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Food packaging wastes amid the COVID-19 pandemic: Trends and challenges

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ABSTRACT

Background: The COVID-19 crisis generated changes in consumer behavior related to food purchase and the management of food packaging. Due to the intensification of online purchases for home delivery, there has been an increase in the use of food packaging (mostly non-biodegradable or non-renewable). Moreover, the fear of contamination with SARS-CoV-2 through contact with materials and surfaces has led to an intensified disposal of food packaging, promoting a setback in waste management.

Scope and approach: The purpose of this short commentary is to address the impacts of increased use and disposal of food packaging during the COVID-19 pandemic. Technological solutions have been presented as tools to minimize the environmental impacts of the increased volume of disposed food packaging (namely, the development of biodegradable food packaging) as well as to minimize the occurrence of cross-contamination (namely, the incorporation of active antiviral components).

Key findings and conclusions: The consumer behavior in the COVID-19 pandemic requires actions concerning adoption of bioplastics for single-use food packaging. Polylactide (PLA) stands out for high production viability, performance comparable to those of petroleum-based thermoplastics, and carbon neutral life cycle. Moreover, active components including organic compounds (resveratrol, luteolin, myricetin etc.) and metals (*e.g.*, copper, zinc, silver) can mitigate cross-contamination. Therefore, there are opportunities to reduce food packaging-related environmental footprints while also decreasing the occurrence of surface-mediated cross-contamination.

1. Introduction

The COVID-19 pandemic has forced public health measures to contain virus transmission, generating sudden, rapid and unprecedented changes in the behavior of the general population (Tchetchik et al., 2021). The whole world has adopted some human mobility restriction strategy such as remote working, curfew or lockdown, which has resulted in some positive environmental impacts, such as cleaner rivers and skies, as well as roaming of once hidden animals to urban areas (Arora et al., 2020; Shakoor et al., 2020).

On the other hand, the pandemic has brought about some negative environmental consequences related to the increased demand for materials intended for the protection of people and products, deeply affecting the solid waste management requirements (Khan et al., 2020; Tenenbaum, 2020; WasteAdvantage, 2020).

The pandemic-induced fear of in-store shopping has spurred online shopping, especially for food, whose online purchases has grown in several countries (Hyun, 2020; Sarkodie & Owusu, 2020). Despite some initiatives to ensure sustainable waste management (*e.g.*, using paper-based packaging or returnable plastic packaging), the total or partial closure of food establishments for indoor services promoted an increased demand by about 15% for delivery services, contributing to an intensified use of single-use plastics (SUPs) (EAE Business School, 2020; Patrício Silva et al., 2021; Sattlegger et al., 2020). SUPs are usually

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based on petroleum-derived polymers, which are well established as effective and (usually) inexpensive materials for food packaging. However, the problem with their intensive use for single-use applications is that, besides being typically from non-renewable sources (although there are companies producing some of them from renewable sources), they are mostly non-biodegradable, and thus persisting in the environment. As a response to the environmental impacts caused by SUPs, several countries have adopted regulations banning or establishing taxes on them (Chen et al., 2021). On the other hand, there has also been resistance on SUP regulations, mainly in the USA (Nielsen et al., 2019). Although some states have enacted restrictions to SUPs, there is no federal regulations to restrict them. Actually, there have been campaigns, some of them promoted by the Plastics Industry Association (PIA), addressing the risks of SUPs helping spread SARS-CoV-2, leading many local governments to retreat from restrictions to SUPs and discouraging use of reusable bags (Hale & Song, 2020).

Another problem related to food packaging is the possibility that SARS-CoV-2 can survive for a relatively long time in food packaging surfaces. Although there are mostly uncertainties on how long the virus could survive on different surfaces (Hakovirta & Hakovirta, 2020; Malenovská, 2020), there are evidences that food packaging materials may carry the virus, as recently reported by China in packaging with Brazilian chicken (Associação Brasileira de Proteína Animal, 2020; Kampf et al., 2020). Despite the contact with surfaces not being the main route of COVID-19 transmission, it also raised concerns about cross-contamination, which stimulated the culture of disposal and the indiscriminate use of non-biodegradable packaging, generating setbacks to sustainable policies already established (Sharma et al., 2020; Sinclair et al., 2018). In addition to surface contamination, the final disposal of the packaging materials, combined with inadequate collection practices, may represent another important transmission risk (Sharma et al., 2020). In this context, the purpose of this short commentary is to advance the understanding that, while the world watches COVID-19 sweeping across the globe, two requirements related to food packaging have become more urgent than ever, namely, the replacement of petroleum-based materials for renewable and biodegradable packaging materials, and a wide use of active antimicrobial (including antiviral) components on food packaging material formulations. Databases such as Google Scholar, PubMed, Scielo, ScienceDirect, Scopus, and Web of Science were consulted, using the following search terms: (i) COVID-19 AND food packaging; (ii) plastic waste AND COVID-19; (iii) antiviral nanoparticles AND SARS-CoV-2 AND food packaging; (iv) natural antivirals against AND SARS-CoV-2; (v) food packaging OR bioplastic OR polylactide, in the title, abstract and keywords. Studies published until 2020 were selected. Specifically, 28 studies published in 2020–2021 were included.

2. Pandemic and increase in non-biodegradable packaging

The COVID-19 pandemic has generated pressure on foodservice companies, which had to reinvent themselves during the economic crisis, that is, to face consumer germophobia and to ensure food security. In this setting, the demand for food delivery services have grown rapidly (for example, a 12% and 36% increase in revenues for Grubhub and Just Eat, respectively), and those services were especially essential for high-risk populations (elderly, chronically ill, immunosuppressed, immunocompromised, among others) (Grubhub, 2020; Perkins, 2020; Rizou et al., 2020). At the same time that sales of fresh food have fallen (*e.g.*, fish, meat and cheese, whose sales volumes fell in 41.8%, 45.8%, and 15.2% respectively), the sales of processed and pre-packaged foods have increased by 20–54% (Perkins, 2020). Therefore, a growing wave of non-biodegradable food packaging has emerged as an increased risk to public health, with a wide impact on ecosystems and organisms (Prata et al., 2020; Rizou et al., 2020). Fig. 1 addresses the main causes and outcomes of the increased use of single-use non-biodegradable packaging during COVID-19. According to Sharma et al. (2020), solid waste management practices during the COVID-19 crisis have been reduced, contributing to increased pollution, mainly from plastics. Under the effect of environmental conditions, plastic materials may decompose into small fragments, with an increased potential to spread across the globe (Prata et al., 2020). Recently, micro- and nanoplastics were found in 47 samples of human liver and adipose tissue, in the form of monomers or building blocks. In the same study, bisphenol A (BPA), for example, still used in food packaging, was found in all 47 human

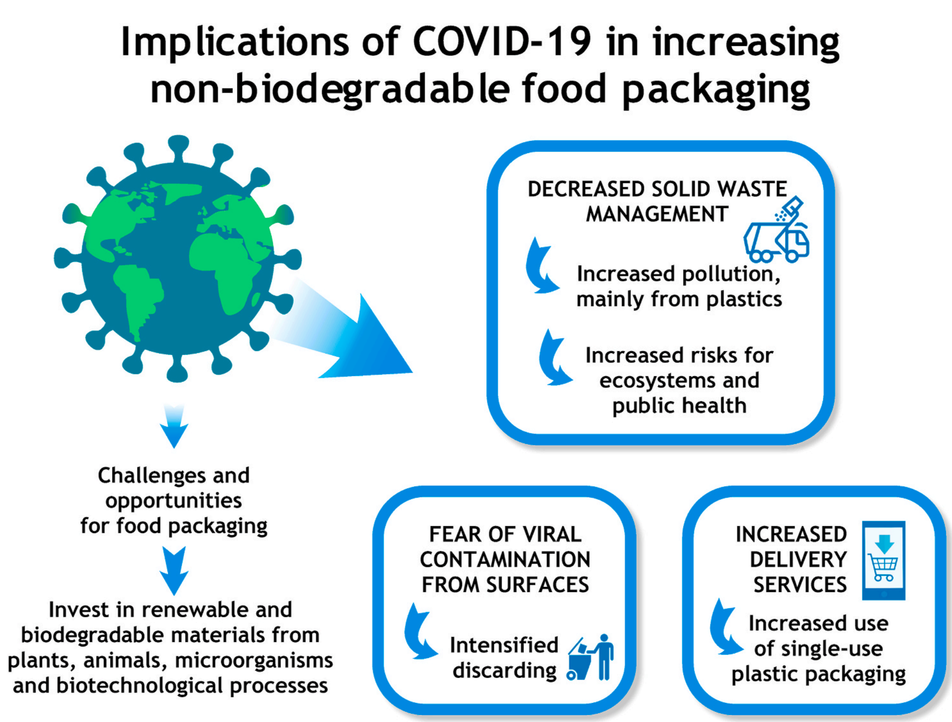

Fig. 1. Crisis of COVID-19 and increase in non-biodegradable food packaging.

samples analyzed, despite its alleged health risks (Rolsky & Halden, 2020). On the other hand, biodegradable polymers can decompose into smaller molecules (CO_2, CH_4 e H_2O), by microorganisms (aerobically or anaerobically) or by abiotic reactions (photodegradation, oxidation and hydrolysis) (Nature Communications, 2018). In general, polymers for renewable and biodegradable packaging are produced from plants (polysaccharides and some proteins), animals (proteins mostly), microorganisms (polyesters/PHAs, bacterial cellulose), or synthesized by biotechnological processes (polylactides/PLA) (Asgher et al., 2020). The most commonly known biodegradable polymers are polyglycolide (PGA), polycaprolactone (PCL), polyhydroxyalkanoates (PHA), poly (butylene succinate) (PBS), poly (adipate-*co*-terephthalate) (PBAT) and polylactide (PLA) (Nature Communications, 2018).

3. Polylactide (PLA)

PLA, in particular, is the most widely used bioplastic at the commercial level for short-term applications, being obtained through different polymerization processes from lactic acid (polycondensation, ring-opening polymerization, azeotropic dehydration and enzymatic polymerization) (Farah et al., 2016). It is considered safe (GRAS) by the US Food and Drug Administration (FDA) and has high production viability since it can be easily processed using the same technology used in petroleum-based thermoplastics (extrusion, injection molding, blow molding, extrusion cast film, and thermoforming) (Garcia-Garcia et al., 2020; Gerometta et al., 2019). Reported as carbon neutral life cycle material, PLA can also be produced from food waste, *e.g.*, fish, rice bran, vinification lees, soy protein hydrolyzate, and unpolished aged rice, among others (Shi et al., 2018; Tsang et al., 2019), being an appropriate material to promote a circular, sustainable and less wasteful economy (Jribi et al., 2020). Recent studies show that several technologies have been developed so as to produce PLA materials comparable to those obtained from petroleum-based polymers (Asgher et al., 2020; Farah et al., 2016; Garcia-Garcia et al., 2020; Kalita et al., 2020). Various types of food with a wide range of water activity (a_w), pH and composition have already been packaged and marketed with PLA-based materials, including potato chips, ready-to-eat salads, yogurts, citrus juices, and water (Gerometta et al., 2019).

At the end of its life, PLA can be fully recycled. Chemical recycling, for example, presents itself as an attractive alternative, since it recovers the monomer for the production of virgin biopolymer, closing the cycle and resuming the economic value of post-consumption material (Sangroniz et al., 2019). On the other hand, in the composting process, PLA deteriorates at a daily rate of 1.14% of total biomass (Eichelman et al., 2020). It is also noteworthy that biodegradation can be caused by microorganisms widely spread in nature, such as *Fusarium moniliforme, Penicillium roqueforti*, thermophilic bacteria, *Tritirachium album* and *Aspergillus flavus* (Karimi-Avargani et al., 2020; Nature Communications, 2018). The PLA life cycle assessment showed reductions of up to 40% in greenhouse gas emissions and up to 25% in the use of non-renewable energy compared to petroleum-derived polymers, such as polyethylene or PET (Zhu et al., 2016).

4. Food packaging and antiviral action

Another problem that requires attention is the contamination of food packaging by SARS-CoV-2. There are two main approaches to the use of biopolymers for antiviral action. The first includes the use of biopolymers as carriers of antiviral compounds. The second comprises the use of biopolymers containing antiviral fractions, such as amines, carboxylic acid, sulfates, phenols, among others (Jarach et al., 2020). Although the second has been the focus of relevant research, the first has been shown to be more viable and will be the focus addressed below.

There is no scientific evidence that the transmission of COVID-19 may occur through food, however, the coronavirus can reach fresh food products and packaging through sneezing, coughing, contact with dirty hands or by body secretions of an infected person (Prata et al., 2020; Rizou et al., 2020). Transmission, by surface contact, appears to be possible if the virus is then transferred by hand or by the food itself to the mucous membranes of the mouth, throat or eyes (Rizou et al., 2020). It was previously described that the coronavirus remains viable on surfaces: (i) glass (5 days), (ii) cardboard (8 h), (iii) silicone (5 days), (iv) PVC and Teflon (5 days), (v) other plastics (72 h–6 days) (Kampf et al., 2020; Rawlinson et al., 2020). Plastics, in particular, are known to adsorb organic and inorganic nutrients from the environment, providing a relatively stable environment for pathogenic bacteria and/or viruses, such as the SARS type (Prata et al., 2020).

4.1. Natural additives and antiviral potential

On the other hand, there is a wide range of natural additives, with antiviral potential that can be incorporated into biodegradable food packaging to mitigate cross-contamination, including: (a) hydrolyzable tannins (*e.g.*, chebulagic acid and punicalagin), effective in inactivating the herpes simplex virus type 1 (HSV-1) (Lin et al., 2013); (b) pomegranate leaf extract (*Punica granatum* L), potent against human Herpesvirus 3 (HHV-3) and with *in vitro* activity comparable to acyclovir (Angamuthu et al., 2019); (c) rutin, flavonoid extracted from plum (*Prunus domestica*), efficient in inhibiting hepatitis C virus (HCV) (Bose et al., 2017). Specifically for coronaviruses, some compounds have been reported: (a) resveratrol, a polyphenol found in grape skins (*Vitis vinifera*) and peanuts (*Arachis hypogaea*); (b) crocin, a carotenoid from saffron (*Crocus sativus* L.); (c) digitoxigenin, a saponin; (d) β-Eudesmol, an oxygenated sesquiterpene; (e) flavonoids, including curcumin, luteolin, myricetin and theaflavin (theaflavin-3,3′-digallate); (f) baicalin, a flavone glycoside from *Scuttelaria baicalensis*; (g) lycorine alkaloid, from lily (*Clivia miniata*); (h) licorice roots (*Glycyrrhiza glabra*); (i) Japanese honeysuckle (*Lonicera japonica*); (j) Korean ginseng (*Panax ginseng*), and others (Aanouz et al., 2020; Boukhatem & Setzer, 2020; McKee et al., 2020; Mhatre et al., 2020; Yang et al., 2020).

4.2. Viricidal inorganic nanostructures

Nanostructures have been widely studied as components for a variety of applications, including food packaging (Azeredo et al., 2015). In addition to serving as reinforcement, some of them can have multiple functions, such as antiviral effect. Copper, zinc and silver nanoparticles, especially, have been shown to be virucidal. Most viruses have negative charges due to prototrophic groups (carboxyl, amino, guanidyl and imidazole). Antiviral cations bind to DNA, RNA, through virus membrane fitting channels, affecting their fixation and action (Jarach et al., 2020). For example, the addition of Ag nanoparticles (10–80 nm) to acacia gum had antiviral action on Monkeypox and Tacaribe viruses (Rogers et al., 2008; Speshock et al., 2010). Ag-chitosan nanoparticles (3.5–12.9 nm) exhibited antiviral activity against influenza A H1N1 virus (Mori et al., 2013). Recently, silver nanoclusters have shown a promising virucidal effect on SARS-CoV-2 (Balagna et al., 2020).

5. Conclusions and future prospects

The COVID-19 crisis has generated disruption and setbacks in waste management, resulting in a new plague of plastics that the world will have to face. The post-COVID-19 expected drop in oil prices may further reduce the cost of plastics production, directly affecting corporate commitments to sustainable packaging (Sharma et al., 2020; Vanapalli et al., 2021). Alongside this, delays in environmental summits can divert many countries to shift the agenda towards COVID-19's health and economic recovery policies. The increased online purchases motivated by the closure of restaurants and cafeterias to indoor services has led to an intensified use of single-use packaging materials (mostly petroleum-derived plastics), while the panic of contamination by SARS-CoV-2 have motivated an intensified disposal of those materials.

Initiatives on replacing single-use petroleum-based plastics for bioplastics such as PLA may help to contain the environmental pressure caused by the huge volume of plastics discarded daily, although the development of the necessary infrastructure should also be encouraged for effective management of bioplastic waste (Vanapalli et al., 2021). The post-COVID-19 scenario will probably require intensified governmental policies to promote the development of active environmentally friendly bioplastics as well as technologies that promote circular economic principles (particularly valorization of food byproducts) (Umaraw et al., 2020).

Author contributions

Williara Queiroz de Oliveira: Conceptualization, Writing – review & editing. Henriette Monteiro Cordeiro de Azeredo: Conceptualization, Writing – review & editing. Iramaia Angélica Neri-Numa: Conceptualization, Writing – review & editing. Glaucia Maria Pastore: Conceptualization, Supervision and Funding acquisition.

Ethical approval

This Commentary does not contain any studies with human participants or animals performed by any of the authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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