Novel probiotic functional foods

Nuevos alimentos funcionales probióticos

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Abstract

The importance of food consumption in relation to human health has increased consumer attention in nutraceutical components and foods, especially fruits and vegetables. Berries (*Vaccinium* ssp.) are a species from the family *Ericaceae*, including approximately 450 species. Berries, having commonly recognized taste properties, are also a valuable source of health-promoting bioactive compounds. For several decades, berries have gained popularity all over the world, and recent years have seen not only an increase in fresh consumption, but also for the processing industry.

Postharvest berries are highly perishable. As a soft fruit, the firmness of berries is one of the most essential quality attributes, which is in relation to fruit quality, resistance to postharvest diseases, shelf life, and especially the acceptability of consumers, thereby limiting their commercial value. Several preservation technologies have been used to maintain bioactive compounds, reduce deterioration, and prolong shelf life of fresh berries. This review enhanced the importance of berries postharvest quality maintenance through the application of several preservation technologies. In addition, the application of minimally processed berries as an alternative to dairy products to deliver probiotics was revised. Ready-to-eat berries constitute novel, healthy and multifunctional alternatives of non-dairy probiotic foods that would allow meeting the current consumer demand.

Keywords: non-dairy functional foods, postharvest quality, pathogens, healthy fruits.

Resumen

La importancia del consumo de alimentos relacionados con la salud humana ha incrementado la atención de los consumidores por los alimentos funcionales, especialmente por las frutas y verduras. Las bayas (*Vaccinium* ssp.) son una especie de la familia *Ericaceae*, que incluye aproximadamente 450 especies. Las bayas, con propiedades organolépticas reconocidas, son también una valiosa fuente de compuestos bioactivos potencialmente beneficiosos para la salud. Desde hace varias décadas, las bayas han ganado popularidad en todo el mundo, y en los últimos años se ha observado no sólo un aumento de su consumo en fresco, sino también industrializada en diferentes formas.

Tras la cosecha, las bayas son muy perecederas; tomando en consideración que son frutas que se ablandan fácilmente, su firmeza es uno de los atributos de calidad más importantes, confiriéndoles además resistencia a las enfermedades poscosecha, mayor vida útil y, sobre todo, la aceptabilidad de los consumidores, lo que limita su valor comercial. Se han utilizado varias tecnologías de conservación para mantener el contenido de compuestos bioactivos presentes en las bayas frescas, reducir el deterioro y prolongar su vida útil. Esta revisión destaca la importancia del mantenimiento de la calidad poscosecha de las bayas mediante la aplicación de diversas tecnologías de conservación. Además, se realiza una revisión de la aplicación de bayas mínimamente procesadas como alternativa a los productos lácteos para suministrar probióticos. Las bayas listas para el consumo constituyen así alternativas novedosas, saludables y multifuncionales de alimentos probióticos no lácteos que permitirían satisfacer la demanda actual de los consumidores.

Palabras clave: alimentos funcionales no lacteos, calidad poscosecha, patogneos, frutas saludables.

1. INTRODUCTION

Globally, fruit production has increased in recent years due to their increased consumption in human diet. Dietary guidelines around the world recommend the increased consumption of fruits and vegetables as good sources of antioxidant phytochemicals for the prevention of chronic diseases. Therefore, there has been an increasing demand for fresh fruits and vegetables because of its health benefits. Fruits are rich in nutrients associated with a beneficial effect on human health. While the fresh-cut vegetable industries have consolidated their position in both food service and retail markets, fresh-cut fruit processors are still trying to develop products that attract consumers' interest because of their fresh-like quality [Pem and Jeewon, 2015]. The shelf life of fresh-cut fruits is dramatically reduced by the removal of the protective skin as well as by the deleterious effects of cutting and handling operations [Moreira et al., 2015; Moreira et al., 2017]. They are products with a relatively short postharvest life, since they remain as living tissues up until the time they are used for consumption and are prone to physiological and biochemical changes, which can also have physical or pathological origins, leading to important economic losses. Fruits and vegetables lose weight during postharvest handling and storage by transpiration, resulting in textural changes and surface shrinkage that affects their shelf life [Radev and Pashova, 2020; Sapper and Chiralt, 2018]. In addition, microbial growth and mechanical damage are the main causes of quality decay. During their production, significant losses can occur; mechanical stress during processing results in biochemical deteriorations such as enzymatic browning, off-flavor, and texture breakdown. The postharvest stage is the key for fruit preservation; in this step, fruits are treated with different technologies in order to maintain fruit quality. Aside, the presence of microorganisms on the surface of fruit may compromise the safety of fresh-cut produce [Alvarez et al., 2013; Moreira et al., 2015]. Furthermore, these increased consumption results in illnesses and outbreaks when the products make contact with pathogenic microorganisms. Fresh horticultural produce is known to be a major vehicle of pathogens [Bambace et al., 2021; Ponce et al., 2005].

Specifically, berries are highly perishable in the postharvest. On the one hand, because they have thin skin and juicy pulp; on the other hand, they are harvested in summer with high temperature and high humidity, field heat and strong respiration, which accelerate the aging metabolism of berries, resulting in weight loss, softening, and decay [Paniagua et al., 2017; Zhou et al., 2014]. As a soft fruit, the firmness of berries is one of the most essential quality attributes, influencing the fruit quality, resistance to postharvest diseases, shelf life, and the transportation capacity, especially the acceptability of consumers, thereby limiting its commercial value [Chen et al., 2015].

Fruit softening is a major factor that causes a decline in postharvest berry fruits quality and consumer acceptability. Excessive softening of berries enables them to be prone to decay and mechanical damage; this is responsible for limitations in transportability, storage and shelf life [Zhou et al., 2014]. Fruit softening is a complex horticultural trait that may be caused by water loss, quality decline; cell wall disintegration, turgor, and membrane damage [Wang et al., 2020]. The loss of firmness of most fruit could be attributed to the degradation of cell wall polysaccharides; including pectin, cellulose, and hemicellulose, which all play important roles in cell-to-cell adhesion and rigidity. During postharvest storage of fruits, many changes occur in secondary metabolism, and these changes can affect berry quality and flavor [Chen et al., 2019; Ren et al., 2020].

Fresh-market blackberries harvested when firm and shiny-black can be held in postharvest cold storage for a week or more, but storability depends greatly on genotype. Berries are one of the most perishable types of fruit because of their thin and fragile skin and high respiration and transpiration rates. Hence, rapid changes in berry physiochemical and sensory properties, along with decay can occur during postharvest storage [Kim et al., 2015]. Temperature management, including rapid cooling after harvest and maintenance of low temperatures, is the single-most important factor in minimizing berry deterioration and maximizing quality and postharvest storage. For berry storage, temperatures from 0 ○ C to 5 ○ C and modified atmosphere (5–10% O_2/ 15–20% CO_2) are recommended during shipping. During postharvest storage of fruits, many changes occur in secondary metabolism, and these changes can affect berry quality and flavor [Segantini et al., 2017].

Several preservation technologies, including cold storage, high oxygen atmospheres storage, allyl isothiocyanate and edible coating, have been used to maintain bioactive compounds, reduce deterioration, and prolong shelf life of fresh berries.

The globalization of soft fruit production combined with the development of agricultural mechanization and automation caused a severe problem with the overproduction and unequal distribution of berry products throughout the world, even making them a political issue. The overproduction of highly perishable soft fruit results in a huge amount of waste. At the same time, it becomes a challenge for the food industry and an objective of food processing technologies to preserve not only the quantity of fruit products, but also to develop novel products and, thus, to offer consumers a broader selection of healthy foodstuffs [Michalska and Łysiak, 2015].

2. BERRIES PRODUCTION IN THE WORLD

Blueberries (*Vaccinium* ssp.) are a species from the family *Ericaceae*, which includes approximately 450 species. Besides cranberries and lingonberries, blueberries were domesticated in the 20th century. Its popularity was increased throughout the last decade. According to the FAO [2021] and the United States Department of Agriculture (USDA), the United States is the largest berry-producing country, with an average production of over 200 thousand tons (2013–2018) accounting for over half of the global production. During the last two decades, blueberry production has been increasing rapidly in the Central Valley of California due to the establishment of low-chill southern high bush blueberry cultivars that grow well under the semi-arid climate of the region [Saito et al., 2022]. The second country is Canada (average 93,000 tons of berries), and the third is Poland (10,600 tons). However, the North American Blueberry Council's (NABC) (2012) report points to a high (and growing) berry production in South American countries, mainly Chile, a fact that the FAO does not mention. The global production of berry is growing rapidly [Brazelton, 2015; Evans et al., 2014]. The revision on the use of native berries in Patagonia (Argentina) allowed the identification of 28 species mainly used as food, but also as medicinal in Eastern and Western Patagonia. Most of them are available in both sides of the Andes dividing Argentina and Chile. Chemical and bioactivity studies have been focused mainly in maqui, calafate and the native strawberry because of their potential development into new crops. The chemical constituents show a wide array of compounds belonging to different chemical structures, acting by different and complementary mechanisms. Further studies are required to investigate other species that have not been considered so far [Schmeda-Hirschmann et al., 2019].

3. BERRIES AS ALTERNATIVE SUPPLY HEALTH-PROMOTING BIOACTIVE COMPOUNDS

The importance of food consumption in relation to human health has increased consumer attention in nutraceutical components and foods, especially fruits and vegetables. Berries (*Vaccinium* ssp.) are a species from the family *Ericaceae*, which includes approximately 450 species. Berries has a growing consumer market mainly because of its rich composition of flavonoids, phenolic acids, and anthocyanins, thereby possessing high nutritional and health-promoting benefits, such as prevention of obesity, diabetes, cardiovascular disease, cancer, and other chronic diseases [Norberto et al., 2013; Pap et al., 2021]. Bioactive compounds from berries have potent antioxidant, anticancer, antimutagenic, antimicrobial, anti-inflammatory, and antineurodegenerative properties, both in vitro and in vivo. Berries, besides having commonly recognized taste properties, are also a valuable source of health-promoting bioactive compounds. For several decades, berries have gained in popularity all over the world, and recent years have seen not only an increase in fresh consumption, but also in the importance of berries for the processing industry [Buda et al., 2021].

Consumers purchase fresh blackberries for their unique fruit characteristics and potential health benefits. Intensely colored fruit, like blackberries, contain high levels of phytochemicals known for their potential biological benefits. In addition to nutraceutical properties, phytochemicals in fruits are highly related to flavor perception, since they may affect the taste of food, giving sweet, bitter or astringent flavors [Liu et al., 2019]. Consumers tend to select foods with a low content of lignin and/or tannin, and higher anthocyanin content [Segantini et al., 2017]. Some key blackberry attributes include sweetness, acidity, bitterness, color, firmness and symmetry of shape along with postharvest potential. Heavy emphasis in breeding efforts was placed on firmness of fresh-market blackberries because of enhanced potential for shipping and postharvest storage. Blackberries with a unique firmness or crispiness have high postharvest storage potential due to low incidence of red drupelets and retention of firmness. These crispy genotypes maintain cell wall and cell–cell adhesion during ripening and storage that results in better performance when compared to non-crispy genotypes [Salgado and Clark, 2018]. Physiochemical and sensory analyses can be used to establish the acceptability of fresh blackberries by identifying the desired attributes and overall quality.

Berries have been the focus of recent interest among researchers and health professionals for their role in human health and prevention of chronic diseases. Raspberries hold a special position among the berries due to their ideal nutritional profile of low calories, fat, and saturated fats, high fiber, presence of several essential micronutrients, and phytochemical composition. They contain a whole range of polyphenolic antioxidant compounds that play a significant role in mitigating the damaging effects of oxidative stress on cells and reducing the risk of chronic diseases. Among the polyphenolic compounds, raspberries contain significant levels of ellagitannins and anthocyanins [Rao and Snyder, 2010].

More studies are needed on the mechanisms of action related to the health promoting properties from these native berries, as well as to encourage the agronomic development of these wild species into commercial crops [Michalska and Łysiak, 2015].

3.1. Berries and human health

Dietary guidelines around the world recommend the increased consumption of fruits and vegetables, as good sources of dietary fiber, essential nutrients, and beneficial phytochemicals, to improve overall health and reduce chronic disease risk [Bincy et al., 2018; Bustamante et al., 2018]. Fruits, and in particular berries, have been the focus of recent interest among researchers and health professionals for their role in human health and prevention of chronic diseases. In recent years, several berries such as the strawberry, blueberry, cranberry, and black raspberry have been studied for their beneficial effects on health. These health benefits include prevention of certain types of cancer, cardiovascular diseases, type II diabetes, obesity, neurodegenerative diseases associated with aging, and infections. Raspberries hold a special position among the berries due to their ideal nutritional profile of low calories, fat, and saturated fats, high fiber, presence of several essential micronutrients, and phytochemical composition. They contain a whole range of polyphenolic antioxidant compounds that play a significant role in mitigating the damaging effects of oxidative stress on cells and reducing the risk of chronic diseases. Among the polyphenolic compounds, raspberries contain significant levels of ellagitannins and anthocyanins [Bustamante et al., 2018].

Berries, notably the popular ones such as strawberry, raspberry, blueberry, blackberry, and the Indian gooseberry, are among the best-known dietary sources due to the presence of a wide range of bioactive nutritive components. Bioactive components in berries include phenolic compounds, flavonoids, and tannins apart from vitamins, minerals, sugars, and fibers. Individually or synergistically, these have been shown to provide protection against several disorders. Mounting evidence suggests that consumption of berries confer antioxidant and anticancer protection to humans and animals. Free radical scavenging, protection from DNA damage, induction of apoptosis, and inhibition of growth and proliferation of cancer cells are just to name a few [Bincy et al., 2018]. In this way, berries hold an important position among the fruits attributable to their high antioxidant phytochemical contents. In addition to their attractive color and superior flavor, berries contain a unique phytochemical profile rich in ellagitannins and anthocyanins that distinguishes them from other fruits [Pap et al., 2021]. Red raspberries are of economic importance and widely consumed fresh, frozen, or in processed forms such as jellies, jams, and juices, whereas black raspberries are less commonly grown and consumed. In recent years, several berries such as the strawberry, blueberry, cranberry, and black raspberry have been studied for their beneficial effects on health. These health benefits include prevention of certain types of cancer, obesity, neurodegenerative diseases associated with aging, and infections [Bincy et al., 2018]. Red raspberries are unique berries with a rich history and nutrient and bioactive composition. They possess several essential micronutrients, dietary fibers, and polyphenolic components, especially ellagitannins and anthocyanins, the latter of which give them their distinctive red coloring. In vitro and in vivo studies have revealed various mechanisms through which anthocyanins and ellagitannins and red raspberry extracts (or the entire fruit) could reduce the risk of or reverse metabolically associated pathophysiologies [Burton-Freeman et al., 2016].

4. POST-HARVEST FACTORS INFLUENCING THE NUTRITIONAL VALUE OF BLUEBERRIES

Blueberries, one of the most widely consumed fruit in the world, contain high amounts of phenolic compounds, including anthocyanins, flavonols, chlorogenic acid and procyanidins [Chen et al., 2015]. They have been shown a wide diversity of bioactivities such as antioxidant, antidiabetic, antimicrobial, antiproliferative, apoptotic, liver protection, lifespan-prolonging, anti-inflammatory, cancer preventive and cardioprotective activities [Bunea et al., 2013; Ren et al., 2022]. Due to their various health benefits, unique taste, and nutritional value, worldwide production and consumption of blueberries have increased rapidly in recent years and they have become the second most important soft fruit species after strawberry [Giongo et al., 2013]. However, berries are highly perishable and susceptible to rapid spoilage. Chen et al., (2015) reported that fresh berries have a shelf life of 1–8 weeks depending on stage of fruit ripeness, method of harvest, presence of fruit disease, and storage conditions. One of the main factors limiting postharvest life of berries is softening, which may influence not only the quality of the fruit, but also its storage life, transportability and resistance of postharvest diseases [Chen et al., 2015].

Softening in any fruit is primarily due to the change in cell-wall carbohydrate metabolism, leading to a net decrease in certain structural components. During fruit softening, the loss of firmness is associated with the decrease in total water-soluble pectin and the disassembly of primary cell wall and middle lamella structures [Giongo et al., 2013]. The modification of cell wall components in postharvest berries during storage is still not clear, and its possible mechanism during softening is not understood. Maintaining textural quality during storage is of interest to the fruit growing and distribution industries of blueberries [Michalska and Łysiak, 2015]. Chen et al., (2015) studied the composition modifications in the cell wall and changes of the activities of cell wall degrading enzymes of blueberries to explore the softening mechanism in this kind of fruit during storage. These authors demonstrated that during fruit softening in blueberries, the decline of fruit firmness was associated with increased in water-soluble pectin (WSP) content and decreased levels of sodium carbonate soluble pectin (SSP), hemicellulose and cellulose. Liu et al., (2019) designed a study to observe the dynamic changes in fruit firmness, quality traits and cell wall components. Two highbush blueberries (*Vaccinium corymbosum* cv. Bluecrop and *Vaccinium corymbosum* cv. Sierra) were studied during 50 days of postharvest storage at 0 ℃ and 90% RH, as well as the correlation relationships between fruit firmness and physicochemical compositions. The results reported by Liu et al., (2019) showed that during fruit softening in blueberries, the decline of fruit firmness accompanying with flavor loss was associated with increased WSP content [Liu et al., 2019].

Berry processing mostly consists of freezing and juicing. Recently, more attention has been drawn to dewatering and drying, which are promising areas for developing novel blueberry products [Michalska and Łysiak, 2015]. Decay is a major cause of postharvest loss in fresh blueberries and is a major problem for the berries industry. Weight loss is associated with fruit deterioration during postharvest handling and can affect cell turgor and contribute to the lower firmness in the berries [Liu et al., 2019]. Zhou et al., (2014) indicated that postharvest metabolism of blueberries is strongly affect by cold storage, which inhibited aging and delayed ripening. Blueberries exposed to low temperature were firmer and showed less membrane damage.

Postharvest softening related to enzymatic reactions of polyphenols and oxidative stress from reactive oxygen species is also a primary reason for the short shelf-life, and significantly reduces commercial value of berry fruits. Low-temperature storage delays senescence and helps to preserve quality, and is thus recommended for extending the postharvest life of blueberries. However, pitting can be observed when blueberries are stored at shelf-life conditions after cold storage. Fruit stored directly at 20 °C show no such problems. Pitting is one of the physiological symptoms of berries. Physiological manifestations of chilling injury usually precede or occur concomitantly with the appearance of visible symptoms [Wang et al., 2019].

5. MAIN DESEASES IN POSTHARVEST BLUEBERRIES

Blueberries are minimally processed or consumed raw and are not washed before packaging. Thus, contamination risks must be balanced with minimizing shelf life, competing outcomes that are both economically undesirable. Many methods of disinfection have been used, including chemical washing and spraying procedures, irradiative treatments and natural (biological) methods [El-Ramady et al., 2015]. Industry has focused on chemical techniques despite the potential storage risks for these reagents. For example, to reduce microorganism populations, blueberries are usually washed or sprayed with chlorinated water. Although other chemical methods were assessed for microbial reduction, the efficacy of these methods varied greatly and scientific data were lacking, making it difficult to draw firm conclusions concerning their efficacy [El-Ramady et al., 2015]. In fact, 95% of post-harvest blueberries exhibit a broad range of fungal contamination. Several outbreaks of foodborne illnesses have also been associated with berry fruits consumption, attributed to possible fecal contamination during growing, harvesting and handling [Zang et al., 2015]. As the choice and the efficacy of decontamination methods are evidenced by the reduction of microorganisms, more effective and secure methods for microbial safety of blueberries are profusely studied. The use of “hurdle” technologies as a preservation strategy appears to be most effective, as they involve combinations of different preservation techniques [Liato et al., 2017].

5.1. Berries postharvest diseases

Fresh berry fruits are highly perishable during storage and transit, thus appropriate postharvest management practices are studied to meet the domestic and international market demands for high quality of these fruits.

Fruit rots caused by fungal pathogens are a limiting factor for the storage of berries and can cause significant economic losses in the market. The main postharvest diseases the blueberries fruits are gray mold (*Botrytis cinerea*), fruit's putrefaction (*Alternaria* spp.), and anthracnose (*Colletotrichum* spp.). Furthermore, it also has been reported that blueberries are attacked by the fungus *Penicillium chrysogenum, Fusarium oxysporum*, and some bacteria such as *Salmonella typhimurium, Escherichia coli*, and *Listeria monocytogenes* [Umagiliyage et al., 2017].

In this way, fruit decay in berries is usually caused by fungi, with Anthracnose (*Colletotrichum acutatum*) being the most common fungal disease, followed by Alternaria rot (*Alternaria* spp.) and gray mold (*Botrytis cinerea*) [Saito et al., 2021]. In many previous laboratory tests, fungicides failed to control gray mold caused by *B. cinerea* isolates that are resistant to the fungicides [Saito et al., 2020]. Given current fungicide resistance situation of this pathogen, alternatives to chemical fungicides are needed to manage postharvest gray mold. *Botrytis cinerea* is a necrotrophic fungus responsible for gray mold disease in berries. In blueberry fruits, *B. cinerea* attacks during all year in humidity conditions higher than 95% and temperature between 15 and 25 °C. The symptoms for this disease were observed in leaves, and fruits, *Botrytis* presents a latent infection process during the first stages of growth and fruit development, expressing symptoms during the postharvest period. In mature fruits, fruit softening, opaque color, juice release, dehydration, and development of gray color mycelium mass characterize the disease symptoms [Saito et al., 2020; Saito et al., 2021].

Alternaria is considered an opportunistic fungus that can penetrate the fruit through wounds, natural openings, or directly through a rupture in the host's cuticle [Garcia et al., 2021]. The fruit putrefaction symptoms are dark and sunken wounds on the fruit, along with white to greenish-gray mycelium and green olive conidial growth. *Alternaria* spp. produces secondary metabolites that include several toxins that influence plant pathology as well as food security [Wang et al., 2021].

The postharvest losses of berries are also due to the attack of pathogenic bacteria, whether Gram-positive or negative such as *Salmonella typhimurium*, *Escherichia coli*, and *Listeria monocytogenes* that were transmitted by soil or water [Zhang et al., 2020]. During the production and harvesting chain of berries, there are various sources of contamination of the fruit by these pathogens [Bell et al., 2021]. Although to a lesser extent than fungi, these microbial pathogens not only detract from the quality of the fruit but can also cause food reactions in consumers with serious consequences for their health. Hence, the importance of controlling and preventing the attack of these pathogens can damage the fruit during its different stages of growth [Zhang et al., 2022].

6. CHITOSAN AND ALGINATE COATINGS AS POSTHARVEST TECHNOLOGIES USED TO CONTROL BLUEBERRY DECAY

Adequate postharvest technologies, such as edible coatings and films are used combined with cold storage. In this sense, the use of edible coatings could be a new technological alternative to improve fruit quality during postharvest storage and shelf life [Salgado et al., 2021; Vieira et al., 2016]. Edible coatings may contribute to extend the shelf life of fruit and vegetables producing a semipermeable barrier to external elements that can reduce moisture loss, solutes migration, respiration and oxidative reactions and retard the natural physiological ripening process [Salgado et al., 2021]. Maintenance of fruit quality has been reached using different coatings such as chitosan; in blueberry, some effects on fruit quality have been obtained with edible coating based on chitosan [Bambace et al., 2019; Quijada et al., 2021]

Edible coatings are attractive strategies for blueberries postharvest preservation. In this sense, sodium alginate coated berry samples showed higher values of firmness and lightness during storage, but lower values of total soluble solids content and titratable acidity compared to the other samples. Furthermore, sodium alginate coated blueberries showed higher total phenolic content. Unfortunately, the results showed that alginate coating promoted the growth of yeasts and molds at the end of storage period. On the contrary, chitosan coating delayed ripening as indicated by lower respiration rate, higher total soluble solids content and titratable acidity values compared to other treatments. Moreover, chitosan coating inhibited the growth of yeasts and molds. For these reasons, chitosan coating could be considered for commercial application in extending shelf life and maintaining quality of blueberry during storage and marketing [Chiabrando et al., 2015; Liu et al., 2023; Mannozzi et al., 2017].

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Liu et al., (2023) reported that the combination of coating with heat-shock treatment could effectively improve the post-harvest quality and aroma compound concentration of blueberries, showing good application potential in storage and preservation of fresh fruits such as blueberries. Mannozzi et al., (2017) studied the application of different coatings analyzing its effects on post-harvest berry fruits quality. In general, alginate coating showed higher values of firmness and lightness during storage, but lower values of total soluble solids content and titratable acidity. Regarding yeast and mold growth, the treatment with sodium alginate coating induces an undesired increase of the proliferation during postharvest storage period. Chitosan showed lower weight losses, higher total soluble solids content and titratable acidity values compared to other treatments. In addition, chitosan-based coatings had the added advantage of an antifungal property. Results reported by Bambace and Moreira (2022) indicate the possibility of using alginate and chitosan edible coating in blueberry with no reduction in shelf life. Chitosan coating could be considered for commercial application in extending shelf life and maintaining quality of blueberries during storage and marketing. Medina-Jaramillo et al., (2020) reported that the coating formulation containing 0.09% of carvacrol proved to be the most effective in improving the postharvest quality of blueberries and delayed mesophilic bacteria and yeasts/molds grown during 21 days of refrigerated storage. These coatings were useful for enhancing the polyphenol content of the fruits. These are important results since these attributes are closely related to consumer acceptance. Edible carvacrol/alginate coatings could be considered as a useful alternative to complement the benefits of refrigerated storage by delaying post-harvest spoilage of Andean blueberries.

7. BERRIES AS NOVEL PROBIOTIC FUNCTIONAL FOODS

The development of non-dairy probiotic food products is possible, allowing the consumption of these beneficial microorganisms by people who do not like dairy products or with intolerance or allergy to milk components. Probiotic and prebiotic in non-dairy products have a great marketing future, since recent studies have shown the application of strains that adapt well in alternative matrices. There are two main challenges during manufacture; the maintenance of the probiotic viability during the shelf life of the products and after ingestion to the gastrointestinal tract and the maintenance of the physicochemical and sensory characteristics of the conventional products. Despite the challenges, the future of non-dairy probiotic products, with bioactive coating as carrier of probiotic bacteria is promising [Vidović et al., 2022].

Berry fruits are frequently consumed worldwide due to their richness in highly valuable bioactive compounds, which potentially positively influences human health [Golovinskaia and Wang, 2021]. In addition to dietary fibers, vitamins, and minerals, berries contain phytochemicals, such as phenolic compounds and carotenoids, which exert antioxidant, anti-inflammatory, and many other health-promoting effects [Salo et al., 2021]. Berries are consumed fresh, frozen, or dried and are used as ingredients in different food products and dietary supplements [Chang et al., 2019]. As a marketing strategy to promote their extraordinary health benefits, berries are widely advertised as superfruits and functional foods [Skenderis et al., 2019]. These superfruits can considered as a valuable source of functional foods due to the phytochemical compositions and their corresponding antioxidant activities. The phytochemicals from superfruits are bioaccessible and bioavailable in humans with promising health benefits [Chang et al., 2019]. Among exotic and superfruits berry, goji berries are gaining more importance in different countries, from medical and pharmaceutical standpoints, as well as their further application in the food industry. Skenderidis et al., (2019) reported that the completely aqueous extracts of goji berries encapsulated in maltodextrin could be used as potentially prebiotic food additives, because they have been shown to support growth and viability, and stimulate the proliferation of probiotic strains of bacteria, such as *Bifidobacterium* and *Lactobacillus*, in simulated gastrointestinal conditions. These authors have also demonstrated that the aqueous extracts of goji berries, where the encapsulation was performed with minimal maltodextrin content and high polyphenols content, had high antioxidant and antimicrobial activity. Such products could be used for the preservation of food or plant protection.

Terpou et al., (2019) studied the development of a novel frozen yogurt fortified with berries supported probiotic cells. Berries originated were used as immobilization carrier of the probiotic strain *Lactobacillus casei*. Terpou et al., (2019) demonstrated that the viability of the immobilized probiotic cells was maintained in high levels during 90 storage days (−18 °C). Gastrointestinal simulation showed that cell immobilization offer protection to probiotic cells against the harsh environmental conditions of the gastrointestinal tract and help in maintaining the minimum viable cell counts required to offer health benefits to the consumers (>10^7 CFU g^{-1}). Wu et al., (2021) analyzed a potential application of three probiotic strains (*Lactobacillus plantarum*, *Streptococcus thermophilus* and *Bifidobacterium bifidum*) to ferment blueberry and blackberry juices. The metabolism of phenolics probably contributed to the enhancement of antioxidant activity in fermented berry juices. Moreover, the three strains presented different capacities on changing the quality of berry juices. The contents of individual organic acids had positive correlations with sensory quality, especially for sourness. Overall, probiotic fermentation could improve the sensory quality of berry juices.

Taking into account the demand for non-dairy functional food and healthy products, researchers and industry aimed to develop sustainable functional foods with high nutritional properties. In this way, berry pomace is a by-product from the juice industry, and a valuable source of bioactive compounds. Its composition allows it to be used as a functional ingredient with antioxidant and antimicrobial properties. Moreover, pomace possesses specific techno-functional properties that can lead to changes in the characteristics of the food where it is incorporated. Techno-functional properties of berry pomace allow its use as an ingredient in different foods [Irigoytia et al., 2022]. Fuentes et al. (2019) studied the healthy potential of Patagonian berries, specifically *Murta* and *Arrayán* berries. Its phenolic compounds are effective antioxidants and can display various effects, including anti-microbial, anti-inflammatory, anti-mutagenic, anti-carcinogenic, anti-allergic, anti-platelet, vasodilator, and neuroprotective effects. These properties have given rise to a new interest in finding plant species with a high phenolic content and relevant biological activity. The epidemiological evidence supporting the benefits of consuming a diet rich in foods containing polyphenols is strong, for example berries fruits. The high content of flavonoids, such as quercetin, present in arrayan and murta, suggests its participation as a protective agent in inflammatory diseases. According to the novel food catalog of the European Union, maqui berry has an authorized use only as or in food supplements, and any other food uses have to be approved for the EU-Novel Food Regulation. Regarding murta berry, the information currently available suggests that this fruit meets the requirements for the novel food solicitation [Fuentes 2019; Schon et al., 2018]. Goji berries have long been used for their nutritional value and medicinal purposes in Asian countries. In addition, they are gaining increased research attention as a source of functional ingredients with potential industrial applications. Vidovic et al., (2022) focuses their study on the antioxidant properties of goji berries, scientific evidence on their health effects based on human interventional studies, safety concerns, goji berry processing technologies, and applications of goji berry-based ingredients in developing functional food products. Goji berries exert various biological activities and health benefits, such as antioxidant, anti-inflammatory, antimicrobial, immuno-stimulating, anti-diabetic, neuroprotective, anti-cancer, prebiotic, and anti-obesogenic effects, which have been reviewed by several authors [Jiang et al., 2021]. These beneficial properties are attributed to the individual or combined effects of the constituents of goji berries, water-soluble polysaccharides are considered the most important bioactive components of goji berries.

Bambace et al. (2021) analyzed the potential use of fresh blueberries as carriers of *Lacticaseibacillus casei* and *Bifidobacterium animalis* subsp. *lactis* incorporated into alginate-based prebiotic coatings. These authors reported that a protective effect was observed since prebiotic enrichment allowed maintaining both *L. casei* and *B. lactis* viability above the minimum recommended levels (10^6 CFU/g) up to the end of storage, and therefore, ensuring their beneficial health action. Regarding safety issues, both probiotics exerted a biocontrol effect on inoculated *L. innocua* with reductions up to 2.3 log. Moreover, enrichment of blueberries with *B. lactis* through the application of prebiotic coatings maintained quality and sensory characteristics for 14 days at 5 °C [7]. In addition, Bambace et al. (2019) studied the application of probiotic *Lactobacillus rhamnosus* added to alginate-based coatings enriched with inulin and oligofructose and applied on fresh-blueberries. *L. rhamnosus* was tested for its antagonistic effect against inoculated *Listeria innocua* and *E. coli* O157:H7. Advantageously, prebiotic compounds allowed improving probiotic viability with counts above 6.2 log CFU/g for the entire period. Native microbiota counts remained under safe levels. Overall visual quality, odor and flavor were acceptable up to day 14 of storage. Regarding antimicrobial activity, *L. rhamnosus* was able to reduce *L. innocua* counts by 1.7 log in inoculated blueberries.

8. CONCLUSION

Nowadays, the consumption of food products containing probiotics, has increased worldwide due to concerns regarding healthy diet and wellbeing. This trend has received a lot of attention from the food industries, aiming to produce novel probiotic non-dairy foods, and from researchers, to improve the existing methodologies for probiotic delivery or to develop and investigate new possible applications. In this sense, fresh berries are being studied as probiotic carriers with many applications.

Thus, the development of functional berries constitute novel, healthy and multifunctional alternatives of non-dairy probiotic foods that would allow meeting the current consumer demand. The further implementation of new fruit-based foods with multifunctional properties needs more studies.

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