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Physical treatments to control postharvest diseases of fresh fruits and vegetables

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ABSTRACT

Physical treatments have gained great interest in recent years to control many postharvest diseases in fruits and vegetables because the total absence of residues in the treated product and minimal environmental impact. The present review shows the extensive research work conducted during many years and increased in the last 10 years, developing physical means for consistent disease control. The review include the use of cold storage as the main physical method for delaying or reducing biotic and abiotic diseases. Physical treatments, like heat, including hot water and hot air treatments, radio frequency and microwave, hypobaric and hyperbaric pressure and far ultraviolet radiation (UV-C light), are treated as promising control means, and controlled and modified atmospheres as complementary physical tools essential to reduce or delay the development of postharvest pathogens. A particular emphasis is given to the mode of action, which involve direct effect to the pathogen (lethal or sub-lethal) of spore germination and mycelial growth of fungi and the resistance induction in the host which is not well known but nowadays, with the new tools available in molecular biology will be easy to highlight other physiological and biochemical pathways on which the phenomenon are based. Besides benefits of treatment in different commodities, also limitations of use, including low persistence, risk of adverse effects and technological problems for commercial application are discussed.

1. Introduction

Fruits and vegetables are susceptible to many postharvest diseases caused by a large number of fungal pathogens. The current strategy to control these diseases is the use of synthetic fungicides, because are relatively inexpensive, easy to apply, and have both curative and preventive action against established and new infections, respectively. However, the use of fungicides is becoming more limited because the concerns of the consumers and the administration about human health and the release of fungicides in the environment. In addition, organic products becoming more popular, retailers ask for products with a very limited number of residues and the cost of developing and registering new fungicides is very high especially for a small market as postharvest. For all these reasons, the development of nonchemical techniques to control postharvest diseases is increasing in many research programs worldwide.

Physical treatments has gained great interest in recent years to control many postharvest diseases because the total absence of residues in the treated product and minimal environmental impact. However, they could have also some limitations, including low persistence, the risk of adverse effects on quality of produce or technological problems for commercial application.

The most well-known physical treatment is the heat. Traditionally it could be applied in the form of hot water dip, hot water rinsing and brushing, vapor, hot air and curing (Fallik, 2004; Ben-Yehoshua and Porat, 2005). More recently, the interest in the use of the radio frequency or microwave energy to heat fruits has increased (Sisquella et al., 2014a). Other promising technologies are hypobaric and hyperbaric pressure (Thompson, 2015) and especially far ultraviolet radiation (UV-C light), due to the direct activity against the pathogens and the resistance induction in the host (Romanazzi et al., 2016). Cold storage, controlled and modified atmospheres are complementary physical tools to reduce or delay the development postharvest pathogens, but they are used mainly to maintain fruit quality after harvest.

This review emphasizes the benefits and limitations of the main physical treatments and describes the most interesting and recent

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accomplishments in the development of these treatments to control major postharvest diseases of fruits and vegetables.

2. Cold storage

Cold storage can be considered the main physical method for delaying or reducing biotic and abiotic diseases on fresh fruits and vegetables (Eckert and Sommer, 1967). The deterioration of fruits and vegetables dependents on the temperature, the rate of respiration, and the stress caused by harvesting and postharvest handling. Lowering the temperature of the product as quickly as possible after harvest will maintain a high level of quality remaining attractive for customers. Obviously, storage at low temperature is not an antifungal treatment, but its effects have consequences able to reduce produce weakening, influencing both the host and the pathogen simultaneously. Indeed, low temperature exerts its activity (a) indirectly, by reducing the metabolism of the host, and thus delaying its senescence and contributing to the maintenance of fruit resistance to fungal infection and (b) directly, by inhibiting or delaying the growth and enzymatic activity of the pathogens. Moreover, low temperature prevents moisture loss from the host tissues and consequent shrivelling, which allows tissues to maintain a high level of resistance to pathogens as compared to fruit kept in low moisture environment (Ippolito et al., 1994). Regarding the effect on the pathogen it is well known that the minimum temperature for growth of various fungal species is around 0 °C, while other species are capable of growth even at temperatures as low as −4 °C as *Cladosporium herbarum* (−4 °C), *Alternaria alternata* (−3 °C), *Penicillium expansum* (−3 °C) and *Botrytis cinerea* (−2 °C). However, important postharvest fungi stop to grow at temperatures well above 0 °C, as *Aspergillus niger* (11 °C), *Colletotrichum gloeosporioides* and *Colletotrichum musae* (9 °C) (Sommer, 1985), for which a cold storage at 0 ± 1 °C, would arrest their growth, preventing disease development. For those growing at temperatures below 0 °C cold storage would only delay the appearance of the disease or, in other words, would prolong their incubation period (Barkai-Golan, 2001). Considering that the closer is the temperature to the minimum for growth of the pathogen and the longer is the incubation time, a general desire is to lower the storage temperature as much as possible. However, the susceptibility of some fruits or vegetables to chilling injury limit this possibility, being the sensitivity related to the species, cultivars, season, location of the crop, duration of exposure, and state of maturity (Barkai-Golan, 2001).

3. Heat treatments

3.1. Hot water treatments

Hot water treatment (HWT) is a non-conventional approach to control postharvest decay based on the use of water at temperature above 40 °C. The technique is completely safe for human and environment (residue-free and environment-friendly) and of feasible use without registration rules. For these reasons, HWT appears to be especially recommended for organic crops or to comply with the stringent regulations of markets that require minimal or no chemical postharvest treatment on commodities. The system provides more efficient transfer of heat than air, so needs shorter times of treatment than hot air. In addition, it is cheap when compared to other heat treatments, such as vapor treatment or forced air (Jacobi et al., 2001; Sivakumar and Fallik, 2013). HWT may be suitable also for the control of pests of quarantine importance, such as fruit flies and codling moth (Lay-Yee et al., 1997; Feng et al., 2004). Quarantine treatments by HWT are, for example, used in mango against the Mediterranean and Mexican fruit flies (*Ceratitis capitata* and *Anastrepha ludens*) in the USA and Central America. However, in the case of quarantine treatments, the commodity should be heated for longer time (*i.e.* 43–49 °C for 1–2 h in mango, 50 °C for 10 min in cherry) than for decay control (Jacobi et al., 2001; Fallik, 2004; Feng et al., 2004). In addition, the use of HWT for disinfestation is particularly interesting for tropical fruits that develop chilling injury at the temperatures used for the phytosanitary cold treatment or for the conditioning of subtropical fruits before cold disinfestation (Hofman et al., 2002).

HWT is usually applied by a complete immersion of the commodity (hot water dip, HWD) or in the form of hot water rinse brushing (HWRB). This latter technique provides a first rinsing of commodity by tap water sprayed above commodity rolling over brushes on sorting line, followed by pressurized hot water rinse and final forced-air drying (Fallik, 2004; Sivakumar and Fallik, 2013). HWRB was reported to provide a more effective cleaning than HWD or dry-brushing, and it was considered particularly important to remove the dirt and dust that accumulate in the calix or blossom-end of pepper (Fallik et al., 1999). The HWRB is employed in commercial lines of a variety of commodities (*i.e.* pepper, melon, mango and grapefruit) in Israel, with a capacity of 3–4 t/h, in addition it is commercially adopted in Egypt, Indonesia and Morocco (Sivakumar and Fallik, 2013). The use of HWD for mango is widespread in USA, Central America and in the Philippines (Jacobi et al., 2001; Alvindia and Acda, 2015). In Europe the use of HWT currently regards organic apples (Bompeix and Coureau, 2007; Maxin et al., 2012). However, the technique may be commercially suitable for postharvest treatment of other commodities, such as peaches and nectarines (Spadoni et al., 2013).

Effective treatments in decay control usually included temperatures between 45 and 60 °C, for duration ranging from few seconds to 20 min (Table 1). Many factors have been reported to influence the effect of HWT: the commodity (species, cultivars, size, shape, thermal conductivity of tissue, growing conditions, maturity at harvest), the target pathogen (species, location on or within the host) and the conditions of treatment (temperature, duration, method used for heat application, quantity of commodity treated, and time of application). Achieving proper temperature in heated produce is essential in effective disease control, so the system of treatment should assure the maintaining of optimal temperature both on produce surface and through the mass of the produce. A sufficient initial heat input is needed to compensate for the heat lost (as the commodity absorbs heat), particularly for high-volume application in commercial conditions, and the flow of water over the produce must be sufficient to achieve a high rate of heat transfer, especially at the center of the mass of the produce in palletized boxes (Vigneault et al., 2012). The larger the commodity, the longer the required time of exposure to heat. For products that have heterogeneous shape (*i.e.* broccoli) or hidden surface (*i.e.* celery), HWD was found to provide more uniformity of treatment than HWRB (Vigneault et al., 2012). Consistent decay control (60–100% efficacy) was reported in peaches and nectarines against brown rot by treatment at 60 °C for 20–60 s (Casals et al., 2010c; Karabulut et al., 2010; Spadoni et al., 2013, 2014) and in apples against bull's eye rot and blue mold by treatment at 45 °C for 10 min (Neri et al., 2009; Spadoni et al., 2015a), without detrimental effects on fruit appearance and quality traits. An increase of the efficacy of treatment was achieved in some commodities by combining HWT with other non-conventional control means, such as organic salts, ethanol, biocontrol agents, and ultraviolet light (Margosan et al., 1997; Porat et al., 2000; Palou et al., 2001; Zhang et al., 2008). Moreover, it is well documented that, compared to cold treatment, several postharvest fungicides applied as heated solutions increase their deposition on/within fruit, providing a higher active ingredient residue level (Schirra