Vitamin and Non-Vitamin Antioxidants and Their Interaction in Food

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ABSTRACT

Aerobic life has been challenged by the changing conditions appearing through evolution resulting in appearance of both hydrophilic and lipophilic antioxidants as an indispensable protection against the ubiquitous reactive oxygen- and nitrogen species. Interaction between hydrophilic and lipophilic antioxidants at interfaces often results in synergistic effects important for food stability. Such concerted actions by antioxidants also seem of relevance for human nutrition, but need a more mechanistic description. Non-vitamin antioxidants like the hydrophilic polyphenols including their glycosides thus show synergism through enhancing the lipophilic tocopherols as chainbreaking antioxidants. While this tocopherol/polyphenol synergism seems to be controlled kinetically, the synergism between the lipophilic tocopherols and the lipophilic carotenoids is rather thermodynamically controlled through a regeneration of the carotenoids by the tocopherols. Antioxidant interaction between carotenoids and polyphenols is less investigated and more complex, but may explain the special role of the non-vitamin carotenoids as antioxidants. Carotenoids act as electron donors reducing lipid radicals in membranes subsequently being regenerated at interfaces by hydrophilic polyphenols. Taking distribution phenomena into account, a kinetic description may be possible. Carotenoid radical cations of the less reducing carotenoids like astaxanthin is regenerated faster to form the parent carotenoids showing the importance of the keto group for electron transfer in favour of kinetic control as is further confirmed by linear-free-energy relationships.

Key words: tocopherols, polyphenols, carotenoids, free radical kinetic, synergism

INTRODUCTION

Current nutritional advices include recommendations of a higher intake of polyunsaturated lipids at the expenses of saturated lipids for protection against cardiovascular diseases(1) . Another recommendation is to reduce intake of red meat in order to limit the risk of certain cancers in the digestive tract initiated by heme-iron catalyzed formation of free radicals during digestion(2). Both of these recommendations should, however, also lead to a consideration of a higher intake of antioxidants.

As for an intake of more unsaturated fat through pork from pigs, which had been raised on a feed supplemented with rapeseed oil, it became evident, that total serum cholesterol concentration become significantly lower even in healthy young men having had pork and pork-fat from pigs being raised on the supplemented feed in their diet opposed to a diet based on pork and pork-fat from pigs being raised on a standard feed(3). However, also the plasma α-tocopherol concentration in the healthy young men decreased during the period they had the more unsaturated pork and pork-fat in their diet and needed to be matched by a higher intake of α-tocopherol.

Iron is essential and meat is an excellent source of iron but especially red meat carries the risk of generating aggressive free radicals in the digestive tract. Plant polyphenols will, however, interfere with the catalytic cycle of heme-pigments otherwise generating the free radicals or will scavenge free radicals once formed.

While α-tocopherol is a lipid soluble antioxidant and known as vitamin E, the plant polyphenols, especially their glycosides, are water-soluble antioxidants and have no vitamin function in humans. Other groups of antioxidants are also important components of our diet. Ascorbic acid is the water-soluble vitamin C, and carotenoids are lipophilic non-vitamin antioxidants.

Interaction between antioxidants has increasingly been recognized as important for protective effect against oxidative stress both in food during processing and storage and in the digestive tract during digestion of food and after possible absorption also in body fluids and tissue(4). The four groups of antioxidants as seen in Table 1 opens up for six binary combinations, and the mechanism of their interaction leading both to synergistic and antagonistic antioxidant effects needs further consideration for optimal dietary recommendations and food preservation strategies(5).

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Table 1. 4 groups, 6 binary combinations of antioxidants

	Nutrient	Non-nutrient
Lipophilic:	tocopherols	carotenoids
Hydrophilic:	ascorbic acid	plant phenols

EVOLUTION OF ANTIOXIDANTS

The appearance of oxygen in the atmosphere as the result of photosynthesis initially developed by blue-green algae dramatically changed the conditions for all living organisms(6). Oxygen is thermodynamically a strong oxidant although rather inert unless activated. During the continuing evolution protection against such activated oxygen (and nitrogen) species became necessary. Carotenoids appeared originally for enforcement of membranes but are also efficient quenchers of electronically excited states and scavengers of radicals. Iodide leaking to the sea during erosion of mountains protected light exposed marine life through iodide/ iodine cycling, while polyphenols developed for allelopathy and surface protection of plants also became important as radical scavengers and metal-ion chelators. Tocopherols and tocotrienols secured as lipophilic radical scavengers stability of membranes and longevity of seeds. Protection of aqueous compartments seems to have been linked to diversification in nitrogen excretion with uric acid as an important antioxidant in mammals together with ascorbic acid related to herbivore/omnivorous differentiation(4).

ANTIOXIDANT SYNERGISM IN FOOD

Apolar lipids like the triglycerides are energy-dense and important for energy-storage. Depending on the degree of unsaturation, such lipids are subject to oxidation. The more unsaturated lipids are in general the more vulnerable (marine lipids > plant lipids > lipids from monogastric animals > lipids from ruminant animals).

Lipid oxidation in our food is recognized as rancidity as in fried fatty fish, reheated meat, and in plant oils having been exposed to light. Protein oxidation changes the flavour of milk being exposed to light and makes minced beef less tender and juicy following storage in high-oxygen atmosphere package for preservation of colour and control of microbial spoilage(8,9). Lipid and protein oxidation is also important to our health and involved in development of life-style related diseases. Proper use of natural antioxidants will protect our food and beverages, and a balanced intake of nutrients including natural antioxidants to control and counteract pro-oxidants during digestion is important for our health.

The optimal protection against oxidative stress seems to occur through combined action among the members of the 4 groups of antioxidants resulting in what has been termed antioxidant synergism. Mechanism behind carotenoid/tocopherol synergism has been identified as a sacrificial oxidation of less efficient carotenoids protecting the more efficient tocopherols. Polyphenol/carotenoid synergism is the result of an effective regeneration of carotenoids active as antioxidants in the lipid phase by the water-soluble polyphenols at the lipid/water interface. Polyphenols from herbs and teas protect vitamin E in meat products during cooking and storage. Zinc may protect proteins against oxidation through coordinating to imidazole withdrawing electron density(10).

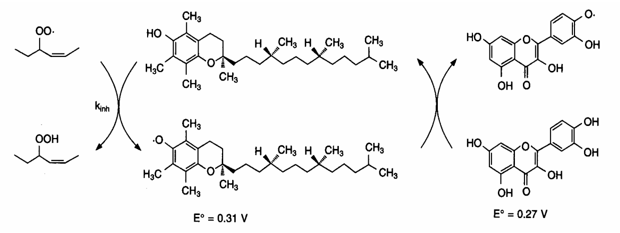

Figure 1. Quercetin, the least effective of the antioxidants, regenerates α-tocopherol, the more effective as an example of thermodynamically controlled antioxidants synergism.

MECHANISMS BEHIND SYNERGISM

In palm oil carotenoids protects the tocopherols and tocotrienols during heating. Carotenoids are becoming depleted during this protection. However, carotenoids does not act as antioxidants alone when added to palm oil completely depleted for possible antioxidants ("stripped oil")(11). Carotenoids does not regenerate tocopherols or tocotrienols from tocopheryl radicals, as shown by fast kinetic methods, and the clear synergistic effect of carotenoids with tocopherol and tocopherols as antioxidants in liposomes (and palm oil) seems to depend on a "sacrificial" oxidation of the carotenoids of the less efficient and less reducing antioxidant protecting the more efficient chain-breaking antioxidants. This effect must be considered kinetic as it depends on a competition between radical scavenging of carotenoids and tocopherols/tocotrienols, while the regeneration is a thermodynamic phenomenon depending on the potentials. It has been demonstrated, that black chokeberry ("aronia") juice, extremely rich in polyphenols, protects α-tocopherol better than black currant juice, rich in ascorbic acid. This effect has been classified as kinetic, since ascorbate is more reducing than the polyphenols present in aronia juice(12). Still the polyphenols react faster with oxidized tocopherol.

Quercetin being more reducing than α-tocopherol has been shown to act synergistic with α-tocopherol as an antioxidant through regeneration of α-tocopherol from its oxidized form in agreement with the ordering of the reduction potentials, see Figure 1(13). Such regeneration also explains the protective effects of herbs and tea extracts on vitamin E in meat products during storage and must be

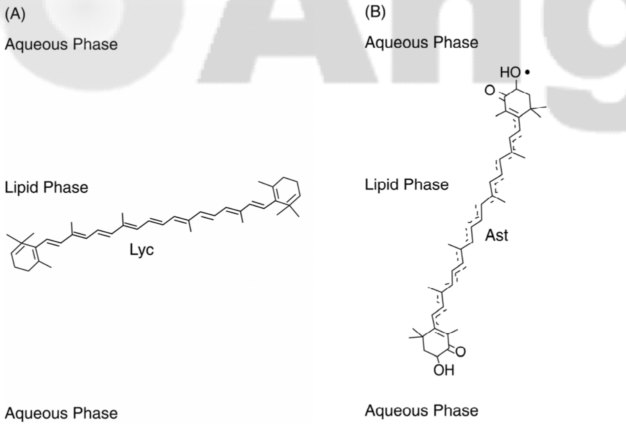

Figure 2. Lycopene and astaxanthin are differently embedded in membranes and astaxanthin may serve as a molecular wire while lycopene is more reducing.

classified as a thermodynamic effect since the regeneration follows the ordering of the reduction potentials[14]. The synergistic effect observed for the carotenoids lycopene and astaxanthin as antioxidants seems also to be in agreement with lycopene being more reducing and lipophilic than astaxanthin (Figure 2) and has been classified as a thermodynamic effect[15].

More mechanistic studies of carotenoids as antioxidants in lipid phases indicate that the carotenoid radical cation may be reduced at lipid/water interfaces by glycosides of plant phenols.

The partition of the polyphenols into the interface determines the rate of regeneration of the carotenoid and in contrast to the carotenoid/carotenoid regeneration in homogeneous phases as seen for lycopene and astaxanthin, the synergistic effect of plant polyphenols on carotenoids as antioxidants is of kinetic nature[16].

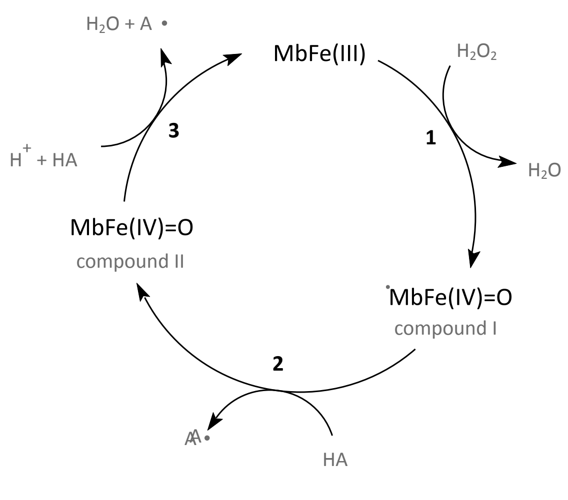

Figure 3. Heme-catalyzed formation of free radicals in relation to digestion of red meat. Polyphenol seems to interfere with the catalytic cycle.

CONCLUSION

Current nutritional recommendations include a low intake of red meat in order to reduce incidence of certain types of cancers. The high content of heme-iron in red meat induces formation of free radicals in the digestive tract, see Figure 3. The radical scavenging efficiency of carotenoids supported by polyphenols, as for example present in green tea, may protect against such oxidative stress induced by heme-iron present in meat. It is time to look for the optimal combinations of antioxidants for protection against free radicals being formed in our food and during digestion of food.

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