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Review Article

More data about Ascorbic Acid as food Additives for Consumer

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Abstract

Ascorbic acid (C6H8O6) is an organic compound belonging to the family of monosaccharide. It is highly soluble in water, and is often called one of the secrets of the Mediterranean diet. Its use is widespread in the food industry is also important, having always been exploited for its antioxidant and stabilising ability. Many indeed are the additive formulations that take advantage of these properties.

Keywords: ascorbic acid; food industry; additive formulations; antioxidant

Introduction

The ascorbic acid (C6H8O6) – better known as vitamin C – is an organic compound belonging to the family of monosaccharide. It is strongly water-soluble and it is often considered as one of the elements that characterises the Mediterranean diet. The diffusion of its use is also most important in the food industry, which has always used its stabilised and antioxidant property. Indeed, there are several formulations of additives that contain ascorbic acid.

One of the most important characteristics of the ascorbic acid is its reducing ability. In the presence of oxygen, ascorbic acid tends to oxidise with a strong result, especially in relation to catalyst metals, removing the environmental resources of oxygen. Furthermore, the ascorbic acid can react with free radicals, arresting the chain reactions that may provoke dangerous effects on organisms, such as neoplastic pathologies of the oral cavity, alimentary system, etc (1-7). It allows maintaining stable other important elements, such as vitamin A, E, folic acid and thiamine in organisms and foods. and it is essential for synthesis of collagen, connective issue's protein, important to heal wounds, sores and lesions, and to the prevention of hemorrhages. In addition to prevent the onset of the atherosclerosis, vitamin C contributes to the development of the adrenaline and the endogenous serotonin and to the hydroxylation of aromatic compounds in the liver. It operates in processes of the cellular defense, facilitates the intestinal absorption of the iron and the elimination of toxic heavy metals (such as cadmium, nickel and lead) with which it is able to tie. Its action is also important in the synthesis of the carnitine in the zymotic transformation of the cholesterol in bile acid or in vitamin D (8-15). The use of the ascorbic acid is important, especially in production activities of the ground meat and cold cuts. In meat and ground meat the ascorbic acid prevents the oxidation and the discoloration of the product during the storage. This effect delays the appearance of an abnormal coloration that could be unpleasant to the consumer but it is not associated to the organoleptic alteration of the product. The use of the ascorbic acid in meats, with the addition of nitrites, is important for the activity of reduction dependent upon nitrousmetamyoglobin-Fe (III) converted into nitrousmetamyoglobin-Fe (II), which maintains the colour of the product most brilliant. Furthermore, the ascorbic acid prevents the development of nitrosamines (16-22). The unauthorised use of the ascorbic acid as additive in the preparation of ground meat is often object of control by the competent authorities, with official samples. Whether the result of the laboratory analysis, made at the Institutes for Experimental Veterinary Medicine will be positive, the food business operator (FBO) will be indicted for the misdemeanor.In the preparation of food and drink is banned using, selling, possessing to sell the ascorbic acid or administers it like compensation of employees or distributes it to the consumption of food substances with the addiction of not authorized chemical additives, under the decree of the Minister of Health or, whether they would be authorized, without the compliance of required rule of law for their use (23-29).

Discussion:

Ascorbate is one of the most important vitamins in the human diet, being obtained largely from vegetables, fruit, and other plant material. Green leaves may contain as much ascorbate as chlorophyll. The presence of such a remarkable amount of ascorbate may suggest considerable metabolic significance, particularly if the amount is related to biological importance. Glutathione peroxidase, which is important in H2O2 detoxification in animals is largely absent from plant tissues. Seasonal variations in the ascorbate content of leaves have been found; on the whole, the ascorbate pool in chloroplasts and leaves is maintained at a remarkably constant level. Oxidation of ascorbic acid occurs in two sequential steps, forming, in the first instance, monodehydroascorbate, and subsequently dehydroascorbate. The monodehydroascorbate radical spontaneously disproportionates to ascorbate and dehydroascorbate. The conversion of glucosone and sorbosone to ascorbic acid has been observed in bean and spinach leaves (30-36).

Ascorbic Acid Sources

Ascorbic acid is synthesized from glucose and is soluble in water. Most animals cannot synthesize ascorbic acid endogenously, but poultry, animals can synthesize it due to the L-gulonolactone oxidase enzyme, which is available in the animals' body. This enzyme is available in the kidney tissue where L-gulono-g-lactone is converted into ascorbic acid by the L-gulonolactone oxidase enzyme. In birds, ascorbic acid is produced in the kidney, while in mammals, it is produced in the liver. Ascorbic acid can be found in natural plants or synthesized through industrial processes. For plants, ascorbic acid is found from rose hips and sea buckthorn as the richest resource. Furthermore, other fruits such as guava, star fruit, black currant, strawberry, and kiwi also contained a high amount of ascorbic acid. As we know, citrus fruits such as orange, lime, grapefruit, and so on contain ascorbic acid. Thus, the ascorbic acid content of the latter is much less than the former. The amount of ascorbic acid per fruit is shown in . This table shows that guava, cashew apple, and sea buckthorn contain high ascorbic acid levels (37-43). An ordinary diet of natural and synthetic ascorbic acid is the only way to maintain the physiological requirements. The well-known symptom of ascorbic acid deficiency is associated with connective tissue damage, such as scurvy, which is characterized by fragile tissues and poor wound healing. The currently recommended dietary allowances (RDA) for ascorbic acid are 90 mg/day and 75 mg/day for men and women, respectively. Researchers have found that the steady-state concentration of ascorbic acid in plasma is about 80 μmol/L, when sufficient fruits and vegetables are consumed every day. Oral dosing of ascorbic acid (1.25 g) can improve the concentration of ascorbic acid in plasma to 134.8 ± 20.6 μmol/L. In order to maintain the ascorbic acid concentration required by the body, ascorbic acid-fortified dietary supplements or foods have attracted interest from consumers, in addition to fruits and vegetables found in nature (44-50). The main challenge in the development of ascorbic acid products is its high instability and reactivity. Ascorbic acid is reversibly oxidized into dehydroascorbic acid (DHA) upon exposure to light, heat, transition metal ions and pH (alkaline condition), then DHA further irreversibly hydrolyzes to form 2,3-diketogulonic acid. In recent decades, the strategy of shielding ascorbic acid from sensitive environments by encapsulating ascorbic acid within a layer of wall material has attracted much interest among researchers. A series of innovation delivery technologies have emerged, including microfluidic, melt extrusion, spray drying and chilling. The particles prepared by these methods are usually on the microscale. Under certain conditions, nano-encapsulation of ascorbic acid can be realized through ion gelation of chitosan or complex coacervation with anionic polymers. On the other hand, some bioactive compounds with low molecular weight can protect ascorbic acid by scavenging the pro-degradation factors of ascorbic acid in the solution (51-57).

Bioactivity of Ascorbic Acid

Antioxidant

The by-products of normal cell metabolism are reactive oxygen species (ROS), including superoxide radicals ($O2\cdot-$), singlet oxygen (1O2), hydrogen peroxide (H2O2) and highly reactive hydroxyl radicals ($OH\cdot$). The adverse effect of ROS is that it can initiate a cascade of radicals, producing hydroxyl free radicals and other destructive species. These further induce protein and DNA damage, lipid peroxidation and finally lead to cell apoptosis.The antioxidant defense system cannot fully eliminate the toxic ROS accumulated in the cells, that is, the so-called “oxidative stress” occurs . In addition to enzymatic reactions, ROS can also be eliminated through non-enzymatic means such as antioxidants. Ascorbic acid is a free radical and other oxygen species scavenger, which can protect cells from oxidative damage caused by ROS. Antiradical capability commonly reflects the antioxidant ability, and ascorbic acid in foodstuff and bio-systems acts as antioxidant. As the most effective and natural antioxidant with the least side effects, ascorbic acid can inhibit various diseases caused by oxidative stress in the body, such as cancer, cardiovascular disease, aging and cataracts (58-64). Studies have shown that the mortality from these diseases is inversely related to plasma concentration of ascorbic acid. Ascorbic acid and its derivatives can reduce the level of lipid peroxidation in vivo due to aging. In the absence of transition metals, ascorbic acid can reduce the frequency of mutations induced by H2O2 in human cells. Compared with other polyphenols or flavonoid antioxidants, ascorbic acid terminates the free radical chain reaction through disproportionation reaction, and the reaction products such as DHA and 2,3-diketogulonic acid.are non-damaging and non-radical products. Another manifestation of antioxidant property is that ascorbic acid can form relatively stable ascorbic acid free radicals to donate single electrons. As reported, antioxidants can also repair tryptophan free radicals produced by the one-electron oxidation of free tryptophan in lysozyme to maintain protein integrity (65-71). Ascorbic acid is also used as an antioxidant to protect the sensory and nutritional properties of foods. As an anti-browning agent, it can inhibit the browning of vegetables and fruits caused by oxidation. The formation of quinones mediated by polyphenol oxidase causes the accumulation of H2O2, which in turn causes the browning of polyphenols mediated by peroxidase. Ascorbic acid inhibits browning by reducing the o-quinone produced by polyphenol oxidase to the original diphenol through a process called “deactivation reaction”. In addition to the regeneration mechanism of polyphenols, the protective effect is also attributed to the competitive inhibition of polyphenol oxidase activity by ascorbic acid. Meanwhile, addition of ascorbic acid causes a decrease in pH and is not conducive to the expression of polyphenol oxidase activity (72-78). In meat products, ascorbic acid is widely used as a natural agent for color retention, which can inhibit lipid oxidation and maintain color stability. Compared with other organic acids such as malic acid, citric acid and tartaric acid, ascorbic acid had the best protective effect on the quality of cured meat and was a suitable ingredient for cured meat products. The surface of the pork sprayed with ascorbic acid and a mix of that and rosemary extract maintained good stability in color, water content and pH after frozen storage. It is worth noting that this dietary source of ascorbic acid added in meat products is often overlooked. Norwegian researchers found that the content of ascorbic acid in sausages is 11–40 mg/mL, but ascorbic acid is usually ignored in the table of food ingredients because the added ascorbic acid is used as a color retention agent rather than a nutrient component. As a result, the actual ascorbic acid intake of Norwegian residents increased by 3–10%. The ascorbic acid added to the edible polysaccharide film can eliminate or quench the free radicals generated by radiation (79-85). As a radiation inhibitor, ascorbic acid can inhibit the decrease in the viscosity of carrageenan caused by radiation and protect its rheological properties. Ascorbic acid can inhibit food-borne pathogens in the early stage of biofilm formation due to its anti-quorum sensing activity and inhibition of extracellular polymer production. The efficacy of ascorbic acid is related to its concentration and the strain. For Escherichia coli and Staphylococcus aureus, the inhibitory effect of ascorbic acid at 25 mg/mL is the greatest, and lower concentrations of ascorbic acid are ineffective. For Listeria monocytogenes, ascorbic acid at 0.25 mg/mL shows an inhibitory effect (86-92).

Pro-Oxidant

Pro-oxidant activity is defined as the ability of antioxidants to reduce transition metal ions to a lower oxidation state, which refers to the Fenton reaction. In the Fenton reaction, transition metal ions such as Fe3+ are reduced by ascorbic acid and then Fe2+ further react with oxygen and hydrogen peroxide to form highly active and destructive hydroxyl radicals’ Ascorbic acid does not always express antioxidant activity, and may be converted into a pro-oxidant and show toxic effects under certain conditions. The effect of ascorbic acid on the redox properties of bovine hemoglobin is dual with an antioxidant effect at the initial stage of the reaction. During the reaction process, ascorbic acid generates hydrogen peroxide under the mediation of oxygen or oxygenated hemoglobin (93-99). With the consumption of ascorbic acid, its own scavenging ability cannot balance the accumulated hydrogen peroxide, which leads to the formation of bilirubin and accelerates the oxidation of hemoglobin . Studies have shown that ascorbic acid will transform from an antioxidant under physiological conditions to a pro-oxidant at higher concentrations. Researchers found that supplementation of 500 mg of ascorbic acid in the diet for 6 weeks increases the level of oxidative damage to peripheral blood lymphocytes, although this result is still controversial in the academic community (100-106). Furthermore, the presence of transition metal ions in the system is also a key factor for ascorbic acid exerting pro-oxidant activity. In mayonnaise, the added ascorbic acid works as a lipid antioxidant or pro-oxidant depending on the presence or absence of the fat-soluble antioxidant vitamin E. In the system containing vitamin E, the synergistically antioxidant effect of these two vitamins is stronger than the pro-oxidant effect of ascorbic acid. Without the addition of vitamin E, the hydrogen peroxide at the interface of the oil droplets promotes the lipid oxidation of lipoprotein particles in the mayonnaise, which in turn induces the oxidation of apolipoproteins and produces volatile odors (107-113). In addition, dehydroascorbic acid may irreversibly degrade and produce highly reactive carbonyl intermediates, which can induce glycosylation of proteins. This is a non-enzymatic, non-specific reaction between carbonyl and amino groups, which is involved in a variety of age-related diseases. It is worth noting that the pro-oxidation of ascorbic acid can induce the apoptosis of cancer cells, thereby exerting anti-cancer effects to a certain extent. As reported, the copper-dependent cellular redox state is an important factor in the cytotoxic effect of ascorbic acid on cancer cells. Ascorbic acid mobilizes nuclear copper to cause pro-oxidative cleavage of cellular DNA, and nuclear copper serves as a new molecular target for the toxic effects of cancer cells. From this perspective, the pro-oxidation effect of ascorbic acid is beneficial (114-120). Up to now, the mechanism and conditions that induce ascorbic acid to express pro-oxidant properties have not been clearly elucidated, and the definition of the conversion concentration between antioxidant and pro-oxidant is also unclear. Moreover, most of the reports on the promotion of oxidation of ascorbic acid are concentrated in vitro (121-127).

Co-Factors

Ascorbic acid can also be used as a co-factor for enzymes and other bioactive components to indirectly exert biological activities by acting as a free radical scavenger and electron transfer donor/acceptor to directly express its antioxidant properties. In the metabolic process of animals and plants, ascorbic acid does not directly participate in the catalytic cycle. As an enzyme co-factor, ascorbic acid exerts its indispensable function by regulating hydroxylation processes in multiple enzymatic reactions (128-134). For the active part of the enzyme with iron or copper, the role of ascorbic acid is to maintain the transition metal ions of these enzymes in a reduced form to exert their maximum physiological activity. Ascorbic acid is a co-factor for non-heme iron α-ketoglutarate-dependent dioxygenases such as prolyl 4-hydroxylase with the role in the synthesis of collagen. As an electron donor, ascorbic acid can keep iron in the ferrous state, thereby maintaining the full activity of collagen hydroxylase (135-141). This promotes the hydroxylation of proline and lysine residues, allowing pro-collagen correct intracellular folding. Ascorbic acid can also promote catecholamine synthesis by circulating tetrahydrobiopterin and enhance adrenal steroid production by increasing the expression of tyrosine hydroxylase. As a co-factor, it helps dopamine β-hydroxylase convert dopamine to norepinephrine. In addition, ascorbic acid can regulate cardiomyopathy and neurometabolic diseases. For example, as a co-factor for carnitine synthesis, it can shuttle fatty acids into the mitochondria and reduce oxidative stress. In some clinical situations, as a co-factor for the biosynthesis of amidated opioid peptides, taking ascorbic acid can exhibit analgesic effects (142-148).

Synergistic Effect

As a natural antioxidant, ascorbic acid mostly exists in the form of coexistence with other components in nature. Combining it with other antioxidants may produce additive or even synergistic effects. Ascorbic acid and vitamin E, as chain-scission antioxidants, have an important inhibitory effect on the auto-oxidation of cell membrane polyunsaturated liposomes in vivo and the oxidation of lipids in vitro. Studies have shown that the combination of 15% ascorbic acid and 1% α-tocopherol can significantly inhibit erythema and the formation of sunburn cells. The synergy between α-tocopherol and ascorbic acid relies on the ability of ascorbic acid to regenerate α-tocopherol, and maintain the antioxidant capacity of α-tocopherol through circulation and inhibition of pro-oxidation. The combined use of ascorbic acid and gallic acid is a promising strategy to prevent the formation of advanced glycation end products, showing the synergistic effect in the inhibition of amyloid cross-β-structure and protein carbonyl formation in fructose-induced BSA glycosylation samples. Lycopene can inhibit inflammation and further stimulate the release of anti-inflammatory cytokine IL-10 when it combined with ascorbic acid and/or α-tocopherol. Understanding the synergy between ascorbic acid and other bioactive compounds allows the antioxidant system of foods and drugs to be selected more specifically (149-155).

Sensitivity to Environment:

Concentration and pH:

Ascorbic acid is unstable in aqueous solutions, and its degradation has been considered the main cause of quality and color changes during food storage and processing. Stability analysis of ascorbic acid is a key point in its application. In addition to the interference of external factors, the concentration of ascorbic acid in the solution will also affect its stability. As reported, after storage at room temperature in the presence of light for 27 days, an aqueous solution of 1% concentration of ascorbic acid lost around 21% of its initial concentration, while the 10% ascorbic acid system only degraded about 8%. In order to ensure sufficient content of ascorbic acid in the product, reinforcing the ascorbic acid content is a method commonly used in the food industry. The content of ascorbic acid in fortified milk decreased from 36.4 mg/L to 26.1 mg/L after sterilization, while the ascorbic acid content of normal milk dropped from 12.2 mg/L to 8.3 mg/L. Although the loss content of ascorbic acid increased with the addition of ascorbic acid, the loss efficiency decreased compared with the initial concentration of ascorbic acid. According to the stability and the degradation kinetics of ascorbic acid, a higher concentration of ascorbic acid has a lower degradation rate constant. However, some studies have shown that excessive ascorbic acid (AH2) is prone to auto-oxidation to produce dehydroascorbic acid anions (156-162).

Temperature

Ascorbic acid is severely degraded by heat, and the instability of ascorbic acid in thermal-processed foods impedes its application. The degradation of ascorbic acid involves complex oxidation and intermolecular rearrangement reactions, and is considered to be one of the main reasons for quality and color changes during food processing and storage. From an analysis of the effects of temperature and pressure on the retention of ascorbic acid in processed juices, it revealed that the dominant factor determining the stability of ascorbic acid is the temperature, which directly affects the degradation rate of ascorbic acid. Products containing ascorbic acid, such as fruit juice, need to undergo high-temperature pasteurization in order to guarantee safety and stability. The content of ascorbic acid in fresh orange juice ranges from 25–68 mg/100 mL. Studies have shown that the retention of ascorbic acid in the product after pasteurization (90 °C, 1 min) is about 82–92%. It was observed that the maximum temperature of the ultra-high pressure homogenization treatment at 100, 200 and 300 MPa was 45 °C, 70 °C and 94 °C, respectively, and the continuous treatment time under the maximum temperature was 0.7 s or less. The loss of ascorbic acid in the ultra-high pressure treated juice is less than that in the traditionally heat-pasteurized juice. As detected, the content of ascorbic acid in guava juice was around 42.2 ± 0.01 mg/mL. After 7 days of storage at 25 and 35 °C in the dark, ascorbic acid was degraded by 23.4% and 56.4%, respectively. Its degradation is significantly reduced at 4–10 °C. The use of relatively mild temperature (75 °C) for heat treatment and a storage temperature below 25 °C is optimal for maintaining the ascorbic acid content of the product. The degradation of ascorbic acid during storage and heat treatment follows first-order kinetics based on a classic dynamic model (163-169).

The degradation or oxidation products of ascorbic acid heated at 100 °C for 2 h include furfural, 2-furoic acid, 3-hydroxy-2-pyrone and an unknown compound. Among them, furfural is one of the main degradation products of ascorbic acid, which can polymerize or combine with amino acids to form brown melanoids, causing the browning of ascorbic acid-containing juice products. Furthermore, thermally oxidized ascorbic acid was identified as a potential precursor of furan; it is a possible carcinogen usually produced in some heated food products. Meanwhile, natural and synthetic antioxidants, such as chlorogenic acid, have a certain mitigation effect on the formation of furan induced by heated ascorbic acid, but the mitigation effect may decrease with the increase in heating time. In addition, the thermal degradation process of ascorbic acid is also affected by pH, oxygen concentration, transition metal ions and oxidases, which is a complex system. Some researchers in food science believe that oxygen saturation decreases with increasing temperature and drops to 0 at 100 °C. However, according to the Tromans and Battino model, although 100–130 °C is the minimum oxygen solubility temperature, there is still dissolved oxygen in the system. At temperatures above 100 °C, oxygen has a greater effect on ascorbic acid degradation than temperature. Therefore, removing all oxygen including dissolved oxygen is the best way to preserve ascorbic acid at high temperatures (170-176).

Light

In addition to heat-treatment sterilization, ultraviolet radiation (240 nm–300 nm) is a promising alternative and is gradually being used more for fruit juice sterilization. The ultraviolet sterilization method includes the use of high-intensity pulsed ultraviolet radiation with wavelengths between 200 and 400 nm and a monochromatic ultraviolet system of which approximately 90% of the energy comes from a single wavelength. However, ascorbic acid absorbs ultraviolet radiation in the wavelength range of 229–330 nm and undergoes degradation. The formation of UV-induced free radicals may accelerate the loss of ascorbic acid. Ascorbic acid continues to degrade after UV treatment; higher initial UV dose values and storage temperature accelerate the degradation of ascorbic acid in the later stage. In addition, the pH of the solution also affects the photo-degradation of ascorbic acid. Under alkaline conditions, AH- produced by ionization of AH2 is more prone to photo-degradation than AH2 . It is worth noting that the ingredients in products may absorb or scatter UV radiation, thereby affecting the degradation of ascorbic acid. Niacinamide, as a component of vitamin B-complex with vitamin C, acts as a photo-degradation accelerator to reduce the stability of ascorbic acid under UV-irradiation (177-183).

Commercial Application of Ascorbic Acid:

Based on the afore-mentioned biological activity of ascorbic acid, ascorbic acid is mainly used as an antioxidant to inhibit food browning and as a dietary supplement for humans. Ascorbic acid is mainly used as an antioxidant to protect the senses of foods. As is well known, polyphenol oxidase catalyzes the enzymatic browning of phenol substrates to yield dark-colored melanin. Browning affects product sensory qualities and reduces consumer acceptance. Adding xyloglucan microcapsules containing ascorbic acid to baked foods such as tilapia fish burgers can significantly inhibit the browning that occurs during the preparation process and maintain the sensory qualities of the product. The chitosan/tripolyphosphate nano-aggregates containing ascorbic acid enhanced the inhibition of mushroom slices browning induced by tyrosinase. Acute heat stress during transport is known to predispose rainbow trout quality to deterioration, with negative effects on the histological, physicochemical and microbiological quality of fillets. Treatment with added ascorbic acid partially mitigated damage caused by acute heat stress. It can maintain tissue structure, delay protein oxidation and then prolong the shelf life of fish fillets to about 2 days. In addition, as a nutritional supplement, ascorbic acid plays an important role as a co-factor in many biological processes. Unfortunately, fishes lack L-gluconolactone oxidase and cannot biosynthesize ascorbic acid by themselves, which is not conducive to the growth of their bone matrix and connective tissue. Lack of ascorbic acid can cause reduced wound-healing capacity and bone deformities in fish. At present, in the aquaculture area, ascorbic acid is widely added to fish diets. Based on the healthcare function of ascorbic acid, it is also vital in nutrition fortification products. As an important source of protein supplementation, dairy products are popular beverages all over the world. At present, milk and soymilk have been fortified with ascorbic acid, including ascorbate and ascorbic acid isomers, to improve the iron absorption in the small intestine. Food fortification can improve micronutrient malnutrition. It is worth noting that a category of foods tailored according to the necessary nutrients for a healthy life and their specific concentrations and ratios are called designer foods, also known as health foods, and are sought after and recognized by consumers. Such products often contain a variety of bioactive compounds. By adding calcium and antioxidants such as vitamins E and C to low-fat chicken patties, a high-quality product with high-quality animal protein, fat, multivitamins and minerals can be prepared. Ascorbic acid not only acted as a nutritional additive, but also maintained better color and flavor of chicken patties, and inhibited the formation of nitrosamines in the meat. The addition of sodium ascorbate and vitamin A to pig feed can significantly improve the growth performance, antioxidant capacity and immune function of weaned piglets. Meanwhile, as an antioxidant, sodium ascorbate can delay the degradation of vitamin A. A cornstarch-based baking premix was developed by addition of vitamin B, vitamin C and digestible iron, zinc, selenium and iodine. Although the added ascorbic acid in the baked bread degraded due to high temperature, it strengthened the structure of the bread and was benefit to product quality. Meanwhile, it was found that the combination of butylated hydroxytoluene and ascorbic acid significantly inhibited the oxidation and isomerization of vitamin A in skim milk powder during thermally accelerated storage. There are two major aspects in the current development of ascorbic acid-fortified products. On the one hand, the natural ascorbic acid is directly added, in order to use its antioxidant activity to maintain the sensory appearance of the product during the shelf life. The cost is low, but the retention activity of the final product is low. Another aspect is the addition of ascorbic acid derivatives, which is to ensure that sufficient physiological activity can be expressed after ingestion of the product. However, the cost of ascorbic acid derivatives is high, and they need to be converted before they can exert their functional properties. Although various delivery technologies are available, they are still in the developmental stage of industrial transformation and have not been widely used. Combined with the above analysis of delivery strategies, these may be limited by the cost of wall materials, and the complexity of the process, which is not suitable for large-scale industrial production. Therefore, researchers still need to explore low-cost, simple, and high-yield encapsulation techniques of ascorbic acid for industrial application (179- 184).

Conclusions:

In this review, the bioactivity and stability of ascorbic acid are introduced. There are many strategies for improving the bioavailability of ascorbic acid, and the influence of delivery systems on the stability and release properties of ascorbic acid is discussed. Besides the addition of low-molecular-weight antioxidants and preservatives, encapsulation technology is more and more widely used in the food field. The stabilization mechanism includes chemical chelation and physical barrier. Since the positively charged chitosan can interact with ascorbic acid through electrostatic interaction and hydrogen bond, it is the most superior carrier material. The complex system is mostly in the form of nano-sized particles. On the other hand, biomacromolecules can construct microcapsules with coatings through a series of technologies, such as spray drying, microfluidic technique and complex coacervation. The physical barrier restricts ascorbic acid within the inner core, reducing the contact between it and the external environment. The two mechanisms have their own limitations. For example, chemically complexed nanoparticles are beneficial to the absorption by mucosal membranes, but the encapsulation efficiency of ascorbic acid is low and ascorbic acid is accessible to solvent. The coating of the microcapsules can effectively shield the inner ascorbic acid from external environment, but the operation is more complicated and requires the assistance of a variety of equipment. In addition, the larger size and poor water-solubility of the microcapsules limit the absorption in the body to a certain extent. Therefore, understanding the pro-degradation factors of ascorbic acid and its properties are conducive to the targeted design of delivery systems. Adopting low-cost methods to design an effective fortification strategy to improve the stability of ascorbic acid during processing and storage is still the focus and challenge for researchers.

Conflicts of Interest

The authors declare no conflicts of interest.

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