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The *Weissella* genus in the food industry: A review

O gênero *Weissella* na indústria de alimentos: Uma revisão

El género *Weissella* en la industria alimentaria: Una revisión

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Abstract
The genus *Weissella* is composed of bacteria classified as Gram-positive, catalase negative, non-spore forming, coccoid morphology or short bacilli. They belong to the group of lactic acid bacteria (LAB), mainly by production of lactic acid from the fermentation of carbohydrates. *Weissella* species are distributed in different habitats, such as soils, milking machines, sugar cane and some strains with interesting technological features can be isolated from fermented foods, such as cheeses made from raw milk, fermented vegetables and fermented milk. From the point of view of food technology, some strains have potential in the production of exopolysaccharides, non-digestible oligosaccharides, which is beyond their probiotic potential. Therefore, the bacteria belonging to the genus *Weissella* might have great technological importance, being also involved in the control of foodborne diseases by production of bacteriocins and hydrogen peroxide. This genus has great potential for use in the food industry.
Keywords: *Weissella;* Food industry; Metabolism; Ecology; Technological potential; Bacteriocins.

Resumo
O gênero *Weissella* é composto por bactérias classificadas como Gram-positivas, catalase negativas, não formadoras de esporos, morfologia cocóide ou bacilos curtos. Pertencem ao grupo das bactérias lácticas (BAL), principalmente pela produção de ácido láctico a partir da fermentação de carboidratos. As espécies de *Weissella* estão distribuídas em diferentes habitats, como solos, ordenhadeiras, cana-de-açúcar e algumas cepas com características tecnológicas interessantes podem ser isoladas de alimentos fermentados, como queijos de leite cru, vegetais fermentados e leite fermentado. Do ponto de vista da tecnologia de alimentos, algumas cepas apresentam potencial na produção de exopolissacarídeos, oligossacarídeos não digeríveis, que está além de seu potencial probiótico. Portanto, as bactérias pertencentes ao gênero *Weissella* podem ter grande importância tecnológica, estando também envolvidas no controle de doenças de origem alimentar pela produção de bacteriocinas e peróxido de hidrogênio. Este gênero possui grande potencial para uso na indústria alimentícia.
Palavras-chave: *Weissella*; Indústria alimentícia; Metabolismo; Ecologia; Potencial tecnológico; Bacteriocinas.

Resumen

El género *Weissella* está compuesto por bacterias clasificadas como gram-positivas, catalasa negativas, no formadoras de esporas, de morfología cocoide o bacilos cortos. Pertenecen al grupo de las bacterias del ácido láctico (BAL), principalmente por la producción de ácido láctico a partir de la fermentación de carbohidratos. Las especies de *Weissella* se encuentran distribuidas en distintos hábitats, como suelos, ordeñadoras, caña de azúcar y algunas cepas con interesantes características tecnológicas pueden aislarse de alimentos fermentados, como quesos elaborados a partir de leche cruda, vegetales fermentados y leche fermentada. Desde el punto de vista de la tecnología de los alimentos, algunas cepas tienen potencial en la producción de exopolisacáridos, oligosacáridos no digeribles, que está más allá de su potencial probiótico. Por tanto, las bacterias pertenecientes al género *Weissella* podrían tener una gran importancia tecnológica, estando también implicadas en el control de enfermedades transmitidas por alimentos mediante la producción de bacteriocinas y peróxido de hidrógeno. Este género tiene un gran potencial para su uso en la industria alimentaria.

Palabras clave: *Weissella*; Industria de alimentos; Metabolismo; Ecología; Potencial tecnológico; Bacteriocinas.

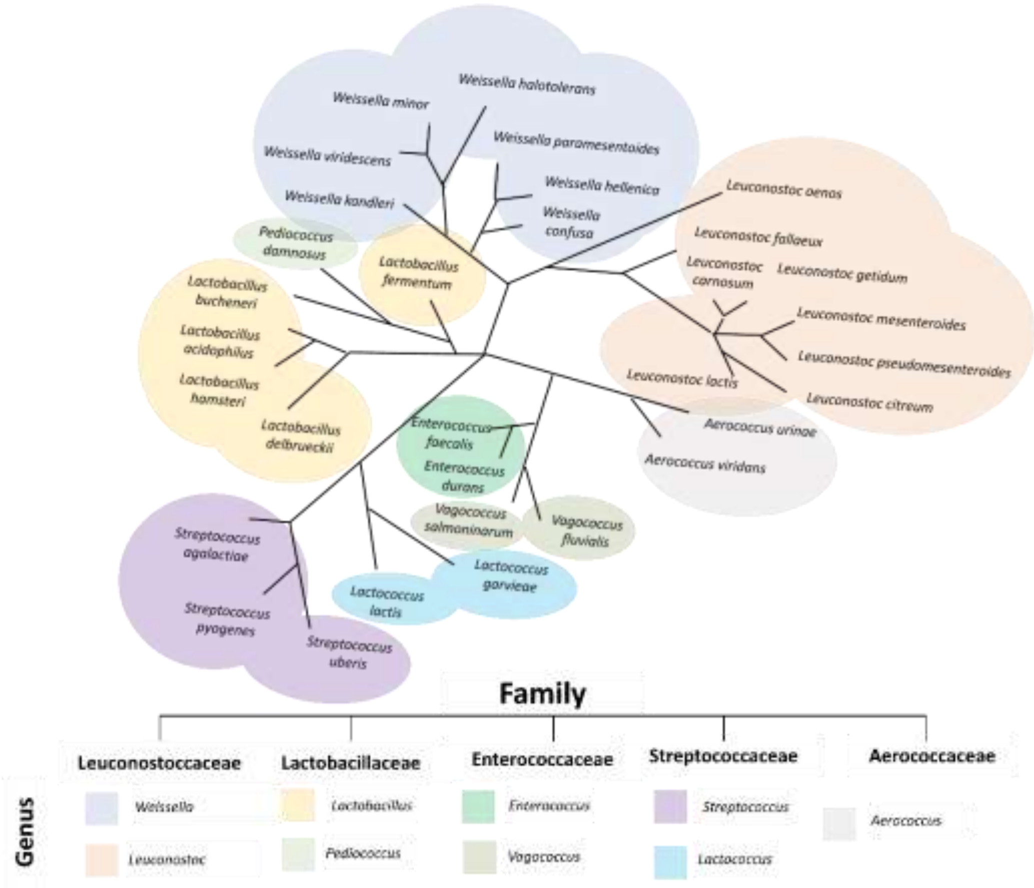
1. Introduction

At first, microbiology techniques for identification of genus and species were based only on phenotypic tests such as morphological and biochemical tests for typing, subtyping and identification of microbial genera, species and subspecies. However, despite presenting atypical characteristics, many microorganisms were mistakenly grouped due to the low discriminatory power of these techniques when it comes to microorganisms with little genetic variability. Nevertheless, since the 80's, the techniques of manipulation of the genetic material, allow the evaluation of the bacterial genome. Because of the advancement in the studies of molecular biology, it is now possible to construct more and more precise phylogenetic techniques, such as the evaluation of rDNA (Fakruddin & Mannan, 2013, Gandra, Gandra, de Mello & da Godoi, 2008).

In 1993, using the rDNA technique, Collins found that strains with very close phenotypic characteristics, previously classified as *Leuconostoc*, presented profiles of bands very different from others belonging to the same genus. This was discovered after the study of atypical *Leuconostoc* cultures present in fermented and dried sausages produced in Greece. These isolated microorganisms resembled the bacterium *Leuconostoc* sp. for producing D (-) lactic acid but differed in several biochemical tests. The name of this genus was proposed by Collins *et al*. (Collins, Samelis, Metaxopoulos & Wallbanks, 1993) in honor of the German microbiologist Norbert Weiss due to his many contributions in the field of research related to LAB.

Collins *et al*. (1993) used genetic sequencing of the 16S rDNA to investigate the relationship between isolated bacteria and recognized strains of the genus *Leuconostoc*. They showed that the strains analyzed were phylogenetically closer to the *Leuconostoc paramesenteroides* than to the other *Leuconostoc* species (Figure 1). They proposed that *L. paramesenteroides*, the new species isolated from the fermented sausages, and some heterofermentative *Lactobacillus,* should belong to the new genus, named *Weissella*. The name *Weissella hellenica* was proposed to name the new species.

Figure 1. Phylogenetic tree showing the proximity of the genus *Weissella* with other genera of lactic acid bacteria.



Source: Adapted from Collins (1993).

Bacteria belonging to *Weissella* genus are hardly differentiated from *Leuconostoc* strains and heterofermentative *Lactobacillus* by phenotypic characteristics; thus, the description was only possible through molecular taxonomic analyzes. Collins *et al*. (1993) proposed the reclassification of *L. paramesenteroides*, *Lb. confusus*, *Lb. halotolerans*, *Lb. kandleri*, *Lb. minor*, and *Lb. viridescens* to *W. paramesenteroides*, *W. confusa*, *W. halotolerans*, *W. kandleri*, *W. minor* and *W. viridescens*, respectively. Subsequently, other studies have identified new species, and currently 25 species are validated: *W. viridescens*, (Niven & Evans, 1956), *W. paramesenteroides* (Garvie, 1967), *W. confusa* (Holzapfel e Kandler, 1969 apud Collins et al., 1993), *W. kandleri* (Holzapfel & Van Wyk, 1982), *W. halotolerans* (Kandler, Schillinger & Weiss, 1983), *W. minor* (Kandler *et al*., 1983), *W. hellenica* (Collins *et al*., 1993), *W. thailandensis* (Tanasupawat, Shida, Okada, & Komagata, 2000), *W. soli* (Magnusson, Jonsson, Schnurer & Roos, 2002), *W. cibaria* (Björkroth, K. J. et al., 2002), *W. koreensis* (Lee, *et al*., 2002), *W. ghanensis* (De Bruyne, Camu, Lefebvre, De Vuyst & Vandamme, 2008), *W. beninenses* (Padonou, *et al*. 2010), *W. fabaria* (De Bruyne, Camu, De Vuyst, & Vandamme, 2010), *W. ceti* (Vela *et al*., 2011), *W. fabalis* (Snauwaert, Papalexandratou, De Vuyst, & Vandamme, 2013), *W. oryzae* (Tohno *et al*., 2013), *W. diestrammenae* (Oh, *et al*., 2013), *W. uvarum* (Nisiotou, Dourou, Filippousi, Banilas, & Tassou, 2014), *W. cryptocerci* (Heo, *et al*. 2019), *W. bombi* (Praet, *et al*., 2015), *W. jogaejeotgali* (Lee *et al*. 2015), *W. kimchi* (Choi *et al*., 2002), *W. muntiaci* (Lin *et al*., 2020) and *W. sagaensis* (Li, Tian & Gu, 2020).

The genus *Weissella* belongs to the phylum *Firmicutes*, class *Bacilli*, order *Lactobacillales* and family *Leuconostocaceae*. The bacteria belonging to this genus may have different morphologies, being short rods with rounded to tapered ends or coccoid in shape, which is the morphology of microorganisms belonging to the genus *Leuconostocs*, *Oenococcus* and *Streptococci* (Collins *et al*., 1993). In some species a tendency to pleomorphism occurs depending on the stress condition to which the bacterium is submitted. In relation to the organization, they can also be found in pairs, alone or in small chains (Gandra, *et al.*, 2008, Collins *et al*., 1993). *Weissella* is a relatively new genus, which is not yet used as a starter or adjunct culture by the food industry, as there are still few studies on its use as such. The purpose of this review is to bring the most relevant research in this genus to the food industry, presenting the potential application of the strains of the genus *Weissella* in food.

2. Methodology

This paper is a bibliographic research (Pereira, Shitsuka, Parreira & Shitsuka, 2018). Therefore, the objective is the verification of scientific data and the discussion about them on the proposed theme. This article was done in a descriptive and qualitative way in order to present how *Weissela* sp. can be applied in the food industry.

To obtain the theoretical foundation it was use the database of the websites: *Google academic, Scielo, PubMed* and *Science direct* and for the research was used keywords as *Weissela*, bacteriocin, exopolysaccharides and lactic acid bacteria. The time period used was from the year 1993, when the species was recognized, until the year 2021 as a form to compare the evolution of researches and application of the *Weisella* genus and their compounds. Also for this research there was no limitation about language as a way to gather as much information as possible. By the end, was select 90 sources of information.

3. Physiological and Metabolic Characteristics

Bacteria from the genus *Weissella* are chemoorganotrophic, facultative anaerobic, Gram-positive, non-spore forming, catalase negative (Collins *et al*., 1993) and have no motility with except to *W. beninenses* that has peritrichous flagella (Padonou, *et al*. 2010). All the microorganisms of this genus are compulsory heterofermenters producing lactic acid, carbon dioxide, ethanol and/or acetic acid from carbohydrate fermentation. They use the phospho-ketolase and the hexose monophosphate pathways to perform the carbohydrate fermentation (Garvie, 1967, Holzapfel & Van Wyk, 1982).

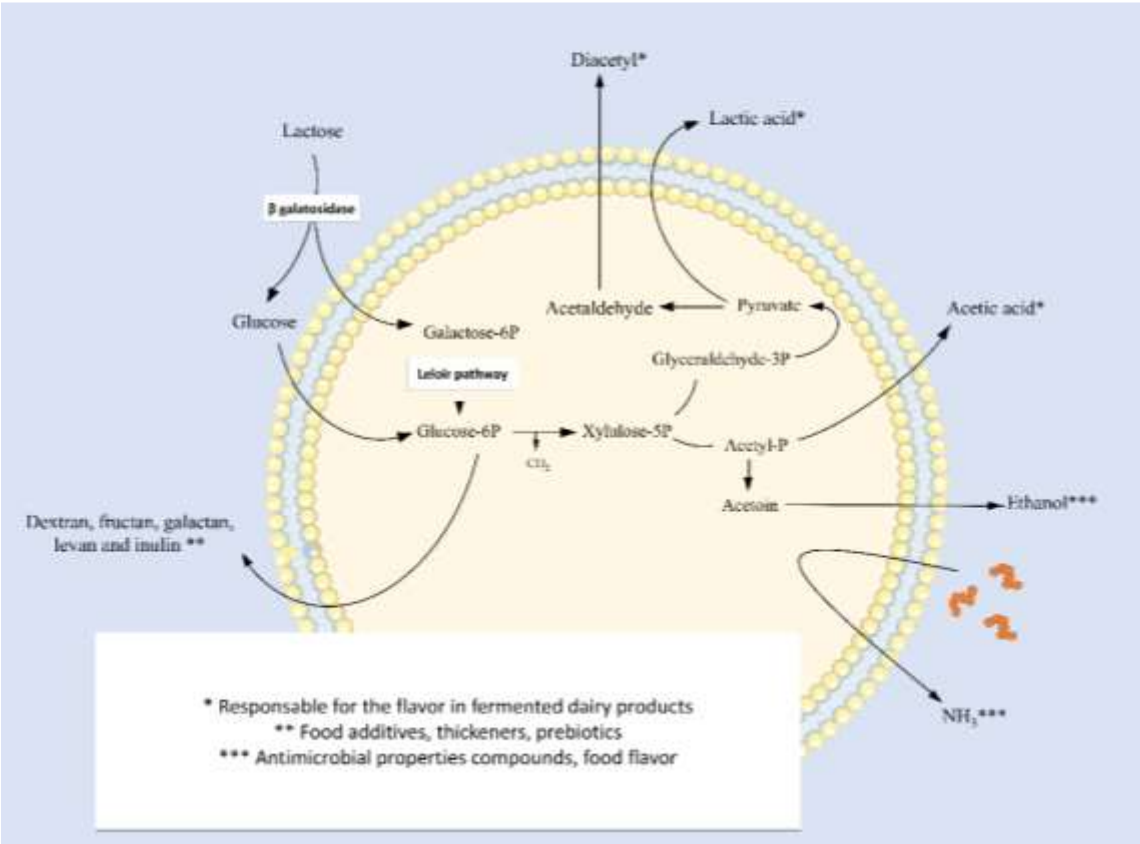
Weissella sp. have very complex nutritional needs requiring peptides, amino acids (arginine, aspartic acid, cystine, glutamic acid, histidine, isoleucine, phenylalanine, serine, threonine, tryptophan and valine), fatty acids, nucleic acids, fermentable carbohydrates (glucose, fructose, mannose, maltose, sucrose, trehalose) and vitamins (riboflavin, pyridoxal, folic acid, biotin, nicotine, thiamine, panthotenic acid) for their development (Gandra, *et al.*, 2008, Björkroth, Dicks, & Endo, 2014, Kandler *et al.*, 1983). However, culture media used as Man Rogosa and Sharp (MRS) and M17 for lactic acid bacteria are easily employed for the multiplication of these microorganisms. Moreover, all the nutritional requirements can be found in many raw materials used in the food industry such as milk, meat and vegetables, providing the use of such cultures for fermentation thereof.

As part of the LAB group, the species of the genus *Weissella* are chemoorganotrophic microorganisms with strictly fermentative metabolism being unable to synthesize porphyrinic groups (e.g. heme). All species can multiply at 15 °C while some multiply at temperatures between 42 °C and 45 °C, having an optimum temperature of multiplication between 20 °C and 30 °C (Garvie, 1967). These bacteria can be applied in fermented dairy products like fermented milk which has the temperature of incubation of the microorganisms around 40 °C and fermented meat sausages with an incubation temperature of 25 °C.

Different species produces dextran, hydrolyzed esculin and produces ammonia from arginine. Dextran is an exopolysaccharide, and these are important for the manufacture of products such as yogurt, in which it is desired to have viscosity (Mende, Rohm, & Jaros, 2016). In addition, as these bacteria are able to ferment several sugars such as cellobiose, fructose, galactose, maltose, raffinose, ribose, trehalose and xylose (Fusco *et al.*, 2015). they can be used as starter cultures for the manufacture of products with different sensory characteristics.

W. cibaria MG1 possesses all the necessary genes for the use of the phosphoketolase pathway and metabolize the galactose via the Leloir pathway and in the figure 2 is possible to understand how it is the metabolism. It can also use maltose, fructose, ribose, xylose, sucrose and gluconate as carbon sources. In addition, a β-galactosidase has been known to indicate that lactose can also be metabolized (Lynch *et al.*, 2015). which suggests that this strain can be used in the fermentation of dairy products that have lactose as their main sugar.

Figure 2. Metabolic pathways used by bacteria of the genus *Weissella.*



Source: Own authorship (2021).

Most EPS produced by strains of the genus *Weissella* are homopolysaccharides (HoPS) such as dextran, fructan, galactan, levan and inulin for example (Björkroth, et al., 2002, Lee, *et al.*, 2002). Strains of the genus *Weissella* use sucrose as the obligatory substrate for the extracellular synthesis of HoPS. The enzymes used to hydrolyze sucrose are glycosyltransferase, glucan-sucrase (GS) or fructan-sucrase (FS), these being highly specific (Zeidan, *et al.*, 2017). The GS and FS enzymes cleave the glycosidic linkage of sucrose and couple a glucose (GS)/fructose (FS) unit to a glucan (GS)/fructan (FS) chain, water, sucrose or other acceptor (Meng, *et al.*, 2016).

The *Weissella* strains are dependent on the proteolytic system to obtain essential amino acids, which are precursors of peptides, proteins and aromatic compounds. Lynch et al. (2015) studied the metabolic traits of *W. cibaria* and noted that the secretome of the genus *Weissella* includes both extracellular proteins, and cell wall proteins, that are secreted. It has been found that many of the secretome proteins were large, containing multiple domains, and greater than 1000 amino acids. They also showed that *W. cibaria* and *W. confusa* have a similar number of secretory proteins as *Lb. rhamnosus* GG, which is a known probiotic strain.

The strain *W. cibaria* MG1 has the production capacity of acetate, via the pyruvate oxidase pathway in the presence of oxygen, and the production of lactic acid, diacetyl or acetoin via the diacetyl/acetoin pathway in anaerobiosis (Lynch *et al.*, 2015). Some strains of *W. confusa, W. paramesenteroides* and *W. cibaria* have the ability to metabolize D-xylose, glucose, D-fructose, D-mannose, sucrose, D-maltose and cellobiose and also showed β-glucosidase and β-galactosidase activity (López-Hernández, Rodríguez-Alegría, López-Munguía, & Wacher, 2017).

4. Ecology

Although *Weissella* sp. has a very complex nutritional requirement, it is found as autochthonous bacteria in different ecosystems. Due to this fact, they may contaminate food since it can spread easily in the processing environment. Different strains were isolated from soil (Padonou, *et al.* 2010), sediments of swamps (De Bruyne, *et al.*, 2010), lake water (Vela *et al.*, 2011), being identified, mainly, in fermented foods as cheese made with raw milk (Snauwaert *et al.*, 2013, Tohno *et al.*, 2013), fermented milk (Oh, *et al.*, 2013, Nisiotou, *et al.*, 2014, 85], vegetables (Wouters, Grosu-Tudor, Zamfir, & De Vuyst, 2013). and sausages (Huys, Leisner, & Björkroth, 2012, Mende, Rohm, & Jaros, 2016) in Table 1 those species and their habitat are better explained.

Table 1. Occurrence of *Weissella* species in different ecosystems.

Species	Habitat or source	Reference
W. cibaria	Orange, pineapple, banana	Endo, *et al.*, 2009
	Tomato	Di Cagno, *et al.*, 2009
	Wheat flour	Alfonzo, *et al.*, 2013
	Blackberry, papaya	Di Cagno, Minervini, Rizzello, De Angelis & Gobbetti, 2011
W. confuse	Rhizosphere of the olive trees and surrounding soil	Fhoula *et al.*, 2013
	Red and yellow raw pepper	Di Cagno, *et al.*, 2009
W. halotolerans	Rhizosphere of the olive trees and surrounding soil	Alfonzo, *et al.*, 2013
	Fermented sausage	Tenea & Lara, 2019
W. hellenica	Vegetable forage crops	Tohno, Kobayashi, Nomura, Uegaki & Cai, 2012
	Croatian cheese fermented from raw milk	Fuka, *et al.*, 2013
W. kandleri	Desert plants	Holzapfel & Van Wyk, 1982
W. uvarum	Wine grapes	Nisiotou, *et al.*, 2014
W. sagaensis	Chinese yogurt	Li, *et al.*, 2020
W. paramesenteroides	Raw milk cheeses	Masoud, *et al.*, 2012
	Fermented sausage	Juárez-Castelán, *et al.*, 2019

Source: Own authorship (2021).

Lynch and colleagues investigated the genome of the *W. cibaria* species and according to the study of pan-proteome and core-proteome at the species level. Pan-proteome are all the proteins which are present in a given condition for all the species of a given life branch and the core-proteome are the proteins which are conserved in all the species of a given life branch and produced for a given condition (Trapp, *et al.*, 2016). Lynch and colleagues noted that the pan-proteome was much smaller and the core-proteome much larger in a level of genus. The fact that the core-proteome is much larger (corresponding to 69% of the pan-proteome of the species) may explain the ability of *W. cibaria* to survive in several ecological niches where they were found since they have a higher number of proteins (729 proteins) that help in their adaptation (Lynch *et al.*, 2015).

Some strains of *Weissella* such as *W. cibaria* MG1 (Lynch *et al.*, 2015) and *W. cetti* (Ortega, *et al*., 2018) can hydrolyze arginine, which favors its survival in environments where it is subjected to stress. A good example for this is providing a greater amount of ATP when the carbon source is scarce or producing ammonia by protecting from acid stress (Lynch *et al.*, 2015). A technological benefit of arginine deamination is the production of ornithine which is an important precursor of crust aroma compounds in the sourdough (De Angelis, *et al*., 2002).

Because they are autochthonous in many places, some strains of *Weissella* can be important in the characterization of traditional products of certain regions. As an example, strains of *W. thailandensis* and *W. cibaria* have been related to Thai fermented fish (Björkroth, Dicks & Endo, 2014, Mende, Rohm, & Jaros, 2016), while the strains *W. cibaria, W. confusa* and *W. koreensis* were detected in fermented foods of vegetal origin (Fusco *et al.*, 2015, Lynch *et al.*, 2015). In addition, the bacterium *W. beninensis* was isolated from the submerged fermentation of cassava (Padonou, *et al.* 2010) and the bacteria *W. ghanensis* and *W. fabaria* were detected in piles of fermented Ghana cocoa beans (De Bruyne, *et al.*, 2010). These products may not have the same characteristics if they were manufactured without the presence of these strains.

5. Some Applications of Bacteria from Genus *Weissella* in food

Weissella sp. has great potential in its application in food and for this reason it has been studied. Some strains show antagonistic activity against pathogens due to the production of several compounds like bacteriocins, organic acids, hydrogen peroxide, among others (Fusco *et al.*, 2015, Meng, *et al.*, 2016, López-Hernández, Rodríguez-Alegría, López-Munguía, & Wacher, 2017, Goh, & Philip, 2015, Yu *et al*., 2019, Trias, Bañeras, Montesinos & Badosa, 2008). In Table 2, the types of bacteriocin and what species are able to produce these compounds are demonstrated. *W. cibaria* TM 128 presented the production of organic acids and hydrogen peroxide, acting as inhibitors of the growth of phytopathogenic and deteriorating fungi and bacteria of fruits and vegetables (Trias, *et al.*, 2008). Some research demonstrates the antimicrobial capacity of the compounds produced by *Weissella* against Gram-positive and Gram-negative bacteria growth (Trias, *et al.*, 2008, Kariyawasam, Jeewanthi, Lee & Paik, 2019).

Table 2. Bacteriocins produced by *Weissella* strains.

Bacteriocin	Producing species	Reference
Weissellicin 110	*W. cibaria* 110	Srionnual, Yanagida, Lin, Hsiao, & Chen, 2007
Weissellin A	*W. paramesenteroides* DX	Di Cagno, Minervini, Rizzello, De Angelis, M. & Gobbetti, 2011
Weissellicin L	*W. hellenica* 4-7	Leong, K. H. *et al.*, 2013
Weissellicin D	*W. hellenica* D1501	Chen, *et al.*, 2014
Weissellicin M	*W. hellenica* QU 13	Masuda, *et al.*, 2012
Weissellicin Y	*W. hellenica* QU 13	Kariyawasam, *et al.*, 2019

Source: Own authorship (2021).

Kariyawasam *et al*. (2019), used the strain *W. cibaria* D30 as an adjunct culture in cottage cheese manufacture and the strain increases the prevention of the growth of *Listeria monocytogenes* and ensure the microbial safety of ready-to-eat soft cheeses. Nam, Ha, Bae & Lee (2014), showed that *W. confusa* has antagonistic activity against the pathogen *Helicobacter pylori* a gram-negative microorganism that causes gastritis and gastric carcinoma, infects through the intake of food, and attaches to gastric and duodenal mucous membranes. *W. confusa* strain PL9001 inhibited the binding of *H. pylori* to human gastric-cell line MKN-45 cells by more than 90%. The results suggest that *Weissella* strains can be used as probiotics added in fermented milk, for example with the aim of fighting *H. pylori*. Besides that, *W. confusa* DD-A7 has antagonistic activity against the multidrug-resistant *Escherichia coli* which is resistant against almost all antibiotics used for its treatment. The strain *W. confuse* DD-A7 was capable to trigger an oxidative attack and limits the growth of the pathogen (Dey, Khan & Kang, 2019).

The first new bacteriocin produced by *Weissella* strains to be discovered was Weissellicin 110 in the year 2007. This compound is produced by the strain *W. cibaria* 110 isolated from the Thai fermented fish product plaa-som. This bacteriocin has antimicrobial activity against some Gram-positive microorganisms and it is resistant to high temperatures and catalase, but loses its activity when exposed to proteinase K and trypsin (Srionnual *et al.*, 2007).

In the year 2014, Chen and collegues (Chen, *et al.*, 2014) discovered a new bacteriocin called Weissellicin D produced by the strain *W. hellenica* D1501 associated with Chinese Dong fermented meat. This bacteriocin has antimicrobial activity against the pathogenic bacteria *Staphylococcus aureus, L. monocytogenes* and *E. coli*. This same strain has already been tested for its antagonistic capacity against the pathogens *Kurthia gibsonii, S. aureus* and *E. coli* in soybean milk and was subsequently used in the manufacture of a new type of Tofu with increased shelf life due to presence of volatile antimicrobial compounds and bacteriocins (Chen, Rui, Lu, Li & Dong, 2014).

Besides of Weissellicin D, others isolate of *W. hellenica* demonstrated the production of Weissellicins L, M and Y which showed antagonist activity against *L. monocytogenes* and *Bacillus coagulans* (Ayeni, *et al.*, 2011, Masoud, *et al.*, 2012). Bacteriocins are natural antimicrobial compounds, there is an interest in their use by the food industry for the purpose of application as bioconservants, i.e. natural preservatives and possible substitutes for chemical preservatives (O'Connor, *et al.*, 2012). Some characteristics that make bacteriocins that are produced by lactic acid bacteria safe when used at industrial level are their non-toxicity to eukaryotic cells inactivation by digestive proteases, little influence on the intestinal microbiota (Jawan *et al.*, 2019, Wouters *et al.*, 2013) tolerance to different temperatures and pHs, action against pathogens and microorganisms spoilage of food, and do not generating cross-resistance to antibiotics (Wouters *et al.*, 2013, Juárez-Castelán, *et al.*, 2019, Tenea & Lara, 2019).

Bacteriocins are also of great importance in the food industry, for example in the production of biodegradable food packaging with antimicrobial properties (Teixeira, *et al.*, 2021). By incorporating the Bacteriocin 7293 produced by the strain *W. hellenica* BCC 7293, it was possible to control pathogenic bacteria in fillets of pangasius fish. The film produced inhibited the multiplication of both Gram-positive bacteria such *as L. monocytogenes* and *S. aureus* as well as Gram-negative bacteria such as *Pseudomonas aeruginosa, Aeromonas hydrophila, E. coli* and *Salmonella Typhimurium* (Woraprayote, *et al.* 2018).

Weissella can also be useful for the food industry due to its capacity of some strains to produce EPS in sucrose culture medium (Woraprayote, *et al.* 2018). EPS are structures of high molecular mass, composed of carbohydrates, which when added to the food, behave mainly as thickening and emulsifying agents. The polysaccharides that adds thickening and gelling properties are irreplaceable in the food industry formulations. In addition to its ability as probiotics, EPS imposes highly desirable rheological changes in the food matrix, such as viscosity increase, improved texture and reduced syneresis (Lakra, Domdi, Tilwani & Arul,2020). They can be used to replace corn starch in manufacturing puddings, for example, where these characteristics are desired. Some studies have been tested strategies to improve the EPS characteristics in order to enlarge its application in the food industry (Kavitake, *et al.*, 2019). Most of the strains of *Weissella* have the capacity to produce the EPS dextran and can also produce other EPS as shown in Table 3.

Table 3. Exopolysaccharides produced by *Weissella* strains.

Species	Product	Reference
Weissella cibaria RBA12	Dextran	Baruah, Maina, Katina, Juvonen & Goyal, 2017
W. confusa	Dextran	Kajala I. *et al.*, 2016
Weissella confusa KR780676	Linear exopolysaccharide galactan	Devi, Kavitake & Shetty, 2016, Kavitake, Devi & Shetty, 2016
W. confusa and *W. cibaria*	Dextran, fructan from sucrose, ropy capsular polysaccharide, levan and inulin	Malang, Maina, Schwab, Tenkanen & Lacroix, 2015
W. confusa XG-3	Dextran	Zhao, *et al.*, 2021
W. cibaria MD2	Fructan	Lakra,, Ramatchandirane, Kumar, Suchiang & Arul, 2021

Source: Own authorship (2021).

The EPS dextran has great efficacy as soluble dietary fiber since it has the capacity to be fermented by the probiotic intestinal microbiota due to its low digestibility when compared to commercial prebiotic inulin (Teixeira, *et al.*, 2021). The basis for EPS production by *Weissella* strains is diverse, some studies use wheat flour and rye as the basis for fermentation. *W. confusa* presented higher rye meal production due to the higher optimum pH period for the synthesis of dextran during fermentation (Cotter, Ross & Hill, 2013, Kavitake, *et al.*, 2019).

The strains that have the capacity to produce more than one exopolysaccharide are of great interest when it comes to the food industry because of their synergistic effect on the texture and also the nutritional improvement (Malang, *et al.*, 2015). Some EPS that are being produced, such as galactan, has good emulsifying and stabilizing capacities which provides its future use in cosmetic and food emulsions (Ortega, *et al*., 2018, De Angelis, *et al*., 2002, Kavitake, Balvan, Devi & Shetty, 2020). The high molecular weight dextran produced by *W. confusa* QS813 can form hydrogens bonds and steric interactions with proteins. When this EPS is used in frozen dough it's maintained the structural integrity of gluten during the freeze-thaw-cycles being appropriated to use as a cryoprotectant in wheat gluten-based frozen food (Tang, *et al.*, 2019).

Because the production of exopolysaccharide, the application of *W. cibaria* as an assistant in the manufacture of cheddar cheese was performed resulting in a product with higher retention of humidity and without alteration of the proteolysis degree (Lynch, *et al*., 2014). In addition, *W. cibaria* MG1 produces exopolysaccharides (dextran) and oligosaccharides (glucooligosaccharides) and because of that was studies with the intention of producing a new fermented drink from wort sucrose-supplemented barley-malt-derived (Zannini, *et al.*, 2013). The oligosaccharides are being applied in some foods as prebiotics, when it is impossible to use probiotics, an example of this are infant formulas. In the developing countries, infant formulas are heated before consumption, because of their dubious quality of the water. In this way, the addition of probiotics is impossible, and prebiotics are added instead. The oligosaccharides produced by *Weissella* can be a source of prebiotics for the food industry.

Rosca *et al*. (2018), verified that *W. confusa* produced a dextran with high structural stability and purity that have pharmaceutical importance due to its antifungal characteristics against the pathogenic yeast *Candida albicans*. Some strains such as the *W. cibaria* strain isolated from goat's milk also have been shown to have great potential as probiotics, such as resistance to 1% bile salt and tolerance to pH 3.0 (Elavarasi, Pugazhendhi, Poornima Priyadharsani, Valsala, & Thamaraiselvi, 2014). In addition, *W. cibaria,* jointly with *Lb. plantarum,* showed *in vitro* tests high antioxidant capacity, survived simulated gastric and intestinal transit, and tolerated bile acids and salts (Yu *et al*., 2019). Furthermore, the two strains were administered to male Wistar albino rats and showed an improvement in liver and kidney functions, damaged by heavy metals compared to rats that received only the heavy metals in their diet (Ojekunle, Banwo, & Sanni, 2017).

In addition, the *Weissella* species-pair *W. cibaria/confusa*, considered potentially probiotic by Immerzeel *et al*. (2014), were studied in relation to the use of xylooligosaccharides (XOS) as carbon source, since these are considered prebiotic. The study showed that strains absorbed XOS, both xylobiose and xylotriose, and gave an increase in the production of lactic acid when xylan hydrolyzed was used. Not only but some stains can also use xylooligosaccharides (XOS) to produce short-chain fatty acids a feature only observed in *Leuconostoc lactis* and a few strains of the established probiotics *Lactobacillus* (Månberger, *et al*., 2020).

Adesulu-Dahunsi *et al*. (2018) suggest that EPS produced by *W. cibaria* GA44 may be a commercial alternative for the food industry once it presents strong properties as antioxidant when compared to commercial antioxidant ascorbic acid, especially scavenging of superoxide anions and hydroxyl radicals.

On the other hand, the EPS glucansucrase produced by *Weissella* sp. TN610 has the ability to solidify semi-skimmed milk supplemented with sucrose which shows its potential in the application as a safe additive food to improve the texture of dairy products (Bejar, *et al*., 2013). Besides that, a novel quinoa-based yoghurt fermented with dextran producer *W. cibaria* MG1 was developed and the concentration of EPS (40 mg/L) ensured the high-water retention capacity and viscosity (0.57 mPa s) of the final product (Zaninni, Jeske, Lynch & Arendt, 2018).

The EPS dextran, levan and ropy capsular polysaccharide, produced by *W. confusa* were evaluated in breads when it comes to the delaying of the deterioration by fungus, as well as improving of the texture were observed (Tinzl-Malang, Rast, Grattepanche, Sych, & Lacroix, 2015). In addition to the production of EPS, some strains of *W. cibaria* and *W. confusa* as well as producing lactic acid also have the capacity to produce folate (vitamin B9), which allows the nutritional improvement of fermented products that use these strains in the fermentation process (Deatraksa *et al*., 2018).

6. Conclusion

Weissella sp. may have a wide range of potential applications in food products, since they can produce a high variety of compounds from the production of EPS, bacteriocins, even vitamin such as B9. However, a few studies have been conducted and the industrial application of *Weissella* strains it is still not a reality. There are still some obstacles that prevent the use of *Weissella* as a starter culture in the food industry, such as the lack of knowledge about the pathogenicity of some strains of the genus and its antagonistic capacity against other microorganisms of industrial interest due to its production of bacteriocins. Because some strains have a potential for opportunistic infection in humans, the food industry should always be vigilant for safety testing of any strain before its technological application.

Thereby, for the future use of this potential species in food industry, is necessary more researches about how the *Weissella* sp. and their compounds can be apply and with this review article it's possible to understand that it's necessary more research about the safety use of this strains in food.

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