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Biological control of postharvest diseases: The Second half of sustainability

By Prof. Samir Droby

ABSTRACT

Postharvest biological control agents as a viable alternative to the use of synthetic chemicals have been the focus of considerable research for the last 30 years by many scientists and several commercial companies worldwide. Several antagonists of postharvest pathogens have been identified and tested in laboratory, semi-commercial, and commercial settings and were developed into commercial products. One of the success stories in this field is the development of *Metschnikowia fructicola* as a commercial product under the commercial trade name "Shemer. This product was developed by Droby's team at ARO in conjunction with a commercial company, and proved to be effective against a wide range of pre and postharvest diseases of fruits and vegetables. The yeast strain possesses unique features of being heat- and osmotolerant, and proved to successfully colonize plant and fruit surfaces. The progress made in recent years in metagenomic technologies can be exploited to characterize the composition of microbial communities on fruits and vegetables. Information on the dynamics and diversity of microbiota may be useful to developing a new paradigm in postharvest biocontrol that is based on constructing synthetic microbial communities that provide superior control of pathogens.

INTRODUCTION

Sustainable agricultural production systems, organic agriculture, regional food production, home gardening, public aversion to genetically-modified crops, and environmental stewardship, are all topics that over the last 20 – 30 years have fueled a greater interest in finding alternative approaches to plant disease management that do not rely on the use of synthetic chemical pesticides. Based on these public concerns and legitimate health and safety concerns, government regulatory agencies have become more restrictive about the materials and products that can be used in agricultural production. This has been especially true for the use of postharvest fungicides and these restrictions have had a great impact on the export and shipment of harvested produce to foreign markets.

Postharvest fungal pathogens are the main cause of losses of fresh fruits and vegetables at the postharvest, distribution, and consumption levels. While reports on the level of these losses are conflicting, a report by the Food and Agriculture Organization (FAO, 2011) indicated that global average loss in Europe, North America and Oceania is about 29%, compared to an average of about 38% in industrialized Asia, South East Asia, Africa and Latin America.

Chemical control of postharvest diseases, applied in orchard or after harvesting, chemical control is still the most widely used method to reduce fresh produce losses. Biological control based on naturally occurring microorganisms, has been suggested as viable alternative to chemicals and was the most studied among other alternatives (Droby 2016). The primary justification for conducting postharvest biocontrol research was to reduce or replace the use of synthetic chemicals (Wilson and Wisniewski, 1989). The assumption is that prospects for the success of postharvest biocontrol products were greater than that of biocontrol agents developed to manage soil and foliar diseases. Factors supporting this premise were the ability to better regulate the physical environment (temperature, humidity, etc.) during postharvest processing and storage, the ability to target high numbers of the biocontrol agent directly to the desired location of activity, and the overall value of the commodity.

THE DISCOVERY AND DEVELOPMENT OF POSTHARVEST BIOLOGICAL CONTROL PRODUCTS

The use of fungal and bacterial species to either modify or preserve food has been an integral part of human civilization. To extend this concept into a scientific approach for managing postharvest decay is perhaps very logical rather than farfetched. Regarding postharvest biocontrol, there has been an underlying hypothesis that there are species of microbes present on fruit and vegetable surfaces, as well as on harvested grain, that are antagonistic to fungi that cause decay. By identifying these species, and reapplying them to the surface of harvested commodities in high numbers, one could extend the shelf life of the commodity without the use of a synthetic chemical.

In the past thirty years, there have been extensive research activities to explore and develop strategies based on microbial antagonists to biologically control postharvest pathogens (Spadaro and Gullino, 2004; Droby et al., 2009; Sharma et al., 2009). Impressive progress was made in development, registration and commercialization of biocontrol products to manage key postharvest pathogens, such as *Penicillium expansum*, *Penicillium digitatum*, *Penicillium italicum*, *Fusarium sambucinum*, *Rhizopus stolonifer* and *Botrytis cinerea*. Different products reached advanced stages of development and commercialization. Biosave™ (*Pseudomonas syringae* Van Hall) was originally registered in the USA for postharvest application on pome and citrus fruits, and it was later extended to cherries, potatoes and sweet potatoes (Janisiewcz and Peterson, 2004). Among yeast-based products, Aspire™ (based on *Candida oleophila*) (Liu et al., 2013) and Yieldplus™ (based on *Cryptococcus albidus*) (Janisiewicz and Korsten, 2002) were commercialized for some years but were withdrawn from the market due to various reasons; including low and inconsistent efficacy under commercial conditions, low profitability, difficulties in market penetration and perception of the customers/industry, small size companies with low available resources to maintain development and commercialization. Other products have been more successful, including Shemer™, based on the yeast *Metschnikowia fructicola* (Droby et al., 2009, see below), initially registered in Israel for both pre- and postharvest application on various fruits and vegetables, including apricots, citrus fruit, grapes, peaches, peppers, strawberries, and sweet potatoes. Shemer™ was later acquired by Bayer CropScience (Germany) and recently sublicensed to Koppert (Netherlands). A commercial formulation of *Candida sake* has been developed for use on pome fruit and grapevine and registered in Spain under the name Candifruit™ (Calvo-Garrido et al., 2014), however, it is not yet used due to distribution constrains. In South Africa, Avogreen™ has been introduced for the control of Cercospora spot, a postharvest disease of avocado, but its use has been limited due to inconsistent results (Demoz and Korsten, 2006). Furthermore, Nexy, based on another strain of C. oleophila was developed in Belgium and is now registered throughout the European Union (Lahlali et al., 2011). Finally, BoniProtect™, developed in Germany and based on two antagonistic strains of *Aureobasidium pullulans*, is used as preharvest application to control wound pathogens developing on apples during storage.

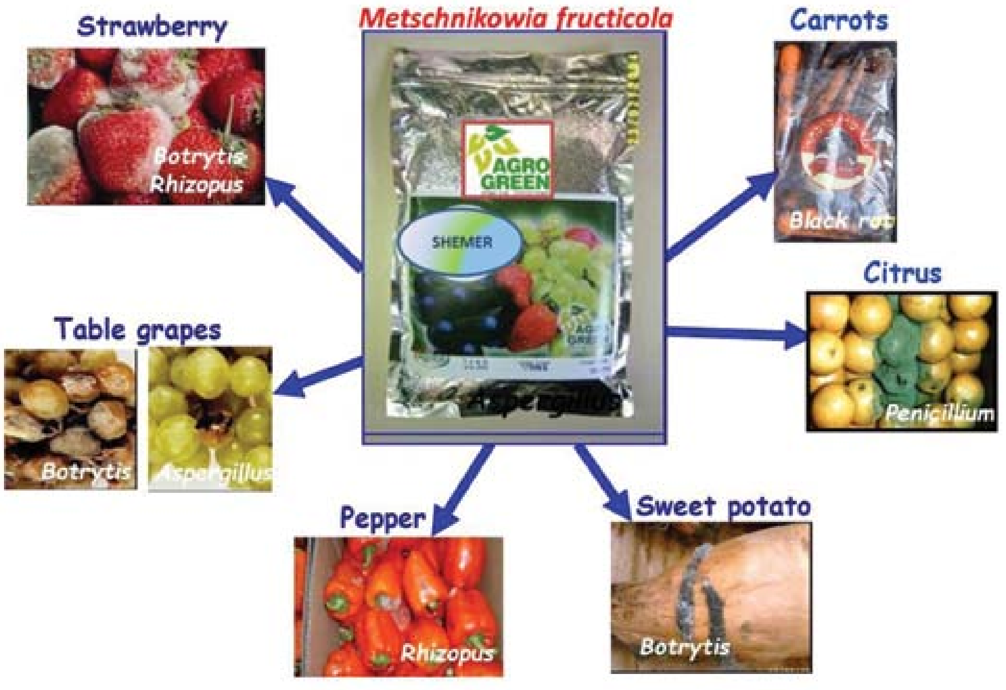

Figure 1. The commercial yeast product "Shemer" is registered in Israel for use against various postharvest diseases of fruits and vegetables.

METSCHNIKOWIA FRUCTICOLA AS POSTHARVEST BIOCONTROL AGENT

The yeast Metschnikowia fructicola (type strain NRRL Y-27328, CBS 8853) was first isolated from grapes in the Volcani Center by Droby et al in 2000 and was identified as new species by Kurtzman and Droby in 2001 (Kurtzman and Droby, 2001). This yeast was further developed as commercial product and reached the market under the trade name "Shemer" (Droby et al., 2009). It was initially registered in Israel for both pre- and postharvest application on a variety of fruits and vegetables, including apricots, citrus fruit, grapes, peaches, peppers, strawberries, and sweet potatoes and was then acquired by Bayer CropScience (Germany) and sublicensed to Koppert (Netherlands) (Droby et al., 2016).

M. fructicola possess unique features of being a heat- and osmotolerant strain and proved to successfully colonize plant and fruit surfaces. In this regard, Blachinsky et al. (2007), ↘

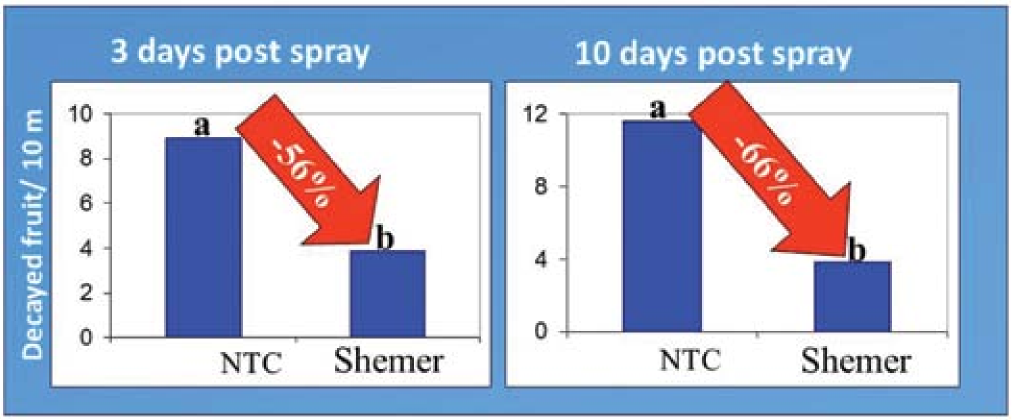

Figure 2. Efficacy of preharvest application of "Shemer" against grey mold development on strawberries

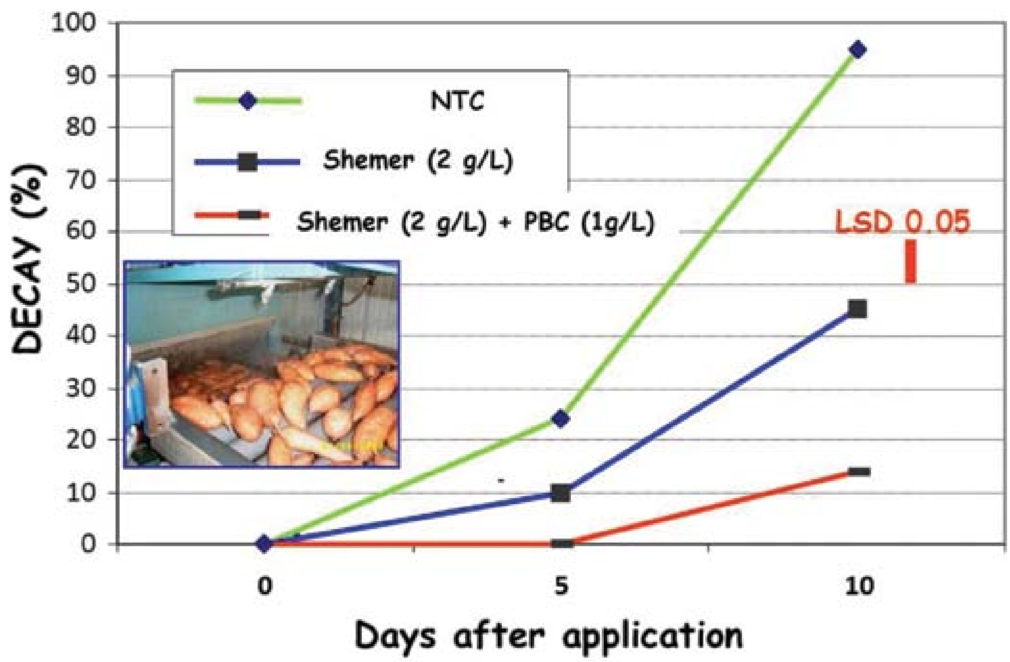

Figure 3. Prevention of Rhizopus rot of sweet potatoes during storage by the Shemer and potassium bicarbonate.

→ has taken the approach of preventing postharvest decay by administering several preharvest applications of a yeast to strawberry flowers and fruit in the field throughout the growing season (Fig. 1). This approach addresses the problems of pre-established and latent infections. Shemer has been shown to be effective against rots caused by Botrytis, Penicillium, Rhizopus and Aspergillus on strawberries (Karabulut et al., 2004), grapes, sweet potatoes, carrots and citrus (Blachinsky et al., 2007). The product is registered in Israel for use as pre and postharvest application (Fig. 2). Additionally, efficacy of the product for postharvest applications was markedly enhanced by addition of a relatively low concentration (0.1%) of potassium bicarbonate (Fig. 3) (Blachinsky et al., 2007). M. fructicola was recently (September 2018) granted registration for use in the US by the Environmental Protection Agency (EPA) and also it has reached its final stages of registration in Europe.

POSTHARVEST BIOCONTROL IN THE MICROBIOME ERA

While postharvest biocontrol research has been conducted for the past 30 years (Wisniewski et al. 2016, Droby et al. 2016), with several biological control products being produced, the era of microbiome-based research has opened a whole new frontier that will greatly expand our knowledge of postharvest pathology and biology and offer new application opportunities (Droby and Wisniewski 2018). The growing evidence

that plants and their microbiomes have evolved together, or at least form a composite meta-organism, offers a new perspective on how we may utilize the microbiome to develop innovative strategies for preserving food. The composition and fate of the microbiome on fruit and vegetables over time and in response to postharvest management practices has begun to be explored but the role and function of the microbiome of harvested produce is still somewhat unknown. This is especially true for fruits (Droby et al. 2018). While the rhizosphere is generally considered to be nutrient rich and host a high level of microbial diversity, the phyllosphere, again in general, is seen as lacking in nutrients and hosting a much lower level of microbial diversity. Which model pertains to developing fruit, however, is an open question, since its nutrient status changes with development, becoming rich in sugars and amino acids, other metabolites, and volatiles, as it matures and ripen. How this affects the epiphytic and endophytic microbiome, and how the microbiome impacts the host, remains to be determined. The human microbiome is clearly impacted by what we eat and how that food has been grown, handled, and processed (Berg et al. 2015), yet the postharvest microbiome is only beginning to be the subject of investigation. The function and fate of the microbiome on produce once it is harvested represents an area of unknown knowledge. The practices and environments that affect produce once it is harvested are completely different from the parameters that affect the microbiome when produce is being grown.

CONCLUSIONS

Pesticide residues in fresh fruits and vegetables have been and will continue to be one of the main concerns of regulatory agencies and consumers. Therefore, reducing or eliminating the pre- and postharvest use of synthetic chemical fungicides by developing alternative management strategies remains a high research priority. All indications show that the biopesticide industry will continue to grow and eventually become a mainstream approach to diseases control. We are definitely moving into an "age of biology" and away from the "age of chemicals."

Numerous microbial antagonists (yeasts and bacteria) of postharvest pathogens have been identified and tested in both laboratory, semi-commercial, and commercial studies. Several of these antagonists reached advanced levels of development and commercialization. Nonetheless, numerous challenges and opportunities still exist as this field of research matures. A probable scenario is that the use of postharvest biocontrol will continue to increase slowly but will complement or be combined with low risk chemical fungicides, natural antimicrobial substances and other physical means. ❑

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