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Current Practices in Bread Packaging and Possibility of Improving Bread Shelf Life by Nanotechnology

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Abstract Bread products without packaging stay fresh only until few hours after baking. The main causes that reduce the quality of bread are staling and growth of microorganisms. There are many packaging methods to increase bread shelf life and to reduce growth of microorganisms. In this paper, the current practices of bread packaging in bakery industry, and recent advances in methods of improving bread shelf life has been reviewed. Advances in nanotechnology for application to active food packaging such as antimicrobial packaging have also been described. Finally, risk of using nanoparticle in food packaging has been briefly reported. With recent advances in nanotechnology, bread shelf life and bread quality may be improved by incorporating nanoparticles in packaging materials. However, health and environmental risk factors must be evaluated and tested before commercializing nanoparticle based bread packaging materials.

Keywords Nanoparticles in Food Packaging, Antimicrobial Packaging, Antimicrobial Agent, Bread Quality, Bread Shelf Life

1. Introduction

Bread is a staple food in the western world, and consumers prefer to consume it freshly. Unfortunately, it remains fresh for just few hours after baking, and that is a big problem for the people that deal with bakery product packaging. The main factors that cause bread properties to deteriorate are microbial spoilage and chemical or physical changes[1]. There are many traditional ways to increase bread shelf life, such as modified atmosphere packaging (MAP)[2], antimicrobial additives[3], ultraviolet irradiation and gamma radiation[1]. Also, there are many ways to improve bread properties and delay bread staling, such as frozen storage, adding sugar or pentosans, alcohol treatment, etc.[1].

Recently, nanoparticles have been used to enhance mechanical performance of food packaging, such as flexibility, stability of humidity and temperature, reducing gaseous permeation, and ultraviolet light resistance[4]. In addition, they have antimicrobial activity as growth inhibitors, killing agents and antimicrobial carriers[5]. So the bakery industry may benefit from nanoparticles enhancement to increase bread shelf life and keep bread properties stable by active or intelligent bakery packaging. This review article will show the most common ways which are already being used, and also will show some advantages and disadvantages of nanoparticles in the food packaging sector.

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2. Profile of Packaging Methods

The most important function of food packaging is to protect food from environmental effects, such as microbial spoilage, chemical pollutants, oxygen and moisture, in addition to keep shelf life stability and enhance food safety[5]. Also the microbial spoilage and the chemical and physical changes are the main factors to bread spoilage[1]. Conventional packaging methods protect food in a passive way, and that means it is not supposed to interact with the food[5]. Food packaging is divided into two types: respiring food products and non-respiring. For respiring food, it should make an optimum equilibrium atmosphere between O_2 and CO_2 to prevent rapidly respiring and ethylene biosynthesis. With respect to the non-respiring food products, we can use many types of packaging to increase shelf life and improve food properties, such as vacuum packaging, modified atmosphere packaging (MAP), active packaging, or a combination of more than one type of packaging[6].

3. Factors Affecting Bread Shelf Life

3.1. Microorganisms

Microbial contamination is caused either by ingredients or by external sources during or after processing[2]. There are three kinds of microorganisms that have an effect on the bread. First, mold is considered the main reason for bread spoilage, as it contaminates bread during slicing and packaging and not in baking processes because the baking temperatures are enough to kill microorganisms and their spores[1]. Furthermore, molds are responsible for the off-flavor, mycotoxin and allergic compounds. These compounds are probably formed before colonies appear[2]. Bacteria are a second factor, especially bacteria which produces ropes, for example, *Bacillus*. In general, bacteria have higher nutritional needs than molds. Although contamination by yeast is considered unlikely, it sometimes occurs because of wild yeast contamination when dough is fermented for a long time[1].

Other research group[7] determined the common fungi which cause spoilage of bakery products are *Euotiumamstelodami, E. herbariorum, E. repens, E. rubrum, Aspergillus flavus, A. niger and Penicillium corylophilum*. Recently it was mentioned that 60% of bakery products spoilage is caused by *Penicillium* spp and *Aspergillus niger*[8].

3.2. Bread Staling

Staling refers to the reducing of acceptability of bread because of physical and chemical changes during storage (Non-microbial changes). It remains responsible for huge economic losses[9]. The main reasons for these changes are moisture and starch[1]. For the former, bread staling occurs during the transfer of moisture from interior crumb to the crust. For the latter, because 50 % of bread is composed of starch, it has a large effect on the bread quality. Although starch changes into many forms during baking and storage, the main reason for bread staling is the re-crystallization and aggregation of starch after cooling. Another component which has an effect on bread staling is gluten, but there is controversy about its role[1].

To improve bread properties and delay staling by using partly-baked bread along with frozen storage; in one study, the researchers used two temperatures (180°C and 200°C) and two different times (10 to 40 min) for re-baking. They found that the percentage weight lost during re-baking was higher at 200°C than at 180°C. They also had similar findings in regards to baking time, except the moisture lost was found only in the crust, while the crumb bread still maintained its moisture. Also, they mentioned storage at 4°C is good for the prevention of microbial growth, but it is not good for the prevention of staling after re-baking[10]. Other reserchers[9] studied the difference between the moisture contents and the firmness of partly baked (PB) and fully baked (FB) bread. They stored breads for different periods (7, 21, 63, 92, 126 and 188 days), and they found that moisture transferred from the crumb to the crust in all treatments, but it was lessened in PB treatment. Starch recrystallization and firmness were also less in the PB after thawing and re-baking than they were in the FB. At the same time, there are many additives to improve bread properties or to slow bread staling, such as enzymes, emulsifiers, pentosans, alcohol and sugars[1].

4. Traditional Methods for Increasing Bread Shelf Life

4.1. Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is used for non-respiring food packaging to reduce O_2 on the food surface to inhibit growth of aerobic microorganisms[2]. There are many studies to determine which concentration or which gas is the best to increase shelf life. One of these studies tested nitrogen gas (N_2) and Carbon dioxide (CO_2) in different concentrations (100% N_2, 70% N_2 + 30% CO_2, 50% N_2 + 50% CO_2, 30% N_2 + 70% CO_2, and 100% CO_2), and they found the treatment 100% CO_2 was the best. It could reduce total bacteria, mold and yeast more than other treatments[2]. While other researchers found the combination of (40% CO_2 + 60% N_2) did not affect Bacillus growth, it effected on molds growth negatively[10].

Gutierrez et al[8] used three types of packaging to determine which one is the best to increase shelf life and maintain texture for gluten-free sliced bread: essential oils (Eos) Cinnamomum zeylanicum, modified atmosphere packaging (Amixture of 60% CO_2 and 40% N2) and a combination of them. They found that the best antimicrobial activity by using a mix of active packaging and MAP while sensory properties were better without MAP. MAP helped to prevent the growth of microorganisms, but it effected the bread's flavor negatively because it increased the perception of cinnamon flavor. Also, Guynot et al[7] tried to increase shelf life by adding O_2 absorbent in the packaging to reduce mold growth, and compared this treatment with MAP. The O_2 absorbent reduced O_2 to less than 0.014%, while it was 0.6-1.0% by MAP, and that prevented mold growth because they need 0.4% of O_2 as a minimum concentration for growth.

4.2. Antimicrobial Additives

Another way to increase shelf life of bread is by adding antimicrobial additives. For example, it is used three types of antimicrobial additives to increase shelf life: sodium propionate, calcium acetate and potassium sorbate. They were added in different stages during bread processing, and the authors found that the chemical additives had a positive effect on the shelf life. They mentioned the best treatment was to spray an 8 ml mixture of antimicrobial additives in different stages of the processes (2 ml to coat pan, 2 ml on dough, 2 ml on slicer and 2 ml on packaging). They concluded that spray additives had a potential activity against microorganisms, and had a positive effect on sensory attributes up to 96 hours after storage. On the other hand, storage had a negative effect on the texture, aroma and color of the crust and crumb[3]. Also, it is found the same result when they added potassium sorbate to the flour to increase shelf life of bread[2]. Other study tested 16 essential oils as antimicrobial agents against common fungi in bakery products, and they found that five of them had strong antimicrobial activity: lemongrass, clove, cinnamon leaf, bay and thyme against different type of *Eurotium* spp[7].

5. Active Packaging

Active packaging is one type of packaging which allows some materials to interact with food to enhance food properties, maintain food quality[11] and extend food shelf life[12] . Whereas smart or intelligent packaging provides consumers some information about food status[13]. From these two short definitions, active packaging is more important to increase food shelf life and to improve or keep products as long as possible, so we will discuss at length about it.

Active packaging has been mostly used toabsorb oxygen, carbon dioxide, moisture, ethylene, odors and to relsease some material such as antimicrobial agent, antioxidants and carbon dioxide. To explain more about each one, materials absorbing oxygen or oxygen-scavengers, such as iron powder, ascorbic acid, enzymes and photosenative dye, work to absorb O_2 after packaging and to reduce O_2 less than 0.01%. Incorporating iron powder in a sachates, for example, one gram of iron will react 300cc of O_2. It is possible to use this technique with several food packaging including bakery products.Another example of O_2 scavengers is enzyme reaction; the science based on this is: an enzyme (such as glucose oxidase incorporated in a film surface) reacts with some substrate to reduce O_2. keeping food fresh and without deteriorating. It is necessary to reduce CO_2 which is produced s a result of reserpation reaction. The concepts the similar to O_2 scavengers but the material used is different; in this case CaO is used with hydrating agents in a sachet to react by producing CO_2. The result is $CaCO_3$ with water.[14]

Other applications for active packaging are moisture regulator and ethylene absorption.The moisture around a product has to be in a certain amount because higher moisture makes the product softer and motivate the growth of microorganisms, and if it is less makes the surface of products dry. To maintain themoisture level, one can use water vapor permeability film or moisture controlling sachet.

Antimicrobial food packaging is another type of active packaging, and it works to minimize the growth of microorganisms in order to increase a shelf life of products and to maintain food quality as long as possible. Incorporation and immobilization of antimicrobial agent in a film leads to get antimicrobial food packaging or by modification or coating the. There are two types of antimicrobial films, the first one, the films contain an antimicrobial agent which can migrate to the food surface. Second one can affect microorganism growth without migration. There is different material using as antimicrobial agent in food packaging such as, alcohol, bacteriocine, antimicrobial peptide, metal (silver, copper), etc.[15]

Another problem in the bakeryindustry can probably be treated by active packaging, oxidation which causes many food deterioration, such as off-odors, off-flavors, nutritional losses, and color change. All these changes lead to reduce the shelf life of bakeryproducts. Traditionally, it is treated by adding an antioxidant in food, but synthetic antioxidants probably have negative effects on the humanhealth[16]. As other active packaging, one can use sachets, adhesive-bonded labels, noncovalent adsorption and covalently bind compounds to films. For example, Tain et al[16] mentioned modification of the polyethylene surface by adding metal chelating carboxylic acids to have a metal chelating activity that minimizesoxidation reactions as a result increase theproduct shelf life.

6. Using Nanocomposites in the Packaging

Nanocomposites are particles between the sizes of 1-100 nanometers. Because of their size they have better properties than their microscale counterparts. The main reason that makes nanomaterial an improvement packaging material is that it has a large surface area[17]. There are many benefits of using nanoparticles (NPs) in food packaging. First, nanoparticles can reduce the amount of material used while perform packaging function better. It can also increase tensile strength up to forty percent, and that decreases the amount of film used in pouch producing. Third, nanoparticles can increase thermal stability up to 350 percent, and that keeps food fresh and can be reheated it in its original packaging. Fourth, it can enhance barrier properties against gas permeations such as oxygen and carbon dioxide, ultraviolet permeation, moisture, and volatile compounds. Finally, nanoparticles can reduce the change of food properties by creating a “tortuous path”, which is difficult for moisture and gases to navigate[18, 12]. Furthermore, the benefits of using nanomaterial in food packaging such as increased shelf life, intelligent packaging, and active packaging is determined[19].

At the same time, NPs may also improve mechanical performance, such as increased film flexibility, humidity and temperature stability, reducing gaseous permeation, and resistance to ultraviolet light. It provides active and intelligent food packaging, which means it can remove undesirable tastes and flavors and detect food spoilage respectively. Finally, it can be made from biodegradable materials, such as polylactic acid (PLA) and montmorillonite (MMT)[4].

In regards to the process of manufacturing nanocomposite packaging materials, nanoparticles may be incorporated in food packaging with three possible distributions of the layered clays in the polymer matrix. First, non-intercalated nanocomposites are obtained when clays cannot be intercalated between silicate sheets. Second, intercalated arrangements are obtained when clays are separated between silicate sheets and they increase interlayer spacing. Third, exfoliated structure which is obtained when clays are distributed randomly in sheets. The latter is considered the best one[12]. Also, the same source mentioned that there are that three methods to get these distributions; two of them depend on solvent and the other depends on the incorporation of clay into the molten state of the polymer. Furthermore, it is described three types of nanomaterials in food packaging: first, one dimensional nanomaterials such as coatings, layers or plates give barrier properties. Second, two dimensional nanomaterials such as rods or fibers give structural strength. Third, three dimensional nanomaterials gives a large surface area for high chemical activities[19].

Another use of nanoparticles in food packaging is added nanocomposites into a degradable polymer to enhance gas barrier properties, mechanical and thermal properties of the packaging[20]. Other studytested many percentages of amorphous poly lactic acid (aPLA), polycarbonate (PCL) and a nanocomposite of these materials, and the researchers found that blends of aPLA with PCL improved mechanical and thermal properties without a significant decline in barrier properties[21]. Also, it is explained that the properties of biodegradable polymer can improved by adding nanocomposites clays to them, which reduces waste materials[12]. At the same time, MMT nanoparticles enhanced the structural and mechanical properties of biodegradable starch packaging[22].

7. Effects of Nanocomposites on Microorganisms

Nanocomposite materials have antimicrobial activity as growth inhibitors, killing agents and antimicrobial carriers[5. One research group[23] divided antimicrobial activity of nanoparticles into many types. The first, silver nanoparticles, has antimicrobial activity against gram positive bacteria (G^+), gram negative bacteria (G^-), molds and yeast. Second, metal oxide like titanium dioxide and zinc oxide, have an antimicrobial affect against fecal coliforms for TiO_2 and against many types of microorganisms, such as *S. aureus*, *E. coli*, G^+, G^-, molds and yeast for ZnO. Third, metal hydroxides, such as Ca(OH) and $Mg(OH)_2$ have an antimicrobial affect against *E. coli*. Fourth, Chitosan which is a polysaccharide has an antimicrobial agent against a wide variety of microorganisms including G^+ and G^-. Fifth, carbon nanotubes and Tourmaline also have antimicrobial activities against microorganisms. Finally, although nanoclays do not have antimicrobial activities, they may assist antimicrobial agents to be more affective[20].

The ZnO NP were more effective than ZnO powder. Also they found that using a minimal amount of ZnO NP could reduce the number of *Staphylococcus aureus* and *Salmonella typhimurium* to zero[24]. Using polymer/metal nanocomposites in coating, release metals, which can reduce or inhibit microorganisms in the food. They used it against fungi, and the amount reduced depended on the nanoparticle load. So they put Cu NPs in complex matrix to control the amount of Cu in the medium[25].

During same period, it is used nanoparticles of curcumin as antimicrobial agent to avoid the aggregation that occurs if curcumin powder is used. It is found that Curcumin nanoparticles were water soluble, and they had higher antimicrobial activities than curcumin powder. Also they reduced gram positive bacteria more than gram negative bacteria[26]. In addition, they were considered antibacterial more than antifungal. Other group research tried to compare the efficacy between nano and micro-composites of silver as antimicrobial agents against *E. coli*. The average nanoparticle was 10 to 20 nm, and there were some composites that had bigger particles, but they were still less than 100 nm, while the average microcomposite was 300 nm. They found that 0.06 wt % of nano-silver was enough to kill all bacteria within 24 h, while 1.9 wt % microsilver killed 80% of the bacteria at the same period[27].

8. Using Nanocomposites as Antimicrobial agent in the Packaging

Active food packaging provides interaction between food and packaging material, inhibiting antimicrobial growth more than other factors[5]. Some researchers[28] tried to benefit from bactericidal property of silver (Ag) to use it in food packaging by pairing with hydroxypropyl methylcellulose (HPMC). Also, they tested the mechanical properties and antimicrobial agents for AgNPs. They found that the HPMC/AgNPs films exhibited good mechanical properties, and they increased the tensile strength from 28.3 to 51.0 MPa. In addition, they found that 41 nm Ag was better than 100 nm Ag for the mechanical properties. Furthermore, they found that HPMC/AgNPs films decreased water vapor permeation (WVP). The most antimicrobial activity was against *S. aureus*, and the lowest was *E. coli*. At the same time, it is increased shelf life for asparagus to 25 days by inhibiting microorganism growth and reducing weight loss by using a coating of silver nanoparticles[19].

Son et al[30] added Ag nanoparticles into cellulose acetate (CA) polymer nanofibers after irradiating with UV light. They found that the best wave-length was at 245 nm and for 240 min to change the Ag^+ to the Ag nanoparticles (21 nm). Furthermore, they found the Ag NPs increased their size when exposure time increased. After that, they examined CA/AgNPs with *S. aureus, E. coli, K. pneumonia* and *P. aeruginosa*, and they found the bacteria decreased by 99.9% after 18 h incubation.

Bradley et al[19] tried to perceive other benefits of nanomaterials in food packaging when they used this technique to help the developing countries. They thought this technique may inhibit or lessen growth of microorganisms and result in less mycotoxin in some countries which cannot provide a clean water to wash containers[19].

9. Fears of Using Nanocomposites in the Food Packaging

There are many problems of using nanoparticles, such as the difficulty of separating nanoparticles from packaging materials, and the fear of re-using these materials on humans and environment in the future[18]. Weil et al[4] mentioned some specific problems, such as certain nano-composites migrating from packaging to the food, and as a result entering human bodies. The second problem is inhalation because nano-composites are very small and can permeate the lungs and reach the blood. Third, toxicity occurs when nanomaterials react with oxygen within cells, increasing oxidative stress[4].

Some researchers expected there to be a backlash from using nanoparticles in food industry, so they made a survey to learn how people feel about adding nanoparticles to foods or using them in food packaging[31]. Cioffi and Rai[23] described some fears about using nanoparticles in food packaging, especially if it is used with edible coating[23]. It is alsomentioned that using nanoparticles in the food industry may pose risk that do not exist in bigger size materials[20]. They reported the customers found it more acceptable to use them in packaging than inside food because in packaging they are not inhaled or ingested. If consumed, the very small size of nanoparticle materials may allow them into cells, making changes to the system. While we know the effects of using normal material, the data is limited on the use of nanomaterials[17].

10. Conclusions

Bread is essential staple food in western world and the main problems with keeping it fresh are microorganisms and staling. Currently there are many packaging methods either to increase its shelf life or maintain its properties. The nanotechnology provides broader opportunity for enhancements for food packaging, and can hopefully both increase bread shelf life and enhance its properties. However, before releasing any new product with the nanotechnology in food system, manufacturers must thoroughly assess its risk on human, animal and environmental health.

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