Paper-based Products as Promising Substitutes for Plastics in the Context of Bans on Non-biodegradables

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As a global environmental problem, plastic pollution has attracted worldwide attention. Plastic wastes not only disrupt ecosystems and biodiversity, but they also threaten human life and health. Countries around the world have enacted regulations in recent years to limit the use of plastics. Paper products have been proposed as promising substitutes for plastics, which undoubtedly brings unprecedented opportunities to the pulp and paper industry. However, paper products have some deficiencies in replacing certain plastic products. Research and development to improve paper properties and reduce production costs is needed to meet such challenges.

Keywords: Plastic; Plastic bans; Pulp and paper industry; Paper-based materials

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Plastics and Plastic Bans

Plastic products have the advantages of light weight, low cost, good ductility, and excellent insulation, which explains why they have been widely used in industry, agriculture, medicine, and other fields (Geyer *et al.* 2017). Over the past few decades, the production of plastics has experienced rapid growth. It is reported that by 2015, 8.3 billion tons of plastics had been produced in the world; however, of that amount, 6.3 billion tons had become plastic waste (Geyer *et al.* 2017). The plastic waste has posed a severe and irreversible impact on the global ecosystem and biodiversity (Abel *et al.* 2017). In order to avoid or alleviate these problems, many countries and regions around the world have successively launched a series of policies and regulations that prohibit, partially prohibit, and restrict the use of plastic products.

These days, the scope of plastic restrictions has gradually expanded from plastic bags to disposable plastic products such as plastic tableware and plastic cups. The limited use of plastic products has prompted many countries to look for environmentally friendly and cost-effective alternatives. At present, materials such as glass, metals, biodegradable plastics, and paper products have been considered as alternatives to plastic products (Eriksen *et al.* 2018). Among them, paper products have unparalleled desirability of promoting environmental sustainability, since these products are produced from renewable and abundant lignocellulosic biomass, and they have the advantages of recyclability, biodegradability, and low cost.

How Can Paper Be Engineered to Replace Plastics

Although paper products possess many advantages, as mentioned above, they do have limitations when compared to plastics. Thus, it is of great significance for papermakers to promote the development of manufacturing technologies to address the deficiencies of paper products and expand their applications in replacing traditional plastic products. Details will be discussed in the following sections.

Food packaging products

With the implementation of plastic bans, the demand for disposable paper boxes, paper cups, straws, paper bags, paper cans, and other related paper-based products for food packaging will increase, especially during the COVID-19 pandemic period (Liu *et al.* 2020). However, paper products are normally opaque, porous, and not heat-sealed. They have poor barrier performance against oxygen and water vapor. There are several ways in the industry to ameliorate these drawbacks, one of which is by coating paper with one or more layers of polymer or metal foil. However, such multilayered paper products face recycling problems. Two other popular strategies involve chemical additives, which can be applied either in the course of surface sizing or at the paper machine wet end. However, there are limited options of chemicals for these purposes because of the high safety standards for use in food packaging materials. Notably, a recent editorial by Wan *et al.* (2020) pointed out that edible additives could be promising alternatives used for cellulosic paper, especially for food packaging applications. The edible additives can be biobased polymers such as starch, carboxymethylcellulose, protein, chitosan, and rosin, as well as mineral particles (*e.g.* bentonite, calcium carbonate, and silica). These edible additives are expected to be used for both internal and surface applications, which may provide enhanced mechanical strength, water resistance, and barrier properties of the final products.

Molded pulp products

Molded pulp products (MPP) can be made from various natural fibrous materials such as wheat straw, sugarcane, and recycled paper. Due to the advantages of low toxicity and biodegradability, MPP have the potential to replace plastic products in a wide range of fields, including food containers and tableware, electronic product packaging, compostable containers for agricultural seedlings, medical and health products, building materials, and living furniture. However, MPP are susceptible to environmental humidity and moisture because of the hygroscopic nature of cellulose fibers. Getting wet may reduce their structural integrity and storage life. In order to solve this problem, colloidal rosin and wax emulsions are widely used in the industry. In addition, fluorocarbon polymers are usually used in combination with cationic retention aids to impart repellency to low surface tension oils and greasy liquids. However, the above-mentioned chemicals are not environmentally friendly. Thus, developing green and sustainable additives for MPP will be an important research direction in the future.

Shopping bags

The ban of disposable plastic bags will usher in a new growth point for paper shopping bags. However, the high cost and inferior mechanical strength of paper shopping bags are the main hurdles to large-scale replacement of plastic shopping bags. In the paper industry, paper properties can be tailored by wet-end and surface strategies (Fan *et al.* 2017). For example, the rational use of chemical additives (*e.g.* alkyl ketene dimer, alkenyl succinic anhydride, rosin) can enhance the water resistance of paper shopping bags. In addition, surface sizing has been demonstrated as an effective way to improve the physical properties of paper, including mechanical strength, surface morphology, barrier properties, and water and oil tolerance (Chen *et al.* 2017). Further efforts are needed to develop sustainable additives and sizing agents, as well as advanced manufacturing technology to produce high-performance paper for various types of paper shopping bags.

Agricultural mulch

Agricultural mulch is mainly made of plastics such as polyethylene and polypropylene. However, the plastic mulch is not biodegradable and must be removed and landfilled at the end of the growing season, which will cause environmental pollution. Recently, paper-based agricultural mulch has emerged as a promising alternative due to its great biodegradability. To date, many types of paper such as kraft paper, wax paper, and shredded paper have been used as paper mulches. Among them, kraft paper is currently the most widely used paper mulch. However, the paper mulches have several deficiencies such as overly rapid degradation, poor barrier properties, modest mechanical strength, and difficulty in commercial agricultural operations, which limit their large-scale applications. In order to solve these problems, coated papers for use as mulch with various organic resins and plastic coatings such as polyethylene, polyvinyl chloride, polyvinyl acetate, wax coatings, and latex coatings have been developed in recent years (Haapala *et al.* 2014). However, these coatings still face the biodegradability problem. Therefore, it is of critical importance for papermakers to develop fully biodegradable paper mulches with controllable degradation rate, good barrier properties, and high mechanical strength. Applying pulp refining, suitable chemical additives, and biodegradable sizing agents may be potential strategies to this purpose.

Nanocellulose and self-assembled nanostructures

The rapid development of nanotechnology can open opportunities for the traditional pulp and paper industry. Cellulose nanomaterials, also known as nanocellulose, that can be produced from lignocellulosic biomass have attracted extensive attention due to their unique properties (Du *et al.* 2019). Recently, self-assembled cellulose nanopaper (CNP) formed from a nanocellulose suspension has been widely studied due to its superior mechanical properties, tunable optical properties, high thermal stability, low thermal expansion coefficient, excellent oxygen barrier, and biodegradability (Miao *et al.* 2020). CNP has been highlighted as an alternative to traditional plastic. It has broad application prospects not only for packaging but also in the fields of flexible electronics, biomedical devices, and water treatment (Zhao *et al.* 2020). In addition, nanocellulose can be used as thin coatings for paper products to increase their barrier performance in packaging applications (Hubbe *et al*. 2017). Intriguingly, a recent study demonstrated that high-performance bulk structural plates (*e.g.* 320 mm × 220 mm × 27 mm) can be processed from cellulose nanofibers with light weight, excellent strength and toughness, and high thermal dimensional stability (Guan *et al.* 2020). The assembled plates can be considered as promising substitutes for plastics, ceramics, and metals, making them a strong competitor for the lightweight materials used for automotive and aerospace applications. Related research is expected to provide a variety of high-performance and environmental-friendly structural materials to replace plastics in the near future.

Future Opportunities

In the context of plastic bans, paper products can replace many plastic products and have numerous advantages in terms of sustainable development and environmental protection. This makes them promising green packaging materials. The plastic bans may provide unprecedented opportunities for the pulp and paper manufacturers. However, certain paper products (*e.g.* shopping bags) still have deficiencies such as high cost and inferior mechanical strength. Thus, papermakers need to devote effort to develop advanced manufacturing technologies for the low-cost production of high-performance products. In addition, self-assembled nanostructures from nanocellulose, *e.g.* CNP and bulk structural plate, show great promise in replacing plastics for high-end applications.

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