methyl groups. This is shown in Fig. 3, in which the hydrophilic and hydrophobic parts of the molecules can also be seen.

Hydrophilic



Hydrophobic

Compound	R^1	R^2	R^3
α-tocopherol	CH_3	CH_3	CH_3
β-tocopherol	CH_3	H	CH_3
γ-tocopherol	H	CH_3	CH_3
δ-tocopherol	H	H	CH_3

Fig. 3. Chemical structure of tocopherols.

"Vitamin E" is a generic term used for all tocopherols and tocotrienols, as all exert the same biological action. The efficacy with which they do so is very low in the case of the tocotrienols, whereas tocopherols, and in particular α-tocopherol, are much more active and potent and account for almost all the vitamin E activity of living tissues.

Absorption of vitamin E occurs mostly via the lymphatic system, the molecules being transported to the liver inside triglyceride-rich chylomicrons. Vitamin E is then secreted by the liver and incorporated into very-low-density lipoproteins (VLDL). It is transported to the interior of cells inside low-density lipoproteins (LDL), which are recognized and removed from the plasma by LDL-specific receptors.

Vitamin E deficiency can lead to lesions of the reproductive, nervous, cardiovascular, and musculoskeletal systems and the liver. Vitamin E acts as an immunomodulator, however its most important function is as an *in vivo* antioxidant that protects fatty tissues from attack by free radicals.

Vitamin E is found in biological membranes in a system stabilized by physicochemical forces that include lipid-lipid interactions between α-tocopherol and polyunsaturated phospholipids. At this site (Fig. 4) α-tocopherol protects polyunsaturated fatty acids, which are extremely susceptible to oxidation, from peroxidation by free radicals produced in many cases by enzymes of the membrane itself (NADPH oxidase).

Though vitamin E plays a crucial role as an antioxidant in cell membranes, its concentration can be as low as one molecule per 2,000 to 3,000 lipid molecules.

Despite this low molar concentration in the membrane, vitamin E is the principal lipid-soluble antioxidant that acts at the level of cellular membranes to prevent peroxidation and to modulate the metabolism of arachidonic acid initiated by lipooxygenase and/or cyclooxygenase.

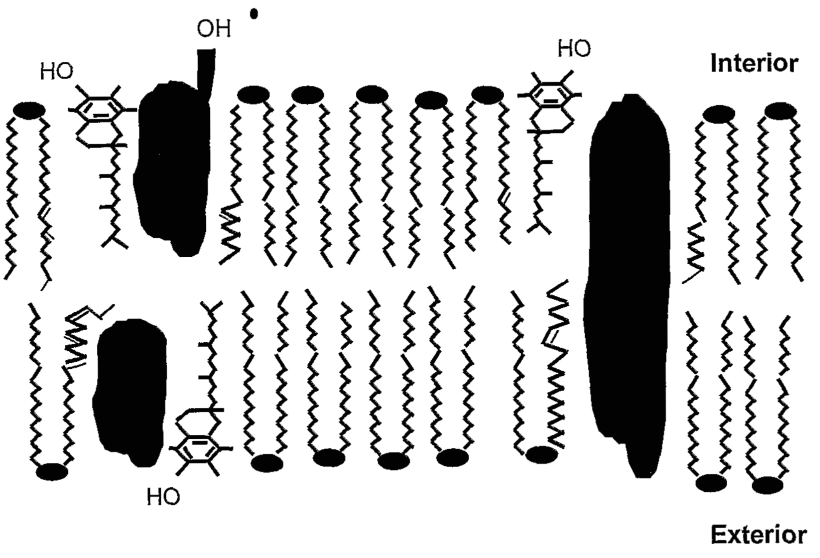


Fig. 4. Localization of vitamin E in the cell membrane.

Deposition of vitamin E in various tissues

Differences in the affinity of α-tocopherol for cellular membranes and for various organs and tissues result in different concentrations of the substance at different sites. Two important factors that determine the concentration of the substance are the duration and amount of dietary supplementation.

In a study in which the diet of broilers was supplemented with 200 mg of α-tocopherol acetate per kg of feed for variable periods (1, 2, 3, 4, and 5 weeks prior to slaughter), Brandon *et al.* (1993) found α-tocopherol concentration to vary considerably between tissues, being highest in the heart, lowest in the brain, and intermediate in the lungs, liver, thigh, and breast. In the case of the heart the highest concentration was reached with three weeks of supplementation prior to slaughter, whereas in the case of thigh and breast a period of four weeks was required (Fig. 5).

Fig. 5. Deposition of vitamin E in various muscles of the broiler.

There are important differences between chickens and turkeys in terms of the efficacy of deposition of vitamin E, the latter animals being less efficient in terms of deposition of α-tocopherol both in fat and in muscle (Mecchi *et al.*, 1956; Marusich *et al.*, 1994) (Table 1). The fact that levels of vitamin E are lower in turkeys appears to be due to greater production and excretion of products derived from the catalytic metabolism of tocopherol (tocopheryl glucuronides), the extent of this being two to nine times greater in turkeys than in chickens (Jones, 1989).

Table 1. Deposition of vitamin E in the breast of chickens and turkeys (Marusich *et al.*, 1994)

	Suppl. vit. E (IU/kg feed)	IU vit. E ingested/day/kg live wt (43-56 days)	α-tocopherol (mg/kg) in breast (Age: 8 weeks)
Chicken	40	2.57	5.0
Turkey	37	2.92	1.4

Sheldon *et al.* (1984) found that the muscle of the thigh of turkeys can contain up to six times as much α-tocopherol as the breast or fat, presumably because of the greater vascularity of the leg of the turkey.

The lower concentration of α-tocopherol in turkey meat that results from less efficient deposition renders turkey meat susceptible to oxidation and explains the greater vitamin E requirements of this species as compared with chickens.

Studies on beef cattle have confirmed that deposition of vitamin E in cellular membranes increases the α-tocopherol content of muscle. This can be seen in Fig. 6 (control or 1,200 mg vitamin E per calf per day) and Fig. 7 (200, 850, or 2,000 mg vitamin E per calf per day).

This has major consequences in terms of the organoleptic characteristics of meat.

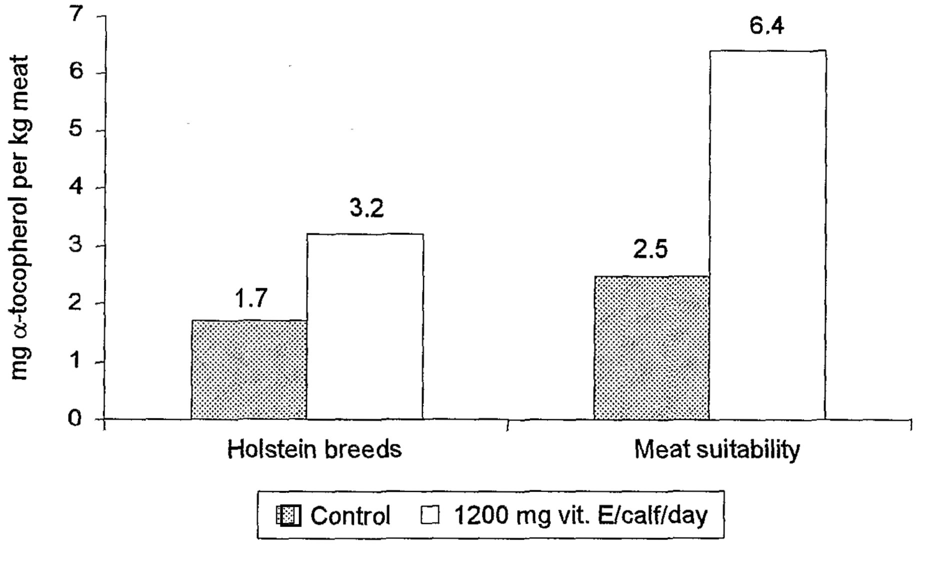


Fig. 6. Increase in vitamin E content of muscle due to dietary supplementation (Mitsumoto *et al.*, 1991).

If the vitamin E content of meat is less than that recommended, all the oxidative processes that give rise to metmyoglobin commence very rapidly, giving rise to an undesirable colour.

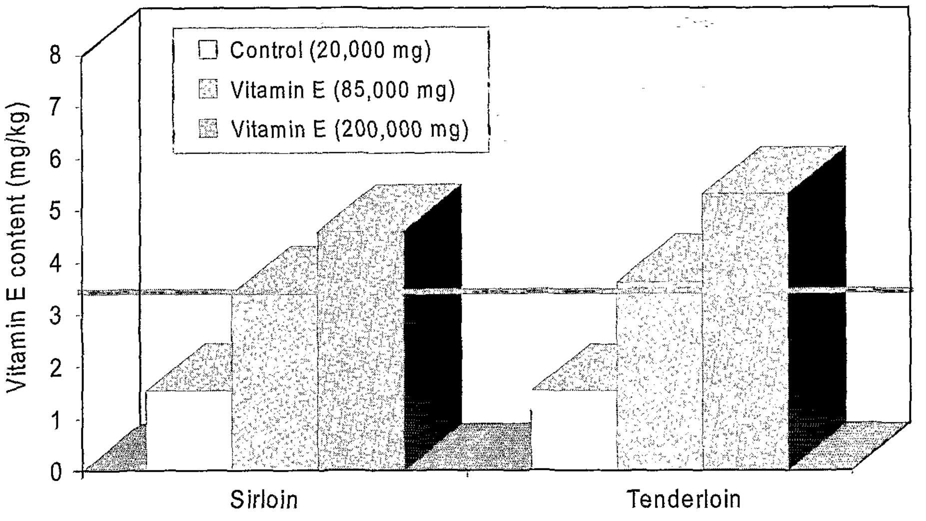


Fig. 7. Increase in vitamin E content of muscle by dietary supplementation (20,000, 85,000, or 200,000 mg of vitamin E in the last 100 days of feeding before slaughter) (Institut de l'élevage, France, 1996, unpublished data).

The quality of meat can be impaired in three principal ways: (i) microbiologic contamination; (ii) discoloration; and (iii) lipid oxidation.

Vitamin E plays a very important role in preventing the latter two of these.

Vitamin E and prevention of lipid oxidation

General considerations

The presence or absence of vitamin E in animal tissues has a critical influence on the stability of lipids during the storage of meat. By trapping free radicals (Figs 8 and 9), Vitamin E protects fatty acids and cholesterol from oxidation. In this process vitamin E releases a hydrogen atom, which is captured by a peroxyl radical which is thereby reduced to form a hydroperoxide. Vitamin E radicals are extremely stable and do not react with polyunsaturated fatty acids. They can also react with other radicals and thus terminate the chain of reactions of lipid oxidation at this point.

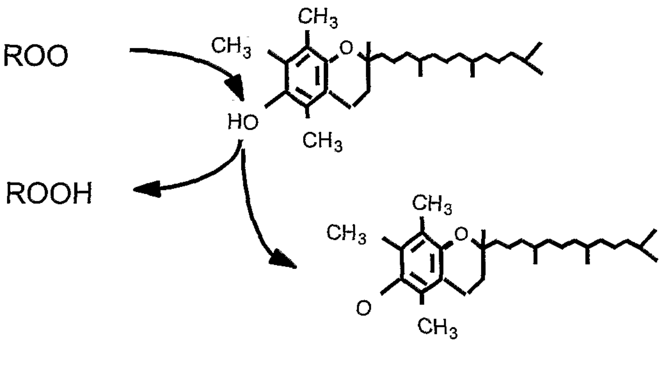


Fig. 8. Antioxidant effect of vitamin E.

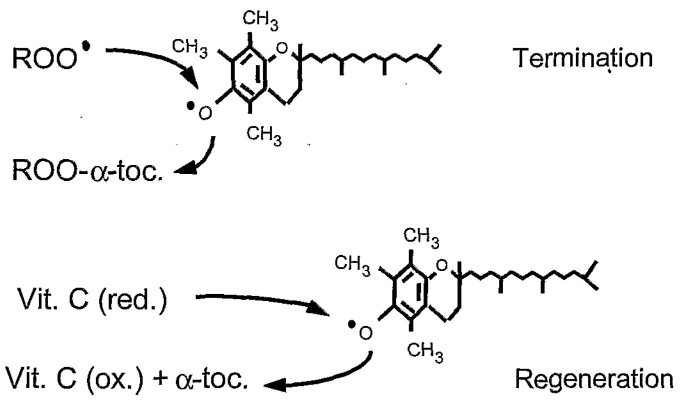


Fig. 9. Antioxidant effect of vitamin E.

Vitamin E is highly efficient as an antioxidant. From chemical and biochemical studies it is known that after being oxidized and before undergoing decomposition, vitamin E can be re-reduced. Ascorbic acid (vitamin C) and the enzyme glutathione are the principal water-soluble intracellular antioxidants (reductants) that generate reduced vitamin E (Fig. 9). This reaction depends on the concentration of these substances and/or of the enzymes that maintain them in their reduced form.

Effect of composition and quality of dietary fat on lipid oxidation of meat. Antioxidant effect of vitamin E

Both the composition and the quality of dietary fat influence the oxidative stability of meat during storage.

The more unsaturated is the dietary fat, the more unsaturated will be the fat of muscles and membranes. A number of studies have shown that meat with a high content of polyunsaturated fatty acids is more susceptible to oxidation and that the antioxidant effect of vitamin E plays an important role in the prevention of this oxidation.

Lin *et al.* (1989a) found that dietary supplementation with coconut oil, olive oil, linseed oil, and partially hydrogenated soybean oil modified the lipid profile of meat derived from broiler chickens. They also found that meat produced with a diet rich in linseed oil, which has a high content of α-linolenic acid (ω-3), was more susceptible to oxidation. Addition of 100 mg of α-tocopherol acetate per kg of feed significantly improved the oxidative stability of the chicken meat.

In a recent study by Ajuyah *et al.* (1993) it was found that addition of linseed oil to chicken feed increased the content of α-linolenic acid (ω-3) in the meat produced. In view of the need to protect this meat from oxidative processes, the authors compared the efficacy of canthaxanthin and α-tocopherol as antioxidants. It was found that α-tocopherol had a greater antioxidant effect.

Miller *et al.* (1993) studied the effect of dietary supplementation with 0, 10, or 20 g of fish oil and 50, 250, or 450 mg of α-tocopherol acetate per kg of feed for 52 days. Supplementation with fish oil reduced the ω-6/ω-3 ratio from 10.2 to 1.3 in breast and from 16.1 to 2.1 in thigh. Supplementation with α-tocopherol acetate significantly increased the resistance of the meat to oxidation.

Inclusion of oxidized oils in animals' diets leads to a reduction in the concentration of α-tocopherol in muscle tissue. From the results referred to above it can be concluded that the use of low-quality (oxidized) fats and oils in animals' diets calls for an increase in dietary α-tocopherol in order to counteract the oxidative stress suffered by tissues, meat, and meat derivatives (Sheehy *et al.*, 1993b,c).

Effect of vitamin E on oxidation of cholesterol

Cholesterol, which is present in cellular membranes, is susceptible to oxidative processes initiated by free radicals. Concern about the presence of *cholesterol oxidation products* (COPs) has increased in recent years. Scientific opinion has linked the presence of these compounds (7-ketocholesterol, 25-hydroxycholesterol, cholestane triol, etc.) to the development of atherosclerotic lesions (Steinberg *et al.*, 1989).

López Bote *et al.* (1992) studied the effect of supplementation with vitamin E and spice extracts in terms of prevention of lipid and cholesterol oxidation in chicken meat. The TBARS values with the four treatments (control, rosemary, sage, and 200 IU of vitamin E per kg) were 0.51, 0.30, 0.35, and 0.25, respectively. The concentration of COPs in cooked meat was 44, 42, and 58% lower in the rosemary, sage, and vitamin E groups, respectively, than in the control group.

Galvin *et al.* (unpublished data) found production of COPs to be inversely related to the concentration of α-tocopherol acetate in the diet. The concentration of COPs in the muscle of chickens given 200 and 400 mg of α-tocopherol acetate per kg of feed was respectively 75 and 51% of that found in the muscle of chickens given 100 mg of α-tocopherol acetate (Fig. 10).

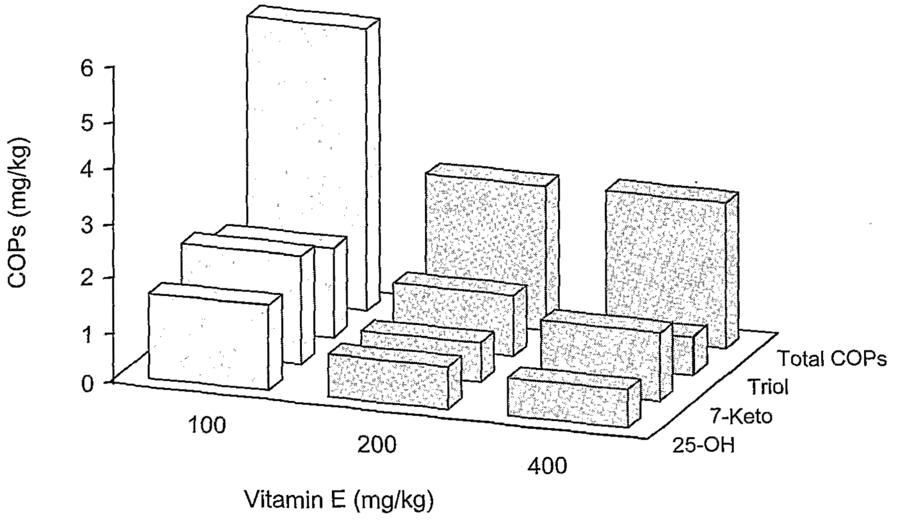


Fig. 10. COPs in muscle of chicken. Cooked and stored for 5 days at 4°C.

Galvin *et al.* (1995) determined the effect of storage of meat and supplementation with α-tocopherol acetate on the formation of COPs (25-hydroxycholesterol, 20-α-hydroxycholesterol, 7-ketocholesterol, etc.) in the breast and thigh of chickens. The diet was supplemented with 20, 200, or 800 mg of α-tocopherol acetate per kg of feed. The samples of meat were cooked, vacuum-packed, and stored at -20°C. All the samples were found to contain 25-hydroxycholesterol immediately after cooking; 20-α-hydroxycholesterol was detected in breast meat from day 6; and 7-ketocholesterol was detected in breast and thigh meat from day 12. The total amount of COPs did not increase appreciably until day 12 of storage. Supplementation with 200 and 800 mg of α-tocopherol acetate per kg of feed reduced the level of COPs by 40–50% and 60–70%, respectively, in both breast and thigh.

Effect of vitamin E on the organoleptic qualities of meat

Deposition of vitamin E in cellular membranes increases the α-tocopherol content of muscle, and this has very important consequences in terms of the organoleptic qualities of the meat.

Supplementation of the diet with vitamin E increases the concentration of α-tocopherol in membranes, especially those of mitochondria and microsomes, and thus significantly reduces the susceptibility of membranes to lipid oxidation (Monahan *et al.*, 1990; Ashgar *et al.*, 1991; Mitsumoto *et al.*, 1991).

The degree of oxidation of meat is generally assessed by measuring the content of secondary degradation products that arise from oxidation of polyunsaturated fatty acids. The analytical method uses substances that react with thiobarbituric acid (TBARS value) as a measure of the degree of this oxidation. A higher TBARS value indicates a greater degree of oxidation of meat. The time-course of TBARS values in meat and the effect of vitamin E in preventing oxidation are seen in Table 2.

Table 2. Time-course of TBARS value of meat in relation to vitamin E content (Faustman *et al.*, 1989)[†]

	α-tocopherol (g/kg of meat)	TBARS		
		0 months	1.5 months	3 months
Control	1.6	0.11	1.19[a]	1.48[a]
Vitamin E	4.4	0.13	0.13[b]	0.26[b]

[†]Pieces of loin frozen at 18°C
a,b: Values marked with different letters are significantly different P<0.05

The TBARS value also depends on the content of polyunsaturated fatty acids (PUFAs) in the diet. Walsh *et al.* (1992) found that the degree of oxidation of the meat of calves fed on a vitamin E-deficient diet varied significantly with the PUFA content of the diet, being greater in animals fed on a diet with a higher PUFA content.

Colour is the principal factor determining the acceptability of meat to the consumer (Faustman and Cassens, 1989).

In a study performed at the Institut de l'élevage (France, 1996) it was found that global appreciation of steak with a low content of vitamin E that had been on display for 13 days was much lower than that of steak with adequate levels of vitamin E that had been on display for the same period, significant differences being present from as early as day 7 (Fig. 11).

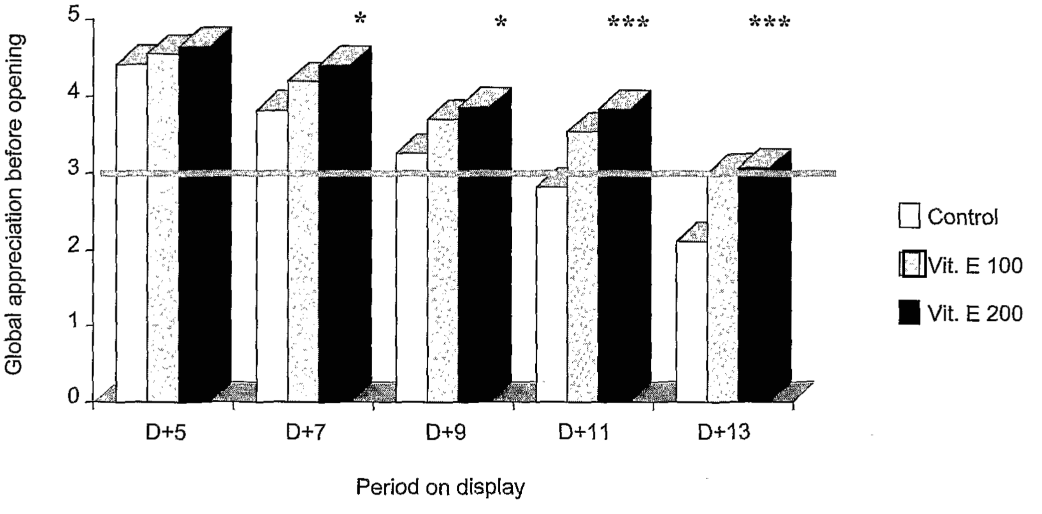


Fig. 11. Global appreciation of meat as a function of time on display (Institut de l'élevage, France, 1996, unpublished data).

The same study included an analysis of the shelf life -as measured by change in colour and organoleptic characteristics- of various cuts of meat kept under plastic film or in a modified atmosphere. As seen from Fig 12, the shelf life of the meat was greater where higher levels of supplementation with vitamin E had been given.

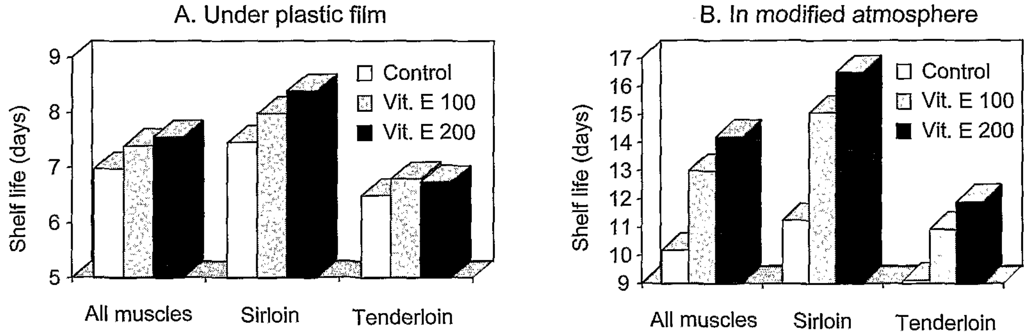


Fig. 12. A: Shelf life of meat under plastic film; or B: in a modified atmosphere as a function of level of supplementation of diet with vitamin E (Institut de l'élevage, France, 1996, unpublished data).

Supplementation of calves' diets with vitamin E leads to an increase of 1.5 to 6 days in the time meat can be displayed in the butcher's shop without suffering changes in its organoleptic qualities. This conclusion was reached in the recent review by Willians and is shown in Table 3.

Table 3. Increase in shelf life of meat (in days) as a function of supplementation of calves and concentration of vitamin E in the meat (Willians, 1992)

Study	Dose vitamin E (mg/day)	Concentration α-tocopherol (mg/kg loin)	Increase in shelf life of meat due to suppl. (days)[†]
Basal	0	1.4	0
1	300	3.8	5.3
2	1140	6.2	2.0
3	360	4.1	2.5
	1280	6.8	4.0
4	2080	6.7	3.1
	3520	7.6	5.2
5	1200	3.5	4.8

[†]Meat from calves supplemented with vitamin E as compared with meat from unsupplemented calves

In this context it is necessary to consider the amount of supplement given daily and the period over which it is given. The concentration of vitamin E in plasma and muscle depends on the amount of supplement given and is lower with less supplementation (Walsh *et al.,* 1992).

Khattak *et al.* (1995) studied oxidation of the meat of chickens fed with either rapeseed oil or fish oil. *The degree of oxidation (TBARS value)* was found to be greater in meat produced with fish oil, regardless of whether the meat had been refrigerated (4°C for 16 days) or frozen (-20°C for 90 days). Supplementation of the diet with 300 mg of α-tocopherol acetate reduced the TBARS value (P<0.01) in both fresh and frozen meat with both types of diet.

Wen *et al.* (1996) measured the effect of supplementation of a commercial turkey diet with 20, 300, or 600 mg of α-tocopherol acetate per kg firstly on the TBARS value of raw and cooked turkey meat hamburgers stored either refrigerated (4°C) or frozen (-20°C), and secondly on the α-tocopherol content of the meat. They found that supplementation with α-tocopherol acetate significantly reduced (P<0.01) the TBARS value of meat regardless of whether the meat was raw or cooked or had been refrigerated or frozen.

The α-tocopherol content of the refrigerated meat showed no variation, whereas after four months of storage that of the frozen (-20°C) raw hamburgers had fallen from 5.67 to 3.54 and from 3.56 to 2.3 mg/kg in the 600 and 300 ppm treatment groups, respectively. After five months of treatment the α-tocopherol content of the frozen cooked hamburgers had fallen from 5.6 to 2.88 and from 3.29 to 1.85 mg/kg in the 600 and 300 ppm treatment groups, respectively.

The authors suggest that the fact that the α-tocopherol content of the refrigerated meat was maintained could be because at the temperatures concerned oxidation reactions occur in a liquid/liquid phase in which, together with α-tocopherol, water-soluble antioxidants help to prevent oxidation. The great capacity of vitamin E to act as an effective antioxidant at the concentrations at which it is present in the membrane is due also to its ability to be re-reduced from the radical to the active form by other intracellular reductants (Morrisey, 1994b).

In frozen meat, some catalysts and antioxidants remain trapped in the solid (frozen) phase and the antioxidant activity of the cytosolic phase does not function optimally. In addition, free lipid radicals are soluble in the lipid fraction and more stable at low temperatures. This allows them to diffuse over considerable distances and thus extend the oxidation reaction. Being lipid-soluble, vitamin E acts as the first line of antioxidant defense and can thus be consumed rapidly.

A problem of great economic importance in the marketing of meat is formation of *PSE meat* (pale, soft, and exudative). By increasing metabolic rate, stress prior to slaughter causes accumulation of lactic acid and thus a fall in the pH of muscle. Tenderness of meat diminishes as final pH diminishes, and colour is also affected.

The occurrence of PSE meat in chickens and turkeys is due to an over-reaction of the animals to stress. Animals deficient in vitamin E have high plasma levels of pyruvate kinase and creatine kinase as a result of damage to cellular membranes by free radicals. Increased deposition of α-tocopherol in cellular and subcellular membranes of muscle as a result of increased dietary supplementation not only improves the integrity of membranes, but also influences the degree to which PSE meat is formed.

Ferket *et al.* (1994) found that the incidence of PSE meat fell when the diet of turkeys was supplemented with 200 IU of vitamin E for two to three weeks prior to slaughter. Also, the longer the period of supplementation, the lower was the incidence of PSE meat. This effect appears to be related to the amount of vitamin E incorporated into muscular tissue: the greater the amount of vitamin E present, the greater is the capacity of the muscle to counteract oxygen-reactive metabolites produced during the stress reaction.

In an unpublished study on pigs, Monahan *et al.* found that in this species also, supplementation with 200 mg of α–tocopherol per kg of feed *for 14 weeks* led to a reduction in exudative losses from fresh chops (Fig. 13).

Supplementation with 200 IU of vitamin E also maintained the original colour (Hunter "a" value) of both fresh and frozen chops (Fig. 14).

Piretti *et al.* (1995) studied the effect of supplementation with vitamin E on the TBARS value of the fat and muscle of ham during maturation (Fig. 15). Supplementation with 250 mg of α-tocopherol per kg of feed led to a fall in the degree of oxidation.

Schaefer *et al.* traced control samples of beef and samples of beef with an adequate level of vitamin E sent to three different distribution centres in Las Vegas, Lenexa, and Houston. They found the percentage losses due to discoloration (Table 4).

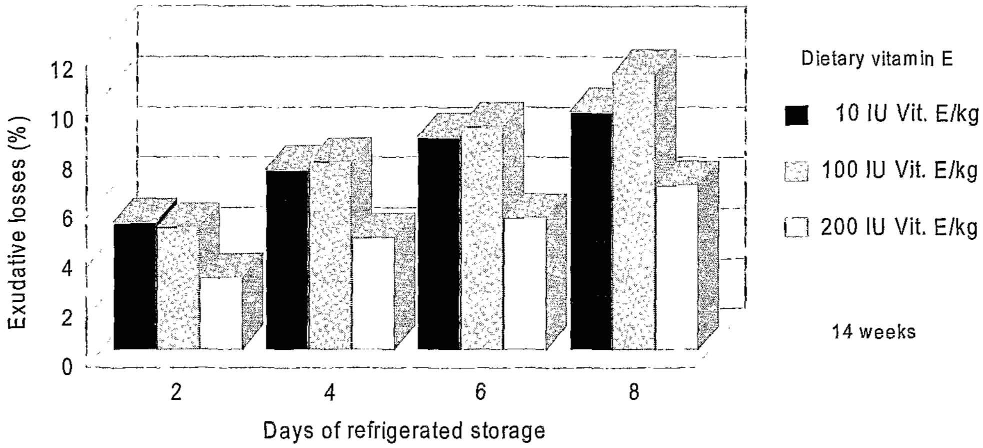


Fig. 13. Effect of dietary vitamin E on exudative losses (%) from fresh pork chops (Monahan *et al.*, unpublished data).

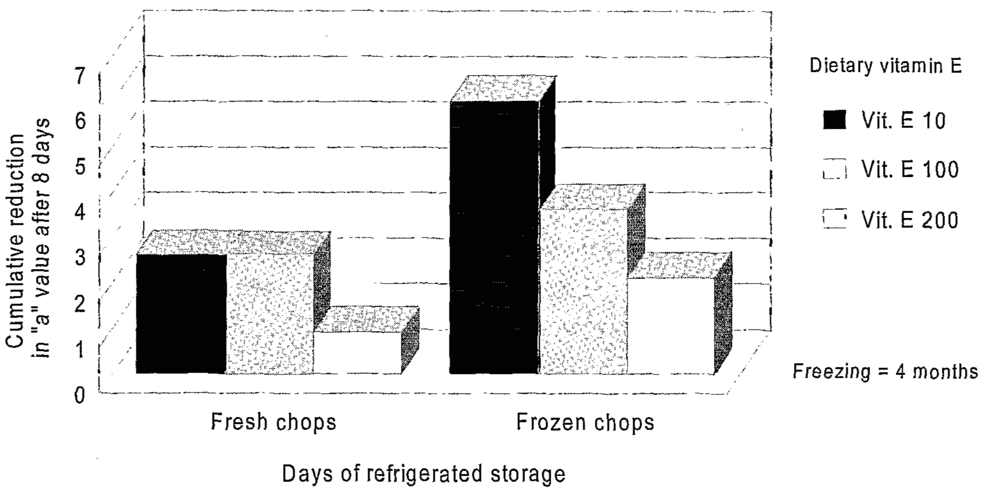


Fig. 14. Effect of vitamin E on the fall in the Hunter "a" value of fresh and frozen pork chops (Monahan *et al.*, 1993).

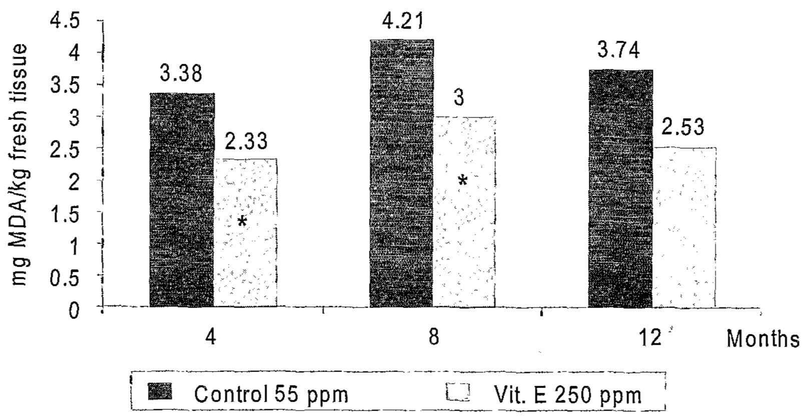


Fig. 15. Mean TBARS values in the fat of ham during maturation (*P<0.05)

Table 4. Fall in price of meat due to discoloration (% of initial value)

	Control	Vitamin E
Las Vegas	9.09	3.27
Lenexa	4.27	2.45
Houston	4.68	0.32
Mean	5.62	1.98

The improvement obtained by adding vitamin E was significant, there being a *65%* reduction in losses due to discoloration, a figure consistent with other results cited above.

Figure 16, which shows results obtained in a recent study by Brad Morgan, of the University of Oklahoma, shows the approximate cost of vitamin E supplementation and the benefit that such supplementation brings to the meat producer and trader. The producer is able to supply meat of higher quality that should fetch a higher price, while the trader benefits from the smaller losses due to exudation and discoloration of the meat and is able to market a product of higher organoleptic and nutritional quality.

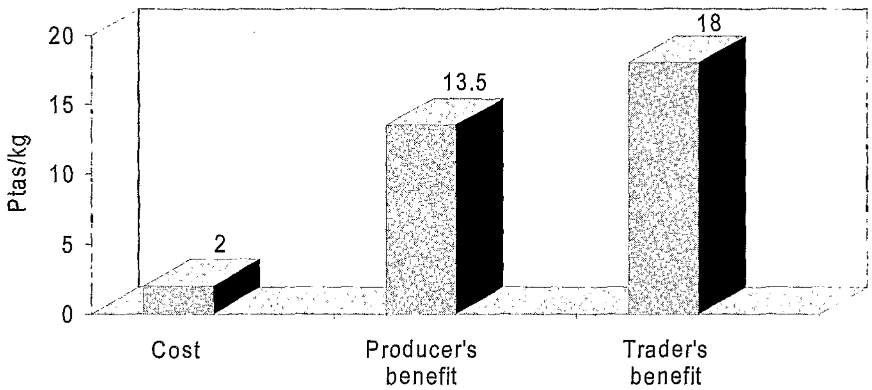


Fig. 16. Benefit of vitamin E supplementation in terms of smaller losses due to discoloration of meat (Brad Morgan, 1997, Oklahoma State University, Department of Animal Science).

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