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REVIEW

Research on Application of Nanomaterials in Food Packaging Design

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Abstract

Nowadays, food packaging is an indispensable part of food processing. In the process of food processing, food packaging can protect food from external biological, chemical and physical factors, and ensure the stability of food performance. With the increasing awareness of food safety and environmental protection, people pay more attention to the selection of packaging materials. Therefore, the application development of nanomaterials is increasing year by year. During the processing of food packaging materials, the addition of some nano-materials can improve the preservation effect and texture of the packaging materials to a certain extent, and can even effectively protect the nutritional components in food. This has great benefits for people's health. However, there are some safety problems in the application of nanomaterials. This paper summarizes the applications of nanomaterials in food packaging, the main detection techniques of nanomaterials, the problems of nanomaterials in food packaging, the safety evaluation of nanomaterials and the development of nanomaterials.

Keywords

Nanomaterials; food packaging; applied research; safety evaluation

1. INTRODUCTION

Food packaging design is very important in many production links of food industry. Good food packaging design can ensure the quality and safety of food, effectively maintain its texture stability, and is conducive to the storage of food. To some extent, it can also increase the commercial value of food. From the perspective of food packaging, packaging material design has always been an important design point in packaging design. The development of nano-materials has effectively solved the problem of selecting materials in food packaging design. Nowadays, many food packaging use nanomaterials, which makes nanomaterials develop rapidly in the field of food packaging.

2. THE CONCEPT OF NANO PACKAGING MATERIALS

Nanomaterials are composed of nanoparticles. At present, many industries are applying nanomaterials, such as food packaging, environmental design, medicine and so on. The food packaging of nanomaterials has the characteristics of air barrier, heat resistance and antibacterial. However, in the case of not being familiar with the safety of nanomaterials, it is

necessary to control the source and content of nanomaterials in food for the health and ecological environment of consumers[1]. According to statistics, nanomaterials used in food packaging materials are increasing every year, with an annual growth rate of about 15.8%. By 2020, the utilization rate of nanomaterials is expected to reach about 30.89%. In traditional food packaging, the packaging materials used are generally paper, metal and plastic, and most of these materials have pollution effects[2]. The long-term use of these materials can seriously threaten people's health. Table 1 shows the harmful effects of common packaging materials and harmful substances on the human body. It is worth noting that nanomaterials are only used under a clear material usage regime[3]. In China, there are many studies on nanomaterials. Through continuous research and improvement, a new type of nano-material was finally obtained, which made the food packaging design of nano-material popular.

Table 1 Harmfulness of traditional packaging

Material	Types of pollutants contained	Harmfulness
Paper material	brightening agent	damage to human liver and lung organs, and even cause cancer
Metal material	heavy metal	cause cancer
Plastic material	plasticizer	harm to the endocrine system of human body

3. APPLICATION OF NANO MATERIALS IN FOOD PACKAGING DESIGN

3.1 Application of Nanometer Fresh-Keeping Materials

3.1.1 Nano Silver

Nanometer silver is a relatively new material design. Nanoscale silver has a larger surface area than normal silver. It can be combined with proteins in microbial cells to cause cellular metabolic disorders. Therefore, the surface of nanometer silver is easy to be oxidized off, thus releasing more silver ions with characteristics of light resistance, heat resistance and antibacterial. Even tiny nanoscale silver can play a strong bactericidal role. It has no obvious drug resistance and is a relatively new type of antibacterial agent at present. Therefore, nano-silver is mainly used in enhanced packaging materials and food preservation and antibacterial aspects. Nano silver can destroy the normal metabolic function and bacterial structure. Therefore, it can reduce the growth of bacteria on tableware, so that food is not easy to spoil due to sunlight[4]. Nanometer silver packaging has a good development prospect in the field of catering utensils in public places. For example, when the fruit needs to be packaged after ripening, nanoscale silver packaging materials can be used for packaging. In this way, the decay rate of fruit can be reduced to a certain extent, and the fruit can be kept fresh. The common nanometer silver material packaging has the fresh-keeping box, the milk bag and so on.

3.1.2 Nano Titanium Dioxide

Nano titanium dioxide has high catalytic and antibacterial properties. It is an inorganic antibacterial material with stable properties, non-toxic and tasteless. Nano titanium dioxide is often used in fruit and vegetable packaging. It can oxidize and decompose the ethylene produced in the storage of fruits and vegetables, and reduce the concentration of ethylene, thereby increasing the fresh-keeping time of fruits and vegetables. For example, nano titanium dioxide coating can inhibit the activity of peroxidase to preserve fresh cut yam. Composite coatings made of different concentrations of nano titanium dioxide and riboic acid can be used to keep potatoes fresh for a long time. Packaging made of low-concentration titanium dioxide and polyethylene can reduce acetaldehyde and phenol in pecans and preserve them. Moreover, nanometer titanium dioxide can effectively prevent the irradiation of ultraviolet rays on fruits and vegetables, so as to better prevent the oxidation of fruits and vegetables.

3.1.3 Nano Silicon Oxide

The surface of nanometer silicon oxide is amorphous white powder. It is an inorganic non-metal material with no pollution and no taste. Compared with other metal nano materials, nano silicon oxide has the advantages of good compatibility and optical permeability[5]. At present, nano silica is a common nano material in silicon oxide. Because of its strong thermal stability and environmental protection, it is often used in coatings, rubber and other materials. Moreover, nanometer silicon oxide also has a certain role in fruit and vegetable preservation. For example, in mango packaging, the use of nano-silicon oxide materials for packaging can effectively increase the freshness of mango and inhibit the softening of mango[6].

3.2 Application of Nano Antibacterial Materials

Zinc is one of the trace elements needed by human body, which is closely related to the normal development of human body. Zinc oxide is a kind of semiconductor material with the characteristics of stability and catalysis. At the same time, as a form of zinc, nanometer zinc oxide has been widely used in food packaging. Nanometer zinc oxide is a kind of wideband gap semiconductor which can be excited by certain wavelength ultraviolet light. It has the advantages of good photocatalytic activity, non-toxicity, low cost and good biological adaptability. Nano zinc oxide can act as an antibacterial agent by contacting or penetrating microbial cells. It has good antibacterial effect on common escherichia coli and staphylococcus aureus[7]. As a common antibacterial material, nano zinc oxide has been used in food industry, such as breakfast cereals, bread, biscuits and so on. Nanometer zinc oxide has a remarkable effect on the control of anti-bacterial preservation of food.

3.3 Application of Nano Barrier Materials

3.3.1 Nano Clay

Because of the abundant resources and low cost of raw materials, nano clay is the first new material used in packaging. In the nano clay, montmorillonite is a common nano clay material. Nano montmorillonite has the characteristics of good heat resistance and natural viscosity, which can reduce the water absorption and light permeability of food in food packaging. Therefore, montmorillonite can be made into a variety of functional composite materials. As for the composite material made of montmorillonite, it can improve the rupture rate and tensile strength of the film, and has antibacterial effect. For example, the tensile strength of food packages made with 5% montmorillonite is the highest among food packages. It is often used in the package design of salted duck eggs, which can extend the shelf life of salted duck egg packages.

3.3.2 Carbon Nanotubes

Carbon nanotubes are composed of small cylinders of nanometer size, which are one-dimensional nano materials. Carbon nanotubes have strong mechanical and antibacterial properties. Although the nanomaterials have good properties, there are still safety problems in food packaging. Studies have found that long exposure to carbon nanotubes by human or aquatic organisms will have a safety impact on themselves[8]. In addition, some carbon nanotubes are programmed as carcinogens, so carbon nanotubes should be treated with caution, and safer carbon nanotubes should be used for packaging.

3.3.3 Nanocopper

Compared with the traditional copper, the chemical properties of nano copper are more active and easy to be oxidized, which leads to the release of copper ions. However, the release of copper ion will fuse with microorganism, so it has bactericidal effect. At the same time, nano-copper also has the advantages of super strong extension and barrier, and is a pure substance. In food packaging, it can effectively isolate food from the outside world[9]. The packaging made of nano-copper has many peculiar properties. For example, due to the superplastic ductility of nanometer copper, it will not crack when stretched more than 50 times at room temperature of about 20 °C. Copper crystals with a volume of 80 nanometers have strong mechanical properties. Its strength is about four times higher than ordinary copper, the deformation state is more uniform, and there is no part of the problem of narrowing. Thus, nanometer copper has a broad prospect in food packaging.

3.4 Application of Other Nano Materials in Food Packaging Design

There are many types of nanomaterials used in food packaging, such as nanocalcium carbonate, nanographene and other nanomaterials. For example, packaging made of nano-calcium carbonate materials can effectively extend the preservation time of food. The packaging made of nano-graphene material has the function of preventing the food from being exposed to strong light and ultraviolet rays, which causes the problem of food oxidation.

4. THE MAIN DETECTION TECHNOLOGY OF NANOMATERIALS

4.1 Pre-treatment Technology for Nanomaterials

The processing methods before the detection of nanomaterials include soaking, microwave digestion and direct calcination at high temperature. According to China's food safety standards, for some nano-materials, packaging materials that require direct contact with food should be immersed for disinfection. For the appearance and content detection of nanomaterials, microwave digestion method is used, which can be used quickly and make the subsequent interference less. In order to observe the particle state of nanomaterials, nanomaterials should be treated by direct calcination at high temperature[10].

4.2 Imaging Technology

Since all nanomaterials are relatively small, in order to observe the nanometer components of food packaging more intuitively, it is necessary to use a microscope for observation. The nanomaterials observed by different microscopes are different. If the nanomaterial is not damaged, a near-field scanning optical microscope with a resolution below 10mm can be used. For imaging analysis of nanomaterials and to understand their distribution, laser scanning confocal microscopy can be used[11]. In addition to the use of microscopy, nuclear magnetic resonance spectroscopy can also be used. The technology can be used to analyze the nanometer components and the state of the packaging.

4.3 Component Analysis Technology

The component analysis technology is to observe and analyze the nano components and distribution in food packaging. In the process of component analysis, the more commonly used techniques are chromatography, spectroscopy and mass spectrometry. When analyzing the composition of nanomaterials, several technologies are often used together, so that the nanomaterials can be better analyzed, and the composition results are more clear and intuitive[12]. When studying the migration of nanomaterials in food packaging, chromatographic detection technology can be used together with mass spectrometry to make the components of nanomaterials more comprehensive and accurate.

5. SAFETY EVALUATION OF NANO FOOD PACKAGING MATERIALS

5.1 Migration Studies

Although nanomaterials are widely used in today's food packaging, due to their complex structure and chemical composition, the safety impact analysis of nanomaterials is very important. Therefore, the migration of nanomaterials in food was studied by the relevant inspectors, and the use of the migration results was related to the system. The study found that the harm to the human body in the packaging of nanomaterials is mainly due to the migration of chemical components in nanomaterials. Moreover, the amount of migration of nanoparticles and the effects of migration are affected by various external factors, such as the characteristics of food, baking at different temperatures and other factors. Relevant researchers have used some techniques to determine the addition and migration of different silver nanometer packaging materials, as shown in Table 2. Because all nanoparticles will migrate when they encounter different problems, the appearance and microcosm of the packaging material will be affected.

Table 2 The amount of addition and migration of nano-silver in different commercially available nano-silver packaging materials

Item	Nano silver polypropylene fresh-keeping lunch box	Nano silver milk storage bag
Amount of addition (g/g)	30.12	28.53
Amount of migration (g/mL)	0.058	0.005

5.2 Hazard Research

According to the research, there are some nano materials that may migrate when they are used in food packaging. If migration occurs, there will be serious security risks. Therefore, it is necessary to study the detection process of nanomaterials. By studying the harmful phenomena after nanomaterials migrate to food, food safety can be guaranteed. There are three main ways for nanoparticles to enter the human body: oral cavity, respiratory tract, and skin. Since most of the nanomaterials in food packaging will migrate to food, the harmful substances transferred in the nanomaterials mainly enter the human body through the mouth, thereby causing certain losses to the human body.

The toxic mechanism of nanoparticles on the human body generally has two effects. The first is that nanoparticles stimulate the nerves of the human body to produce a large number of reactive oxygen species in the body, resulting in poisoning. The second is that the nanoparticles are in direct contact with the human body, resulting in the combination of toxic nanoparticles with proteins in the body, which impairs the function of the human organ. Table 3 shows the hazardous properties of some nanomaterials used in food packaging due to migration. Currently, relevant food safety regulations have not yet concluded whether there is overall safety of nanoparticles. The toxicity of nanoparticles to organisms is also under preliminary

investigation. Therefore, the safety of nanomaterials needs to be further studied.

Table 3 Description of migration hazard characteristics of nanomaterials used in food packaging

Nanomaterials and their applications	Dimensions and physical properties	Danger
Tio_2 Used for sterilization and ultraviolet (UV) resistance in packaging	30 nm rutile	1. destroy the DNA structure of the human body 2. affects human liver and lung function
Ag Used in packaging for bacteriostasis	15 nm and 100 nm of solid silver	1. strongly toxic to human liver cells 2. strongly toxic to human brain cells
Zn and ZnO Used in packaging for bacteriostasis	20 nm and 120 nm ZnO powder	1. 20 nm particles can cause liver and spleen damage 2. 120 nm particles can cause liver, spleen and heart damage

6. PROBLEMS OF NANOMATERIALS IN FOOD PACKAGING DESIGN

While studying the application of nanomaterials in food packaging, it is also necessary to understand what are the harmful substances migrated out of nanomaterials and what harm can be caused to human body. After understanding the migration characteristics of nanomaterials, the problems of nanomaterials in food packaging were summarized. When nanomaterials have not yet become universal packaging materials, some researchers have found the following problems with nanomaterials in food packaging when researching nanomaterials:

1. There is a lack of effective screening and separation methods for nanomaterial packaging materials, including nanomaterials in ceramics, paper and plastics. Compared with oligomers, the content, morphology and other information of the nanomaterials are required during the detection of nanoparticles. As far as the current detection technology is concerned, only microscopic analysis of nanoparticles in composite films can be performed. More complex substrates, such as nanoparticles in ceramics, paper and plastics, have no technology to detect them.

2. Nanoparticles do not have a comprehensive and physical and chemical performance standard. In the study of the early migration of nanoparticles and the harm caused by the later stage, the detection of nanoparticles is useless if the basic characteristics of nanoparticles, such as the size, crystal structure, reaction activity on the surface of nanoparticles, even the morphology in different pH values and the reaction activity of proteins, are not fully understood.

3. In testing, the functionality of the nanomaterials was not linked to the toxicity caused by the nanoparticles during migration. For some packaging that combines traditional materials with nanomaterials, the complexity has a significant impact on the functionality of nanomaterials. Furthermore, the toxicity of nanomaterials during migration is closely related to the packaging materials. Therefore, it is important to link the function of nanomaterials with the toxicity caused by nanoparticles during migration.

7. THE PROSPECT OF NANOMATERIALS

Nanomaterials are now used in many food packaging. It not only brings convenience to people's life, but also promotes the development of nanotechnology.

In the design of food packaging, the safety of nano materials has always been the focus of nano research. If nano materials are used in food packaging when they are unsafe, it is likely to cause toxic substances generated by the migration of nano materials. When people eat the food, toxic substances can enter the body, resulting in health hazards.

The detection and analysis technology of nanomaterials in food packaging is one of the problems to be solved by relevant scientists. At the same time, the detection of nanomaterials should not only understand the quantification of nanomaterials, but also understand their surface characteristics. In order to understand more specifically the components contained in nanomaterials in food packaging, a variety of detection technologies are connected and used together, which is also one of the developments in the field of nanomaterials research.

Combining traditional food packaging materials with nanomaterials is a new combination of high-tech and multi-functional materials. Food packaging for new nanocomposites like these is also being updated. The emerging new material packaging has greatly improved the original quality of food and promoted the rapid development of the food industry. However, in the continuous development of new nanometer packaging materials, the safety of new materials should also be studied and

analyzed. Therefore, before the widespread use of nanometer food packaging materials, the migration of nanoparticles in food and the safety of harmful substances produced by human bodies should be the focus of future research.

8. CONCLUSION

To sum up, due to the continuous progress of science and technology, nanomaterials are increasingly used in food packaging. Through the research on some nanomaterials, we can find many nanomaterials that are beneficial to food packaging, such as the discovery of silver nanomaterials. Because of its stability and heat resistance, nano-silver is often used in packaging design of food preservation. Because the nano titanium dioxide material has good bacteriostatic properties, it increases the fresh-keeping time of fruits and vegetables. Although nanomaterials have a lot of good properties, it has been found that some nanomaterials will also bring bad effects due to migration. Therefore, further research is needed.

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