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Review

# Effects of the ethylene-action inhibitor 1-methylcyclopropene on postharvest quality of non-climacteric fruit crops

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ABSTRACT

1-Methylcyclopropene (1-MCP) (SmartFresh™) is an ethylene antagonist widely used to retain quality and prolong the postharvest storage period of various climacteric fruits in which ethylene plays a critical role in regulation of the ripening process. Nonetheless, it has been found that exposure to 1-MCP may affect certain ripening-related processes also in non-climacteric fruits. In this review, we summarize the current knowledge regarding the effects of 1-MCP on quality and postharvest storage performances of various non-climacteric fruit crops, including grape, cherry, pomegranate, citrus, strawberry, pitaya, prickly pear, lychee, loquat, and olive. Overall, the main observed effects of 1-MCP on postharvest storage performance of non-climacteric fruits were: (1) inhibition of senescence processes, such as rachis browning in grapes, scale senescence in pitaya, and leaf senescence of 'Shatangju' mandarins marketed with attached leaves; (2) inhibition of development of physiological disorders such as scald development in pomegranate, pericarp browning in litchi, and internal browning in loquat; and (3) inhibition of degreening and color change, as observed in various citrus fruits, strawberry, pitaya, prickly pear and olive. Beside these major effects, exposure to 1-MCP had divergent effects on fruit respiration and ethylene production rates, and on decay development, with differing and sometimes contradictory effects observed in different crops and tissues. Finally, exposure to 1-MCP had just minor effects on internal fruit-quality parameters, including nutritional quality and flavor. In the future, it may be worth considering the commercial application of 1-MCP as a means of retaining the green color, reducing physiological disorders, and retarding senescence processes in certain non-climacteric fruits.


**Contents**



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## 1. Introduction

According to their respiratory behavior and ethylene production rates during ripening, fruits and vegetables are classified into two major groups, known as “climacteric” and “non-climacteric” (Kidd and West, 1927, 1930; Baile, 1964). Climacteric fruits are those whose ripening process is accompanied by peaks in respiration and ethylene production rates, whereas non-climacteric fruits do not exhibit such increases (Giovannoni, 2001; Cherian et al., 2014). In climacteric fruits, ethylene plays a key role in governing the physiological and biochemical changes that occur during ripening, whereas in non-climacteric fruits ethylene is generally not necessary for coordination and completion of the ripening process (Lelievre et al., 1997; Barry and Giovanoni, 2007). Nonetheless, although non-climacteric fruits do not exhibit any clear increases in ethylene production rates during ripening, in certain cases, their exposure to exogenously applied ethylene may stimulate certain ripening-related processes, such as degreening of citrus fruit (Reid, 2002).

1-Methylcyclopropene (1-MCP) is an ethylene antagonist that interacts with the fruit ethylene receptors and thereby prevents ethylene action (Sisler and Serek, 1997). As an effective ethylene-action inhibitor, 1-MCP is widely used to extend postharvest storage lives and to prevent spoilage of horticultural produce (Blankenship and Dole, 2003; Lurie, 2005; Watkins, 2006). So far, 1-MCP has been commercially used in dozens of countries worldwide, and has been registered for application to at least 18 distinct horticultural crops, all of which are climacteric fruits, especially apple, pear and persimmon (Sozzi and Beaudry, 2007). The main effect of exposure of climacteric fruits to 1-MCP is to delay the natural increases in respiration and ethylene production rates during ripening, thereby delaying ripening and ripening-related processes such as softening, color change, starch breakdown, etc. (Blankenship and Dole, 2003; Lurie, 2005; Watkins, 2006). In fact, 1-MCP is so effective in inhibiting ripening of climacteric fruits that in some cases, such as banana, immature green tomatoes and guava, exposure to 1-MCP may often be somewhat problematic, because it may irreversibly inhibit the ripening process (Golding et al., 1998; Bassetto et al., 2005; Hurr et al., 2005).

In addition to the well-known, expected effects of 1-MCP in inhibition of ripening of climacteric fruits in which ethylene plays a critical role in regulation of the ripening process, it was found that exposure to 1-MCP might affect certain ripening-related processes, including color change, respiration, softening, and development of decay and physiological disorders in non-climacteric fruit (Huber, 2008). The exact mode of action through which exposure to 1-MCP might inhibit ripening-related processes in non-climacteric fruits is not yet well understood. However, it is reasonable to assume that 1-MCP might inhibit the fruit response to the low basal levels of ethylene that are naturally produced by non-climacteric fruits, and which could affect at least some aspects of fruit ripening (Wills et al., 1999). Alternatively, 1-MCP also may elicit some other, unknown effects not directly related to inhibition of ethylene action. In the present review, we will summarize the current knowledge regarding the effects of exposure to 1-MCP on quality and postharvest storage performance of various non-climacteric fruit crops, including grape, cherry, pomegranate, citrus, strawberry, pitaya, prickly pear, lychee, loquat, and olive (Kader, 2002).

## 2. Effects of 1-MCP on postharvest storage performance and quality of non-climacteric fruits

### 2.1. Grape

Although grape is considered non-climacteric, it has been reported that ethylene may be involved in regulation of grape fruit ripening, since a peak in ethylene production was observed at veraison (inception of ripening), and inhibition of the ethylene response by exposure to 1-MCP at veraison while the grapes were still attached to the vine transiently delayed the increase in berry diameter and inhibited anthocyanin accumulation during ripening of ‘Cabernet Sauvignon’ grapes (Chervin et al., 2004, 2005). Furthermore, it was also demonstrated that ethylene was involved in regulation of sugar metabolism during grape berry ripening, as sucrose accumulation and the expression of two sugar transporter genes (*SUC11* and *SUC12*) were inhibited by exposure to 1-MCP (Chervin et al., 2006). Similarly, the ethylene signal transduction pathway is also involved in up-regulation of alcohol dehydrogenase (ADH) enzyme activity and gene expression at the inception of fruit ripening, since exposure of attached berries to 1-MCP partially inhibited ADH activity and the increase in *VvADH2* transcript levels (Tesniere et al., 2004).

With regard to the potential effects of ethylene and 1-MCP applied after harvest, Bellincontro et al. (2006) have not observed any significant effects on respiration rates of ‘Aleatico’ grape bunches. However, it was noted that exposure to ethylene increased ethylene production rates immediately after the treatment, whereas exposure to 1-MCP completely eliminated ethylene production for up to two days after the treatment, in contrast with control bunches which produced constant basal levels of ethylene. In their study, Bellincontro et al. (2006) did not observe any significant effects of either ethylene or 1-MCP on berry TSS or acidity levels and pH values, but reported that exposure to ethylene increased phenol and anthocyanin levels. Likewise, exposure of clusters of a black grape variety ‘3003’ to 1-MCP reduced the anthocyanin-related autofluorescence of the berries (Li et al., 2015). In this study, it was demonstrated that postharvest exposure to 1-MCP at 1 $\mu L\,L^{-1}$ indeed had no significant effects on respiration and ethylene production rates of intact berries. However, 1-MCP significantly reduced respiration and ethylene production rates of intact rachis, and this phenomenon was observed in three different table-grape varieties: ‘Thompson’, ‘Mystery’, and ‘3003’, both immediately after harvest and after 3-weeks of cold-storage at 0 °C.

Furthermore, it was found that postharvest exposure to 1-MCP at 1 $\mu L\,L^{-1}$ delayed rachis browning in various table-grape varieties, such as ‘Thompson seedless’, thus suggesting the possible involvement of the ethylene signaling pathway in regulation of the rachis browning process (Li et al., 2015) (Fig. 1). Nonetheless, it is still necessary to validate the effectiveness of 1-MCP in retaining the fresh appearance of grapes, also under commercial marketing conditions.

In addition to inhibition of rachis browning, it was recently reported that exposure to 1-MCP significantly reduced the berry drop index in the ‘Isabel’ grape variety, which is very susceptible to berry drop (Silva et al., 2013): exposure to 2 $\mu L\,L^{-1}$ 1-MCP reduced berry abscission from about 50% in untreated control fruit to just 20% after 12 days of storage at 25 °C.

Overall, it can be concluded that while ethylene has significant effects on grape berry development during ripening on the vine,