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Methods for Producing Smart Packaging



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and ease to use. Nanostructured materials as antimicrobial films, oxygen scavengers and gas permeable composites are frequently used to maintain freshness and quality of packaged food items.

Various food regulations on packaging materials are framed in different Southeast Asian countries that focus on prohibitory guidelines for toxic, hazardous, and injurious containers or packaging articles and set limitations on heavy metals or toxic substances [23]. In Thailand, the Food Act of B.E.2522 implements several legislations intended for production, distribution and importation of food packaging materials. The Thai Ministry of Public Health, in year 1979, has issued stringent notifications on specifications of the packaging material intended to be in contact with food item (s). According to the regulation, food packaging material should besafe, previouslyunused, non-contaminated, must not release color and heavy metals into the food content [24]. The Thailand Food Act requires implementation of these three Ministerial Notifications concerned with packaging containers and materials:

i. Ministerial Notification No. 92/2528 specifies the quality and quantities required for food containers those are made up of ceramic, enameled metal and used for infants. The regulation also guides permissible migration limits (not more than 2.5 mg/L) of heavy metals including cadmium and lead leaching from above mentioned small and large deep vessels shaped packaging materials. Although, this regulation (1985) was revised to harmonize international standards.

ii. Ministerial Notification No. 117/2532 was enforced in 1989 that specified regulations on packaging materials for feeding bottles/rubber teat, milk and other liquid preparations meant for children and infants. For instance, the rubber cover and teat should not release heavy metals, nitrosamine (<10 ppm) and color into the food materials. The plastic bottles should be prepared of polycarbonate that could withstand high boiling temperature. Further, Thai FDA regulation is strict on the migration of heavy metals (cadmium and lead) and potassium permanganate (not more than 20 ppm) from plastic milk containers.

iii. Ministerial notification No. 295/2548 was brought by Thai government in the year 2005. It sets standards for 12 types of plastic food packaging containers and their migration testing criteria in different solvent systems namely water/pH < 5, acetic acid/pH < 5, heptane and ethanol. Clause 6 of Notification 295/2548 covers the guidelines for plastic containers to be used for packaging of milk and milk products that should be made up of polyethylene, polystyrene, polypropylene, polyethylene terephthalate. Clause 7 prohibits the application of colored and laminated plastic packaging material for food items. Moreover, this regulation restricts the recycling of food containers that have previously been used to wrap poisonous substance, fertilizer and hazardous things.

The Ministry of Health of Malaysia drives Food Act (1983) and food regulation (1985) for setting regulations for active packaging quite similar to Article 3 of European

CHAPTER 11

Production of smart packaging from sustainable materials

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1. Introduction

Smart packaging is a technology that can perform a dual function of monitoring transformation in a product or its surrounding [1], and them to promote a desirable physical behavior of the product [2]. In most cases, biosensors or chemical sensors are often used to oversee and secure the food during production, distribution, storage, and consumption [3]. This technology offers an avenue to especially detect and analyze freshness, pathogens, oxygen, pH, carbon-dioxide, time, and temperature of the food [1,2]. There is a variation in the functional properties of the SPMs depending on the nature of the product which can be food, medical products, or any other household products [4]. It also depends on some experimental condition like the temperature, humidity and so on, which can adjust the behavior of the SPMs significantly [5]. This can enhance its ability to track, trace, analyze and control the behavior of the product so that manufacturers and the end-users are informed of its condition before and after processing [6].

Most of the SPMs available in the global food market are produced from nondegradable materials that can pose a major challenge to the industry because they are not sustainable and difficult to recycle or ruse [7–9]. Although government policies on recycling and processing packaging waste have long been in place, practical experience shows how difficult it is to recycle certain kinds of packaging waste [8]. Thus, one of the major concerns of the manufacturers of the SPM is in finding a suitable material that will not add to the already existing environmental problem that are caused using none-degradable polymers [10–12].

The sustainable materials of plant and animal origins have been proposed and used in some cases to produce the SPMs with high biosensing abilities [10,13–15]. Due to the increased consumer demand, which are based on societal developments as well as the nutritional benefits of foods derived from animal and plant materials, and the development of good health and wellness [16], novel ideas are sought to enhance safe handling, and quality maintenance [17,18]. In this context, smart food packaging technology plays major roles in food handling, transporting, and storing [19–22]. It has proved to be effective in reducing postharvest losses of food materials [12,16,23]. This review is aimed at

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providing an overview of the production processes of the SPMs via the extrusion and injection molding approaches, and the use of sustainable plant and animal products as major ingredients in their production. During the SPM production, Aerotolerant anaerobes, like Cutibacterium acnes, which can protect the system from gaseous interaction, were proposed as a filler to provide extra gaseous and temperature control within the package. This can enhance the performance of the packaging system in food preservation and other applications.

2. Mechanical production of SPMs

2.1 Extrusion technique

The SPM, based on sustainable materials, can be produced via extrusion techniques, as shown in Fig. 11.1 [4]. This normally involves manual mixing of the composite materials externally before introducing into a screw extruder, which further mixes and homogenizes the product to form pellets [24–26]. The pellets are thereafter crushed, and hot water added to form a gelatinous liquid, which is later transformed into thin sheets or film by drying in a mold. Typical procedures were outlined by Vedove et al. [4] and Fadeyibi et al. [27] in their work on the production of the SPM from starchy food products.

2.2 Injection molding technique

The SPMs can be produce using the injection molding techniques (Fig. 11.2) 28,29. This technique is most suitable to produce sophisticated SPMs for commercial applications. Unlike the extrusion technique, which is time wasting and requires the mixing of the constituent materials to get a film, this technology is fast, efficient, and low cost. During

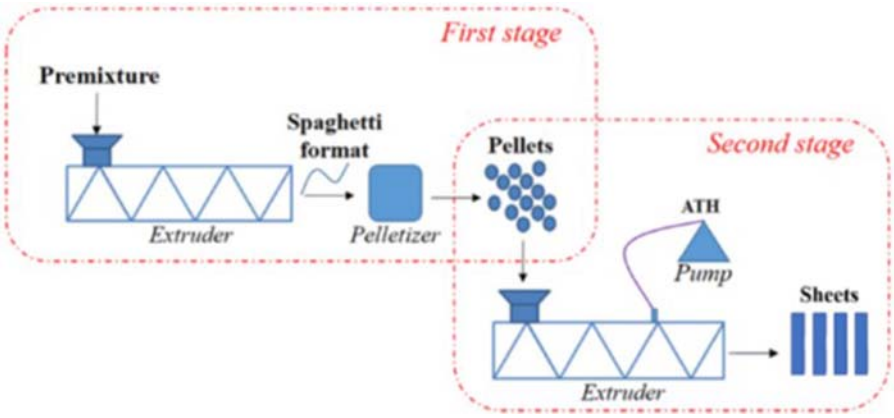


Fig. 11.1 A typical extrusion technique for SPM production [4].



Fig. 11.2 An industrial injection molding machine for production SPMs [36].

the SPM processing, the plastic materials are first heated to form molten substance. It is followed by injection into a mold which has vents to allow air escapes so that bubbles are not formed [30–32]. Once the mold is filled, the workpiece is left to cool for the exact time needed to harden the material. The cooling time is a function of the thickness of the piece and resin type [33–35]. The temperature of the lines during this process is maintained by passing water through the channels.

3. Biochemical production of SPMs

3.1 Production of SPM from sustainable bamboo products

The bamboo is a perennial plant with a high ability for self-regeneration and can be eco-friendly, thus is widely regarded as a sustainable material. It can be incorporated into synthetic materials to enhance strength for food packaging and other useful applications. According to Hai et al. [37], nanocomposite film from a blend of chitin nanofiber and bamboo has been reported to exhibit strong intelligent and active behavior, in terms of its thermal, mechanical, and biodegradable properties, compared to ordinary chitin film. The addition of bamboo leaves into a blend of chitin and zinc oxide nanoparticles generates a smart nanocomposite film which synergistically enhanced the antibacterial activity against *E. coli* and *S. aureus* [38]. It also reduced the UV light transmittance and

significantly enhanced the antioxidant activity of the films [38]. The bamboo particles embedded as reinforcement for the cork-bamboo composite were reported to enhance resistance, water absorption and dimensional stability of cork products [39]. This in turn can be used as a smart material for flooring and other structural applications. The application of bamboo in the design of polymer nanocomposite was reported by Santos et al. [40]. The authors reported that bamboo fibers can enhance the surface hydrophilicity, structural and strength of polyethylene material due to the presence of voids in the structure of the composite, as shown in Fig. 11.3 [40]. However, the commercial application of this type of SPM is limited because the bamboo fillers may absorb moisture and swell thereby causing structural distortion and stability of the matrix of the packaging material. Thus, to correct this, this writer suggests the use of biological fillers, such as the Aerotolerant anaerobes, that can suppress this incidence and create a stable system for the smart package.

3.2 Production of SPM from sustainable wool products

The wool is essential type of sustainable material that can influence the performance of many packaging systems. It is used as a blend with other materials to form composite which has enhanced structural and mechanical advantages. The production of SMP from wool sustainable materials has been reported only sparingly in the literature. Typically, a superheated water hydrolysis method has been used to process waste wool fibre-reinforced for active and intelligent design for food packaging. This involves the utilization of a reactor to mix and turn a bulk sample of the wool at variable temperature and pressure for 1 h. This is followed by mixing with a kraft pulp in water suspensions in fractions of dry weight

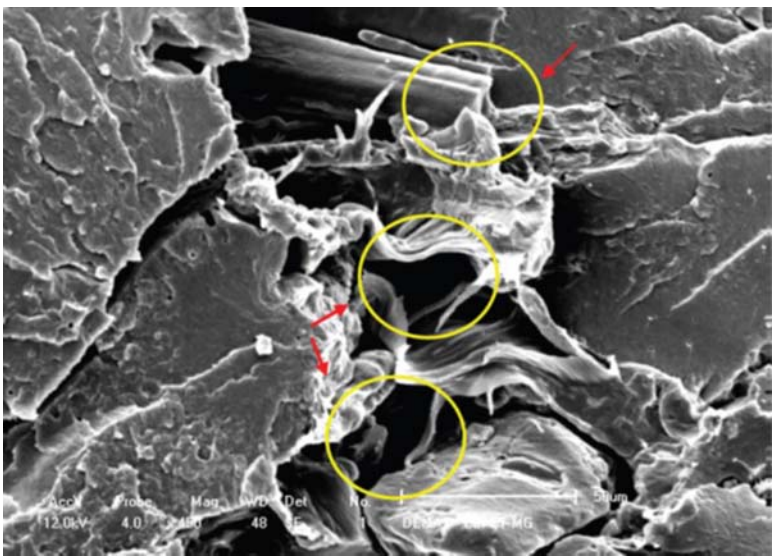


Fig. 11.3 Appearance of void due to presence of bamboo in LDPE [40].

without adding filler or chemical additives [41,42]. Also, wool keratin has been used to prepare other SPMs by dissolving solution of protein in a milk substrate (Fig. 11.4) [43]. This technology has the advantage of improving the ability of the SPMs to control the stability of fresh food products, especially during preservation in temperate conditions. This is because of the high surface absorption ability of the wool-keratin to moisture that may cause cooling and then extends the shelf-life. However, it is rarely applied for food requiring tropical treatments because the cooling effect can encourage microbial growth and encourage deterioration. Thus, the addition of a sustainable nano-wooden material during production into the SPM matrix can help address this problem because its ability to prevent heat transfer, insulate the surface, and prevent subsequent cooling, thereby promoting wider application.

3.3 Production of SPM from sustainable agricultural residues

The use of agricultural residues such as coconut, groundnut, jaropha, sugarcane bagasse, melon shells and other domestic and industrial wastes in the production of SPM is very critical to ensure ecofriendly and sustainable environment. The effectiveness of the production of bioplastics from agricultural residues and its economic viability depend on the type of residues produced in certain areas, treatment costs, biomass availability, transportation costs, raw material expenses and other common industrial expenditure. Since the type of waste generated during each season may vary, the productivity of bioplastics may be affected by seasonal changes, and this can hamper the supply of the raw materials. The production of cellulose acetate biofiber from flax fibers and cotton linters has been reported by Mostafa et al. [44]. This involves the mixture of the refined flax fiber, cotton liter, acetic anhydride, glacial acetic acid as well as sulfuric acid in definite proportions and analytically. A solution of polyethylene glycol was added to ensure the product has sufficient plasticity to withstand external variables such UV light and vibrational loads. A mixture of cellulose

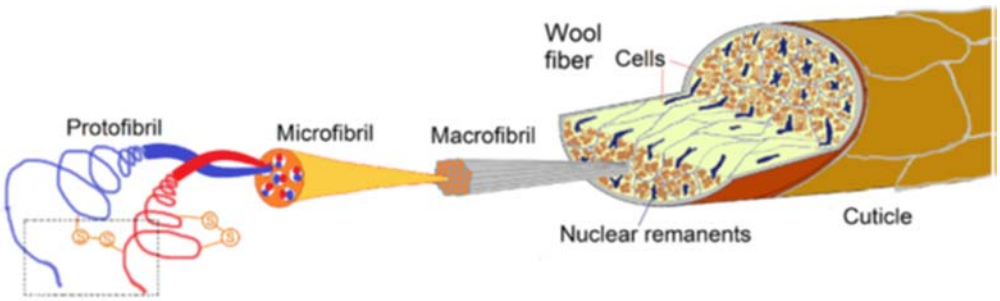


Fig. 11.4 A wool fiber reinforcement for SPM production [43].

cocoa shell incorporated into sugarcane bagasse has been used to formulate excellent bioplastic for smart food packaging [45]. The food waste from diverse sources in an environment can also be chemically transformed to form biodegradable SPMs (Fig. 11.4) [46]. Despite the advantages presented by this technology, the degradation of the bio-wastes can build gas concentration within the package, thereby causing system imbalance that may interfere with the product stability during preservation. This can however be addressed by the inclusion of Aerotolerant anaerobes during production to create an atmosphere that is devoid of excess gases, thereby enhancing the performance of the SPMs.

3.4 Production of SPM from sustainable animal skin product

The inherent properties of the animal skins that can be useful in the design of SPM includes water desorption and absorption abilities, aesthetics and surface pattern, and heat insulation. Although, the production of the SPM based on the animal skin is not very common like the ones from the sustainable plant products, the few reports have demonstrated great potentials for the future needs of the packaging industries. Typically, the production of a skate skin gelatin SPM from the mixture of the stake skin and thyme essential oil has been reported by Lee et al. [47]. The production of another type of SPM from the blend of a skin gelatin brown stripe red and bigeye snappers was also reported by Jongjareonrak et al. [48,49]. In addition, the animal skin substrates are added into the bioplastic majorly to enhance the antimicrobial activities of the resulting SPM. The work of Tkaczewska et al. [50] on the production of SPM by blending a polysaccharide and carpus skin gelatin hydrolysate shows that the skin coatings effectively inhibited microorganism growth and extend the shelf-life of perishable food products, as shown in Fig. 11.5. To the best of knowledge, despite the advantages presented by this class of material, there is no reported research on the commercialization of the SPM derived from the animal skin sources. Also, the production of SPM from the blend of animal skin and other bio-composite ingredients is not yet fully exploited. There is therefore a need for further research on the application of other useful skin sources in the production of the SPM since this can help to improve its inherent properties.

3.5 Production of SPM from sustainable eggshell product

It is a semipermeable membrane which permits gaseous exchange through its pores, and has a thin outer coating called the flower or cuticle that helps keep bacteria and dust from getting in the way. In the food packaging industry, the eggshells have found numerous commercial applications. Here, the eggshells are often transformed into powder with notable particle size in the nano-range and added as fillers to bio-composites to produce thermoplastics for packaging applications. Typically, an eco-friendly SPM with improved functional performance have been developed by combining nano-scale hydroxyapatite synthesized from eggshell and polymer-based protein extracted from soy residues [51]. Also, Kosarsoy [52] developed an ostrich shell and an edible biopolymer made from

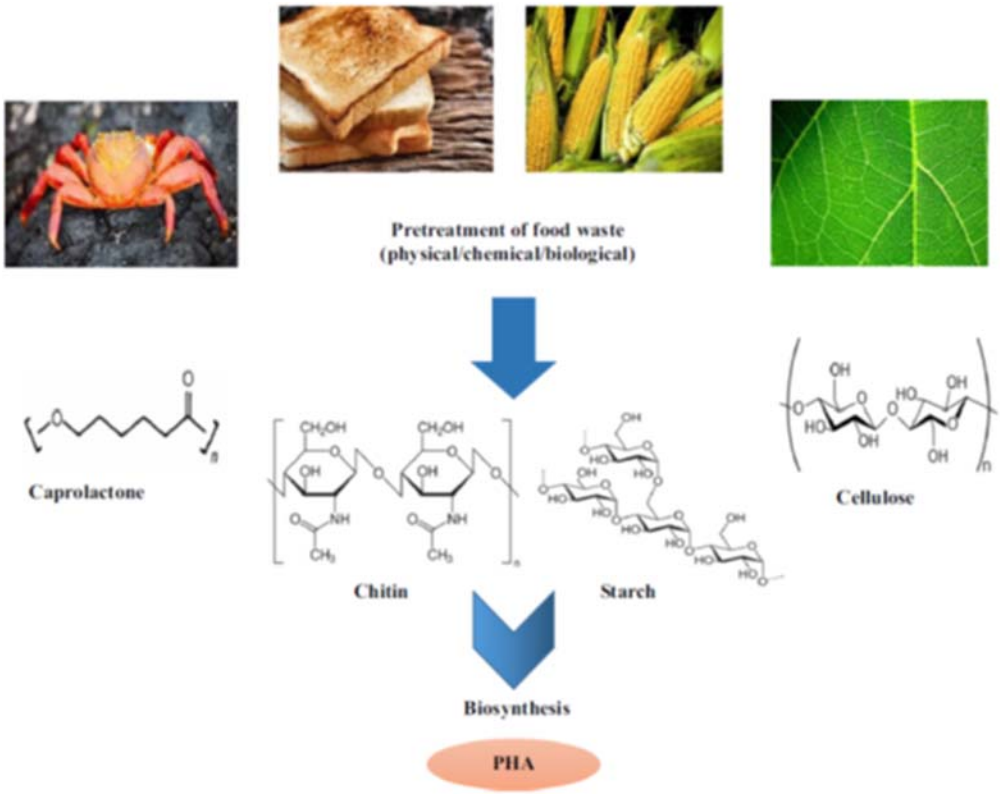


Fig. 11.5 Transformation of some food wastes into bioplastic [46].

nano-levan SPM with excellent mechanical, physical and bioactive properties for food packaging applications. A combined high temperature calcination and hydrothermal synthesis was used to produce SPM from the blending artemia eggshells and zinc oxide nanoparticles for treatment of wastewater in the industry [53]. This was done by calcining the shells high temperature to create a porous organic skeletal material. The structure is then charged with nanoparticles of zinc-oxide to synthesize the target product through a hydrothermal reaction. The material is also used to break down methylene blue, rhodamine B and neutral red under light irradiation (Fig. 11.6) [53]. Moreover, a new strategy to produce an SPM from the mixture of eggshell nanoparticles and starch with characteristics high temperatures and mechanical stabilities has been reported for fire hazard suppression [54]. This involves adding a requisite amount of starch to 30 mL deionized water in a 500 mL reactor and stirred thoroughly. The reaction temperature was controlled using a thermostat and maintained at 80°C. The solution was stirred under nitrogen atmosphere at 25°C for 20 h to synthesize the transplanted copolymer and thereafter synthesized the SPM. The nanomaterials of eggshell incorporated into the package can generate substantial amount of hydroxyapatite, which can collapse the

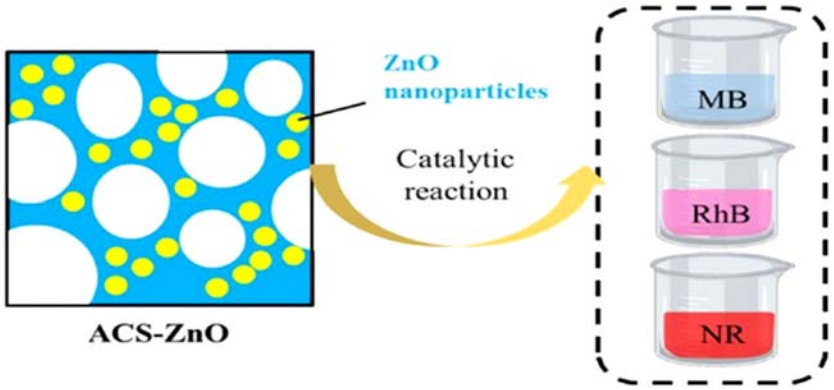


Fig. 11.6 Production of SPM from blend of ACS and ZnO nanoparticles used to degrade MB, RhB and NR material substrates [53].

microsphere into calcium and phosphate ions to cause great instability of the SPM after a long-time use. Accordingly, Piccirillo et al. [55] incorporated titanium dioxide into the hydroxyapatite composite to produce a SPM with improve stability and performance. The hydroxyapatite component of the package did not decompose due to the presence of the oxide. However, the use of biological materials to effect this change has not been widely studied. Hence, there is a need to focus on this in future research.

3.6 Production of SPM from sustainable chicken feathers

The chicken feathers consist mainly of keratin, which is a tough protein like that found in the animal hair, hoofs, and horns, that can enhance the strength and the durability of the SPMs. When the keratin extract is blended into biopolymers, the resulting material, which is characterized with sufficient hydrophilicity, can act intelligently on the food products during packaging improve their quality and durability. Typical is chicken feather protein SPM production containing clove oil was reported by Song et al. [56] for intelligent packaging of smoked salmon fish. This was done by dispersing gelatin solution into a mixture of the chicken feather protein and sorbitol plasticizer. The resulting solution was then heated using a warm 75°C water bath for 30 min, and clove oil and cinnamaldehyde solvent were added to enhance the hydrophilicity of the SPM. Also, Chen et al. [57] reported the production of the SPM from the blend of the feather keratin and plasticizer and stabilized using tris (hydroxymethyl) aminomethane. A bioplastic SPM production by degrading the feather waste using microorganism to obtain the keratin and mixing it with a starch source has been reported by Alshehri et al. [58]. As much as the author knows, the commercial application of the SPMs made from the keratin in the feathers has not been exploited. More research is required to figure out the nature of the macromolecule in the package, and how it influences the surface interaction to effect the change in the food product during packaging and in shelf storage.

4. Prospects and conclusions

The application of sustainable plant materials that influence the environment in the production SPMs for food storage and processing is well known in the literature. Despite this, some bio-wastes used in the SPMs can still decompose, mainly due to overuse, and elevate the concentration of the gases within the package. This can cause a system imbalance that may interfere with the product stability during preservation. In this paper, the inclusion of the Aerotolerant anaerobes during production of the SPMs was proposed to correct this situation. This will create an atmosphere that can tolerate the excess gases, thus enhancing the performance of the package. Other materials, like the wood-powder, which can prevent the transfer of heat, insulate the surface, and prevent subsequent cooling, were also proposed for inclusion during production. However, as much as the author knows, the production and commercialization of the SPMs derived from the blend of the nanoparticles of the sustainable animal products and other bio-composite ingredients have not been fully exploited. It is thus necessary to bridge this gap. Finally, research is needed to understand the nature of the microsphere in the package, and how this influences the surface interaction with the bio-based fillers to control the changes in the food quality during packaging.

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