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MINIREVIEW

Nonconventional yeasts to produce aroma compounds by using agri-food waste materials

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One sentence summary: Production of aroma compounds from agri-food waste materials by using nonconventional yeast strains.

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ABSTRACT

Nowadays, biotechnological applications are emphasized to ensure sustainable development by reutilizing waste materials to prevent ecological problems and to produce or recover compounds that may have positive effects on health. Yeasts are fascinating microorganisms that play a key role in several traditional and innovative processes. Although *Saccharomyces* is the most important genus of yeasts, and they are major producers of biotechnological products worldwide, a variety of other yeast genera and species than *Saccharomyces* that are called 'non-*Saccharomyces*' or 'nonconventional' yeasts also have important potential for use in biotechnological applications. Some of the nonconventional yeast strains offer a unique potential for biotechnological applications to produce valuable secondary metabolites due to their characteristics of surviving and growing in such extreme conditions, e.g. wide substrate range, rapid growth, thermotolerance, etc. In this review, we aimed to summarize potential biotechnological applications of some nonconventional yeasts (*Kluyveromyces* spp., *Yarrowia* spp., *Pichia* spp., *Candida* spp., etc.) to produce industrially important aroma compounds (phenylethyl alcohol, phenylethyl acetate, isobutyl acetate, diacetyl, etc.) by reutilizing agri-food waste materials in order to prevent ecological problems and to produce or recover compounds that may have positive effects on health.

Keywords: volatiles; agri-food waste; aroma; nonconventional yeast; biotechnology; bioaroma

INTRODUCTION

Saccharomyces is the most important genus of yeasts, and they are a major producer of biotechnological products worldwide that can be used in various kinds of industrial fermentation processes such as winemaking, brewing and/or baking as well as in biotechnological studies. A variety of other yeast genera and species than *Saccharomyces*, which are called 'non-*Saccharomyces*' or 'nonconventional' yeasts, have also important potential use in biotechnological applications to produce value-added products (Johnson 2013; Gamero *et al.* 2016; Żymańczyk-Duda *et al.* 2017; Varize *et al.* 2019). Yeasts in bioprocesses can be considered as major producers of diverse natural value-added compounds in industrial biotechnological applications and have been extensively studied in recent years. Most of the conventional and nonconventional yeasts are not pathogenic for humans; therefore, they can be used in a variety of applications. *Saccharomyces cerevisiae* is used in traditional fermentation processes having a high potential for agro-industrial waste management mainly due to its generally recognized as safe (GRAS) characteristics. In addition, some non-*Saccharomyces* yeasts have GRAS assignment as well (e.g. *Kluyveromyces lactis*, *K. marxianus*, *Candida pseudotropicalis*, *C. lipolytica*, etc.) received from the Food and Drug Administration. Fermenting yeast cells may produce wide range

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of volatile metabolites that have strong aromas that are important for the quality of products. They are able to produce complex aromatic compounds such as esters, higher alcohols, carbonyls, sulphur compounds, etc., especially by the metabolism of amino acids, when nutrients requirements are sufficiently provided (Johnson 2013; Dzialo *et al.* 2017; Kregiel *et al.* 2017; Paulinho *et al.* 2017; FDA 2018).

The rapid increase in the human population, industrialization and inefficient management of food waste cause great amounts of waste accumulation worldwide. Thanks to current technological improvements that allow us to recover specific compounds that can be used as functional additives in different applications and products, food wastes are considered as cheap sources of valuable compounds. They can be characterized by their chemical compositions (carbohydrates, proteins, lipids and some other minor compounds) and can be used in various industries such as biorefineries, pharmacy, cosmetic, aroma, etc. The theory of waste valorization is associated with recycling and reusing of waste materials into other resources in order to provide value-added products. Therefore, in recent years, scientists are interested to bring new approaches to waste management applications than incineration, landfills, composting, animal feeding, etc., by reutilizing industrial wastes that are usually rich in carbon and nitrogen sources and can be considered as a perfect feedstock (Galanakis 2012; Ng *et al.* 2020; Saadoun *et al.* 2021). Recently, production of the value-added products such as aromatics, enzymes, single-cell proteins, feed additives, biofuels and variety of other important chemicals from waste biomass has been widely studied (Aggelopoulos *et al.* 2014; Mantzouridou, Paraskevopoulou and Lalou 2015; Melnichuk *et al.* 2020; Cabello *et al.* 2021). Regarding wastes from the food industry, a variety of substrates such as liquid wastes from dairy (whey) and the sugar industry (molasses), solid wastes, lignocellulosic materials, cereal grains, legume seeds, brewer's spent grains, vegetable, fruit processing wastes and microorganisms (yeasts, fungi, bacteria) can be used through fermentation processes. In this biotechnological application, different kinds of factors—microorganisms, solid support, water activity, temperature, aeration and type of fermenter—should be taken into consideration to obtain the high yield of production (Mussatto *et al.* 2011; Aggelopoulos *et al.* 2014; Sadh, Duhan and Duhan 2018; Try *et al.* 2018; Ramamoorthy, Sambavi and Renganathan 2019).

Aroma compounds are extremely important and have numerous applications in different kinds of industries, including food, feed, cosmetics, pharmaceutical and chemicals. They are among the most important petroleum-based feedstock and are highly produced by chemical synthesis or extraction from plants in natural ways. Due to ecological problems, global warming, limited availability of natural sources, low yield and increased consumer's interest in consuming natural products, obtaining of these important metabolites from natural ways by biotechnological applications has arisen in importance (Lee and Wendisch 2017; Try *et al.* 2018). They can be produced biotechnologically in two basic ways: through de novo synthesis and bioconversion/biotransformation. The term 'de novo synthesis' refers to the synthesis of the complex structure of substances (e.g. the production of aromatic compounds by de novo synthesis may generate mixture of components), by metabolizing sugars, amino acids, nitrogen salts and among others by organisms, while bioconversion (single reaction) and/or biotransformation (few reactions) are enzymatically catalyzed reactions by using pure enzymes or within microbial cells (Braga, Guerreiro and Belo 2018).

The classical carbon sources for typical yeast processes are glucose and/or sucrose; however, as an industrial biotechnological application, utilization of alternative carbon sources by nonconventional strains is having a great interest due to their potential by providing alternative metabolic routes for substrate utilization and end-product formation. The use of different microbial cultures for the production of these metabolites is providing a variety of advantages such as the possibility of labeling 'natural', which is important for meeting the increasing awareness of consumer demand about consumption of natural products (Kregiel *et al.* 2017; Do, Theron and Fickers 2019). *Kluyveromyces* spp., *Yarrowia* spp., *Pichia* spp. and *Candida* spp. are the most important nonconventional yeast genera and they are studied to produce some aroma compounds such as phenylethyl alcohol, phenylethyl acetate, isobutyl acetate and diacetyl by reutilizing agri-food waste materials in recent years (Güneşer *et al.* 2016; Martinez *et al.* 2017; Martinez-Avila *et al.* 2020; Rodriguez-Romero *et al.* 2020; Kılmanoğlu *et al.* 2021).

Nowadays, usage of membrane-based technologies is taking into consideration the industrial processing of food products and by-products. Different membrane-based techniques have been actively used for the separation, recovery and concentration of secondary metabolites such as aromas and phenolic compounds from agro-food products and their derivatives, e.g. wastewaters and mainly for production of nonalcoholic beverages. Pervaporation (PV) is a membrane-based separation technique, which is coupling of permeation and evaporation process, that can separate multicomponent mixtures by using selective barrier. The process offers several advantages compared with conventional separation/purification techniques such as distillation, evaporation and solvent extraction by providing reduced number of processing steps and low energy consumption. Over the last decade, according to a number of scientific publications PV process has increased remarkably in chemical, food and pharmaceutical applications (Lisniewska *et al.* 2018; Munoz 2019; Munoz *et al.* 2020; Ugur Nigiz 2020; Zeng *et al.* 2021).

Therefore, in this review, production of some important aroma compounds by using nonconventional yeast strains in agri-food waste materials will be summarized according to recent publications. As future trends and possible uses in further research studies, recovery of these metabolites by PV is also mentioned later.

PRODUCTION OF SOME AROMA COMPOUNDS BY USING NONCONVENTIONAL YEAST STRAINS

Aroma, which is one of the most important characteristics in order to determine the sensory quality of foods, is formed as a result of the natural properties of the raw materials, chemical and biochemical reactions that occur during the processing and storage of the product. Aldehydes, ketones, lactones, esters and terpenes are the most important chemical groups responsible for aroma characteristics (İşleten Hoşoğlu, Güneşer and Karagül Yüceer 2018; Bhari and Singh 2019). Aromatic compounds can be obtained by extraction from natural sources, chemical synthesis and biotechnological processes. It is stated that ~80% of the currently available aroma substances are produced by chemical synthesis. In the case of chemical synthesis, a high yield of production can be obtained; however, low quality of products and not being able to label as 'natural aroma' to obtained products are the main problems of this process. Today, due to consumer awareness of artificial and synthetic additives and their request

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to consume natural products led to developments in obtaining biological origin aromatic compounds. In addition, biotechnological processes for bioaroma production can also be considered as an eco-friendly approach due to the possibilities of use of agri-residues as alternative raw materials (Felipe, Oliveira and Bicas 2017; Poornima and Preetha 2017; Bhari and Singh 2019; Pereira *et al.* 2019; Paulinho *et al.* 2021).

Fermentation is a biological conversion of complex substrates by using various microorganisms in order to obtain simple metabolites such as alcohol and carbon dioxide as primary and a wide range of others called secondary metabolites. For the fermentation processes, old techniques have been further modified in order to maximize productivity and two techniques named submerged (SmF) and solid state fermentation (SSF) have emerged. SmF is a fermentation process that makes possible to produce most of the commercial and desired products where the growth and anaerobic and/or partially anaerobic decomposition of complex substrates such as carbohydrates are accomplished by microorganisms in plenty of free water. In SmF, substrates are consumed very fast and may need to be supplemented by nutrients repetitively. On the contrary to this, technique provides an advantage for microorganisms that require high moisture content for growth such as bacteria. In addition, purification of metabolites obtained by this technique may be easier. On the other hand, in SSF, solid substrates such as agro-industrial wastes are mainly used in order to produce such metabolites. By using these kinds of wastes as low-cost carbon sources, it may help not only in the production of value-added products but also in the reduction of pollution accumulation in ecological system. In this fermentation technique, contrary to SmF, substrates are utilized very slowly and can be used by microorganisms in long fermentation period. In addition, this technique is not available for microorganisms that need high moisture content for their metabolic activities. Aroma compounds can be produced by SSF process in a higher yield and shorter time compared with SmF; however, it is still rarely used for aroma production. In this process, recovery systems are one of the most important challenges that must be combined in order to scale up the applications in industrial level. By optimization of production and combining with recovery systems, it may improve to obtain concentrated purified compounds. These improvements may make the SSF process a promising tool for natural aroma production in future processes (Subramaniyam and Vimala 2012; Sharma, Oberoi and Dhillon 2016; Sadh, Duhan and Duhan 2018; Try *et al.* 2018; Sudhansu and Ramesh 2019). Later, we aim to summarize the production of some volatile compounds that can be used as aromatics obtained by SmF and SSF processes in agri-food waste materials.

Some of the nonconventional yeasts are very interesting model for research in recent years such as the *Kluyveromyces* genera. Kılmanoğlu *et al.* (2021) have investigated the production of alcohols and esters by *Kluyveromyces marxianus* strain from tomato pomace, which is a by-product of the tomato industry. Within the scope of their study, they have performed different pretreatments—ultrasound-assisted dilute acid (UADA) and heat-treated dilute acid (HTDA) followed by enzymatic hydrolysis (EH)—to produce fermentable sugar for used yeast strain in fermentation media. HTDA pretreatment produced more fermentable sugar and as a result, isoamyl alcohol, phenylethyl alcohol, ethyl acetate and phenylethyl acetate were found to be volatile organic compounds produced by *K. marxianus* on tomato pomace substrate. In tomato pomace hydrolysate, rose and sweet floral aromas were described as aroma characteristics at the end of the fermentation period. Güneşer *et al.* (2016) have evaluated agri-food residues—acid whey, tomato, grape and pepper pomaces—as carbon sources to produce flavor compounds by using free and entrapped *Kluyveromyces marxianus* strains. Free and entrapped strains were found to be able to ferment glucose, fructose and lactose in the agri-food waste materials. According to results, concentrations of ethyl acetate, isoamyl alcohol, isoamyl acetate, 2-phenylethyl isobutyrate, phenylethyl acetate and phenylethyl alcohol were found higher in fermented agri-food waste materials compared with the control media for volatiles production. Free and entrapped *K. marxianus* cells in agri-food wastes showed high yield production of some esters, e.g. isoamyl acetate and phenylethyl acetate and alcohols including phenylethyl alcohol and isoamyl alcohol with floral and fruity characteristics. The highest volume of ethanol concentration was found in whey media. The amount of volatile compounds, which were produced on wastes, varied according to used cell type and agri-food waste materials. In addition, according to the results of Güneşer *et al.* (2016), some volatiles have been produced in higher concentrations by using entrapped *K. marxianus* cells. Therefore, it can also be taken into consideration to produce specific volatile compounds in higher concentration by using advantages of immobilized microbial cells in further studies. Martinez *et al.* (2017) used sugarcane bagasse and sugar beet molasses mixture as low-cost fermentation media for *K. marxianus* strain in SSF process. During the SSF of the waste mixture by *K. marxianus*, they have identified some volatiles that belong to chemical groups aldehydes, alcohols, ketones and esters. Most of the volatile compounds belonged to esters such as methyl acetate, ethyl acetate, isobutyl acetate, ethyl butanoate, etc., which were characterized by fruity odor. Some of the other volatile compounds, e.g. acetaldehyde, ethanol, isoamyl alcohol, isobutyl alcohol, acetone and diacetyl, were also detected in waste mixture within the study. According to recent studies summarized earlier, nonconventional yeast strain *K. marxianus* showed fermenting ability for different waste materials. Therefore, in order to produce some aromatic compounds and other value-added metabolites by fermentation processes of low-cost carbon sources as agri-food residues, *Kluyveromyces* genera, e.g. *K. marxianus*, should be taken into consideration for further studies.

2-Phenylethanol (2-PE) and 2-phenylethyl acetate (2-PEA) are valuable flavoring agents that are widely used in different industries as additives due to their characteristic of rose-like odor. Most of these additives are derived from chemical synthesis; however, due to consumer interest in natural products, the most efficient route in order to biologically produce these compounds to meet the growing demand was through the bioconversion of precursor L-phenylalanine via Ehrlich pathway (Martinez-Avila *et al.* 2018). Nowadays, because of that not being cost-effective and limited availability of L-phenylalanine, large-scale production has become a rising problem. Therefore, in order to ensure sustainability, an alternative way of the biosynthesis of these metabolites from cost-effective renewable sugars was of great interest to the researchers (Martinez-Avila *et al.* 2018; Kong *et al.* 2020). As an appropriate example to this situation, Mierzejewska *et al.* (2019) have investigated the production of 2-PE by nonconventional yeast strains—*Metschnikowia chrysoperlae* and *Pichia fermentans*. Within their study, they used corn stover as residue from agriculture, which is a promising feedstock for the production of desirable and highly valuable bioproducts. First of all, by chemical and enzymatic pretreatments, they have obtained fermentable sugars and hydrolysates were

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used as feedstock for 2-PE production by microorganisms mentioned earlier. The highest 2-PE production obtained in *P. fermentans* strains by the amount of 3.66 g/L was found. At the end, they also showed the recovery potential of 2-PE from fermentation broth by ethyl acetate in order to remove 2-PE from fermentation broth and purified by vacuum distillation. In purification, overall process yield and purity of 2-PE were found as 63.20% and 97.27%, respectively. In another study conducted by Kong *et al.* (2020), it was reported that nonconventional yeast strain *Pichia pastoris*, which can synthesize a small amount of 2-PE under regular conditions, may synthesize at higher rates as a result of metabolic engineering. They have demonstrated that overexpressing ARO10 and ADH6 combined with several genetic engineering approaches may increase the production. As a result of their study, they have obtained 1169 mg/L of 2-PE by de-novo synthesis and this result showed the potential of *P. pastoris* as a host strain to produce industrially interested 2-PE by applying metabolic engineering approaches. In the study of Chreptowicz *et al.* (2017), 2-PE production on by-product of milk (whey) and sugar beet processing by supplementation of L-phenylalanine precursor have been investigated. Of the 28 strains that they have isolated from plant material and fermented food, in 10 of them they observed 2-PE concentration up to 2 g/L. In another study conducted for L-phenylalanine supplementation into low-cost carbon sources, Martinez-Avila *et al.* (2020) also reported that sugar industry waste—sugarcane bagasse—with supplementation of L-phenylalanine may also be used in order to produce 2-PE. In another study, Adame-Soto *et al.* (2019), with the addition of L-phenylalanine precursor to fermentation media, observed the highest yield on the production of 2-PE and 2-PEA by using *K. marxianus* strains in the amount of 1.024 and 0.203 g/L, respectively. According to the study of Rodriguez-Romero *et al.* (2020), they have shown that tequila vinasses were appropriate media to produce 2-PEA by shikimate pathway. They used four nonconventional yeast species—*Wickerhamomyces anomalus*, *Candida glabrata*, *Candida utilis* and *Candida parapsilosis*—and reported that the highest concentration of 2-PEA was reached by *C. glabrata* with an amount of 65 mg/L followed by *W. anomalus* strain. According to all studies summarized earlier, nonconventional yeast strains may show efficient performance to produce 2-PE and 2-PEA, which were industrially important compounds. Most of the studies were conducted on L-phenylalanine conversion in order to obtain desired compounds; however, de novo synthesis should also be taken into consideration, particularly by using low-cost substrates for the production of value-added aromatics. Recently, metabolic engineering strategies to overproduce compounds are also of great interest; however, further detailed studies must be carried out to understand the route of producing 2-PE and 2-PEA in order to meet the growing demand of industries, e.g. food and fragrances.

Vanillin (4-hydroxy-3-methoxybenzaldehyde) is a widely used aromatic compound in food and beverages industries, and its pharmaceutical applications can be obtained in different ways including natural extraction from sources chemically or biologically (bio-vanillin) synthesized. According to the European Union regulations (EC 1334/2008), vanillin that is obtained by using natural raw materials and biotechnological methods is considered as a 'natural flavoring substance' that gives the product a quality in terms of marketing. Vanillin is one of the most used flavoring substances in the world and due to its insufficient supply and high costs in natural production, researchers focused on biological synthesis of this compound in recent years (Horvat *et al.* 2019; Singh, Mukhopadhyay and Sachan 2019; Karakaya and Yılmaztekin 2020). Biotechnologically derived approaches for natural-identical vanillin production can be divided into three groups: plant-based, enzyme-based and microorganisms-based. Microorganism-based approaches for natural vanillin production involve the microbial degradation of phenylpropanoid precursors such as ferulic acid, eugenol, isoeugenol, vanillyl alcohol and lignin. In this approach, bacteria, fungi, yeast and/or engineered microbial cells can be used on agricultural by-products to produce natural vanillin because of earlier mentioned precursors (Paul *et al.* 2021). Currently, we have found only one study conducted on vanillin production via bioconversion by using non-*Saccharomyces* yeasts. Ashengroph and Amini (2017) investigated the bioconversion of isoeugenol into vanillin and vanillic acid by using *Trichosporon asahii* and reported that the total concentration of both compounds was found 4.2 g/L with a molar yield of 88.3%. Most of the studies that were conducted for bioconversion of precursors into vanillin were by bacterial strains (Mazhar *et al.* 2017; Paz *et al.* 2018; Singh, Mukhopadhyay and Sachan 2019). According to Singh, Mukhopadhyay and Sachan (2019), *Bacillus safensis* strain was used for the production of vanillin by applying eugenol biotransformation, and they have detected vanillin as a single metabolite with a molar yield of 26%. In another study conducted by Paz *et al.* (2018), they have used ferulic acid to produce vanillin by conversion, which is inexpensive feedstock that can be obtained from lignocellulosic wastes. For this purpose, *Bacillus aryabhattai* strain was used and 0.147 g/L vanillin was obtained at the end. Mazhar *et al.* (2017) used another bacterial strain *Enterobacter hormaechei* and inoculated to waste residues of rice bran-based media containing ferulic acid as a substrate for production of vanillin and obtained 5.2 g/L vanillin with a molar yield of 86.6% in the production process. Production of vanillin from natural ways is quite expensive and not sustainable due to limited natural resources. Therefore, in order to meet consumer demand for the consumption of natural products, producing this compound by biotechnological application in a natural way seems an important challenge for scientists currently. Yeasts, particularly nonconventional yeasts, need to be investigated in detail due to their characteristics of surviving in extreme conditions and producing value-added compounds. Agricultural by-products, which are rich in phenylpropanoid precursors, can also be used for de novo synthesis of vanillin by using natural and/or recombinant microbial cells.

Lactones are fragrant compounds that can be found in fruits and can be defined with peachy and fruity characteristics. The most important lactone is γ-decalactone, due to its high market volume and peach-like flavor. It was stated that ricinoleic acid was generally used as a substrate in the production of γ-decalactone and it can be obtained by peroxisomal β-oxidation of various microorganisms, especially yeasts. Production of γ-decalactone from ricinoleic acid may vary depending on the type, species, strain, etc. (Yılmaztekin, Cabaroğlu and Erten 2008; Guido *et al.* 2011; Braga and Belo 2016; Soares *et al.* 2017). Chemical synthesis of lactones may lead to undesired racemic mixtures; therefore, their de novo synthesis allows obtaining of pure lactones and long-term sustainability in production (Silva *et al.* 2019). Marella *et al.* (2020) investigated the production of lactones by oleaginous yeast *Yarrowia lipolytica* from non-hydroxylated fatty acids. Through metabolic engineering of strain, they have obtained 282 mg/L gamma-dodecalactone in a fed-batch bioreactor. In another study conducted by Malajowicz *et al.* (2020), wild and mutant *Y. lipolytica* strain was used for comparison in terms of production of gamma-decalactone. The mutant strain showed 3-fold more production than wild one.

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There are limited studies in the literature on the production of specific lactones, e.g. γ-decalactone from microbial sources. Evaluation of different microbial sources in terms of lactone production and combining with metabolic engineering approaches were thought to be useful in obtaining high amounts of these aroma compounds. Some of the recent studies conducted on bioaroma production by nonconventional yeasts are summarized in Table 1.

FUTURE TRENDS

Extracts obtained by de novo synthesis may contain soluble and/or suspended compounds with a wide variety of physical and chemical properties. At this point, the separation of specific compounds from the mixture is an important step for future processes. Membrane technologies can be used to separate the compounds in waste and/or by-products from the mixture medium. Membranes can be defined as barriers that provide a selective and controlled transition from one component to another from a multicomponent mixture. By utilizing membrane technologies, various advantages may be obtained compared with traditional methods, e.g. applicability to thermally sensitive products. Separation can be accomplished by developing a suitable membrane process based on the characteristics of the type of interest component. Process development usually involves determining the optimal conditions of commercially available membranes under different operating parameters such as flow rates, permeation rate, operating pressure and temperature. A suitable membrane process to be developed allows for the separation and purification of various secondary metabolites such as volatile compounds from a mixture to suit their specific requirements (Kumar 2007; Nazir *et al.* 2019).

The recovery of many value-added compounds from agricultural food products can be achieved by membrane-based technologies. As mentioned earlier, there is an increasing demand for the natural production of aroma compounds via biotechnological approaches and extraction from its main sources. Although many techniques are used for the recovery of the substances obtained in a natural way (adsorption, absorption, distillation, evaporation), PV, a highly selective membrane technique, has various advantages in the separation of aroma compounds. The recovery of flavoring agents is highly dependent on their chemical stability. At this point, separation can be performed at non-high temperatures (e.g. room temperature) with PV, a membrane-based technology that uses a selective barrier for separation. Another advantage of applying this technique is that characteristics of aromatic compounds are preserved and risk from any contamination may also be reduced due to no need to use chemical substances and/or solvents. The main challenges for PV technology are dealing with the need of purified stream and low permeation fluxes which can be enhanced by temperature but also may decrease the selectivity between the compounds (Munoz 2019; Munoz *et al.* 2020).

As of now, we have found only one research article for the recovery of aromatic compounds obtained by de novo synthesis using low-cost waste materials as carbon sources. Most of the studies mentioned about PV processes for recovery of aroma compounds from food wastes are available as review articles. Therefore, in addition to study conducted for recovery of aromatics obtained by de novo synthesis, some of the recent studies are also summarized later about recovery of some aromatics (e.g. aroma recovery in low-alcohol beverage production, recovery of industrially important aroma compounds, etc.) by applying PV process in order to show process efficiency and availability for possible future processes.

Rossi *et al.* (2017) reported that isoamyl acetate, which is a characteristic compound associated with fruity aromas, was produced mainly in sugarcane molasses by using nonconventional yeast *Pichia fermentans*. They have worked on the recovery of aroma compounds obtained from the fermentation medium by PV using polydimethylsiloxane membrane (Pervap 4060, Sulzer). The optimization of the PV module was carried out under three different temperatures in order to recover the natural fruit flavor with high efficiency. Through the PV process, they were able to achieve the concentration of natural fruit flavor for 13 h under optimal conditions (1.5 mL/min at 45°C and 0.1 kPa pressure). They have reported that isoamyl acetate can be concentrated in the range of 9–61.8 mg/L from the fermentation medium in the first hour and the PV process can effectively be used to recover and concentrate various natural flavors from fermentation medium.

As a result of our literature review, we have found some studies based on PV process for aroma recovery in low-alcohol beverage production in recent years. According to Sun *et al.* (2020), besides the membrane-based technologies, ethanol removing can also be by heat treatment; however, most of the aroma compounds are lost during this process, which may reduce significantly consumer's acceptance. Therefore, membrane processes such as PV, reverse osmosis, osmotic distillation, etc. seem a promising route in order to obtain low-alcohol beverages by protecting desirable compounds in order to meet the consumer's demand. As an appropriate example to this situation, according to the study of Paz *et al.* (2017), they have analyzed five commercial beers and their corresponding no-alcohol versions in terms of five aromatic compounds that consist of three alcohols and two esters: isobutyl alcohol, 2-methyl butanol and 3-methyl butanol; and ethyl acetate and isoamyl acetate, respectively. They have detected substantial reduction in aroma compounds in nonalcoholic beers. For this purpose, they have tested PV of these aromas in order to allow their recovery by using two commercial PV membranes with polydimethylsiloxane (PDMS) active layer: Pervatech (Rijssen, Netherlands) and Sulzer (Winterthur, Switzerland), and reported that they are appropriate for the PV in the recovery of beer aromas. Mass recovery was found higher for the Pervatech membrane in most of aromas, while enrichment factor was found better for Sulzer membrane. They also have mentioned that since active layers are made of PDMS in both membranes, active layer thickness, porosity and chemical modification may play relevant role in the transfer of volatile organic compounds. Similar study to Paz *et al.* (2017), Alves, Silva and Scheer (2020) have also investigated aroma recovery and dealcoholization in beer by two-step PV process. Within their study, they aimed to optimize conditions for both beer aroma recovery and dealcoholization by using a hydrophobic composite membrane (Pervatech BV, Netherlands) made from a 3-μm PDMS functional layer. They also reported that the membrane that they used showed promise in order to recover aromatic compounds together with removing ethanol from beer. Besides the aroma recovery studies in low-alcohol beverages production in order to meet consumer demands, some of the studies are also conducted on recovery of important aromatic compounds. Brazinha, Barbosa and Crespo (2011) have investigated the recovery of vanillin that is one of the most important aroma compounds in the world by applying organophilic PV. They have obtained vanillin from aqueous media as a pure solid free of contaminants by single PV step. As a result of their study, they have found it feasible to recover high boiling compounds

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Table 1. Some of the recent studies about bioaroma production by nonconventional yeasts.

Strain(s)	Substrate(s)	Some of the produced compound(s)	Reference
K. marxianus	Tomato pomace	Isoamyl alcoholPhenylethyl alcohol,Ethyl acetate,Phenylethyl acetate	Kılmanoğlu *et al.* 2021
K. marxianus	Sugarcane bagasseSugar beet molasses	Methyl acetate,Ethyl acetate,Isobutyl acetate,Ethyl butanoate,Acetaldehyde,Ethanol,Isoamyl alcohol,Isobutyl alcohol,Acetone,Diacetyl	Martinez *et al.* 2017
K. marxianus	Acid wheyTomato pomaceGrape pomacePepper pomaces	Ethyl acetate,Ethyl propionate,Isoamyl alcohol,Isovaleric acid,2-Nonanone,Phenyl ethyl alcohol,Phenylethyl acetate,Gamma-decalactone	Güneşer *et al.* 2016
W. anomalus,*C. glabrata*,*C. utilis*,*C. parapsilosis*	Tequila vinasses	2-Phenylethanol2-Phenylethanol acetate	Rodriguez-Romero *et al.* 2020
Clavispora lusitaniae,*K. marxianus*,*Torulaspora delbrueckii*,	Mezcal (alcoholic beverage from agave plant fermentation in Mexico)	2-Phenylethanol2-Phenylethanol acetateEthyl acetate,Isoamyl acetate,Isoamyl alcohol, Benzaldehyde,2-Phenylethyl butyrate,Phenylethyl propionate	Adame-Soto *et al.* 2019
Pichia kudriavzevii	Sugarcane bagasse	2-Phenylethanol	Martinez-Avila *et al.* 2020

as vanillin (~285°C) from aqueous media by PV. In another study, Weschenfelder *et al.* (2015) have investigated the ability to concentrate eight volatile compounds (2,3-butanedione, 2,3-pentanedione, 3-methylbutanal, benzaldehyde, acetaldehyde, furfural, 2,5-dimethylpyrazine and 5-methylfurfural) with different organoleptic characteristics in industrial soluble coffee solution and showed that PV is a promising alternative to concentrate such compounds from soluble coffee. For this purpose, they have used PDMS hydrophobic membrane provided from Pervatech BV Netherlands. Feed flow rate, temperature and permeate pressure were analyzed in order to assess PV performance. For all organic compounds, permeation flux increased by temperature. Except for 5-methyl furfural, fluxes of all aroma compounds decreased with partial pressure.

In order to meet the growing demand of consumers, biotechnological applications such as de novo synthesis are widely applied in recent years for the production of natural important secondary metabolites such as aroma compounds. However, there are only limited studies in order to recover these products produced by de novo synthesis from fermentation media. In this context, further studies related to the recovery potential of such substances will contribute to the development of the food sector by showing the possibility of large-scale production. As mentioned above, PV, which is a membrane-based technology, can be a promising tool for industrial purposes in future processes by applying in recovery of value-added substances such as aromatics. However, integration and optimization of the process should be taken into consideration for researchers in order to recover these important metabolites in higher efficiency. We believe that further studies on recovery systems of metabolites obtained by de novo synthesis, providing economic benefits from an industrial point of view, can also bring sustainable innovative approaches to waste management applications, which is one of the most important issues of today. For this purpose, researchers from interdisciplinary areas such as food and chemical engineering, microbiology, biotechnology and industrial partners should work in collaborative studies in order to achieve progress in this regard.

CONCLUSION

In parallel to rapid population growth and changing nutritional habits worldwide, the demand for a wide variety of foodstuffs is increasing. In order to meet the consumer demand, the production of foodstuffs in high quantities is generating on industrial scale. As a result of industrial production processes, the formations of many waste materials that can cause ecological problems and/or economic losses occur. These wastes may contain many components that can have positive effects on human health and provide opportunities for the acquisition of value-added products. Therefore, it is very important to effectively manage food waste through different approaches and reveal their potential to reuse. Although biotechnological applications are emphasized in order to ensure sustainable development by reutilization of waste materials to prevent environmental pollution and to produce value-added products, further detailed studies are needed. Nonconventional yeast strains offer unique potential for biotechnological applications to produce valuable secondary metabolites. According to recent publications, *Kluyveromyces* spp., *Candida* spp. and *Pichia* spp. were used mainly and it should be taken into consideration for further studies to produce various secondary metabolites that can industrially be important. Apart from these all, some other nonconventional yeast strains and substrates should also be considered to see metabolic characteristics of different microbial sources and optimization of production processes. Microbial

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derived secondary metabolites such as aromatic compounds have been reported in recent years by many authors from non-conventional yeasts. The main challenges for scaling up the process for production of aroma compounds by microbial biotechnological applications can be counted as possible leaks in the bioreactor level and difficulty of purification for the specific interest compounds from the mixture. For this purpose, besides the studies we reviewed within this minireview, further studies for the production optimization of such compounds in bioreactor level are needed. Membrane-based technology, PV, should also be considered in further studies, for purification and concentration of aromatics from the mixture. As a result, different low-cost carbon sources and recovery approaches should be investigated to increase productivity and recover specific industrially important metabolites in further studies. By this way, we believe that economic and ecological benefits can be achieved by bringing new perspectives to waste management applications.

Conflict of interest. None declared.

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