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Review

# Recent advances and current status of the use of heat treatments in postharvest disease management systems: Is it time to turn up the heat?

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ABSTRACT

*Background:* Postharvest diseases of harvested commodities cause significant reductions in food availability and financial profits. Additionally, regulatory agencies are increasingly restricting or banning the postharvest use of synthetic chemical fungicides. This has increased the need to develop more eco-friendly approaches to postharvest disease management, such as heat treatments and biological control using antagonistic yeasts.
*Scope and approach:* The current review focuses on the physiological and molecular effects of heat treatments on the various components of postharvest disease management systems, namely, the commodity, fungal pathogen, and yeast biocontrol agent. The ability of postharvest heat treatments to induce host defense mechanisms and directly inhibit fungal pathogens is reviewed. The preconditioning of biocontrol yeasts by subjecting them to mild heat stress in order to induce cross-protection to abiotic stresses and to enhance biocontrol efficacy, is also discussed. The combined effects of postharvest heat treatments on disease control demonstrate its value as a key component of integrated approaches to postharvest disease management.
*Key findings and conclusions:* A review of the literature indicates that heat treatments can induce host resistance, inhibit pathogen development, and enhance the efficacy of biocontrol agents by making them more resilient to an array of environmental stresses. Therefore, heat treatments should be considered as a key component of an integrated approach to postharvest disease management. Further research will be needed, however, to understand how to effectively adapt this technology for use on different commodities, pathogens, and biocontrol agents.



## 1. Introduction

Postharvest diseases of harvested fruit commodities by fungal pathogens result in significant economic losses (Prusky, Alkan, Mengiste, & Fluhr, 2013; Wilson & Wisniewski, 1989). In addition to economic considerations, some postharvest pathogens also produce fungal metabolites (e.g., mycotoxins) that pose a health risk to humans and can contaminate processed fruit products such as juice, baby food, and wine (Covarelli, Beccari, Marini, & Tosi, 2012; Sarubbi, Formisano, Auriemma, Arrichiello, & Palomba, 2016). The current management of postharvest diseases of fruits primarily relies on the use of synthetic chemical fungicides. Strict government regulatory policies and strong consumer demand to reduce potentially harmful chemicals, however, have driven research efforts to explore and develop alternative means of postharvest disease management, including heat treatments and the use of biological control agents (Janisiewicz & Conway, 2010; Liu, Sui, Wisniewski, Droby, & Liu, 2013).

Heat treatments can be applied to fruit in several different ways: hot water dips, rinses or brushing, vapor heat and hot air (Fallik, 2004). These various approaches to heat treatment have all been demonstrated to be effective in managing postharvest diseases in a variety of fruits without impacting fruit quality (Table 1). The use of heat treatments in managing postharvest diseases can be both protective and curative (Chen, Cheng, Wisniewski, Liu, & Liu, 2015;

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**Table 1**
Representative studies of the use of heat treatments of fruits to manage postharvest diseases. HWD = Hot water dip; HWB = Hot water brushing; HA = Hot air treatment.

| Fruit | Treatment | Optimal temp. (time) | Target pathogen | Reference |
|---|---|---|---|---|
| Apple (cv. Ingrid Marie) | Hot water rinsing Hot water dipping (HWD) | 50–54 °C (3 min)<br>55 °C (20 or 25 s) | *Neofabraea alba*<br>*Neofabraea perennans*<br>*Monilinia fructigena*<br>*Colletotrichum acutatum*<br>*Phacidiopycnis washingtonensis*<br>*Cladosporium* spp. | Maxin, Weber, Pedersen, & Williams, 2012a |
| Apple (cv. Elstar) | HWD | 50 °C (3 min) | *Neonectria galligena*<br>*Botrytis cinerea*<br>*Penicillium expansum* | Maxin et al., 2012b |
| Apple (cv. UltimaGala) | HWD | 45 °C (10 min) | *P. expansum* | Spadoni et al., 2015 |
| Peach (cv. Roig) | HWD | 48 °C (12 min) | *Monilinia laxa* | Jemric et al., 2011 |
| Peach (cv. Swelling) | Hot water brushing (HWB) | 55 or 60 °C (20 s) | *Monilinia. fructicola* | Karabulut et al., 2002 |
| Peach (cv. Royal Summer) | HWD | 60 °C (20 s) | *M. laxa* | Spadoni et al., 2014 |
| Peach (cv. June Prince) | HWD | 40 °C (10 min) | *M. fructicola* | Liu et al., 2012 |
| Nectarine (cv. Venus) | HWD | 48 °C (6 min) | *M. laxa* | Jemric et al., 2011 |
| Nectarine (cv. Flavortop) | HWB | 55 or 60 °C (20 s) | *M. fructicola* | Karabulut et al., 2002 |
| Citrus (cv. Jincheng 447#) | HWD | 53 °C (2 min) | *Penicillium italicum*<br>*Penicillium digitatum* | Zhou et al., 2014 |
| Mandarin (cv. Wuzishatangju) | HWD | 45 °C (2 min) | *P. italicum*<br>*P. digitatum*<br>*Geotrichum citri-aurantii* | Hong et al., 2014 |
| Satsuma mandarin (cv. Kamei) | HWD | 52 °C (2 min) | *P. italicum* | Yun et al., 2013 |
| Grapefruit (cv. Star Ruby) | HWB | 62 °C (20 s) | *P. digitatum* | Pavoncello et al., 2001 |
| Lemon (cv. Eureka) | HWD | 52–53 °C (2 min) | *P. digitatum* | Nafussi et al., 2001 |
| Pear (cv. d'Anjou) | High-pressure hot water washing | 30 °C (414 kPa) | *B.cinerea*<br>*P .expansum*<br>*Mucor piriformis* | Spotts et al., 2006 |
| Banana (cv. Buñgulan) | HWD | 50 °C (20 min) | *Colletotrichum musae*<br>*Fusarium verticillioides*<br>*Lasiodiplodia theobromae*<br>*Thielaviopsis paradoxa* | Alvindia, 2012 |
| Table grape (cv. Sultanina) | Vapor heat treatment | 52.5 °C (21 or 24 min)<br>55 °C (18 or 21 min) | *B. cinerea* | Lydakis & Aked, 2003 |
| Melon (cv. Cuilv) | HWD | 45 °C (25 min) | *Fusarium oxysporum* | Sui et al., 2014 |
| Muskmelon (cv. Yujinxiang) | HWD | 53 °C (3 min) | *Trichothecium roseum* | Yuan et al., 2013 |
| Mango (cv. 'Carabao') | HWD | 53 °C (20 min) | *Colletotrichum gloeosporioides*<br>*L. theobromae* | Alvindia & Acda, 2015 |
| Mango (cv. 'Shelly') | HWB | 55 °C (15–20 s) | *Alternaria alternata*<br>*Phomopsis mangiferae* | Luria et al., 2014 |
| Strawberry (cv. Aromas) | HWD | 63 °C (12 s) | *B. cinerea* | Wszelaki & Mitcham, 2003 |
| Kiwifruit (cv. Yate) | HWD | 45 °C (10 min) | *B. cinerea*<br>*P. expansum* | Chen et al., 2015 |
| Sweet cherry (cv. Hongdeng) | Hot air treatment (HA) | 44 °C (114 min) | *P. expansum* | Wang et al., 2015 |
| Loquat (cv. Jiefangzhong) | HA | 38 °C (36 h) | *C. acutatum* | Liu et al., 2010 |
| Chinese bayberry | HA | 48 °C (3 h) | *Leptographium abietinum* | Wang et al., 2010 |
| Papaya (cv. Sunrise) | HWD | 54 °C (4 min) | *C. gloeosporioides* | Li et al., 2013 |

Liu et al., 2012; Sui, Droby, Zhang, Wang, & Liu, 2014). Protective refers to the application of a heat treatment before an infection is established. This effect influences mainly the level of inoculum load on fruit surface and indirectly results in reducing the chances for infection. On the other hand, curative refers to the application of a heat treatment after a pathogen has already infected fruit, such as occurs with quiescent infections or incipient infections established soon before or after harvest through surface injuries. Regardless of whether or not the application is protective or curative, the induction of disease resistance by heat treatments of harvested fruits has been reported to play a role in its efficacy. The development of high-through '-omics' technologies, such as transcriptomic, proteomic, and metabolomic studies, has provided new insights into how heat treatments induce biotic/abiotic stress resistance in harvested fruit commodities (Cruz-Mendívil et al., 2015; Lara et al., 2009; Luria et al., 2014; Spadoni, Guidarelli, Phillips, Mari, & Wisniewski, 2015; Yun et al., 2013).

Diseases caused by pathogenic fungi are the most abundant postharvest diseases of fruit crops (Prusky et al., 2013). Heat treatments have the direct effect of inhibiting or even killing fungal pathogens, but the basis for this activity has not been fully elucidated. When fungi are exposed to abiotic stresses, including heat, undesirable levels of intracellular reactive oxygen species (ROS) will accumulate in a heat dose-specific manner. Consequently, oxidative damage to nucleic acids, proteins, and lipids occurs, resulting in the impairment of many cell functions which then leads to reduced viability (Hernández-Oñate & Herrera-Estrella, 2015; Liu et al., 2012; Zhao, Wisniewski, Wang, Liu, & Liu, 2014). Heat treatments that are the most lethal to fungal pathogens, however, can also impact fruit quality (e.g. enhanced ripening and senescence, phytotoxicity). Therefore, an integrated management approach utilizing a combination of different eco-friendly treatments, may be required to provide a viable alternative to synthetic, chemical fungicides (Janisiewicz & Conway, 2010; Smilanick, 2008).

Since Wilson and Wisniewski (1989) first outlined the concept of postharvest biocontrol utilizing antagonistic yeasts and its