Mini Review

Received: 1 February 2024 Revised: 24 April 2024 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.13874

Fermentation starters and bacteriocins as biocontrol strategies for table olives preservation: a mini-review

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Abstract

Biopreservation is a powerful strategy to prolong the shelf life of food products by applying naturally occurring microorganisms and/or their metabolites. Current food trends emphasise the need to develop alternatives for chemical or thermal preservation methods. In this line, different fermentation starters from table olives present the potential to control spoilage or pathogen-occurring microorganism in table olives storage. One of the most interesting family used as biopreservative culture is *Lactobacillaceae* and it has also been used in combination with yeasts as olive fermentation starter. Lactic acid bacteria, from *Lactobacillaceae* family, are characterised by the production of bacteriocins, proteins with the potential for preserving food by changing the organisation of the membrane of spoilage microorganisms. These bacteriocins-producing bacteria can be directly inoculated, although nanosystem technology is the most promising incorporation strategy. In table olives, the most commonly used starters are *Lactiplantibacillus plantarum*, *Lactiplantibacillus pentosus*, *Saccharomyces cerevisiae*, *Wickerhamomyces anomalus*, among others. These strains with biopreservation characteristics, inoculated alone or in mixed cultures, ensure food safety by conferring the product added value and prolonging product shelf life.

Keywords: biopreservation; bacteriocin; table olives; starter

INTRODUCTION

Table olives are considered not only one of the oldest fermented vegetables to originate in the Mediterranean Basin but also a major important element in the economy of some countries like Spain, Turkey, Egypt, Italy, Greece and Portugal.[1,2] Throughout history, olives have been dressed for preservation and consumption in months between consecutive harvests.[3] Olives have been traditionally fermented thanks to the spontaneous activity of the fresh product's indigenous microbiota, mainly *Lactiplantibacillus* genus. The main goal of table olive fermentation is to extend the shelf life of the product and to improve its sensory properties. However, if the development of the microbial population is left unchecked, table olives can undergo different alterations that affect their quality and organoleptic properties.

An excellent strategy to control olive fermentation and prevent product spoilage is to use selected starter cultures, which standardise final product characteristics and protect against undesirable microorganisms.[4] In some cases, the employed starters, usually lactic acid bacteria (LAB) cultures, can also exert functional advantages beyond fermentation, during product storage, producing metabolites as bacteriocins that are effective to counteract food spoilage and do not alter the product's sensory quality.[5,6] The incorporation of bioprotective cultures directly into the food product is complicated since the viability of these microorganisms can be significantly affected during the processing and storage period. Therefore, bacteria responsible for vegetable fermentation can also be used as biopreservatives in table olives storage, avoiding the use of chemical additives or any thermal treatment.[7] On this basis, the present review aims to evaluate potential microorganisms with biopreservation activity to establish their effective incorporation to extend the shelf-life of table olives and ensuring product safety.

APPLICATION OF FERMENTATION STARTERS AS BIOPRESERVATIVES

Nowadays, the indigenous microorganisms responsible for spontaneous olive fermentation are being replaced with commercial starter cultures. Fermentation starter cultures were defined by Holzapfel[8] as a preparation or material that contains a considerably large and variable number of microorganisms that may be added to a fermentation process to accelerate or improve it. These cultures have become very important in industrial

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processes to improve table olive production for, on the one hand, their effectiveness in preventing the spoilage caused by indigenous and contaminating microbiota and for, on the other hand, improving the final product's flavour.

Starter cultures must meet specific requirements: resistance or tolerance to high salt concentrations, low pH and the presence of phenolic compounds, easy adaptation to product and process characteristics, good survival against other strains naturally present in fruit, metabolic activity that allows complete sugars fermentation, the development of suitable sensory features, an extended shelf life, and inhibition of undesired microorganisms (possibly associated with bacteriocin production). Moreover, starters must not be pathogenic and toxigenic microorganisms, and may have probiotic features.[7,9,10]

Among possible fermentation starters, the most common genus is *Lactobacillus*. It should be pointed out that the genus *Lactobacillus* has recently been reclassified into 25 novel genera, and this genus is now referred to host-adapted organisms.[11] Previously named *Lactobacillus* genus forms part of the LAB group, which is widely used to preserve foods like meat,[12] dairy products[13] or vegetable products for their high acidification rate.[14]

Some LAB species, mainly *Lactiplantibacillus pentosus* and *Lactiplantibacillus plantarum*, are frequently used as starters in table olive fermentation to standardise the process, reduce preservatives, prevent alterations during storage, and confer the product a pleasant taste. *Lacticaseibacillus paracasei* or *Levilactobacillus brevis* have also been employed as starters, and either alone or co-inoculated with the previous ones.[7,15] To evaluate the effectiveness of LAB as starters, not only the characteristics that they confer the final product are assessed, but also their ability to produce antimicrobial compounds such as organic acids, carbon dioxide (CO_2), hydrogen peroxide (H_2O_2), ethanol, bacteriocins, reuterin, and so forth, which can inhibit the growth of pathogens or spoilage microorganisms.[8,9] Fermentation process reduces available carbohydrates and produces organic acids such as lactic acid, propionic acid, and acetic acid. It has been demonstrated that weak acids have high antimicrobial activity at acidic pH. Some of the LAB produce H_2O_2 in the presence of oxygen, producing a strong bactericidal activity due to its oxidating effect. Moreover, the formation of CO_2 not only generates an anaerobic environment but can also act as antimicrobial agent. Finally, it has been also demonstrated the ability of some LAB to produce bacteriocins or bacteriocins-like substances.

ANALYSIS OF BACTERIOCIN PRODUCTION BY *LACTOBACILLACEAE*

Bacteriocins have been used worldwide for food preservation in dairy, vegetable, and meat industries because of their effect against the microbial agents that cause food spoilage. The effectiveness of bacteriocins has also been demonstrated in numerous biomedical and therapeutic applications. Bacteriocins are amphipathic cationic peptides produced by Gram-positive, Gram-negative and a few archaea bacteria that enter bacterial membranes to cause pores or other mechanisms that produce leakage and thereby the inability to maintain their metabolism, which leads to death.[16] The study by López-Cuellar *et al.*[17] on the bacteriocin applications produced by LAB showed that 31% of the patents granted between 2004 and 2016 focused on biomedical applications and 29% on food preservation. Despite bacteriocins' enormous food preservation potential, the only bacteriocin authorised in the European Union (EU) is nisin (E-234), a bacteriocin produced by *Lactococcus lactis* subsp. *lactis*. Nisin is the only one approved by the US Food and Drug Administration (FDA) in 1988 and is marketed to be employed as a food additive in more than 80 countries.[6,18–21] Application of nisin in table olives processing has not yet been implemented but could be used for reducing some endospore-forming bacteria that could settle on this vegetable surface as reported in the study of Abriouel *et al.*[22] However, commercial starter LAB mixed cultures, such as Bactoferm F-LC® (Christian Hansen, Horsholm, Denmark) or ALTA® 2351 and 2341 (Kerry Bioscience, Cork, Ireland) can be added to food products for fermenting and producing bacteriocins that will improve food safety and extend shelf life.[17,21] Some examples of bacteriocins are pediocin or sakacin, produced by strains of *Pediococcus acidilactici*, *Pediococcus parvulus*, *Latilactobacillus sakei*, among others. They have shown inhibitory action against *Listeria monocytogenes* in meat products.[6,17,23] From a legal point of view, these commercial preparations can be used as ingredients for table olives preservation because specific fermented product components from the olives can provide food with functionality. Moreover, in these products, the bacteriocin activity is further supported by other metabolites with antibacterial activity produced by LAB fermentation, such as organic acids.[24]

Today, the use of bacteriocins is gaining attention due to consumer interest in foods with no synthetic additives which has led the industry to look for natural alternatives that guarantee these products' stability and safety. Bacteriocins have a wide inhibitory activity range against pathogens or spoilage microorganisms[25] and differ from antibiotics as far as several properties are concerned. The bacteriocins spectrum may be restricted to the species strains linked with the production of microbial species, whereas antibiotics have broad-spectrum activity with no preference for closely related species.[6,20] The bacteriocins that inhibit the growth of bacteria from the same species are called narrow-spectrum bacteriocins, while those that inhibit bacteria from other genera are considered broad-spectrum bacteriocins.[18] Bacteriocin similarities have allowed several authors to classify bacteriocins of Gram-positive bacteria into three classes based on physico-chemical properties and molecular weight (class I, lantibiotics; class II, non-lantibiotics; class III, bacteriocins).[20,23,26–28] Given their characteristics, research is currently assessing the use of bacteriocins in clinical applications as an antibiotic alternative, although potential resistance in bacteriocins has been demonstrated. Thus, resistance should be mitigated by knowing the action and production mechanisms of bioengineered derivatives.[29,30]

Drider *et al.*[31] studied LAB's ability to produce and secrete bacteriocins. This study showed that four genes, organised as clusters of inducible operons, are involved in bacteriocin biosynthesis: a structural gene, an immunity gene, a gene encoding the ABC transporter required for secretion, and a gene encoding an accessory protein.[6,20,26] They are usually synthesised on ribosomes as biologically inactive pre-peptides to prevent activation in the producer cell. Once recognised, the leader sequence is removed to be secreted as active peptides to the extracellular environment, where they bind to the receptor on the cell membrane of the target bacterium. It forms pores by inhibiting peptidoglycan synthesis or depolarising the transmembrane electrical potential. Numerous specific modes of action have been described for different bacteriocin types, such as nuclease or protease activity.[28,32]

Most of the interesting bacteriocins in food preservation produced by LAB belong to class IIa, such as plantaricin 423 generated by *Lactiplantibacillus plantarum*. This bacteriocin has been

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demonstrated to inhibit the growth of pathogens, such as *Bacillus cereus*, *Clostridium perfringens*, *Staphylococcus aureus*, and *Listeria monocytogenes*.[6] Mainly, narrow-spectrum bacteriocins should be used in order to have a harmless activity to natural microbiota when consumed.[21,33] Similarly, the application of other bacteriocins produced by *Lactiplantibacillus plantarum* to the food industry has been studied, such as plantaricin S and T, used for table olive fermentation control and product preservation.[6,20,34] Plantaricin S, one of the most widely studied in table olives, is bioactive against competitors of producer strain *Lactiplantibacillus plantarum*, such as *Leuconostoc*, *Pediococcus* and *Streptococcus*, and spoilage agents like *Propionibacterium* and *Clostridium*. Twelve different bacteriocins have been identified in the LAB from processing table olives.[7] Recent *in silico* analysis for other bacteriocin-producing strains isolated from table olives, such as *Lactiplantibacillus pentosus* or *Enterococcus faecium*, were studied for the bacteriocin genes production and they exposed the presence of pediocin, enterocin, and plantaricin genes.[35–38] Also, *Lactiplantibacillus pentosus* has been tested *in vitro* against human pathogens that could appear in the table olive product being an antimicrobial potential agent.[36]

The physicochemical and microbiological conditions of the table olive fermentation lead to a safety product by itself due to the low pH, high acidityand the presence of natural microbiota that could inhibit spontaneous spoilage.[39,40] Even though, these bacteriocin-producing strains could support these conditions in the product preservation. In table olives, bacteriocin production is predetermined by the medium's conditions such as initial pH, temperature, and the presence of salt; in fact, during fermentation, bacteriocin gene expression is dependent on bacterial growth and could be stimulated at stress conditions similar to the ones occurred in natural table olive fermentation.[41] Production could be also affected by other bacteriocin-inducing bacteria.[7]

Similarly, the effectiveness of bacteriocin action depends on several factors, such as the target microorganism, process conditions, the interaction with food components, and the incorporation strategy. For instance, bacteriocins are more effective when added to films and not directly incorporated into products.[6] Specifically, table olives present favourable conditions for their production and for being well spread over the surface of the fruit, and furthermore, some of the occurring-pathogens in the preservation of table olives (*Listeria* spp., *Salmonella* spp., and *Escherichia coli*) are the same target microorganism that inhibit some of the studied bacteriocins. Some authors have even suggested that bacteriocins could be applied in combination with chelating agents, such as EDTA (ethylenediaminetetraacetic acid), or with other technologies, such as high hydrostatic pressure or pulsed electric fields. These combinations can promote synergies and improve efficacy against undesirable microorganisms without altering sensory or nutritional qualities.[42,43] Therefore, when selecting a bacteriocin-producing strain, all these aspects must be analysed.

BACTERIOCINS INCORPORATION STRATEGIES

Due to relevant bacteriocins applications in food preservation, three different strategies have been proposed to incorporate them into packaged products: (i) direct inoculation of the LAB that produce the desired bacteriocins; (ii) incorporation of purified bacteriocins as product-preserving agents; (iii) the use of a previously fermented product that produces bacteriocin as an ingredient that forms part of the process.[29,42] Once the purified bacteriocin is available, it can be incorporated into a food substrate or immobilised in a preparation, which acts as a reservoir.[44] With table olives, bacteriocin-producing bacteria has been employed directly inoculated as a starter culture or a co-culture.[27,34,45]

The inhibition of undesirable microorganisms during storage and distribution can also be achieved by incorporating bacteriocins directly into protective food packaging film. For that purpose, it is necessary to bind them with biodegradable proteins or to adsorb them on a polymeric surface, such as polyethylene or other polymers like ethylene, polypropylene or vinyl acetate.[17,27,44] For example, combined systems of biopolymers and bacteriocins like nisin/chitosan are effective against pathogens such as *Listeria* spp.[17]

Another well-studied strategy for incorporating bacteriocins is nanocapsules formed by nanoemulsions, nanoliposomes, nanoparticles, or nanofibres. The development of nanoscale drug delivery systems (nano-DDS) has contributed to optimise bacteriocin-delivered systems in both biomedical applications and food preservation due to improved pharmacokinetic parameters, immunogenicity, and effectiveness against bacterial resistance mechanisms. Radaic *et al.*[28] reviewed research articles that had focused on nano-DDS and bacteriocins in recent years. Their work showed that 40% of the studies on nisin used liposomes, followed by 20% and 14% for chitosan and nanofibres, respectively. Most of these studies demonstrated the increased efficacy of encapsulated nisin over time, which was still at 4 °C up to 50 days compared to free nisin, whose inhibitory effect was lost after 7 days. These findings suggest that the nanosystem acts as a drug reservoir for bacteriocin by slowly releasing it.[46]

Other bacteriocins, such as plantaricin or pediocin, have been studied with nano-DDS for food preservation purposes and to increase the encapsulated bacteriocin's shelf life. However, most studies show no differences in bacterial inhibition compared to free bacteriocin, which may be due to very slow releases because of bacteriocin's high affinity for the nanosystem.[28]

Despite being an incorporation strategy with enormous potential, some questions need to be further evaluated: safety of these systems, *in vivo* and *ex vivo* efficacy, efficacy after incorporation, and the production costs involved in their development. Therefore, it is a technology that currently needs to be optimised.[17,28]

PROSPECTIVE OF FERMENTATION STARTERS AS BIOPRESERVATIVES

As previously discussed, the use of starters for table olives elaboration is interesting for standardising fermentation, confers a characteristic flavour and prevents alterations during preservation. In the 1980s, the first commercial starter was developed to produce table olives. Some important olive varieties are still processed without adding starters for ensuring authenticity in the product,[5,47,48] despite the fact research on microbiota growth along fermentation had shown no harmful effects by starter use.[49] Nowadays, the development of new commercial starters aims to enhance biodiversity, improve stability, and increase yields in industry. Numerous authors have worked on developing strains of industrial interest for table olive fermentation by optimising their requirements and evidencing the enormous potential that they offer for biopreservation of different olive varieties (Table 1). These strains have been used to scale-up the process

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Table 1. Experimental studies of table olive fermentation with biocontrol strains

Starter	Variety	Biocontrol effect	Reference
Lactiplantibacillus plantarum	Manzanilla	Antimicrobial and fermentation control	Leal-Sánchez *et al.* (2003)[34]
Lactiplantibacillus pentosus	Arbequina	Fermentation control	Hurtado *et al.* (2010)[3]
	Itrana & Lecino	Antimicrobial	Servili *et al.* (2006)[50]
	Manzanilla	Enhancement/induction	Rodríguez-Gómez *et al.*, (2015)[51]
	Kalamon	Antimicrobial and fermentation control	Papadelli *et al.* (2015)[52]
Lactiplantibacillus plantarum/Lactiplantibacillus pentosus	Halkidiki	Enhancement/induction	Blana *et al.* (2014)[46,53]
	Halkidiki	Enhancement/induction	Argyri *et al.* (2015)[54]
Lactiplantibacillus plantarum/ Enterococcus faecium/ Pediococcus pentosaceus	Hojiblanca	Enhancement/induction	Ruiz-Barba *et al.* (2010)[45]
Lactiplantibacillus plantarum/ Lactiplantibacillus paracasei	Nocellara Etnea	Antimicrobial	Pino *et al.* (2019)[55]
Lactiplantibacillus plantarum/Lactiplantibacillus pentosus/ Wickerhamomyces anomalus	Bella di Cerignola	Antimicrobial	Cosmai *et al.* (2018)[56]
	Manzanilla	Enhancement/induction and fermentation control	Benítez-Cabello *et al.* (2020)[57]
Saccharomyces cerevisiae	Picual Manzanilla Kalamàta	Antimicrobial	Tufariello *et al.* (2019)[58]
Saccharomyces cerevisiae/Lactiplantibacillus plantarum	Leccino	Enhancement/induction and fermentation control	Tufariello *et al.* (2015)[59]
Pichia anomala/Lactiplantibacillus plantarum	Cellina di Nardò		
Saccharomyces cerevisiae/ Leuconostoc mesenteroides	Kalamàta		
Debaryomyces hansenii/Lactiplantibacillus plantarum	Conservolea		

by commercial starters such as Vege-Start-60 (Chr. Hansen's Biosystems, Horsholm, Denmark) or OleicaStarter Advance (Oleica Technological & Safety, Málaga, Spain).

As previously mentioned, the most interesting family for starters provider is *Lactobacillaceae* for its effectiveness as biopreservatives. The bacteriocin-producing strains of *Lactiplantibacillus plantarum* (LPCO10 and NC8) have been used as starter cultures in table olive fermentation.[34,45] Ruiz-Barba *et al.*[45] studied *Lactiplantibacillus plantarum* growth enhancement by co-culturing with two specific bacteriocin-inducing strains (*Enterococcus faecium* 6T1a-20 and *Pediococcus pentosaceus* FBB63). Leal-Sánchez *et al.*[34] studied the optimal conditions under which *Lactiplantibacillus plantarum* LPCO10 could dominate the other microorganisms in table olives on the first 25 days of fermentation in brine.

Some bacteriocin-producing strains from *Lactiplantibacillus plantarum* (NRIC 149 and 423) isolated from pineapple and sorghum beer have shown inhibitory activity against *Saccharomyces cerevisiae*, *Bacillus* spp. and *Clostridium* spp.[60,61] These are some of the spoilage microorganisms involved in table olive fermentation, causing gas pockets, softening, and butyric fermentation. Therefore, the use of plantarin 149 and 423 could help to prevent these problems in table olives. Moreover, Lavermicocca *et al.*[62] biopreserved refrigerated table olives with the incorporation of *Lactiplantibacillus plantarum* and ensured safety from *Listeria monocytogenes* in a challenge test for 5 months taking the first steps in the biocontrol of table olives without chemical additives or thermal treatments.

Another widely used species as preservative is *Lactiplantibacillus pentosus* because it limits undesirable microorganisms besides improving fermentation control and yields.[50,52] Papadelli *et al.*[52] concluded that using *Lactiplantibacillus pentosus* results in controlled fermentation and a safer product that does not depend on indigenous microbial activities. Thus, both species, *Lactiplantibacillus plantarum* and *Lactiplantibacillus pentosus*, have been compared individually and co-cultured as starters, and they are independently effective in the table olive fermentation process. Nevertheless, some authors have determined and improved fermentation development with *Lactiplantibacillus pentosus* compared to *Lactiplantibacillus plantarum*.[3,63]

The starter cultures of these bacterial species and co-inoculation with yeasts like *Wickerhamomyces anomalus* have improved the final product's sensory profile and provided added value by increasing the content of phenols, carotenoids, and free amino acids.[56] Furthermore, yeasts have shown killer activity against other yeast strains thanks to the secretion of toxins, thus their incorporation during fermentation has been proposed as a biocontrol method.[64,65] For instance, *W. anomalus* has a demonstrated potential in biocontrol by counteracting *Enterobacteriaceae* and another Gram-negative bacteria. Hence it can be used for biopreservation purposes by preventing *alambrado* spoilage in table olives.[66]

An experiment run by Bevilacqua *et al.*[67] established a procedure to select yeasts that can be used as starters in table olives. They selected four promising strains (*W. anomalus* and *Kluyveromyces lactis*) that can grow in brine at a high sodium chloride (NaCl) concentration and an alkaline pH. They were chosen excluding biogenic amine producing-strains, and also for their *β*-glucosidase activity because it implies controlled spoilage, the

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production of secondary metabolites and because they favour the debittering process.[68] *Saccharomyces cerevisiae* was used as a starter in Picual, Manzanilla and Kalamàta olive fermentation, succeeding in biocontrol thanks to its effectiveness in controlling the formation of biogenic amines, such as cadaverine and tyramine, the metabolites responsible for zapatera spoilage.[58]

In addition to these strategies, sequential inoculation has been designed to control microbial growth and to reduce processing times. This is the case of the low-salt olives of the Nocellara Etnea variety, which were produced with *Lactiplantibacillus plantarum* and *Lactiplantibacillus paracasei* strains,[55] and the Cellina di Nardò, Leccino, Kalamàta and Conservolea varieties, which were fermented with selected autochthonous yeast and LAB strains.[59] Yeasts have also been used following this strategy. The incorporation of yeasts like *W. anomalus* prior to a mixed culture of LAB strains has also led to adequate physico-chemical evolution and a bigger LAB population,[57] which have resulted in a safer unspoiled product.

During commercialisation, packaged table olives frequently undergo alterations because yeasts grow under aerobic conditions. Several studies have proposed an anaerobic atmosphere (CO_2) to ensure the low development of these yeasts. Notably, Doulgeraki *et al.*[69] were the first to present rising and dropping gas levels due to the respiratory activity of the olive microbiota. This phenomenon coincided with the largest amount of *Lactiplantibacillus pentosus* at the end of the storage stage in an oxygen-deficient atmosphere [20% CO_2, 80% nitrogen (N_2)], which promoted *Lactiplantibacillus pentosus* growth at the end of the process as a biopreservative to reduce yeast spoilage during packaging.[69]

Likewise, the combination of a modified anaerobic atmosphere (30% CO_2, 70% N_2) with temperature has been studied in fermented green table olives during storage.[54] Inoculated starters (*Lactiplantibacillus pentosus* and *Lactiplantibacillus plantarum*) remain viable for 6 months at 4 °C, considering modified anaerobic atmosphere combined with refrigeration the best-studied conditions for starter survival. Rodríguez-Gómez *et al.*[51] established storage at 22 °C in plastic bags with N_2 as the best conditions with a probiotic potential for table olives, although packaging in brine would limit shelf life because pH rises. Although these conditions limit a product's shelf life to 3 months, they promote the development of functional table olives with biofilm formation (LAB and yeasts) on the product's surface.

Summing up, the potential in biopreservation of *Lactiplantibacillus* genus has widely been demonstrated, especially, *Lactiplantibacillus pentosus* have shown high survival rates at the end of the table olives process and biocontrol effect against other spoilage bacteria. Nevertheless, *Lactiplantibacillus plantarum* should be necessarily taken into account for bacteriocin production. In addition to that, yeast such as *Saccharomyces cerevisiae* and *W. anomalus* may have an important role in biocontrol avoiding biogenic amines accumulation and promoting sensorial profile. Although numerous studies with these remarkable biocontrol strains have been done to develop appropriate fermentations, there is a lack of information on the impact of their incorporation in the packaging and commercialisation stage.

CONCLUSIONS AND FUTURE PERSPECTIVES

Bacteriocin-producing strains have been demonstrated to limit undesirable microbial growth during table olive fermentation. Nevertheless, it is necessary to value the incorporation type, efficiency, and the involved costs for table olives companies, which could imply the direct inoculation of bacteriocin-producing microorganisms or nanosystem devices to encapsulate bacteriocins. In this way, further studies to assess the viability of bacteria incorporation are very much needed.

Employing starter cultures offers numerous technological and functional advantages during olive fermentation process and also through the storage period. Research seems to point out bacteriocin-producing strains as the most promising alternative to chemical or thermal treatment in table olives preservation, but toxin-yeast strains cannot be excluded. Therefore, relevance now lies in developing and implementing multifunctional starter cultures into biocontrol strains with desirable antimicrobial and technological characteristics for their industrial application in table olive preservation. Accordingly, the main objective will be to generate functional, safe, sensorial-appropriate, and health-promoting olive products.

Furthermore, utilising new biocontrol strategies will avoid the use of heat treatments, such as sterilisation and pasteurisation, as well as synthetic additives, to maintain the product's nutritional and sensory values, reduce the costs associated with heat treatments or food waste, and enhance the image of olives as a natural product.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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