Research and Enlightenment on the Design of Food Packaging Performance Based on New Materials

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Abstract: China has witnessed rapid socio-economic development in recent years. As a result of the high-quality development of modern life, people have increasingly pursued the health and comfort of life and paid particular attention to food safety. As people require richer and more diverse food, the food packaging industry is developing rapidly with the birth of various packaging materials. This article reviews the development status of food and its packaging materials in China and analyzes the main factors affecting the quality of food packaging products. In accordance with the current domestic and foreign regulations and standards related to food packaging materials, the article elaborates how food packaging affects food safety and puts forward the countermeasures to control the quality of food packaging products to safeguard the legitimate rights and interests of consumers in eating safety.

1 INTRODUCTION

Food packaging is inseparably related to food in modern life. Food packaging, commonly known as containers, materials, and auxiliaries, is used to ensure the food quality in circulation and storage and serves as the last process of food production. Aside from being used to promote the food's efficacy, food packaging is mainly aimed at preventing biological, chemical, and physical external damage, maintaining the stable quality of the food and facilitating the transportation, storage, and sale of food.

2 CLASSIFICATION OF FOOD PACKAGING MATERIALS AND THEIR PERFORMANCE

In the past, people tended to pay attention to the visual, tactile, and taste of food. With the development of the national economy, policy adjustment, and the change of consumption concept, they have turned to focus on internal quality and nutrition of food and avoid the potential pollution and hazards. Therefore, they are urgently looking for environment-friendly packaging materials and suitable packaging technology.

2.1 Classification of Food Packaging Materials

China allows the use of various food packaging materials and containers, which come from five main categories of raw materials: food-grade paper packaging materials, synthetic polymer materials (plastics, rubber, adhesives, coatings, etc.), metal materials (steel, aluminum, tin, lead, etc.), glass and ceramic materials, composite materials, fiber materials (natural fibers, synthetic fibers, textiles, etc.), wood, other materials, etc. (Huang, Lei, Huang et al., 2015). According to the packaging function, the packaging materials have the following categories: barrier packaging materials, heat-resistant packaging materials, selective permeability packaging materials, freshness preservation packaging materials, conductive packaging materials,

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decomposable packaging materials, and other functional packaging materials.

2.2 The Performance of Food Packaging Materials

Food products, especially high-fat or high-protein foods, usually require a better and longer shelf life, so they have certain requirements for their packaging materials.

2.2.1 Barrier and Physicomechanical Performance

Packaging materials should have some barrier performance. For example, greasy food requires high oxygen and oil barrier packaging; dry food requires high moisture barrier packaging; aromatic food requires high odor barrier packaging; fruit, vegetables, and fresh food require packaging with certain oxygen, carbon dioxide, and water vapor permeability.

2.2.2 Chemical Safety

As the medical level has improved in recent years, food and medicine safety is of great concern. And plastic packaging materials have a greater impact on the food and drug in direct contact. For example, the barrier function of composite film bags coexists with the mass transfer process of monomers such as additives. Plastics frequently contacted with foodstuffs still have monomers after polymerization, and plastics also have such additives as nucleating agents, lubricants, antistatic agents, foaming agents, plasticizers, phenolic antioxidants, dialkyl hydroxylamines, benzofurans, hindered amine stabilizers, UV absorbers, heat stabilizers, antacids, dehydrating agents, anti-fogging agents, dyes, pigments, and fillers.

2.2.3 Functionality

As packaging materials increasingly demand "fresh-keeping" and other functionalities, there are limited options for packaging materials. Therefore, while ensuring that food products contain fewer preservatives, new packaging materials, which have simple processing, portability, light-shielding, easy storage, and other advantages, are needed to ensure freshness and a longer storage period.

The composite film material of nano-TiO2, which has been successfully developed by Japan, the United States, and Germany, has become popular in recent years. It is shown that nano-TiO2 has a good antibacterial effect on bacteria, fungi, and molds. Moreover, its addition to the packaging materials allows the packaging materials to be antibacterial, resulting in better protection of food and inhibition of food spoilage (Tan, Hu, Wang, 2020).

2.2.4 Antibacterial Performance

During food storage, packaging materials having certain antibacterial performance can inhibit or kill harmful microorganisms inside the packaging and extend the shelf life of food. With the latest surface coating technology achieved by special technology, a layer of antiseptic material is applied to plastic packaging film based on composite resin and other substances to replace the preservatives added to the food, further improving food packaging safety.

2.2.5 Degradability

Photodegradable or photo-biodegradable plastics of starch-filled polyolefins have been widely used in mulch, shopping bags, disposable tableware, etc. However, these plastics are not really "environment-friendly" and still have poor application performance, difficult time-controlled degradation, and high cost. For the sake of sustainable development of the earth's resources, more renewable resource polymers are urgently needed to replace the non-renewable petroleum-based polymer materials, and all-biodegradable plastics come into being. As of 2010, the annual production capacity of biodegradable plastics worldwide has reached one million tons. In the coming 30-50 years, biodegradable plastics will eventually occupy 10% of the overall market share of plastic products, and the proportion of bio-based biodegradable plastics will account for more than 90% (Li, Ma, Jiang et al., 2021). The performance indicators corresponding to each testing item of food packaging are detailed in Table 1.

Table 1 The performance indicators corresponding to each testing item of food packaging

Performance Indicators	Testing items	The performance of the tested sample
Barrier Performance	Oxygen permeability	Barrier performance of the packaging material to oxygen in the environment, prevent products from bulging bags, mildew, rancidity, and other quality problems
	Water vapor transmittance	Barrier performance of the packaging material to water vapor, preventing products from deliquescence, softness, fragrance, color fade, and other problems
	Nitrogen permeability	Preservation performance of the packaging material to the package internal nitrogen, preventing products from deflating and oxidation
	Carbon dioxide transmittance	Preservation performance of the packaging material for carbon dioxide inside the bag, preventing products from color change and shortening shelf life
	Peel strength	Characterize the composite fastness of the composite film, preventing the package from delamination
	Heat sealing strength	The heat-sealing effect of the packaging, ensuring no air leakage, broken bags at the heat seal, and easy unsealing
	Heat sealing performance test	Screening the most suitable heat-sealing temperature, pressure, and time of the packaging material
	Thermal viscosity	Whether the uncooled heat-sealed parts are not easy to leak when the contents or foreign objects impact them

2.3 Testing Indicators

The requirements for the interior packaging of food refer to the technical requirements to ensure the quality of food in the corresponding packaging, including packaging strength, barrier performance, air permeability, heat resistance, and light protection requirements. It is the requirement for the exterior packaging made by the food to maintain its quality.

Food packaging materials usually focus on barrier performance, physical and mechanical performance, and chemical hygiene performance. Among them, the testing items of barrier performance include oxygen, water vapor, nitrogen, carbon dioxide permeability and the permeability of various gases after kneading, gas permeability in high and low temperatures of packaging films specific to the application environment. The testing items of physical and mechanical properties include mechanical contact thickness measurement, peel strength, heat seal strength, heat seal performance test, heat bond strength, elongation at break, tensile force, tensile strength, pendulum impact resistance, oil resistance, falling dart impact energy, ball drop impact resistance, tear strength, right-angle tear strength, and chemical hygiene performance, resistance to pendulum impact, oil resistance, falling dart impact energy, resistance to falling ball impact strength, tear strength, right-angle tearing force, puncture resistance, friction coefficient, bottle mouth rotation torque, cap removal force, opening force, the adhesive force between sealing material and container mouth, ink layer bonding fastness, sealing performance (negative pressure method), bursting pressure, cold resistance test, cooking resistance test, vacuum residual oxygen test, headspace analysis, heat shrinkage force, shrinkage rate, and cold shrinkage force. The testing items of chemical hygiene performance mainly include solvent residues, toluenediamine content, non-volatile migration content, and heavy metal content.

2.3.1 1Packaging Material Structure and Key Indicators Control of Common Food Products

Common food products often refer to dairy products, meat products, vegetable products, cookies, pastries, etc. Different food products require different

performance indicators for their packaging materials, and different food characteristics require different packaging forms and packaging material structures. In this article, the packaging forms, material structures, and their corresponding key indicators control of the above-mentioned common foods are summarized (detailed in Tables 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12) for the reference of relevant industries of food packaging R&D, production and food processing.

Table 2 Packaging forms of dairy products and their key quality control indicators

Food Classification	Examples of products	Packaging material Form	Critical quality control points	Suggested indicators value
Liquid milk	Pure milk/yogurt	Tetra Pak	Oxygen permeation	Barrier film ≤ 10, non-barrier film ≤ 1800 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Thickness	Limit deviation ≤ 10%
			Friction coefficient	0.2 ~ 0.3
			Heat sealing strength	≥ 17 N/15 mm
			Sealing performance (negative pressure method)	-89 KPa, airtight
			Burst pressure	≥ 40 KPa, without breaking the bag
			Solvent residue	Benzene solvents were not detected, and the total residual amount of solvents was less than or equal to 5.0 mg/L
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials
		Aseptic pillow bag	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤ 1. 0cm3/(m2·24h·0.1 MPa)
		Sterile brick	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤ 0. 5 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Oxygen permeation after kneading	/
			Sealing performance (negative pressure method)	-89KPa, airtight
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials
			Sealing performance (negative pressure method)	-89 KPa, airtight

Table 3 Packaging form and material structure characteristics of liquid milk food

Packaging material structure			Material structure (example)	Shelf life	Storage requirements	Oxygen resistance	Impact resistance	Sealability
Composite membrane Packaging	Coextrusion film (Tetra Pak)	Black and white film	High barrier film of ≥ 3 layers (including EVOH, LDPE, LLDPE, black and white masterbatch); Non-barrier film (LDPE, LLDPE, and black and white	High barrier 30-90 days Non-barrier 7-30 days	Ambient temperature Avoid light	Barrier film Higher Non-barrier film Low	Poor	The heat seal is easy to leak

			masterbatch only)					
Single film packaging	Monolayer film	Ecolean bag	70%CaCO3+30%PP, PE	7-21 days	Low temperature	Higher	Good	Good

Table 4 Packaging form and material structure characteristics of milk powder

Packaging material structure		Packaging form	Material structure (example)	Shelf life	Oxygen resistance	Whether it is a modified atmosphere	Anti-rubbing or puncture	Sealability
Composite film packaging	Aluminum-plastic composite film or Aluminized composite film	Four sides Seal bag Stereoscopic bag Back seal Folding bag etc.	PET/Al/LDPE PET/Al/PET/LLDPE PET/Al/PA/PE BOPP/Al/PE BOPA/Al/PA/PE PET/VMPET/PE BOPP/VMPET/LLDPE PET/VMCPP	6-12 months	High	Need Nitrogen filling Or CO_2 charging$_2$ Modified atmosphere	Aluminum foil, thin or too thick, aluminized Composite membrane Not resistant to rubbing or puncture	Easy to leak in heat seal or folded edges on both sides; Occasionally, there are holes in the bag body
	Paper-plastic composite film	Multiple Bag-shaped	PVDC/Paper/Al/PE Paper/PVDC/PE Paper/PVDC/VMPET/PE	3-12 months	Depending on the material		Not resistant to rubbing	Easy to leak in the heat seal
	Plastic composite film	Internal Small package	PET/CPP, KPET/PE, PET/PA/PE, KOPP/PE, etc.	3-12 months	Depending on the material	None	Rubbing resistance Not resistant to puncture	Easy to leak in the heat seal

Table 5 Packaging forms and key quality control indicators of meat products

Food classification	Examples of products	Packaging material form	Critical quality control points	Suggested indicators value
Intestines	Ham sausage	Shrinkage casing membrane	Thickness	Deviation ≤ 10%
			Shrinkage rate and shrinkage force	
			Oxygen permeation	≤ 50 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Water vapor permeability	≤ 5 $g/(m^2 \cdot 24\ h)$
	Crispy sausage/sausage	Plastic composite film	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤ 50 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Tension, elongation, and elastic modulus	/

			Anti-pendulum impact energy	/
			Heat sealing strength	≥ 20 N/15 mm
			Sealing performance (negative pressure method)	-89 KPa, airtight
			Residual solvent	Benzene solvents were not detected, and the total residual amount of solvents was less than or equal to 5.0 mg/L
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials

Table 6 Packaging forms and material structure characteristics of meat products

Packaging Form	Material structure	Advantages	Disadvantages	Application
Degassing shrink packaging	Polyvinylidene chloride (PVDC) casing	Good high-temperature resistance, good barrier performance, and good heat shrinkage	Sensitive to temperature	High temperature steamed ham sausage
	Nylon (PA or NY) casings	Good high-temperature resistance, good oil resistance, high oxygen resistance, good toughness, and strength	Limited shrinkage and poor moisture resistance	High temperature boiled ham sausage, low-temperature sausage
	Cellulose series casings	Good air permeability, can be fumigated	Not edible	Low-temperature intestines
	Collagen casing	Good air permeability, edible, suitable for high automatic enema machine	Not suitable for smoking	

Table 7 Packaging forms and key quality control indicators of cakes and biscuits

Food classification	Examples of products	Packaging material Form	Critical quality control points	Suggested indicators value
Crispy cakes or cakes with more oil content	Heong Peng/sliced bread/cake	Aluminized composite film	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤ 20 cm^3/(m^2·24 h·0.1 MPa)
			Nitrogen permeation (nitrogen-filled package)	
			Water vapor permeability	≤ 1 g/(m^2·24 h)
			Oxygen permeation after kneading	No more than ten times of oxygen permeation before kneading
			Peel strength	/
			Heat sealing strength	/
			Sealing performance (negative pressure method)	≥-70 KPa, no air leakage

			Headspace air body analysis (nitrogen-filled packaging)	It is similar to the gas composition ratio during filling
			Residual solvent	Benzene solvents were not detected, and the total residual amount of solvents was less than or equal to 5.0 mg/L
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials

Table 8 Packaging form and material structure characteristics of biscuits

Packaging material structure		Packaging Form	Material structure (example)	Oxygen resistance	Moisture resistance	Anti-rubbing or puncture	Sealability
Composite film packaging	Aluminized composite film	Ordinary packing	BOPP/VMCPP BOPP/VMPET/CPP (PE) PET/VMPET/PE VMBOPP (Cold Sealed) VMPET (Cold Sealed)	High	High	The aluminized layer is thin and not resistant to rubbing	It is easy to leak in the heat seal or the folded edges on both sides
		Inflatable packing					
		Inner lining tray, outer wrapping package					
	Plastic composite film	Ordinary packing	BOPP/CPP PET/PE OPP/PE KOPP/PE BOPP/KOPP/PE etc.	Depending on the material	Higher	Rubbing resistance Poor puncture resistance	It is easy to leak or break the bag in the heat seal
		Inflatable packing					
		Inner lining tray, outer wrapping package					

Table 9 Packaging form and material structure characteristics of cakes

Packaging material structure		Packaging form	Material structure (example)	Oxygen resistance	Moisture resistance	Nitrogen resistance	Anti-rubbing or puncture	Sealability
Composite film packaging	Aluminized composite film	Ordinary packing	BOPP/VMCPP BOPP/VMPET/CPP (PE) PA/VMPET/PE BOPET/VMCPP	High	High	High	The aluminized layer is thin and not resistant to	It is easy to leak in the heat seal or the
		Inflatable packing						
		Inner lining tray, outer						

		wrapping package	BOPP/VMPET (heat seal with coating on BOPP) BOPP/VMOPP				rubbing	folded edges on both sides
		Inflatable packing						
		Inner lining tray, outer wrapping package						
		Vacuum packaging						

Table 10 Packaging forms and key quality control indicators of convenience food

Food classification	Products Example	Packaging material form	Critical quality control points	Suggested indicators value
Instant noodles, instant rice noodles, instant vermicelli, etc.	Fried instant noodles	Plastic composite film	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤150 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Water vapor permeability	≤4.0 $g/(m^2 \cdot 24\ h)$
			Intensity of puncture	/
			Heat sealing strength	/
			Sealing performance (negative pressure method)	≥-70KPa, no air leakage
			Solvent residue	Benzene solvents were not detected, and the total residual amount of solvents was less than or equal to 5.0 mg/L
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials
		Barreled	Oxygen permeation	/
			Water vapor permeability	/
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials
			Opening force of cover membrane	/
			Sealing performance (negative pressure method)	/
			Compressive strength	/
Other convenience foods	Instant powder drinks such as black sesame paste	Plastic composite film	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤120 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Water vapor permeability	≤3.0$g/(m^2 \cdot 24\ h)$
			Heat sealing strength	/
			Sealing performance (negative pressure method)	-89 KPa, airtight
			Solvent residue	Benzene solvents were not detected, and the total

				residual amount of solvents was less than or equal to 5.0 mg/L
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials
		Aluminized composite film	Thickness	Deviation ≤ 10%
			Oxygen permeation	≤40 $cm^3/(m^2 \cdot 24\ h \cdot 0.1\ MPa)$
			Water vapor permeability	≤1.5 $g/(m^2 \cdot 24\ h)$
			Oxygen permeation after kneading	No more than four times of oxygen permeation before kneading
			Heat sealing strength	/
			Sealing performance (negative pressure method)	-89 KPa, airtight
			Solvent residue	Benzene solvents were not detected, and the total residual amount of solvents was less than or equal to 5.0 mg/L
			Migration amount of non-volatile matter	Formulated according to the hygienic performance standards followed by-product materials

Table 11 Packaging forms and material structure characteristics of instant Powder Drink

Packaging material structure		Packaging Form	Material structure (example)	Oxygen resistance	Water resistance	Rubbing resistance	Sealability
Plastics Film packaging	Aluminum-plastic composite film	Ordinary packing	PET/Al/LDPE PET/Al/PA/CPP	High	High	Poor	It is easy to leak at the heat seal or the crease on both sides of the packaging bag

Table 12 Packaging Forms and Material Structure Characteristics of Instant Noodles and Other Instant Foods

Packaging material structure		Packaging Form	Material structure (Example)	Oxygen resistance	Water resistance	Rubbing or puncture resistance	Sealability
Plastics Film packaging	Aluminum-plastic composite film	Ordinary packing	PET/Al/PA/CPP PET/Al/PE	High	High	Not resistant to rubbing High puncture resistance	It is easy to leak at the heat seal or the crease on both sides of the packaging bag
	Aluminized	Ordinary packagin	BOPP/VMCPP PA/VMPET/P	Higher	Higher	Less resistant to rubbing	Easy to leak in the heat seal

	comp osite film	g or covering film	E BOPP/VMPET /PE PET/VMPET/ PE			High puncture resistance	

3 REGULATIONS AND STANDARDS FOR FOOD PACKAGING MATERIALS

Food containers and packaging materials have a dual significance for food safety. Suitable packaging methods and packaging materials can protect food from external environmental pollution and keep the moisture, quality, and other characteristics of the food unchanged; however, the chemical components contained in the packaging materials may migrate into the food. Food safety will be affected if the migrated amount exceeds a certain value.

In this regard, countries worldwide attach great importance to the quality and safety of food contact materials. To ensure food safety, it is necessary to guarantee the quality and safety of food contact materials. To this end, many countries have established and improved corresponding regulations, formulated relevant quality and safety standards, and developed testing technologies and other measures.

3.1 China

On February 3, 2019, the State Administration for Market Supervision of China announced the notice of the 2019 Legislative Work Plan of the State Administration for Market Supervision. In particular, to strengthen the supervision of food packaging quality and safety, the Measures for Supervision and Administration of Food-related Product Quality and Safety was formulated, which indicates that the State Administration for Market Supervision will tighten the supervision on food-related products.

3.2 Europe and the United States

US FDA (Anonymous, 2020) has the following regulations on associated packaging: food must be packaged under hygienic conditions; the production of food packaging materials must be based on Good Manufacturing Practice (GMP); packaging materials and their components in contact with food must meet the requirements of regulations and standards.

The Safety Regulations on Migration of Food Contact Packaging Materials and Appliances formulated by the US Food and Drug Administration (FDA) and the European Union have constituted a green trade barrier to various importing countries. As a result of this regulation, China's exports of food packaging materials and food products have suffered from a series of obstacles abroad due to contact material (Xu, Li, Wei, 2009). The EU's trade barriers to packaging have increased from a few to dozens in recent years. The EU issues as many as 40 warnings on food packaging materials to China each year, revealing that China has a difficult situation for food packaging materials.

4 ENLIGHTENMENT

As consumers focus on the function, health, convenience, and nutrition of food today, the food industry is continuously putting forward new demands on food packaging. According to this article, the development trend of food packaging is analyzed as follows: food packaging is more convenient, lightweight, and green, which greatly promotes the development of low temperature resistant, microwaveable or special packaging materials. Complex packaging materials are replacing the single type, and environmental-friendly biodegradable materials are preferred for food packaging. Such development of food packaging is more in line with the needs of modern consumption. In the overall assessment of food packaging materials, biodegradable materials have high transportation and storage costs, and edible packaging has many problems to be solved (such as packaging performance, production costs, processing technology, varieties, application targets, safety assessment).

Owing to various factors, China lags in the administration of food packaging materials. The standard of some food containers, packaging materials, and processing aids is too old, and the testing items are relatively few. There are no corresponding standards and testing methods for many components and new products, resulting in

ineffective control of harmful components in packaging materials. In the production of complex packaging materials, there are no sanitary standards and nationally unified product standards for the widely used inks and adhesives. Following the emergence of some new food packaging materials, there is an urgent need to develop, revise and update the standards, and improve the safety evaluation procedures and evaluation mechanisms for new materials.

The market access system for food packaging materials and appliances includes a production licensing system, mandatory inspection system, market access mark system, and supervision and inspection system. We can learn from the successful experience of Europe and the United States and other developed countries to build a traceable food and packaging safety database, establish and improve the food packaging access system and regulatory measures, such as food and packaging quality and safety certification system, food and packaging recall system.

In designing and selecting packaging materials, the following methods can be used to select materials according to needs: referring to existing or already used packaging materials for the same or similar characteristics of food; comparing the advantages and disadvantages of similar food packaging materials on the market; determining the type and specifications of packaging materials through trial and test packaging. Before choosing, the parameters testing of packaging materials can also be carried out. Users should fully understand the parameters of packaging materials such as oxygen permeability, water permeability, pressure resistance, tensile resistance, tear resistance, folding resistance, heat resistance, peeling, mold resistance. They also need to understand the parameters of the packaging parts such as drop, pressure resistance, vibration resistance, impact resistance, and rotation test for the storage and transportation process. Therefore, it requires the user to be aware of packaging regulations and standards to ensure the smooth operation of packaging materials, operations, and circulation.

5 CONCLUSION

China will continue developing food packaging materials and related regulations and standards to achieve high standards and quality. As China becomes a major food production and consumption country, there is an increasing urgency to study the safety of food packaging materials. Therefore, it is suggested that China's food safety-related departments and research institutes are committed to the study of high-quality and safe food packaging materials while promoting the development of corresponding regulations and standards to ensure the healthy and rapid development of China's food packaging industry.

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