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Edible films and coatings – Not just packaging materials

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ABSTRACT

Edible films and coatings (EFC) are macromolecular-based structures forming thin layers that are usually studied as tools to improve food stability, sometimes being considered as parts of both the packaging system and the food itself. However, EFC are not mere packaging materials, and sometimes they do not even play roles related to those of packaging. This graphical review summarizes possible roles of EFC, including primary packaging, keeping water activity gradients between food components, controlling mass transfer on food processing, carrying active components, or serving as sources of sensory appeal. EFC may even be designed in a way that two or more of those roles may be played simultaneously.

1. Introduction

Edible films and coatings (EFC) have been studied as protecting layers to be applied on food products, extending their stability mainly by acting as protecting barriers. Films differ from coatings in that films are stand-alone structures formed separately, while coatings are formed directly onto food surface (Otoni et al., 2017). Fig. 1 presents a schematical comparison of film and coating formation, and examples.

The main component of EFC is an edible biomacromolecule (matrix, binder or binding agent) – usually polysaccharide and/or protein – able to form a continuous and cohesive layer. Moreover, plasticizers (e.g. polyols, sugars) are usually required to reduce brittleness. Sometimes, other components are added with specific purposes, e.g. reinforcement. While the resulting material is a cohesive layer that may benefit food stability, EFC are not usually able to completely substitute conventional fossil-based plastics for packaging applications – in fact, it is not their goal to do so.

First of all, biomacromolecules bear some important limitations when replacing conventional polymers. One of them is that most of them degrade at temperatures close to – usually lower than – their melting points, making the traditional thermal processing methods in the molten state (e.g. extrusion, compression molding, injection molding) challenging and generally unfeasible (Zhao et al., 2020). Therefore, their processing typically requires engineering adaptations or wet processes (based on separation from a solvent) such as casting or regeneration methods (Azeredo et al., 2014; Otoni et al., 2021). Moreover, biomacromolecules usually lead to limited tensile and barrier properties, implying poor performance for classical packaging applications (Otoni et al., 2021; Zhao et al., 2020). The hydrophilic nature of most biomacromolecules is another drawback, making the films highly permeable to water vapor and sensitive to contact with moist surfaces, thus restricting some applications. Finally, their use is limited by their relatively high cost. Although biomacromolecules may be isolated from cheap and abundant feedstocks such as food losses and waste (Otoni et al., 2021), the isolation processes involve time-consuming and expensive methods.

Moreover, food packaging materials are typically exposed to chemical and biological contaminants along the food distribution chain. Without a package, the food itself would be contaminated, affecting food safety. If edible films were used as substitutes for any food packaging materials, their contamination would make them not suitable to be eaten (thus, no longer edible).

On the other hand, EFC have a peculiar characteristic that classical packaging materials lack: their very edibility (and, sometimes, the sensory appeal that comes with it). Indeed, EFC should be viewed as part of the food itself rather than of packaging (although they may be used as packaging materials for specific applications, as we will show). This graphical review proposes to summarize the main rational functions and applications of EFC.

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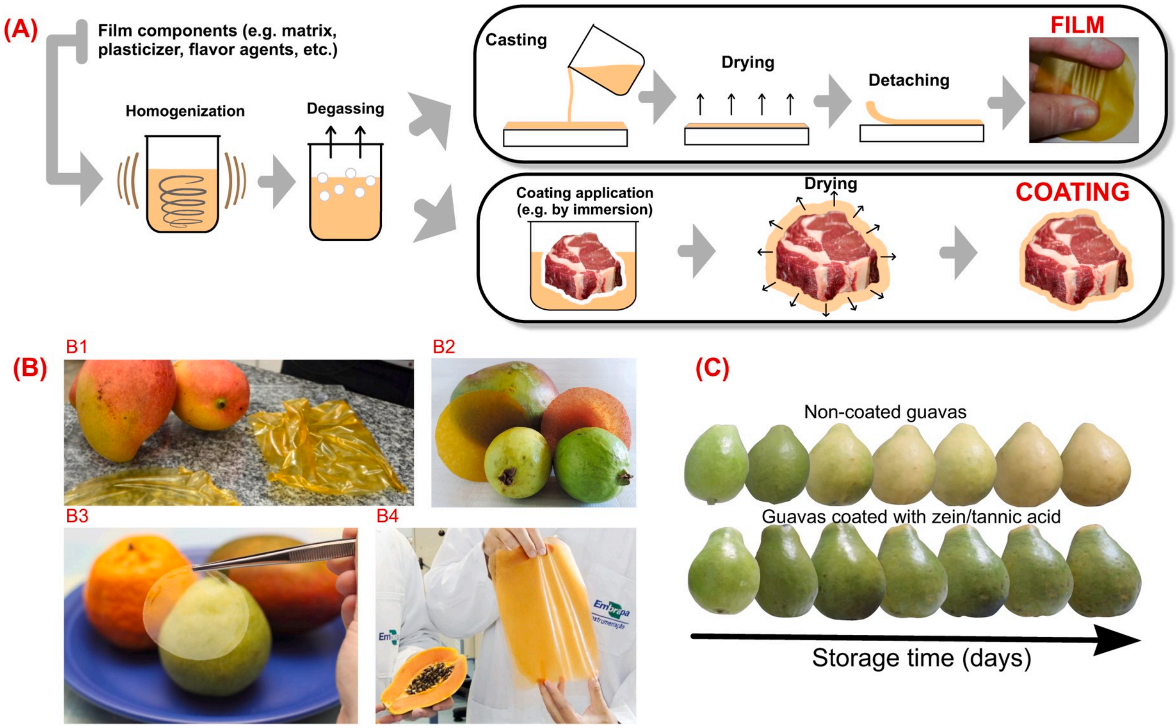
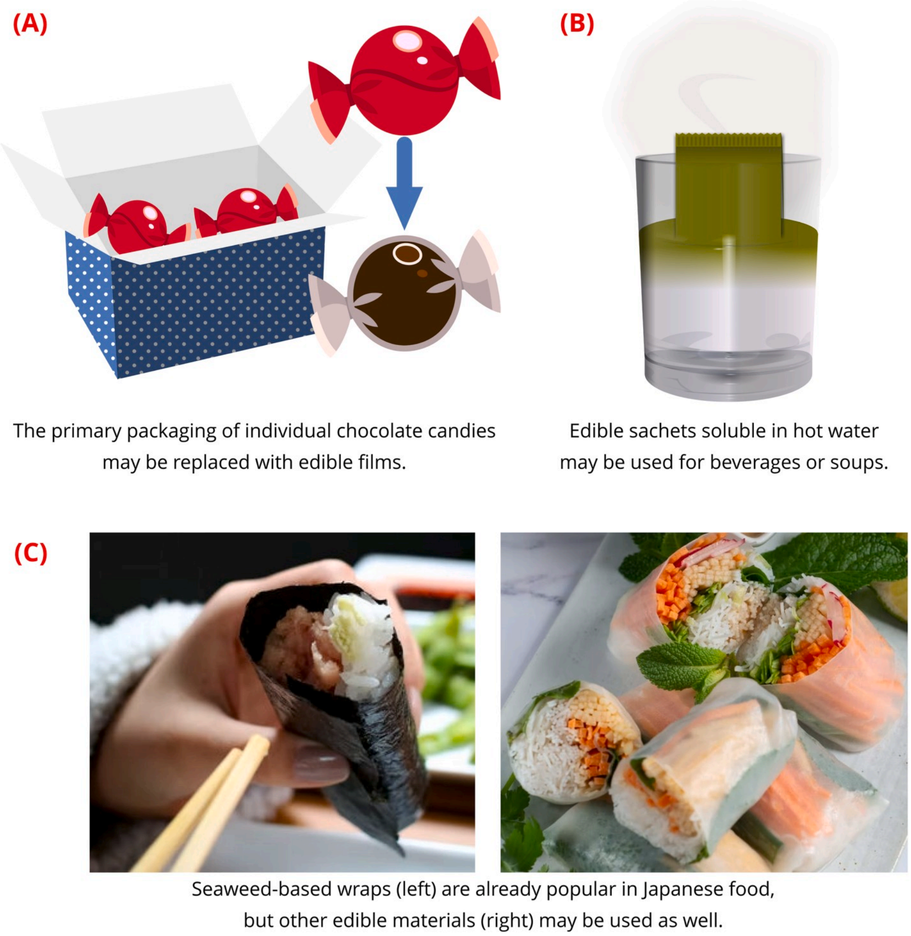


Fig. 1. (A) Typical procedures to form films and coatings, either edible or not (adapted from Otoni et al. (2017), with permission from John Wiley and Sons. (B) Examples of edible films made by our team at Embrapa. B1: mango puree-based films; B2: bacterial cellulose films added with guava and mango puree (Viana et al., 2018); B3: alginate/cashew tree gum film sample; B4: pectin/papaya puree/cinnamaldehyde nanoemulsion film (Otoni et al., 2014). (C) An example of coating on guavas slowing down their repening process (adapted from Santos et al., 2018, with permission from Elsevier).



The primary packaging of individual chocolate candies may be replaced with edible films.

Edible sachets soluble in hot water may be used for beverages or soups.

Seaweed-based wraps (left) are already popular in Japanese food, but other edible materials (right) may be used as well.

Fig. 2. Showcases of films used as primary food packaging.

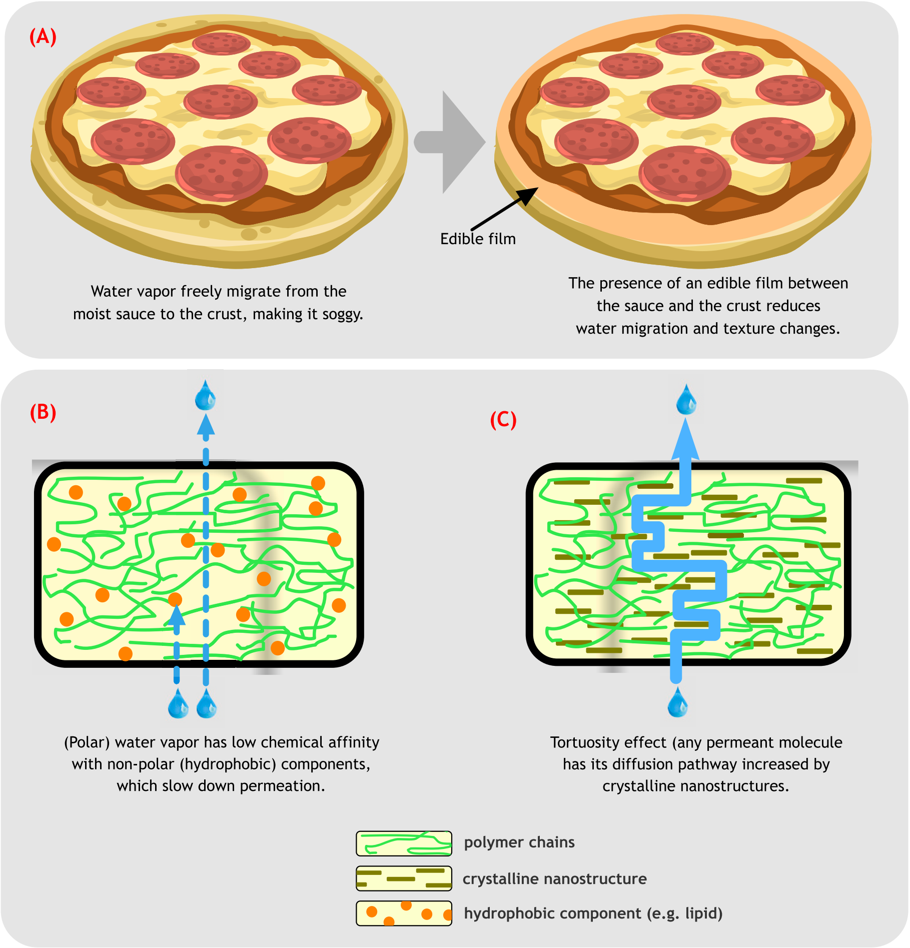


Fig. 3. Edible films as water vapor barrier layers in multicomponent foods. (A): Schematic representation of a film applied between pizza crust and toppings (containing tomato sauce). (B) and (C): Effects of a hydrophobic component and a crystalline nanostructure (respectively) on the water vapor permeability of a film.

2. Primary packaging (when there is a secondary one)

Some food products contain not only a primary packaging (directly in contact with the food), but also a secondary packaging containing the primary one. As an example, some breakfast cereals are packaged into plastic bags (primary packaging) that act mainly as barrier to water vapor (minimizing texture changes) inside a cardboard box (secondary packaging) that, in turn, provides mechanical protection, barrier to light, and communication (printability). Other products are constituted by a number of smaller units, each one inside a primary packaging, with a secondary one grouping them together into a saleable unit and protecting them from contamination, such as in a box of chocolate candies (Fig. 2A). In such cases, EFC should not replace the secondary packaging, but they may replace the primary ones.

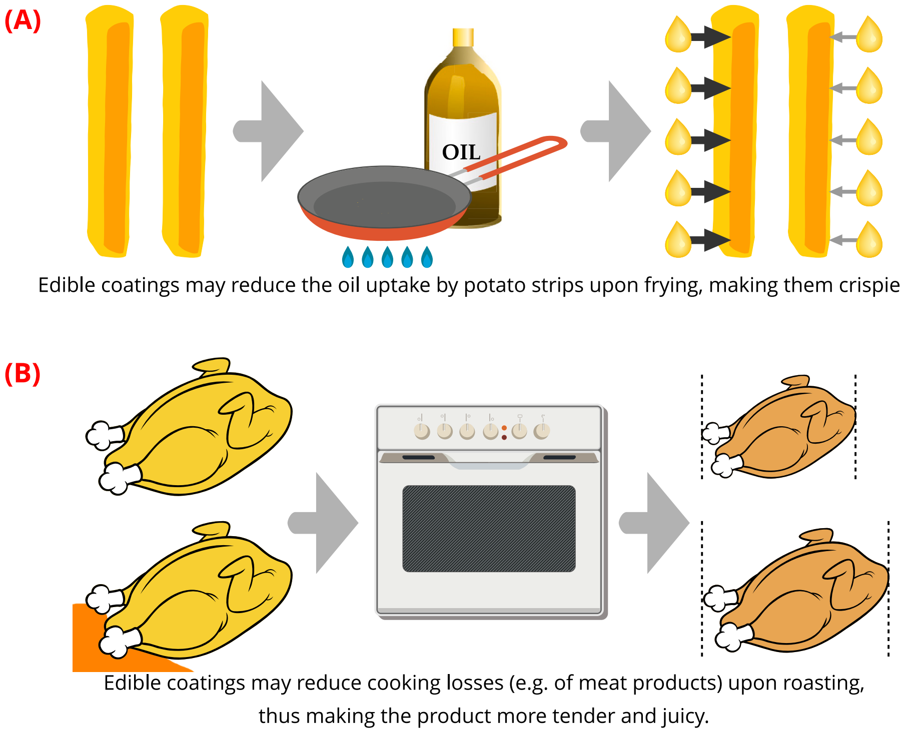
Sachets are frequently used as primary packaging for particulate products, which are to be mixed to other food components (e.g. yogurt) or solubilized in water (e.g. beverages and soups) (Fig. 2B). Although sachets are usually non-edible, edible sachets contribute to reduce the waste disposal, and may even carry flavor compounds, contributing for the whole sensory experience. There is also the case of accidental ingestion of loose sachets packaged together with the food itself, the risk of which being eliminated when the sachet and its content are edible. The choice of a sachet matrix should be based on a variety of factors, including heat seability and seal strength (avoiding premature release of contents), tensile properties (to support the contents), and barrier properties (to minimize chemical degradation of the contents) (Liu et al., 2020). When the sachet is to be solubilized in water, instant water solubility is also desirable (Liu et al., 2020). Moreover, rheological properties should be taken into account, since viscosity changes may be desirable or not, depending on the intended properties of the final product.

Wraps (e.g. seaweed sheets, Fig. 2C) are not conventionally considered as packaging, since they are loose around the food (not sealed). However, they have functions of a packaging material (i.e. unitizing and facilitating handling, even providing some barrier). Gelatin-pectin edible films have been used as wraps for ricotta cheese, decreasing the moisture loss by the product, thus contributing for keeping its soft texture (Jridi et al., 2020). Pectin/fenucreek gum films with phenolic extracts were used to wrap fresh-cut carrots, extending their microbial shelf life, which was ascribed to the polyphenols (Jayaprada and Umapathy, 2020).

3. Keeping water activity gradients in multicomponent foods

Pizza is a typical example of a multicomponent food product with a high water activity (A_w) gradient between a crispy crust and moist toppings. During storage, water molecules move from the toppings to the crust, which tends to become soggy. Other examples of multicomponent foods that lose texture on storage (or delivery) due to water migration between components include tacos and frozen dessert cones.

EFC between food components with high A_w gradients (Fig. 3A) may reduce water migration, helping to keep the crust as crispy as expected. For this kind of application, the EFC should have low water vapor permeability (WVP). Some approaches may decrease the WVP of EFC, including the incorporation of a hydrophobic component (Fig. 3B) such as rapeseed oil (Galus, 2018) or clove essential oil (Xu et al., 2020), or

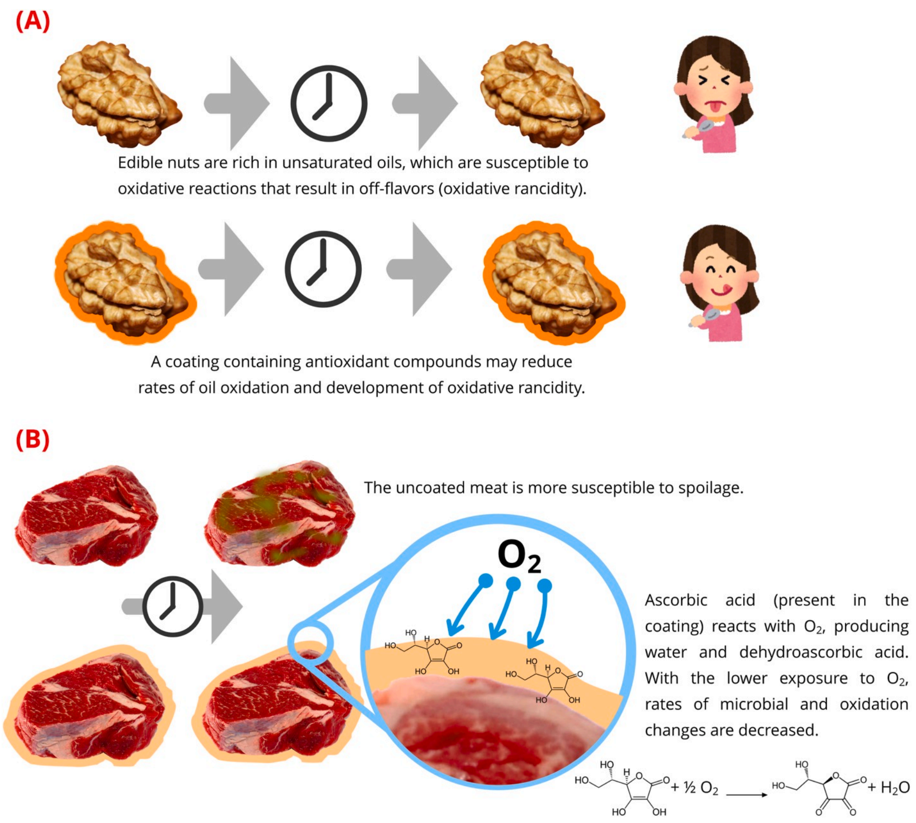


Edible coatings may reduce the oil uptake by potato strips upon frying, making them crispier.

Edible coatings may reduce cooking losses (e.g. of meat products) upon roasting, thus making the product more tender and juicy.

Fig. 4. Examples of edible coatings acting to control mass transfer on food processing.

the addition of hydroxyl-rich compounds such as polyphenols, whose hydroxyl groups may form hydrogen bonds with polar groups of the matrix, limiting their availability for interaction with water (Fabra et al., 2018). The WVP may also be decreased by crystalline nanostructures (Fig. 3C) such as cellulose nanocrystals (CNC) (Sá et al., 2020) and montmorillonite (Ribeiro et al., 2018). The concomitant addition of tannic acid and CNC sharply reduced the WVP of gelatin films, which was ascribed to both tortuosity effect (increasing the diffusion pathway



Edible nuts are rich in unsaturated oils, which are susceptible to oxidative reactions that result in off-flavors (oxidative rancidity).

A coating containing antioxidant compounds may reduce rates of oil oxidation and development of oxidative rancidity.

The uncoated meat is more susceptible to spoilage.

Ascorbic acid (present in the coating) reacts with O_2, producing water and dehydroascorbic acid. With the lower exposure to O_2, rates of microbial and oxidation changes are decreased.

Fig. 5. Schematic representation of edible coatings as potential carriers of (A) antioxidant and (B) oxygen absorbing compounds.

for water vapor) and hydrogen bonds between CNC, tannic acid, and amine groups from gelatin (Leite et al., 2021).

4. Controlling mass transfer on food processing

In deep frying, a food product is immersed in hot oil, which induces water vaporization and oil absorption, among other changes, including starch gelatinization, protein denaturation, and Maillard reaction. Potato fries are popular products of deep frying. While their crispy texture and the flavors from Maillard reaction are highly appreciated, the oil uptake is considered as an undesirable side effect (from both the sensory point of view, since the strips tend to become soggy and less crispy, and also from a health perspective). Coating the strips (previously to frying) with a layer of hydrophilic macromolecules creates a barrier to restrict oil uptake (Lumanlan et al., 2020; Salehi, 2020) (Fig. 4A).

Coatings may also reduce moisture losses on cooking. In meat products, for instance, tenderness and juiciness are important sensory aspects. The texture of cooked meats depends mainly on heat-induced changes in proteins, but it is also affected by cooking losses resulting from water evaporation as well as oil and water dripping on cooking. Cooking losses may be reduced by edible coatings or wraps (Fig. 4B), which has been demonstrated by wrapping chicken meat with caseinate-based films before roasting (Küçüközet and Uslu, 2018).

5. Sources of sensory appeal

EFC may have sensory appealing components such as fruit and/or vegetable purees, which, apart from providing desirable sensory properties, may still contribute for the mechanical properties of the material, since they contain film-forming biomacromolecules and plasticizing sugars. Edible films have been produced from mango (Oldoni et al., 2021; Viana et al., 2018), papaya (Otoni et al., 2014; Rodríguez et al., 2020), guava (Viana et al., 2018) etc.

Films containing such components may be consumed alone as snacks, being in this context related to the concept of fruit and vegetable leathers, differing from those in that films are thinner (Otoni et al., 2017) and usually containing a biopolymer matrix. EFC with flavorful components may also act as functional materials (e.g. barriers to water vapor in multicomponent foods) while also contributing for the whole sensory experience, e.g. having flavors that are complementary or contrasting to those of the main food components.

6. Carriers of active components

EFC may also be carriers of active components, which are capable of extending food stability by mechanisms different from those related to mere (passive) barrier effects. Active EFC (Fig. 5) may either release compounds that enhance food stability, e.g. antimicrobials and antioxidants, or absorb components that shorten food stability, e.g. ethylene, water vapor and oxygen, as reviewed elsewhere (Mellinas et al., 2016; Salgado et al., 2015).

Moreover, EFC may also incorporate bioactive components that confer health benefits for consumers, such as those containing probiotics (Oliveira et al., 2021; Singh et al., 2019).

7. Final remarks

This graphical review has presented possible roles for EFC, but two or more roles may be played simultaneously. As an example, a film between pizza components (designed to act as a moisture barrier) may be formulated with sensory appealing ingredients in such a way as to enrich the sensory properties of the pizza, and may also contain an antimicrobial compound to extend the microbial stability of susceptible components (e.g. cheese and tomato sauce).

Independently on the roles played by EFC, they should be considered as part of food rather than of the packaging system, although they may play some packaging-related function (and usually do so). Moreover, their possible roles should ideally be explored in such a way as to maximize their benefits for both food stability (and safety), the sensory experience of the consumer, and including health benefits whenever there is such an opportunity.

Future studies are required to enhance the feasibility of large-scale processing of edible films, as well as to improve the physical performance of the materials while keeping their food-grade character and safety. One of the greatest challenges on EFC is to create biomimetic edible structures that reproduce the mechanical and barrier performance of fruit skins, pursuing the difficult task of mimicking mother nature.

CRediT authorship contribution statement

Henriette M.C. Azeredo: Conceptualization, Writing – original draft. **Caio G. Otoni:** Writing – review & editing. **Luiz Henrique C. Mattoso:** Writing – review & editing.

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 paper.

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