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PREPARATION OF AGAR EDIBLE FILMS CONTAINING FRUIT EXTRACTS RICH ON NATURAL HEALTH-PROMOTING CHEMICALS

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Abstract: An edible coating or film is originated from natural products such as polysaccharides, proteins and lipids, with the addition of plasticizers and/or surfactants. Agar films are biodegradable, transparent, and heat-sealable edible films made from agar, a polysaccharide extracted from red algae. They are a potential alternative to plastic packaging, offering environmental benefits due to their renewable and biodegradable nature. However, pure agar films have drawbacks, such as brittleness and high moisture permeability, which can be addressed by incorporating other materials, like other polymers, besides plasticizers, and/or reinforcing them with nanomaterials. Agar--based edible films incorporated with fruit extracts offer a promising approach for sustainable food packaging and preservation, with the natural benefits of both materials. Agar, provides a biodegradable base for the films, while fruit extracts enhance functionality with antioxidants and other bioactive compounds. This combination addresses challenges like brittleness and low barrier properties inherent in agar alone, promoting a more sustainable and functional packaging solution. In the present article the challenges of the preparation of agar films incorporated of mulberries or blackberries, Morus genus or Rubus genus extracts are presented and discussed, taking in account the different factors that can modify film structure, such as irradiation, that can improve their functionality and applicability in foods.

Keywords: agar, edible films, mulberries, blackberries, *Morus genus, Rubus genus*, ionizing radiation

INTRODUCTION

In contrast to conventional packaging, which simply contains and safeguards its contents, active packaging interacts with the packaged contents to enhance their longevity, safety, and overall quality. Active edible coatings and films are increasingly important in biobased packaging because they have a prime role in enhancing the organoleptic characteristics of the food products and minimizing the spread of microorganisms. These sustainable ingredients are crucial for a safer and healthier environment. These are created from proteins, polysaccharides, lipids, plasticizers, emulsifiers, and active substances. These are eco-friendly since made from innocuous material. Antioxidant, flavoring, and coloring compounds can be employed to improve the quality, wellbeing, and stability of packaged foods (Matloob *et al*., 2023). The use of synthetic antioxidants in foods has been avoided due to their possible toxic effects. Instead, a wide range of natural antioxidants such as plant extracts, as well as pure compounds, like ascorbic acid and α-tocopherol, have been incorporated into edible films and coatings to improve their bioactive properties. Films and coatings containing added antioxidants help to preserve or enhance the sensory properties of foods and add value to the food products by increasing their shelf life (Eça *et al*., 2014; Jancikova *et al.* 2021).

AGAR PROPERTIES AND USES

Agar is a biopolymer, a complex polysaccharide, that is extracted from certain red algae, specifically the agarophytes, or seaweeds. These algae, like *Gelidium* and *Gracilaria*, produce agar as a supporting structure within their cell walls. Agar can be used as a polymeric matrix to create edible films. Its gelling ability allows for the formation of a thermoreversible gel, which can be cast into films resulting in a renewable alternative for plastic-based food packaging materials.

The interest of researching and published on agar properties and uses is increasing. The earliest papers published on agar were 54 until 1900 according to Web of Science data base. Until 1940 the number was 883 articles and since then the increase was almost exponential (Fig. 1).

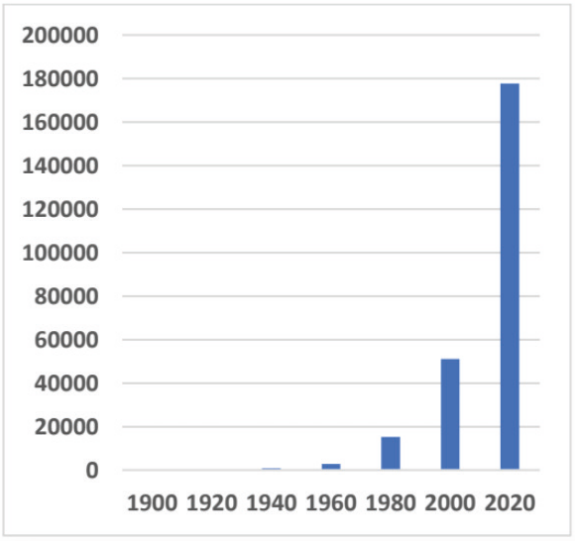

Figure 1. Number of publications on *agar* versus time according to Web of Science data base.

Agar-based packaging films are prepared by employing a solvent (water) and plasticizers like glycerol or sorbitol (Arham *et al*., 2018). However, plain agar film have limitations such as brittleness, high moisture permeability, and poor thermal stability. Considerable researches have been devoted to improving the properties of agar films to extend their applications. These include reinforcements by nanomaterials, blending with other biopolymers, and incorporating plasticizers, hydrophobic components, or antimicrobial agents into their structure ((Wang & Rhim, 2015; Saurabh *et al.,* 2018; Radovanovic *et al.,* 2019; Mostafavi & Zaeim, 2020; Mahumala *et al*., 2020; Amariei *et al*., 2022; Makhloufi *et al*., 2022); Roy *et al.,* 2023; Akbar &Mustari, 2024). Novianto *et al*. (2024)a prepared a blend of agar and Porang-glucomannan that showed enhancing properties. Giordano *et al.* (2022) developed a tool for sustainable treatment based on agar spray.

NATURAL HEALTH-PROMOTING CHEMICALS FROM FRUIT EXTRACTS

The health benefits of fruits vary based on their composition, growth, and environmental circumstances. The term 'small or little fruits' is used in international literature to refer to various crops such as strawberries, blackberries, raspberries, currants, blueberries, among others. The cultivation of small fruits is characterized by high labor requirements and the possibility of obtaining high economic returns. Many species of blackberry are native to southern Brazil (Fachinello *et al.,* 1994). However, it was from cultivars and seedlings obtained in the USA that breeding work began at the *Pelotas Experimental Station*, now *EMBRAPA Clima Temperado*, Rio Grande do Sul, Brazil, starting in 1972 (Moreira, 1989).

The blackberry, like the raspberry, is part of a large group of plants of the genus *Rubus*. This genus belongs to the *Rosaceae* family, in which there are other important genera, such as Malus, Prunus and Pyrus.

Mulberries and blackberries are both little purple fruits that, although have in common several characteristics such as high levels of natural health-promoting chemicals, are two distinct species (https://www.yahoo.com/lifestyle/mulberries-vs-blackberries-whats-difference-011455340.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAFaBBCY3ZCe0gbVtNdjXSUCpO3ewBIxvdCfPt4wIOgCYkMbCCEdib7GsIXt0gJM_gFAjlX_eXDHj9wsWFiE0tZe99Gu_L8s0yjQXb5N,YhEWA9gUWJq6Xk-dv_KP6DSo4KSV6ktmbj_1aH41EtnstoxsedPkRfoVNVai25dRbjKJD).

Mulberries are fruits that come from trees belonging to the *Morus genus* (Zhou *et al*., 2003; Yang *et al*., 2023). Blackberries are succulent and flavorful berries that belong to the *Rubus* genus of the *Rosaceae* family (Santana *et al.,* 2024). Mulberries and blackberries are both known to be rich in polyphenols, particularly anthocyanins, which give them their purple color and contribute to their antioxidant properties; both fruits also offer other benefits like vitamin C, fiber, and various other phytochemicals, all of these beneficial to human health and fitness. Several studies have demonstrated that the phytochemical contents of *R. fruticosus, R. ulmifolius*, and *M. nigra* can act as antioxidant, anti-inflammatory, neuroprotector, and antitumoral agents, and offer cardiovascular protection, although the mechanism of action of the blackberry and mulberry metabolites that trigger the biological activities are not complete understood (Ramirez *et al.,* 2011; Oliveira *et al*., 2018; Rodrigues *et al.,* 2019; Ramappa *et al*., 2020; Vega *et al*., 2021; Martins *et al*, 2023; Pereira Alves *et al*., 2023; Sakart *et al*., 2023; Ferraz *et al*., 2024). Zielinski *et al.* (2014) published their results showing that the group of strawberry, red fruits, blackberry, açai, and grape pulps present the highest contents of total phenolic compounds, total flavonoids, and antioxidant activity among Brazilian frozen fruit pulps when studying the association between chromaticity, phenolics, carotenoids, and in vitro antioxidant activity. According to Souza *et al*. (2014) the blackberry stands out among the fruits evaluated by exhibiting the highest antioxidant activity and the highest levels of phenols, flavonoids, anthocyanins and carotenoids.

The polyphenols are the secondary metabolites produced by the plants which played an imperative role in industrial and therapeutic applications. The polyphenols are composed of the phenolic ring and structural element that bind these phenolic rings to one another. The polyphenols were categorized under different sub-categories according to their nature of action and their structural components (Pabhu et al., 2021). Most polyphenols are moderately to partially soluble in water, meaning they can dissolve to some extent but are not highly water-soluble. Their solubility is influenced by factors like the number of hydroxyl groups and the presence of other functional groups. While some polyphenols are readily extracted by water, others are more soluble in organic solvents or have limited water solubility.

Anthocyanins are a class of water-soluble flavonoids widely present in fruits and vegetables. The main types of polyphenols are: phenolic acids, flavonoids, stilbenes and lignan (Castañeda-Ovando et al., 2009; Bolat et al., 2024). Dietary sources of anthocyanins include red and purple berries, grapes, apples, plums, cabbage, or foods containing high levels of natural colorants. Cyanidin, delphinidin, malvidin, peonidin, petunidin, and pelargonidin are the six common anthocyanidins. Following consumption, anthocyanin, absorption occurs along the gastrointestinal tract, the distal lower bowel being the place where most of the absorption and metabolism occurs. In the intestine, anthocyanins first undergo extensive microbial catabolism followed by absorption and human phase II metabolism. This produces hybrid microbial–human metabolites which are absorbed and subsequently increase the bioavailability of anthocyanins. Health benefits of anthocyanins have been widely described, especially in the prevention of diseases associated with oxidative stress, such as cardiovascular and neurodegenerative diseases. Furthermore, evidence suggests that health-promoting effects attributed to anthocyanins may also be related to modulation of gut microbiota (Mattioli *et al*., 2020).

THE ROLE OF IONIZING RADIATION IN BIOENGINEERING

Radiation-processing technologies are used currently for numerous applications of commercial and economic importance. Radiation can be used to modify edible films, enhancing their properties and improving their suitability for food packaging applications (Drobny, 2013; Del Mastro, 2016; Elbarbary *et al.,* 2023; Aboulfotouh *et al*., 2024; Syahputra *et al.,* 2024; Del Mastro, 2024; Cieśla &Abramowska, 2025).

The role of ionizing radiation on agar films was also studied. Aliste *et al*. (2000) published he first article on the radiation effects on agar, alginates and carrageenan to be used as food additives. The radiation chemistry of polysaccharides was the subject of a publication from the International Atomic Energy Agency (Al--Assaf *et al*., 2016) among others (Sabaghi *et al*. 2020). Novianto *et al.* (2024)b published their results showing that dose of 20-30 kGy of gamma irradiation enhanced functionality of fish gelatin-agar edible films, but at dose of 40 kGy potential chain scission in the film's polymeric structure action occur. The precise role of irradiation must be established in each specific system.

CONCLUSION

Antioxidants from fruits incorporated into agar edible films are a promising area of research for extending the shelf life and enhancing the quality of food products. Mulberries and blackberries are extracts rich on natural health-promoting chemicals such as polyphenols, particularly anthocyanins responsible for their purple color and contribute to the antioxidant properties; both fruits offer many benefits to human health. To achieve a sustainable preparation of agar edible films containing mulberries or blackberries extracts will demand a correct address of all the key factors involved for overcome experimental issues: fruit extraction process, selection and proper proportion of ingredients, method of film preparation and selection of agents that can made possible or enhance the film properties like the use of irradiation.

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