KOREAN J. FOOD SCI. ANI. RESOUR. Vol. 25. No. 1, pp. 60~65(2005)

Antioxidant and Bioactive Films to Enhance Food Quality and Phytochemical Production during Ripening

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Abstract

Antioxidant films are one active packaging technology that can extend food shelf-life through preventing lipid oxidation, stabilizing color, maintaining sensory properties and delaying microbial growth in foods. Because raw, fresh and minimal processed foods are more perishable during storage or under display conditions than further processed foods, they rapidly lose their original quality. Foods are susceptible to physical, chemical, and biochemical hazards to which packaging films can be effective barriers. Although films incorporated natural (tocopherols, flavonoids and phenolic acids) or synthetic antioxidants (BHT, BHA, TBHQ, propyl gallate) have been extensively tested to improve quality and safety of various foods, food applications require addressing issues such as physical properties, chemical action, cost, and legal approval. Increased interest in natural antioxidants as substitutes for synthetic antioxidants has triggered research on use of the new natural antioxidants in films and coatings. Use of new components (phytochemicals) as film additives can improve food quality and human health. The biosynthesis of plant phenolics can potentially be optimized by active coatings on harvested fruits and vegetables. These coatings can trigger the plants natural proline-linked pentose phosphate pathway to increase the phenolic contents and maintain overall plant tissue quality. This alternate metabolic pathway has been proposed by Dr. K. Shetty and is supported by numerous studies. A new generation of active food films will not only preserve the food, but increase food's nutritional quality by optimizing raw food biochemical production of phytochemicals.

Key words : antioxidant, bioactive films, phytochemicals

Introduction

Consumers have many food choices and their demand for safer and higher quality "natural" foods has been increased. The entire food production process has a part in providing a more delicious, safe, and healthy food than in the past. Packaging plays an important role in maintaining quality and improving storage properties such as color, flavor, odor, microbial growth and texture. In general, most foods are packaged to preserve their quality. Films are important for safety since they come in direct contact with foods and the concept of packaging as only protection is gone. Now, packaging films play an active role in food preservation because it is possible to add physical, chemical, biochemical and microbial modulators to films. Active packaging has been defined as a type of packaging that changes packaging conditions to extend shelf-life, improve safety or maintain sensory properties of food (Quintavalla and Vicini, 2002) and includes MAP (modified atmosphere packaging), antioxidant packaging, and other functional components. There is new interest in antioxidant films and in finding new potential antioxidant components. If more effective antioxidants can be successfully applied in films, another useful barrier can be created against oxidation, decomposition and deterioration of foods. We propose the development of a new generation of active films and coatings. Current active packaging slows deterioration changes in food. The next generation of coatings will modify the biochemistry of raw foods to increase the

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concentration of positive health factors such as phenolic antioxidants.

Types of Antioxidants

Antioxidants can be divided into synthetic and natural antioxidants. Typical synthetic food antioxidants are butylated hydroxyanisol (BHA), butylated hydroxytoluene (BHT), tertiary butylhydroquinone (TBHQ) and propyl gallate are under strict regulation and new toxicological data impose some caution in their use (Thompson and Moldeus, 1988). Natural antioxidants have advantages since they are perceived as more healthier and safer than synthetic antioxidants. In addition, due to their variety and functional attributes more research is focused on natural antioxidants. Different from synthetic antioxidant, it is hard to define natural antioxidants because they are found in almost all plants, microorganisms, fungi, and even in animal tissues. The majority of natural antioxidants are phenolic compounds and the most potent groups of natural antioxidants are the tocopherols, flavonoids and phenolic acids (Yanishlieva-Maslarova, 2001).

Mechanism of antioxidant activity

According to Pokorny (2001), fats, oils and lipid-based foods deteriorate through several degradation reactions accelerated by heating and problematic under long term storage. The main deterioration processes are oxidation reactions and decomposition of oxidation products which result in decreased nutritional value and sensory quality. Oxidation may be inhibited by various methods including prevention of oxygen access, use of lower temperature, inactivation of enzymes catalyzing oxidation, reduction of oxygen pressure, and use of suitable packaging (Table 1). Another oxidation protection method is the use of specific additives which inhibit oxidation. These are correctly called oxidation inhibitors, but are now called antioxidants. The most important mechanism is their reaction with lipid free radicals. Antioxidant activity depends on many factors such as the lipid composition, antioxidant concentration, temperature, oxygen pressure, and the presence of other antioxidants and many common food components. One of main reasons for deterioration of food quality is the oxidation process.

Antioxidant Films & Coatings

To improve or maintain food safety and quality during ripening, active packaging can be applied for two goals (Fig. 1);

1) Active packaging that releases antioxidant (AO) to food to slow oxidative reactions thus extend shelf life

2) Active packaging that release elicitors to food that optimizes ripening and the food's production of phenolic antioxidants

Table 1. Mechanism of antioxidant activity (Pokorny, 2001)

Antioxidant class	Mechanism of antioxidant activity	Examples of antioxidants
Proper antioxidants	Inactivating lipid of free radicals	Phenolic compounds
Hydroperoxide stabilizers	Preventing decomposition of hydroperoxides into free radicals	Phenolic compounds
Synergists	Promoting activity of proper antioxidants	Citric acid, ascorbic acid
Metal chelators	Binding heavy metals into inactive compounds	Phosphoric acid, Maillard compounds, citric acid
Singlet oxygen quenchers	Transforming singlet oxygen into triplet oxygen	Carotenes
Substances reducing hydroperoxides	Reducing hydroperoxides in a non-radical way	Proteins, amino acids

Application of Antioxidant Films and Commercialization

Due to the complexity of food, many factors influence the type of film and coating material to be used, including intrinsic food properties (pH, water activity, and composition) and extrinsic factors (temperature and relative humidity in processing and storage conditions) (Krochta and Franssen, 2002). These factors may interact during processing or storage to give unexpected results. Due to the unpredictability of these interactions, commercialization of potential antioxidants in package materials and film forming is difficult. Packaging films incorporated with antioxidants can extend the shelf life of various foods such as beef, pork, poultry, cheese, fish, bakery, cereal, fruit and vegetables. Because antioxidants can prevent or delay lipid peroxidation by binding iron ions and by stabilizing heme compounds, thereby stabilizing color, flavor and sensory properties. For example, LDPE films with 0.1% BHA added resulted in higher "a" (redness) values in fresh beef compared to beef in control and other treated (BHT, rosemary extract and α-tocopherol) films by day 8 and 9 (Moore et al, 2003).

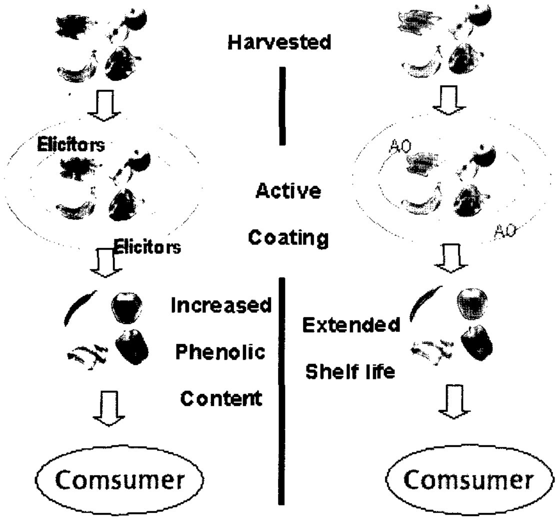

Fig. 1. Model of antioxidant films and coatings.

Film Formation Methods and Migration of Antioxidants

According to Quintavalla and Vicini (2002), there are two common methods to incorporate components during film formation. The component can be placed into the film by addition to the extruder when the film is produced. The disadvantage of this method is poor cost effectiveness since active components not exposed to the surface of the film are generally rendered inactive. An alternative to extrusion is to apply the active component in a controlled manner where the material is needed; for example, it can be incorporated into the food-contact layer of a multilayer packaging material. Also, active films can be classified in 2 types by migration methods : (1) those that contain an active agent that migrates to the surface of the food, and (2) those that are effective without migration (Suppakul et al, 2003). While much of the research has been done with antimicrobials, the antioxidants can be treated in the same manner. Active substances

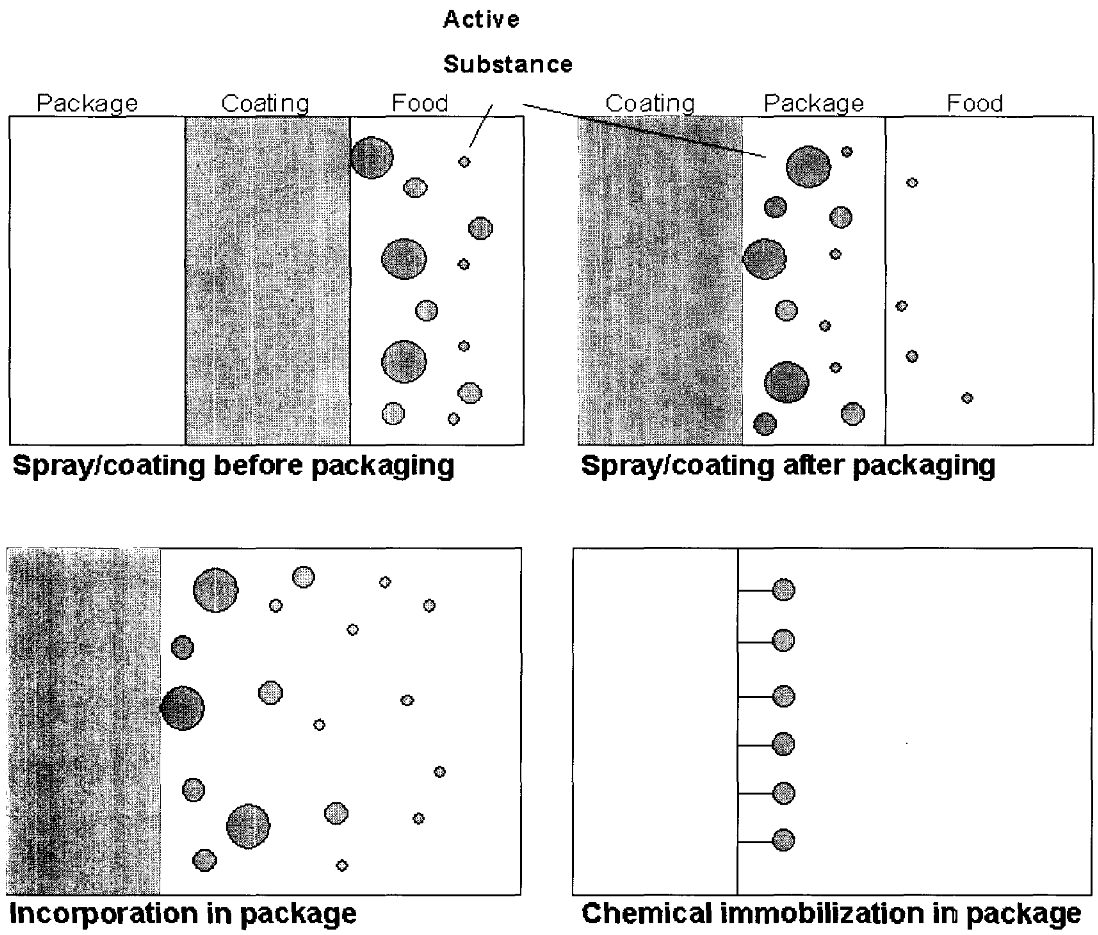

Fig. 2. Migration of active substance (Han, 2000).

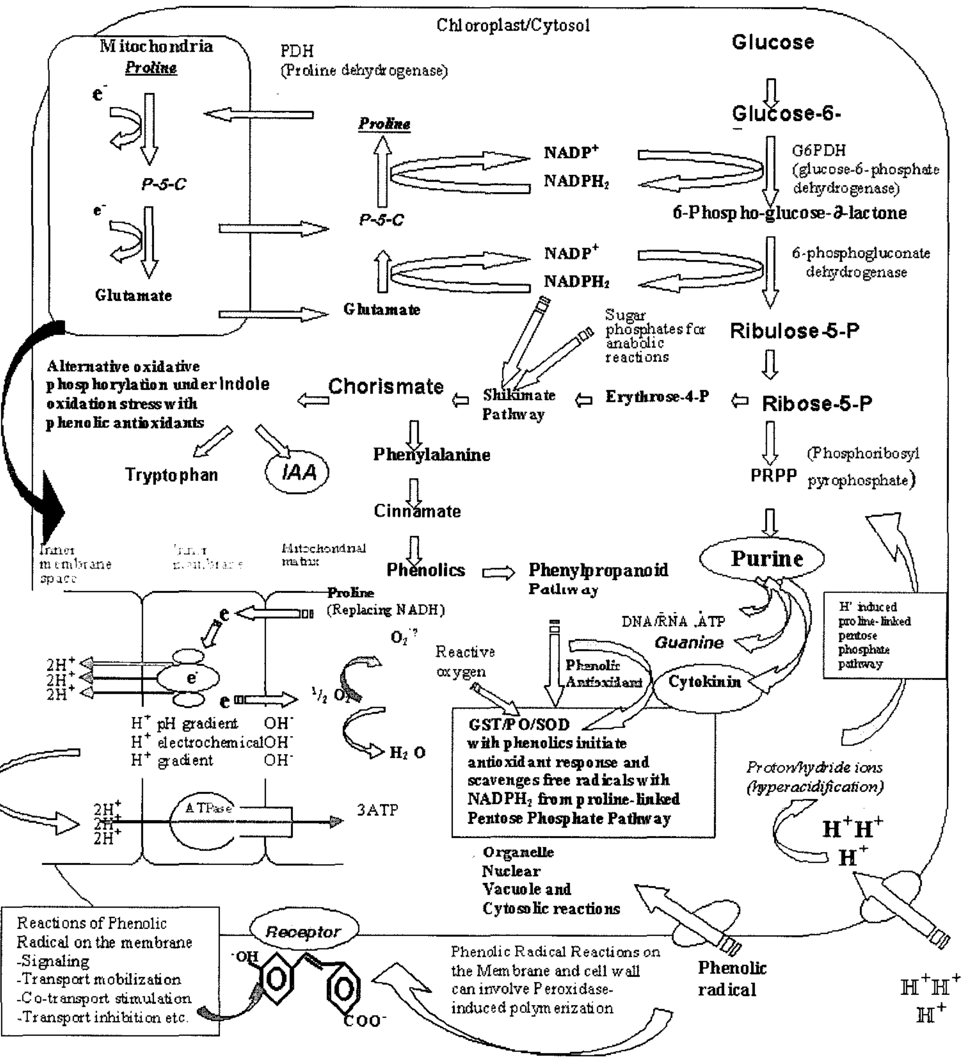

Fig. 3. Model for the role of proline-linked pentose phosphate pathway in regulating phenolic biosynthesis in plants, which also accommodates the mechanism of action of external phenolic phytoemicals (Shetty, 2004).

(antimicrobial or antioxidant components) can be added by different methods such as spray/coating before and after packaging, incorporation of active substances and chemical immobilization after which substance can migrate to foods at different rates (Fig. 2). Chemical immobilization can be performed by a non-food-agent. For successful application of antioxidant films with foods, various factors are to be considered such as water activity, pH, temperature, chemical interaction with film matrix, physical properties of packaging material, cost and FDA approval.

Conclusion

To apply or correctly use antioxidant and bioactive packaging films against lipid oxidation and quality deterioration of foods, intrinsic and extrinsic factors of applicable foods affect to packaging materials must be measured. Because foods have different chemical and biological properties such as pH, water activity, carbon source, nitrogen source, partial pressure of oxygen, and temperature (Han, 2000). It is necessary to investigate a films various material properties (heat resistance, moisture resistance, elongation, thickness, gas permeability), mass transportation activity, migration rate and diffusivity. Interactions between packaging films and antioxidants and elicitors or whether the interaction affects original properties of foods will also be considered. After verifying the interaction *in vitro* & *in vivo* without film malfunction, the film can be recommended for commercialization. A precise determination of standard activity such as concentration of antioxidants or its bioactivity in foods is needed to ensure high quality, increasing phenolic phytochemicals and safe foods in future markets. Research on new antioxidant and bioactive films can deliver safer and healthier foods to the table in the future.

Future Plan

Although there are abundant researches on the effects and mechanism of discovered antioxidants in food systems, there is need to develop and apply new antioxidant components to improve food quality. Phytochemicals can be one of new developing components for film additives. Because phytochemicals have various functions such as anti-oxidation, anti-cancer and bactericidal, we can place phytochemicals extracted from plant, natural fruit and vegetables into packaging films to improve food safety or quality. Natural phenolic phytochemicals can be used in films not only for their intrinsic functional properties for preservation (antioxidants and antimicrobials) and health benefits, but could also be used as exogenous elicitors of endogenous phenolics of fruits and vegetables that are targeted for preservation. Using this approach the health promoting functional phytochemicals of the preserved fruits and vegetables can be enhanced. There is evidence that exogenous phenolics can elicit endogenous phenolics in plant sprout systems (McCue et al., 2000a; McCue and Shetty, 2002; Randhir and Shetty, 2003) and in clonal shoot cultures in response the poly aromatic hydrocarbons (Zheng et al., 1998; Zheng and Shetty, 2000; Zheng et al., 2001). Further, empirical evidence implies that the endogenous natural phenolic biosynthesis in response to exogenous phenolics (synthetic or natural) could be regulated through an alternative proline-linked pentose phosphate pathway (McCue et al., 2000; Zheng et al., 2001; Shetty and McCue, 2003; Fig. 3). Therefore, it is our goal to use dietary phenolic phytochemicals from food-grade plants as components of film additives to 1) act as preservatives and enhance health property and 2) use a more innovative strategy to use same phenolic phytochemicals as exogenous elicitors to enhance endogenous health-relevant phenolics of the preserved fruits and vegetables through the proposed proline-linked pentose phosphate pathway (Shetty, 2004).

References

1. Han, J. H. (2000) Antimicrobial food packaging. *Food Technology* **54**, 56-65.
2. Krochta, J. M. and Franssen, L. R. (2002) Overview of antimicrobials in edible films. 2002 IFT annual meeting abstract.
3. McCue, P., Zheng, Z., Pinkham, J. L., and Shetty, K. (2000) A model for enhanced pea seedling vigor following low pH and salicylic acid treatments. *Process Biochemistry* **35**, 603-613.
4. .McCue, P. and Shetty, K. (2002) Clonal herbal extracts as elicitors of phenolic synthesis in dark germinated mungbeans for improving nutritional value with implications for food safety. *J. Food Biochemistry* **26**, 209-232.
5. Moore, M. E., Han, I. Y., Acton, J. C., Ogale, C. R., Barmore, C. R., and Dawson, P. L. (2003) Effects of antioxidant in polyethylene film on fresh beef color. *Journal of Food Science* **68**, 99-104.
6. Pokorny, J. (2001) Introduction. In: Antioxidant in food - practical applications. Pokorny, J., Yanishlieva, N. and Gordon, M. (eds), Woodhead Publishing Limited, England, pp. 1-3.
7. Quintavalla, S. and Vicini, L. (2002) Antimicrobial food packaging in meat industry. *Meat Science* **62**, 373-380.
8. Randhir, R. and Shetty, K. (2003) Light-mediated fava bean (*Vicia faba*) response to phytochemical and protein elicitors and consequences on nutraceutical enhancement and seed vigor. *Process Biochemistry* **38**, 945-952.
9. Shetty, K. and McCue, P. (2003) Phenolic antioxidant biosynthesis in plants for functional food application: Integration of Systems Biology and Biotechnological Approaches. *Food Biotechnology* **17**, 67-97.
10. Shetty, K. (2004) Role of proline-linked pentose phosphate pathway in biosynthesis of plant phenolics for functional food and environmental applications; A review. *Process Biochemistry* **39**, 789-804.
11. Yanishlieva-Maslarova, N. (2001) Inhibiting oxidation. In: Antioxidant in food. Pokorny, J., Yanishlieva, N., and Gordon, M. (eds), Woodhead Publishing Limited, England, pp. 23-70.
12. Suppakul, P., Miltz, J., Sonneveld, K., and Bigger, S. W. (2003) Active packaging technologies with an emphasis

on antimicrobial packaging and its applications. *Journal of Food Science* **68**, 408-420.

13. Thompson, D. and Moldeus, P. (1988) Citotoxicity of butylated hydroxyanisole and butylated hydroxytoluene in isolated rat hepatocytes. *Biochem. Pharmacol.* **37**, 2201-2207.
14. Zheng, Z. and Shetty, K. (2000) Azo dye-mediated regulation of total phenolics and peroxidase activity in thyme (*Thymus vulgaris* L.) and rosemary (*Rosmarinus officinalis* L.) clonal lines. *J. Agric. Food Chem.* **48**, 932-937.
15. Zheng, Z., Sheth, U., Nadiga, M., Pinkham, J. L., and Shetty, K. (2001) A model for the role of proline-linked regulating phenolic synthesis and peroxidase activity associated with polymeric dye tolerance in oregano. *Process Biochemistry* **36**, 941-946.
16. Zheng, Z., Pinkham, J. L., and Shetty, K. (1998) Identification of polymeric dye-tolerant oregano (*Origanum vulgare*) clonal lines by quantifying total phenolics and peroxidase activity. *J. Agric. Food Chem.* **46**, 4441-4446.

(2005. 1. 3. 접수 ; 2005. 3. 15. 채택)