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Antagonistic yeast: Eco-friendly tool for management plant diseases

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Abstract

Fruit postharvest decay management is crucial because it directly affects financial loss and food security. Various pathogens are to blame for the significant fruit losses during storage and transportation. Abuse of chemical fungicides to prevent postharvest infections causes severe Pollution of the surroundings and harm to human health. Since Gutter and Littauer originally described the use of *Bacillus subtilis* against citrus fruit diseases in 1953 for human health, the biocontrol potential of microbes against postharvest degradation has drawn substantial attention. Yeast and yeast-like fungi are crucial among the various microbial antagonists since they can be genetically improved, have resilient biocontrol efficacy against diseases and are ecologically friendly. In addition, these antagonistic yeasts exhibit an advanced system for handling, culturing, storing, and fermenting, Competition for nutrition and space is just one of the many explanations put out to explain their aggressive behaviour, the parasitism of the pathogen, the dispersion of antifungal agents, the emergence of host resistance, the creation of biofilms, and, most recently, the usage of reactive oxygen species (ROS) during the defence response. Throughout the last couple of decades, there has been plenty of research on the biocontrol mechanisms of antagonistic yeast. Antagonistic yeasts were coupled with additional substances or treatments to enhance the efficacy of biocontrol. This review covers the following topics: improving efficacy, commercial applications, using antagonistic yeasts to control postharvest degradation, including hostile yeast species and sources, antagonistic procedures, and using antagonistic yeasts.

Keywords: Yeast, biological control, disease management

Introduction

The United Nations is worried about the increasing global hunger caused by population growth. The population is expected to reach 9.6 billion people by 2050. To feed this growing population, more food needs to be produced and stored. (Godana *et al.*, 2021) [34]. It has reported that there are different factors which causes 40% crop losses annually (FAO, 2021) [29] and one of such factors are pre and post-harvest diseases. There are different approaches like adjusting sowing date (Abishek *et al.*, 2016) [2], resistant varieties (Thapa *et al.*, 2018) [61] and use of conventional chemicals for management of pre-harvest disease of crops. However, challenge lies in the management of post-harvest diseases. Postharvest losses may result from various causes, although pathogen-caused postharvest illnesses are the main ones. Unfortunately, 40 to 50 per cent of postharvest losses cause one-third of all food waste every year. Additionally, pathogenic decay of fruits and vegetables during handling and storage may account for up to 20-25% of the total in developed countries (Sharma *et al.*, 2009) [56]. Because of inadequate transportation and a lack of cold storage facilities, which lowers the quantity and quality of the produce, these losses may be worse in developing nations. Many fungi produce mycotoxins during infection, which can endanger human health when they enter the food chain through processed and fresh fruit products. For instance, *Penicillium expansum*, which causes blue mould in many fruits, produces Patulin, a teratogenic, carcinogenic, and immunotoxic mycotoxin (Chen Y *et al.*, 2017) [13]. Application of conventional chemicals provides may provide effective results. However, an over-dependence on conventional chemical fungicides has led to several problems, including fungicide residues, environmental contamination, and increased disease resistance to fungicides. Therefore, it is critical to find safe and effective methods to manage postharvest fungal infections (Zhang *et al.*, 2020) [76].

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Due to their efficiency in stifling pre- and postharvest fungal development and lack of adverse effects on the environment or human health, killer yeasts are seen as a potential replacement for conventional fungicides in crop protection (Zhang X *et al*., 2020; Jankowska *et al*., 2016) [76, 39]. Most yeasts can endure various adverse environments, including high or low temperatures, low humidity, oxidative stress, a lack of nutrients, and an unfavourable pH (Fredluund *et al*., 2002) [33]. Because of its capacity to endure these stressful conditions, yeast is a powerful bio-control agent for postharvest infections. It has been established through numerous studies that antagonistic yeasts, including *Candida oleophilic* (Droby S *et al*., 2002) [26], *Pichia membranefaciens* (Tian SP *et al*., 2007) [66], *Rhodosporidium paludamentum*, and *Metschnikowia fructicola* (Lu *et al*., 2013) [48], may be crucial in the induction of the plant's immune response. The release of poisons and enzymes, Competition for food and space, and direct parasitism are other methods bio-control yeast uses to manage plant diseases (Freimoser *et al*., 2019) [32]. Yeasts have been utilized extensively in the food business for thousands of years and are directly taken by people as food additives. The same genus or species, such as *Metschnikowia pulcherrima*, *Saccharomyces cerevisiae, and Candida sake*, are used as bio-control agents, making it a safer practice for applying to crops and harvested fruits and vegetables (European food safety authority 2005) [28].

This article will discuss the recent research findings on yeast. Specifically, we will provide an extensive overview of how antagonistic yeasts can control postharvest decay. It will include information on these yeasts' characteristics, how they prevent decay, ways to improve their effectiveness, and examples of their use in commercial applications.

Characteristics and selection of biocontrol yeasts:

Fungi are diverse group of organism, which shows variation in morphology, pathogenicity and physiological characters even within the same species (Thapa *et al*. 2022; Das *et al*., 2024; Thapa *et al*. 2023, Singh *et al*., 2023) [61, 18, 62, 57]. Likewise yeast also shows diverse characters belonging to different phylum of fungi however, in general yeast are eukaryotic, unicellular fungi which generally multiply by budding (Fig 1). Antagonistic yeasts are yeast or yeast-like fungi that have the potential to inhibit or obstruct phytopathogen growth, development, reproduction, or activity (also known as biocontrol yeasts). Like bacteria, yeasts are organisms supporting biofilm development and adherence. These factors directly impact the ability to survive in the environment, Competition, and improved biocontrol efficacy. (Fanning and Mitchel., 2012) [30]. The extensive research on these yeasts has led to constant improvements in the screening criteria for antagonistic yeasts (Zajc *et al*., 2020) [40, 75]. An effective yeast antagonist to combat fungal infections in various types of fruit should have minimal nutritional needs, perform well in unfavourable weather conditions, and be effective in low concentrations. Additionally, a yeast antagonist with promising commercial potential must adapt to different physical and chemical treatments, including controlled environments, extreme temperatures, fungicides, pesticides, and phytohormones. Moreover, it should be efficient, convenient to store and use, and capable of growing on a budget-friendly growing medium. (Liu *et al*., 2013) [47].

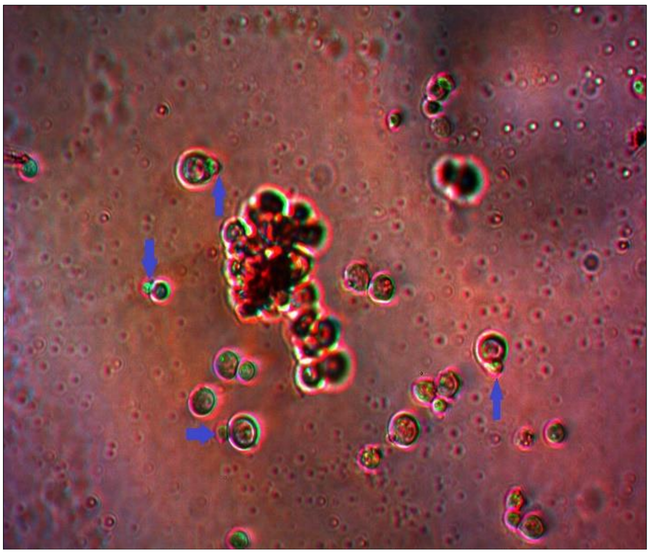

Fig 1: Budding of yeast cells observed under light microscope at 100x magnification

In addition, there are other important factors to consider, such as manufacturing requirements, formulation options, biosafety and registration concerns, production demands and conditions, and necessary equipment for application. These factors may be equally or even more significant than others.t. According to biosafety standards, an appropriate antagonistic yeast should not harm the host fruit's health, produce no hazardous by-products, and cannot spread disease to people (Liu *et al*., 2013) [47]. At first glance, the absence of the intrusive, filamentous growth typical of most yeasts might seem like a disadvantage. However, the yeast's shape provides many benefits, such as favourable formulation properties, diverse applications, and effective fermenter capture

The initial phase in producing a biocontrol agent involves isolating and screening. During this process, most antagonistic yeasts are obtained from fruit surfaces (Qing *et al*., 2000; Liu *et al*., 2011; Huang *et al*., 2011) [55, 45, 37]. However, these microorganisms are present in various natural environments such as leaves, roots, seawater, and even soil found in Antarctica. Numerous species of fungi, such as *Candida*, *Cryptococcus*, *Metschnikowia*, *Pichia*, *Rhodotorula*, and *A. pullulans*, have been thoroughly studied. Some of these species, including *Saccharomyces cerevisiae, Candida sake, Cryptococcus albidus, A. pullulans, Saccharomyces cerevisiae, Candida oleophila* and *Metschnikowia fructicola*, have been developed into commercial products. Studies have demonstrated that they are effective in fighting against common postharvest pathogens such as *Penicillium sp., Botrytis cinerea, Colletotrichum spp., Rhizopus stolonifer, Monilinia fructicola, Aspergillus niger* and *Alternaria alternata*. (Vero *et al*., 2012) [67].

Many of the most significant postharvest illnesses are caused by fungi belonging to the genera *Rhizopus*, *Penicillium*, *Botrytis*, *Alternaria*, *Monilinia*, *Aspergillus*, *Fusarium*, *Geotrichum*, *Gloeosporium*, and *Mucor*, which are postharvest pathogens (Droby *et al*., 1992) [23]. The high levels of decay caused by fungal pathogens are due to the fruit's high nutrient and water content, low pH, and decreased decay resistance after harvest. (Barkai-Golan, 2001) [8].

Table 1: List of different plant diseases managed with bio-control yeast.

Sl. No.	Biocontrol Yeast	Plant Disease Controlled	Reference
1	*Aureobasidium pullulans*	Apple Scab (*Venturia inaequalis*)	Janisiewicz *et al.*, 2000 [42]
2	*Cryptococcus albidus*	Gray Mold (*Botrytis cinerea*)	Bautista-Rosales *et al.* 2008 [12]
3	*Candida oleophila*	*Botrytis* Rot (*Botrytis cinerea*)	Wilson *et al.* 2004 [85]
4	*Cryptococcus albidus*	Postharvest diseases in pear	Liu *et al.*, 2017 [50]
5	*Debaryomyces hansenii*	Gray mold in tomato	Baffi *et al.*, 2018 [5]
6	*Candida oleophila*	Postharvest diseases in citrus fruits (e.g., blue mold, green mold)	Pizzolitto *et al.*, 2010 [64]
	Metschnikowia fructicola	Blue mold in apple	Qin *et al.*, 2007 [80]
7	*Pichia pastoris*	*Botrytis* cinerea in grape	Ma *et al.*, 2018 [56]
8	*Hanseniaspora opuntiae*	Blue Mold (*Penicillium expansum*)	Wu *et al.* 2020 [88]
9	*Candida diversa*	*Botrytis* cinerea in strawberry	Shi *et al.*, 2019 [69]
10	*Hanseniaspora uvarum*	Postharvest diseases in apple	Tang *et al.*, 2016 [74]
11	*Saccharomyces cerevisiae*	Blue Mold (*Penicillium expansum*)	Zhang *et al.*, 2015 [7]
13	*Kluyveromyces lactis*	Postharvest diseases in strawberry	Zhao *et al.*, 2020 [20]
14	*Candida tropicalis*	Anthracnose (*Colletotrichum gloeosporioides*)	Luo *et al.*, 2019 [55]
15	*Pichia membranifaciens*	Postharvest diseases in peach	Zhao *et al.*, 2019 [96]
16	*Candida sake*	*Botrytis* cinerea in strawberry	Wu *et al.*, 2017 [87]
17	*Metschnikowia pulcherrima*	Gray Mold (*Botrytis cinerea*)	Liu *et al.*, 2021 [53]

Mechanism of Action

There are different mechanisms followed by yeast to control different post-pathogenic diseases. All those mechanisms are briefly described below.

Competition for nutrient and space

Postharvest pathogens and antagonistic yeasts need nutrients and space to grow and colonize. Antagonistic yeasts compete with each other for these resources, which helps to reduce postharvest fungal infections. (Spadaro, 2016) [59]. When the damaged fruit's surface is exposed to hostile yeasts, they swiftly invade the wounds and consume the nutrients, hindering the growth of fungal spores. (Li *et al*., 2008) [44]. The rivalry for nutrients and space enters the picture, in addition to suitable measures for combating postharvest pathogens.

For microbes to grow, they need three primary nutrients: carbon, nitrogen, and iron ions. Nitrogen is essential in preventing fruit diseases after harvesting because fruits contain much sugar but not enough nitrogen and amino acids (Barnett, 2007) [10]. Iron also plays a critical role in infections' growth and pathogenicity. It comprises non-heme proteins, cytochromes, and other heme proteins. Additionally, it acts as an enzyme cofactor in fungus cells. (Dukare *et al*., 2018; Talibi *et al*., 2014; Gore *et al*., 2019) [27, 60, 35]. The yeast *Metschnikowia pulcherrima* can create iron chelators that can compete with pathogens for the iron they need, severely reducing the growth of the pathogens. In an environment with low iron levels, specific yeasts can produce siderophores that compete for iron and prevent the growth and spread of harmful pathogens. One example is *Rhodotorula glutinis*, which creates rhodotorulic acid, a type of siderophore that boosts its ability to control the growth of *P. expansum.* In an iron-deficient environment, siderophores produced by *A. pullulans* are crucial for inhibiting pathogen growth and yeast growth (Zajc *et al*., 2020) [40, 75].

Biofilm formation is an effective way for microbes to compete for living space. These communities can thrive and grow on surfaces and consist of single or multiple species working together. For pathogenic bacteria, biofilms are hypothesized to be a virulence factor and can exhibit various characteristics that set them apart from free-floating cells. It explains that a yeast biofilm begins when individual cells stick to a surface. It often involves changes in the cell wall, creating a matrix outside the cells, and the growth of hyphae or pseudohyphae. (Costa *et al*., 2017) [16].

Mycoparasitism

Antagonistic yeasts can consume nutrients from pathogenic cells experiencing nutritional deficits, leading to the death of these cells. This feeding process, called mycoparasitism, involves the yeasts adhering to fungi hyphae and using enzymes to break down their cell walls, ultimately killing or lysing them. Enzymes such as 1,3-glucanase (GLU), chitinase (CHT), and proteases are considered essential for biocontrol due to their role in destroying the fungal pathogen's cell wall (Spadaro *et al*., 2016) [59]. *Pichia guilliermondii* was the first yeast species to be described as carrying out mycoparasitism Wisniewski *et al*., 1991, who found a lectin-like solid interaction between the yeast and B. cinerea mycelium that led to the hyphal breakdown. Additional research has also confirmed the capacity of *Pichia membranefaciens* and *C. albidus* to attach to and degrade hyphae of *P. expansum*, *M. fructicola*, and *R. stolonifer* (Chan Z., 2005) [14].

Induction of host resistance

Numerous studies have determined how antagonistic yeasts increase host resistance to stop fruit from deteriorating after harvest. Hostile yeasts are said to operate as biological elicitors and are used to interact with fruit hosts. (Di Francesco A., 2016) [22]. When treated with yeasts that are hostile towards each other, there is an increase in the expression of defence-related genes and the activity of defence-related enzymes. According to reports, *Cryptococcus laurentii* effectively controls postharvest decay caused by *Alternaria alternata*, *Monilinia fructicola* and *Penicillium expansum*. The success of its biocontrol largely depends on the presence of defence-related enzymes such as GLU, CHT, Peroxidase, and phenylalanine ammonia-lyase (PAL). (Tian *et al*., 2006) [65]. Antagonistic yeasts have been found to increase the effectiveness of antioxidant enzymes in reducing the harm caused by reactive oxygen species (ROS) produced by host plants in response to pathogen infection. In particular, *P. membranaefaciens* has been observed to affect the activity of various antioxidant enzymes, including peroxidase, catalase, glutathione peroxidase, superoxide dismutase, and polyphenol oxidase, in peaches and sweet cherries after being inoculated with *P. expansum*. The expression of related genes is also increased, and four antagonistic yeasts, namely *P. membranaefaciens, C. laurentii, Candida guilliermondii,* and *R. glutinis* have been found to increase POD and CAT activities while reducing protein carbonylation levels caused by *M. fructicola* in peach fruits (Xu X., 2008) [72].

Production of volatile compounds and enzymes

Volatile organic compounds (VOCs) are characterized by low polarity, high vapour pressure, and low molecular weight. Researchers have hypothesized that specific antagonistic yeasts can produce a combination of VOCs to successfully reduce postharvest infections in airtight conditions (Di-Francesco *et al*., 2015) [21]. For instance, *Candida* intermedia 410 was found to suppress the development of B. cinerea in strawberries by releasing VOCs without direct contact. However, the biocontrol activity of C. intermedia 410 was eliminated by the absorption of VOCs by activated carbon (Huang R *et al*., 2011) [37]. Two strains of *A. pullulans* (L1 and L8) have been found to inhibit the growth and infection of postharvest pathogens, such as *B. cinerea*, *Colletotrichum acutatum*, and *Penicillium spp*. (Di Francesco *et al*., 2015) [21]. Furthermore, researchers have discovered that VOCs can prevent *Aspergillus carbonarius* and *Aspergillus ochraceus* from producing spores, mycelial growth, and ochratoxin (Farbo *et al*., 2018) [35].

Volatile organic compounds (VOCs) are being considered as potential biological fumigants. This is due to their volatility, which allows them to prevent postharvest degradation without harming the edible commodities directly. Researchers have found that common antagonistic yeasts produce certain VOCs, including ethyl alcohol, phenyl ethyl alcohol, 3-methyl-1-butanol, ethyl acetate, and isoamyl acetate (Contarino *et al*., 2019) [15]. However, a study by Alpha *et al*. (2015) [3] discovered that VOCs produced by *Muscodor albus* could damage bacterial cells' DNA and lead to cytotoxicity, indicating that some VOCs may be harmful. As a result, further research should meticulously assess the safety of VOCs.

Enzymes involved in the bio-control activity of yeast

All types of host-pathogen interactions involve the secretion of enzymes that break down cellular components, which has been extensively researched. Secreted enzymes like glucanases, proteases, or chitinases are frequently mentioned in antagonistic yeasts and linked to their biocontrol activity.

Chitinase: Chitinases are extensively researched as potential biopesticides, targets for resistance breeding, or as transgenes in genetically modified plants. According to Zajc J *et al*. (2020) [40, 75], having the capability to produce chitinolytic enzymes is an advantageous characteristic for biocontrol agents because it allows them to break down the cell walls of fungi. Biocontrol yeasts of genus *Aureobasidium, Metschnikowia, Candida, Pichia, Debaryomyces, Meyerozyma, Saccharomyces, Tilletiopsis*, and *Wickerhamomyces* have been found to have chitin-degrading activity, and *Saccharomycopsis* has chitinase expression that can be seen when prey cells are present (Bar-Shimon *et al*., 2004) [8]. Biocontrol activity against plant-pathogenic fungi has been demonstrated by chitinases from filamentous fungi, bacteria, and yeasts (Dahiya *et al*., 2006) [17]. The effect of chitinases on biocontrol activity is likely indirect, as the chitooligosaccharides (CHOS) resulting from chitin degradation are potent inducers of plant immune responses (Kombrink A *et al*., 2011; Langner T *et al*., 2015) [42, 43].

Lipases: When testing yeast and yeast-like strains for extracellular enzymatic activity, it is typical to detect the presence of lipolytic activity (Arroyo *et al*., 2008) [4]. This feature has been linked to cold tolerance in extremophilic yeasts and the consumption of previously stored lipids in oleaginous yeasts (Biakowska & Turkiewicz, 2014) [5]. Furthermore, lipase activity has been discovered to be crucial for pathogenic yeasts such as Malassezia, *Cryptococcus* or *Cryptococcus* species. (Mayer FL *et al*., 2013; Park M *et al*., 2013) [49, 53].

Proteases: Biocontrol yeast research has yet to give much attention to proteases, even though they play a significant role in the virulence of filamentous mycoparasites and entomopathogenic fungi. Although protease activity is observed only in the later stages of development (after 6-8 days of growth in nutrient-rich media) in *C. oleophila* cultures, it is hypothesized that proteases have a limited role in biocontrol activity. (Bar-Shimon *et al*., 2004) [8]. The alkaline serine protease Alp5 from *A. pullulans* had the opposite effect on *Penicillium expansum, M. fructicola, B. cinerea* and *Alternaria alternata in vitro* by reducing the length of their germ tubes and spore germination. It also showed a concentration-dependent inhibitory effect on these pathogens on apples (Banani H *et al*., 2015) [6]. It has been observed that protease activity exists in the *Metschnikowia, Pichia*, and *Wickerhamomyces* genera. However, this information needs to be thoroughly researched and confirmed. (Pretscher, 2018) [65]. The mRNA levels of saccharomycopsis protease and glucanase significantly rose due to predation, but no functional analysis was conducted. (Junker K *et al*. 2019) [41].

Constraints

Numerous yeasts with antifungal properties have been discovered over the past few decades, but only a small number have been turned into antifungal products for sale. This is mostly because an antagonistic yeast needs to fulfil extra conditions for commercial application in addition to having great biocontrol efficacy. Various commercial factors, including technology, still need to be fully developed for commercial use and require high costs for further development. Limited postharvest market and low market acceptance hinder the development and commercialization of antagonistic yeasts (Droby S *et al*., 2009) [24].

One of the key justifications for utilizing antagonistic yeasts rather than chemical fungicides is biosafety. Since humans regularly consume fresh fruits and vegetables, they are already exposed to the majority of the antagonistic yeasts that have been identified. As a result, there is frequently less concern regarding the biosafety of antagonistic yeasts. However, in a few uncommon cases, certain yeasts could be the cause of human infection (Opulente *et al*., 2019) [61]. As a result, a thorough evaluation of the biosafety of antagonistic yeasts, including their safety from skin irritation and ingestion, is required.

Table 1: List of different bio-control yeast with their mechanism of action.

Sl. No.	Biocontrol Yeast	Mechanisms of Action	Reference
1	*Pichia guilliermondii*	Production of volatile compounds, competition for nutrients	Nally *et al.*, 2007 [59]
2	*Candida tropicalis*	Competition for nutrients, production of antifungal compounds	Luo *et al.*, 2019 [55]
3	*Debaryomyces hansenii*	Competition for nutrients and space, production of antifungal compounds	Zhang *et al.*, 2019 [95]
	Aureobasidium pullulans	Mycoparasitism, enzyme secretion, volatiles	Freimoser *et al.*, 2019 [32]
4	*Metschnikowia pulcherrima*	Production of volatile organic compounds, competition for nutrients	Liu *et al.*, 2021 [53]
5	*Metschnikowia fructicola*	Antagonism, enzyme secretion, induction of resistance	Freimoser *et al.* 2019 [32]
6	*Pichia anomala*	Competition for nutrients and space, production of antifungal compounds	Comitini *et al.*, 2011 [17]
8	*Cryptococcus albidus*	Induction of plant defense mechanisms, competition for nutrients	Bautista-Rosales *et al.*, 2008 [12]
9	*Candida oleophila*	Competition, enzyme secretion, induction of resistance	Freimoser *et al.* 2019 [32]
10	*Saccharomyces cerevisiae*	Volatiles, enzyme secretion, induction of resistance	Freimoser *et al.*, 2019 [32]
11	*Cryptococcus albidus*	Competition, enzyme secretion, mycoparasitism	Freimoser *et al.*, 2019 [32]

Constraints, Improvements and commercial application of bio-control Yeast

Antagonistic yeasts still need to be developed in many aspects compared to chemical fungicides, which also hinders their commercialization and adoption in the market. Additionally, it is difficult to use antagonistic yeasts because they are more expensive and require more effort to use than chemical fungicides. According to the studies, antagonistic yeast's biocontrol efficacy cannot compare to that of chemical fungicides because of their short shelf life, unstable antifungal action, and stringent storage requirements (Zhang *et al*., 2020) [76].

Improvement of the biocontrol efficacy

Plants use salicylic acid (SA) to activate their defence system against pathogens. Qin *et al*. (2003) [54] found that treating *Rhodotorula glutinis* with SA increased its ability to control *P. expansum* and *A. alternata* in sweet cherry fruits. The growth of the yeast and the two pathogens was not affected by SA, but the activity of defence-related enzymes increased. This means that SA's enhanced biocontrol efficiency was responsible for the host's resistance. Farahani *et al*. (2012) [31] reported that the salicylic acid pathway can also cause host resistance in various yeast species.

Many organic plant extracts, including methyl thujate, hinokitiol, and cinnamic acid, can prevent the growth and development of pathogenic fungi (Bananin H *et al*., 2015) [6]. According to the reports, cinnamic acid increased the biocontrol effectiveness of *Cryptococcus laurentii*, which suggests the potential for using natural plant extracts in combination with antagonistic yeasts to control postharvest infections (Zhang *et al*., 2020) [76]. The effectiveness of antagonistic yeasts for biocontrol can also be increased by using specific chemical agents or other antifungal techniques. $CaCl_2$, for instance, has been noted to increase the effectiveness of hostile yeasts (Tian S *et al*., 2002) [64]. Additionally, the antifungal properties of chitosan, inorganic salts (such as ammonium molybdate, sodium bicarbonate, and trisodium phosphate) and sugar protectants (such as maltose and lactose) enhance the biocontrol efficacy of antagonistic yeasts (Janisiewicz *et al*., 2008; Zheng *et al*., 2019) [42, 77]. Moreover, it has been found that combining a low-dose chemical fungicide with an antagonistic yeast can result in biocontrol efficacy that is comparable to using the chemical fungicide alone at a commercial dosage, which is seen as a successful way to reduce the use of fungicides (Qing F *et al*., 2000) [55].

Application of Antagonistic Yeast

Developing and commercializing an antagonistic yeast is a complex and expensive process involving comprehensive toxicity testing and biocontrol effectiveness in commercial settings. Fortunately, there have been successful developments and commercialization of a few antagonistic yeasts in the past few decades. For a biocontrol product to be effective, it must consistently provide an acceptable level of control for target diseases in the intended commodity, despite variations in processing and storage conditions that may differ between commodities and packing houses. (Droby S *et al*., 2009) [24]. For a product to be approved, its application package must contain information on its effectiveness and safety for human health. In order to evaluate the effectiveness of a biocontrol agent, it is necessary to conduct pilot studies, semi-commercial trials, and large-scale commercial testing using significant amounts of formulated products. (Abadias *et al*., 2003) [1]. In the USA, the registration of biocontrol products for postharvest use is under the responsibility of the Environmental Protection Agency (EPA). Typically, the registration process takes approximately two years to complete. However, in Europe, the registration process takes over seven years. (Nunes, 2011) [50].

The first-generation commercial antagonistic yeasts were Aspire, based on *C. oleophila*, and Yield Plus, based on *C. albidus*. Although they were available on the market for some time, they have since been withdrawn due to challenges in market development, low profitability, and inconsistent and low efficacy under commercial conditions. (Spadaro *et al*., 2016) [59]. Nexy, also based on C. oleophila, was created to control decay on pome, citrus, and banana. It was approved for registration throughout the European Union in 2013. Another product, Shemer, based on M. fructicola, was initially registered in Israel and has been effectively used to manage pre- and postharvest diseases on various fruits and vegetables. (Blachinsky *et al*., 2007) [13]. Bayer Crop Science from Germany acquired it, and later it was sublicensed to Koppert Biological Systems in the Netherlands to increase sales. (Droby, Wisniewski, Teixidó, Spadaro, & Jijakli, 2016) [59]. Moreover, Bio-ferm from Austria has created two products using *A. pullulans* strains: Blossom Protect (also known as Boni-Protect) and Botector. Blossom Protect prevents postharvest decay caused by various fungal pathogens in pome fruit by competing for nutrients and space. Botector is primarily used to combat grey mould in grape, strawberry, and tomato plants. (Zhang *et al*., 2020) [76].

Conclusion

As there is a growing concern regarding food security, decreasing agricultural land due to increasing urbanization and growing population all over the world, which require producing more agricultural outputs from the same unit of land. However, different pests and diseases are further reducing the quality and quantity of agricultural produce. Conventional chemicals which are used for the management of these biotic factors have several negative impacts on the environment and human and animal health. Therefore, a substitute for chemical pesticides for protecting the crop which is eco-friendly, cheaper and effective. Yeast which is ubiquitous in nature, many of which are shown to have biocontrol activity against different pathogens, can be an effective alternative to chemical pesticides. Due to the ill effects of chemical pesticides, governmental bodies all over the world are encouraging eco-friendly management of plant diseases, which also gives scope for the development and commercialization of bio-control yeast. However, more studies on the field level involving farmers should be conducted for better adoption of yeast products.

Author Contributions

Ananya Reetu Gogoi, Vinod Kumar M, Yellangari Srikanth have written the overall content of the paper, Sukram Thapa guided and gave ideas to write the review paper.

Conflicts of Interest

Authors declares no conflict of interest

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