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REVIEW ARTICLE

Ethylene sensitivity in orchid flowers and its management using 1-MCP: A review

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ABSTRACT

Ethylene is produced as a gaseous growth regulator in all plants and their constructive parts such as roots, stems, leaves, flowers and fruits. It is considered as a multifunctional phytohormone that regulates both growth including flowering, fruit ripening, inhibition of root growth, and senescence such as senescence of leaves and flowers and etc. In addition, exposure to external ethylene is caused some changes that are often undesirable and harmful. Some flowers are more sensitive to others and when exposed to ethylene; their aging process is hastened. 1-MCP is an exogenous and endogenous ethylene action inhibitor, which binds to the ethylene receptors in the plants and prevents the ethylene-dependent reactions. The binding affinity of 1-MCP for the receptors is about 10 times more than ethylene. Hence, 1-MCP can be a potential candidate for controlling of ethylene injury in horticultural crops. This review integrates knowledge of ethylene biosenthesis in the plants and also mode of action of 1-MCP in preventing of ethylene injury.

Keywords: Ethylene injury, biosynthesis, ethylene sensitivity, 1-MCP

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1 Introduction

Orchids belong to the family Orchidaceae, comprising 600-800 genera and 25,000- 35,000 species. Orchids are among the most beautiful flowers and form a unique group of plants. In terms of taxonomy, orchids exhibit an extraordinary range of variation in the size, shape and color of flowers (Singh, 2006). Ethylene sensitive flowers include flowers that respond rapidly when exposed to ethylene and accelerate their aging process. Furthermore, the nature of sensitivity and its site of action are still indistinct. Whitehead and Halevy (1989) suggested that a short-chain fatty acid ($C_6 - C_{10}$) may play the role as ethylene 'sensitivity factor'. They reported this short chain fatty acid is synthesized in the stigma and transported to the corolla of petunia and its sensitivity to ethylene is promoted. One proposed theory is that the interaction between the sensitivity factor and the binding site might regulate the sensitivity to ethylene, but this is just one of proposed explanation and not approved yet (Reid and Wu, 1992). The sensitivity factor likely controls the senescence in sensitive flowers which coincided with onset of the ethylene burst. The comparison of this situation in many fruits revealed that the signal could be the endogenous ethylene production, which would interact with the binding site and prompt a response, including induced ethylene biosynthesis, once the tissue had become sensitive (Staden et al., 1988). Ethylene induced senescence of Oncidium was delayed significantly with 1-MCP treatment (Huang et al., 2009). However, Jiang and Joyce (2002) found that the 1-MCP treatment raised the ethylene production of coriander's leaves in spite of positive effect on their freshness. This would suggest a feedback control system of ethylene synthesis in coriander which might be encouraged, rather than prevented, by 1-MCP. The purpose of this study was to collect research on the production of ethylene in plants and its sensitivity in them, as well as the use of 1-MCP in the control of ethylene exposure damages.

2 Ethylene

2.1 Production

Ethylene (C_2H_4), with a molecular weight of 28, is one of the simplest organic molecules with biological activity. It is produced by all plants; angiosperms, gymnosperms, ferns, mosses and liverworts. C_2H_4 is also generated by most variety of fungi, yeast, and bacteria, including *Penicillium digitatum* (a citrus mold), *Cryptococcus albidus* (a yeast), and *Pseudomonas syringaepv. Phaseolicol* (a bacterium infecting *Pueraria labata*), which produce large amounts of ethylene in culture. Large amounts of ethylene produced in soil are from microorganisms. In angiosperms, C_2H_4 is fundamentally generated by all parts of the plant including roots, stems, leaves, flowers, and fruits. Many fruits, like banana, apple, avocado, tomato and flowers such as carnations, gypsophila, and orchids display a sudden and dramatic rise in respiration rate, which is accompanied or even preceded by C_2H_4 production, followed by ripening and senescence in the fruits and flowers (Serek et al., 2006; Srivastava, 2002). Ethylene biosynthesis is shown in Fig. 1. Ethylene is produced through the conversion of S-adenosylmethionine (SAM) to 1-aminocyclopropane-1-carboxylic acid (ACC) by ACC synthase (ACS) and ACC to ethylene by ACC oxidase (ACO) (Srivastava, 2002).

Ethylene encourages senescence and abscission of plant organs (e.g., leaves and flowers) and prompts the synthesis of enzymes and defense or pathogenesis related (PR) proteins linked with these processes. Several stress situations, e.g., exposure of plants to heat or cold, wounding by mechanical means or via insect bites, attacked by fungi and bacteria, and even gentle stroking of plant tissues will elicit ethylene production. Exposure of ethylene to plants will result in drooping of leaves and flowers which are called epinasty. This phenomenon occurs because of unequal (or asymmetric) growth in the petioles or peduncles. Downward curvature of an organ or epinasty basically happens as a result of faster growth rate of the organ in the upper (adaxial) side than lower (abaxial) side (Srivastava, 2002).

2.2 1-amino-cyclopropane-1-carboxylic acid (ACC) content

The immediate precursor of ethylene in plants is ACC (Hoffman et al., 1982). ACC is synthesized by the enzyme ACC synthase from methionine and converted to ethylene by ACC oxidase. The ethylene production increased simultaneously with the respiration climacteric and senescence of cut carnation flowers (*Dianthus caryophyllus* L. cv. White Sim) (Bufler et al., 1980). Meanwhile, the petal ACC content in cut carnation flowers showed an increase of 30 folds. Ethylene production is also regulated through control of ACC levels. Conjugation of ACC to 1-malonylaminocyclopropane-1-carboxylic acid (MACC) by ACC N-malonyltransferase controls levels of ACC (Peiser and Yang, 1998; Yang, 1987). This activity generates a sink for extra ACC and also contributes a supplementary level of auto-inhibitory ethylene regulation, as ethylene can increase levels of malonyltransferase (Abeles et al., 2012).

2.3 Expression of ACC synthase and oxidase genes

Ketsa (2008) reported Den-ACS gene was only expressed in *Dendrobium* petals when they were treated with exogenous ethylene and there was less expression in aminooxy acetic acid (AOA) + ethylene treatment. Furthermore, AOA reduced the ethylene production of flowers with and without ethylene treatment. Hence, the expression of Den-ACS gene was associated with ethylene production and flowers senescence. Thus, it is noted that Den-ACS and Den-ACO have a role in autocatalytic system of flower senescence in cut Dendrobium flowers. Savin et al. (1995) reported that, expression of the ACS and ACO genes in carnation petals were related with the presence of ethylene. Besides, northern analysis data indicated that ethylene production is performed as 'autocatalytic' during the carnation petal senescence. Thus, there is a positive feedback loop in which ethylene prompts expression of at least the ACS and ACO enzymes in the ethylene biosynthesis pathway. Ma (2005) noted that two cut rose cultivars, 'Samantha' and 'Kardinal', were exposed to ethylene and the results showed that ethylene production, ACC synthase (ACS) and ACC oxidase (ACO) activity in their petals increased and peaked in Stage 3 and Stage 4, respectively. A more dramatic accumulation of Rh-ACS3 mRNA was enhanced by ethylene in 'Kardinal' than that of 'Samantha'. Also, an ethylene action inhibitor, STS at concentration of 0.2 mmol L^{-1}, normally prevent the expression of Rh-ACS and Rh-ACO genes in both cultivars.

2.4 Mode of action

Ethylene is one of the major plant hormones which is involved in the growth, flowering, abscission and fruit ripening. The effect of ethylene on growth and development in plant tissues has not yet been totally clarified, but possible pattern based on other plants and animals hormonal responses has been drawn. A proposed model for the action of ethylene in flower senescence is demonstrated in Fig. 2. This chart suggests: first a 'sensitivity factor' activates, or represses a membrane-based binding site. Second the C_2H_4 molecule binds to the site where the inhibitors of ethylene action, Ag+ and 1-MCP, can also bind. Third when the binding site is sensitized and ethylene binds to it, a second message is produced which interacts with the 5′ (promotor) regions of genes involved in ethylene-regulated senescence, inducing transcription of the genes, and synthesis of the proteins encoded by the genes on polyribosomes. Much evidence has been gathered from studies with cut flowers that are in agreement with this scheme (Reid and Wu, 1992).

2.5 Ethylene sensitivity

Whitehead and Halevy (1989) noted that feedback of a plant hormone may cause increased biosynthesis, increased sensitivity to the hormone, or both. As the flower is fully developed their sensitivity to ethylene increase. The sensitivity of cut flowers to ethylene depends on many internal and external factors such as cultivars or hybrids, developmental stage, temperature during exposure to ethylene, concentration and duration of exposure (de Munk, 1973; de Munk and Hoogeterp, 1975). Therefore, regardless of kind of species and cultivar, generally, an enhancement in ethylene sensitivity occur concomitant with increasing age in plant tissues which is well documented, particularly in fruits and flowers (Brady, 1987; Halevy and Mayak, 1981). Furthermore, environmental conditions like temperature and ethylene pollution have important roles in ethylene sensitivity. Mor et al. (1980) reported that carnation petals wilted at the same time, whether attached to the plant or detached and kept individually in small vials. Moreover, detaching of the gynoecium from the flower did not affect the timing of flower wilting. These results indicated that petal aging is merely dependent on the petal tissues. Flowers treated with AOA, an inhibitor of ethylene biosynthesis, which vigorously reduced ethylene production levels (Porat et al., 1994a,b). So, ethylene sensitivity is a weak point for cut flowers because it causes many harmful effects on their postharvest quality. Numerous studies were carried out to control the ethylene sensitivity in cut flowers using chemicals such as anti-ethylene agents, STS and 1-MCP and genetic manipulations.

3 1-methylcyclopropane (1-MCP)

Blankenship and Sisler discovered the role of 1-MCP as an ethylene binding inhibitor in the late 1980's (Prange and DeLong, 2003). At standard pressure and temperature (1 atm and 20 °C), it is a volatile gas which has a molecular weight and formula of 54 and C_4H_6, respectively. 1-MCP is commercially available in the form of an inclusion complex with α-cyclodextrin. The α-cyclodextrin powder releases 1-MCP when is mixed with water (Neoh et al., 2007). 1-MCP concentration can be measured using gas chromatography with Glass Porapak Q columns. Safety, toxicity and environmental profiles of 1-MCP in relation to humans, animals and environment are highly desirable (EPA, 2002). The compound is applied at low concentrations, has a non-toxic mode of action and is chemically similar to natural substances. The lethal dose for rat (LD_{50}) is greater than 2.5 mg L^{-1} (or 1.126 ppm (v/v) active ingredient in air).

3.1 Effect on ethylene production

Manenoi et al. (2007) found that the onset of ethylene production was retarded and the increase in the respiration rate inhibited in papaya fruits treated with 1-MCP. Tatsuki et al. (2007) noted that ethylene production and expression of MdACS1, MdERS1, and MdERS2 genes were prevented in all 1-MCP-treated 'Fuji' fruits. 1-MCP reduced the ethylene production in strawberry (Jiang et al., 2001), delayed ethylene production in apricots and plums (Dong et al., 2002), and prevented ethylene production in 'Red Delicious' and 'Granny Smith' apples (Fan and Mattheis, 1999; Fan et al., 1999). When 1-MCP was applied on avocado fruits, the ethylene climacteric was delayed by 6 days and decreased to more than 50% (Jeong et al., 2002) and it was also reduced in plums (Abdi et al., 1998) and apricots (Fan et al., 1999) treated with 1-MCP. The negative effects of ethylene was inhibited by STS and 1-MCP pre-treatments and hence extended the vase life of cut 'First Red' rose (Chamani et al., 2005). Sisler et al. (1996) reported that the ethylene climacteric rise declined by about $\frac{2}{3}$ using 1-MCP in carnation flowers but could not suppress the production of endogenous ethylene. Fahmy (2005) noted that in cut flowers (rose, carnation, solidago and chrysanthemum), 1-MCP treatment prevents the production of ethylene and ethylene binding to receptors.

3.2 Effect on ACS and ACO

Expression of genes related to enzymes involved in ethylene synthesis, ACC synthase and ACC oxidase, were prevented by the 1-MCP treatment (Nakatsuka et al., 1997; Shiomi et al., 1999; Xue et al., 2008; Yamane et al., 2004). The increase in mRNAs abundance with ripening of tomato was prevented to a large extent by treatment with the ethylene action inhibitor, 1-methylcyclopropene (1-MCP). This was most pronounced in the fruit treated with 1-MCP at the turning stage, in which the accumulation of ACC synthase and ACC oxidase transcripts was almost completely eliminated in the first two days, precisely the same stage at which the control fruit had the greatest level of each mRNA accumulation. The inhibition of transcript accumulation returned to the control level within two to four days. 1-MCP also decreased ethylene biosynthetic activity, although this decrease was not reflected in reduced mRNAs accumulation. These results suggested that a strong positive feed-

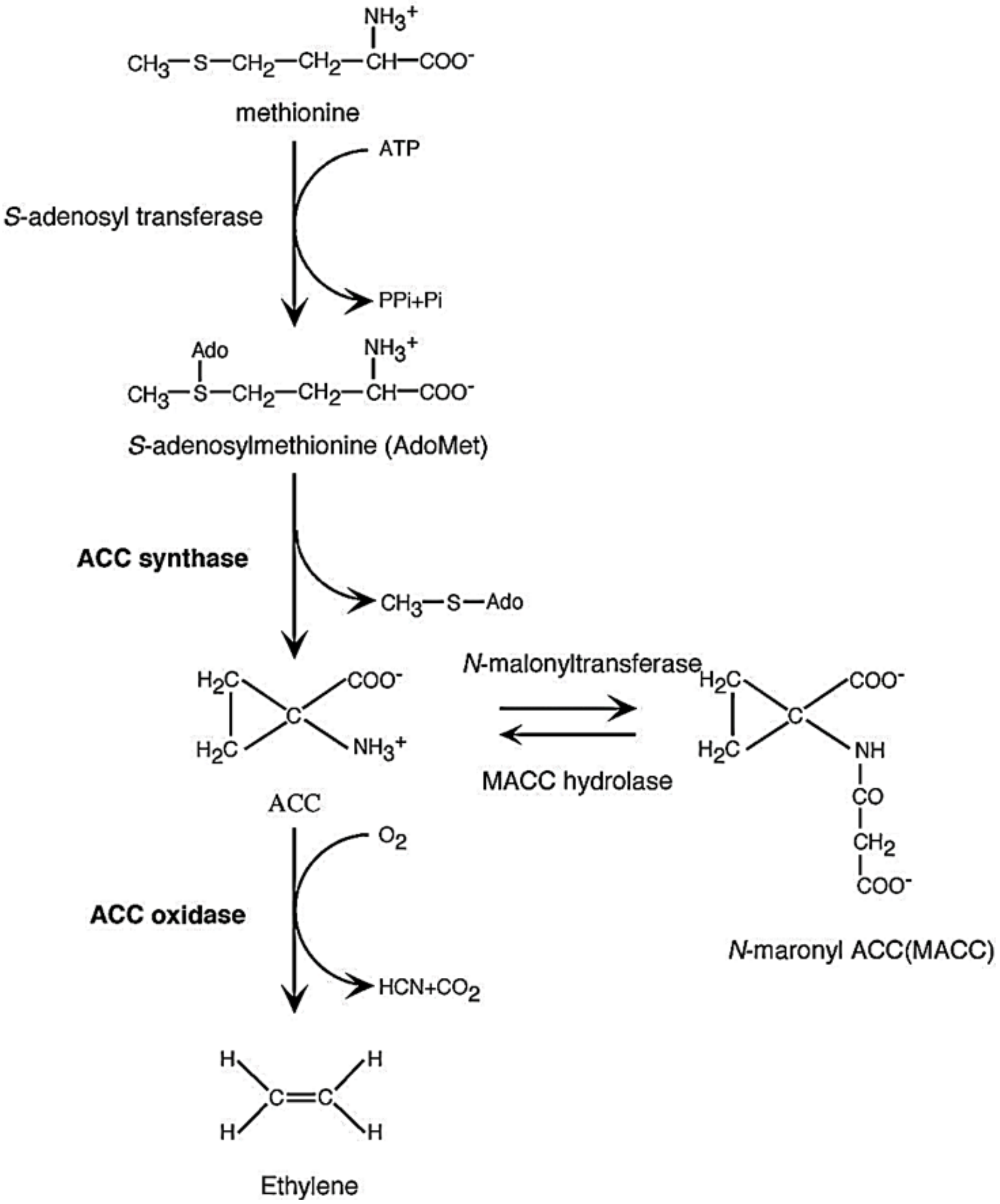

Figure 1. Ethylene biosynthesis in higher plants. From Ose et al. (2003)

back regulation is involved in ethylene biosynthesis at the gene transcriptional level in tomato fruit, even at the stage with a burst of ethylene production (Nakatsuka et al., 1997). 1-MCP pretreatment prior to packing orchid flowers for simulated shipment increased the length of vase life (which was mainly limited by flower wilting) and reduced abscission of open flowers and floral buds. The effect of 1-MCP on abscission was very similar, qualitatively and quantitatively, to STS. 1-MCP inhibited the ethylene production of inflorescences. Since most ethylene was produced by floral buds, and ethylene production in the buds was apparently limited by ACC, the 1-MCP effect seemed to be rooted in a decrease in ACC oxidase activity (Uthaichay et al., 2007). Exogenous ethylene induced flower bud drop in all tested Phalaenopsis cultivars and the different cultivars showed distinct differences in ethylene sensitivity. The cultivar Sogo Vivien exhibited the highest bud drop, water loss and change in membrane permeability in the petals, while cultivar Sogo Berry showed the lowest sensitivity. The ethylene inhibitor, 1-MCP, reduced ethylene-induced floral bud drop in the cultivar Sogo Yenlin (Sun et al., 2009).

3.3 Effects on weight loss and vase life

It is to be noted that within the harvest time, the water forms about 65 to 95% of fresh produces and consequently after harvest, water loss is considered as one of the main reasons of deterioration (Kader, 2002). So, water loss can negatively change the quality of the

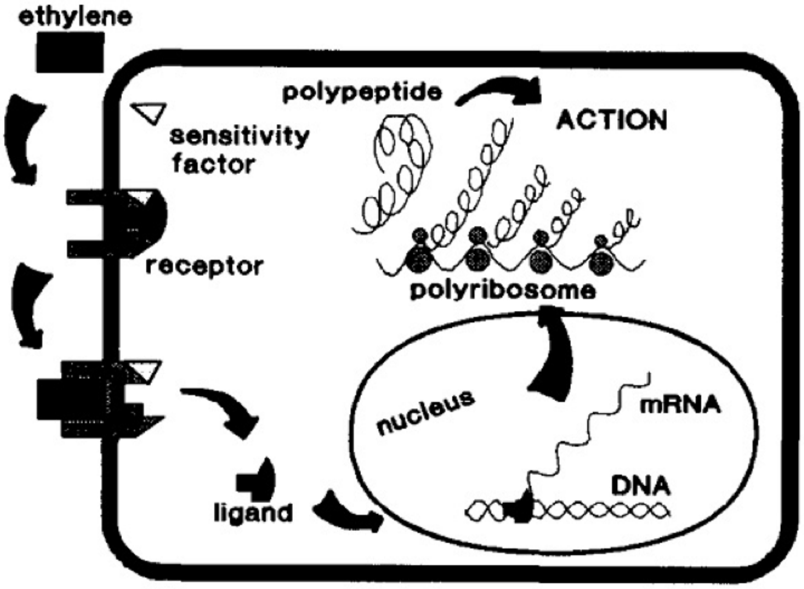

Figure 2. Hypothetical scheme for the action of ethylene in inducing flower senescence. From Reid and Wu (1992)

commodities. The wilting of leaves or flowers happens when small losses (2-5%) occur and in the case of more moisture losses, the permanent shrivel emerges accordingly Spikman (1987). Furthermore, Sankat and Mujaffar (1994) noted that the decline of water loss and its negative consequences in fresh crops such as vegetables and cut flowers will be achieved when their farm heat has been removed as soon as possible and then they has been stored at low temperature. The cut patumma (*Cucurma alismatifolia*) cv. Chiang Mai Pink flowers treated with 300 ppb for 15 h 1-MCP showed minimum loss of weight compared to the control since day 2 till day 10 in vase solution while, 100 ppb for 15 h 1-MCP displayed the maximum vase life (Chutichudet et al., 2011). Also, positive effect of 1-MCP on the reduction of weight losses and extension of vase lives were found in cut carnation, raceme of *Lupinus havardii* Wats (Valenzuela-Vázquez et al., 2007) and in mini *Phalaenopsis* cultivars (Sun et al., 2009).

3.4 Mode of action

A model which explains how 1-MCP can inhibit the binding of ethylene with the receptor is shown in Fig. 3suggested by Sisler and Serek (1997). In a proposed model for antagonist effects of 1-MCP with ethylene and antagonist's interaction with the ethylene receptor has been presented. Binding of 1-MCP to the receptor first requires the withdrawal of electrons into the orbital of 1-MCP. Secondly a ligand on the metal in the receptor, a copper ion for high affinity binding is rearranged in the receptor. Thirdly the ligand in the trans position is either substituted or released followed by further rearrangement and then binding (Sisler and Serek, 1997). The plant will remain insensitive to ethylene for as long as 1-MCP is bound to the receptor (Sisler, 2006). The affinity for 1-MCP by the receptor is about 10 times more than ethylene. Thus, when 1-MCP is applied it can easily compete with ethylene molecules for receptors in binding sites. This occupation of ethylene receptors by 1-MCP makes ethylene unable to bind to the site of action consequently making the reaction not able to occur. 1-MCP is very active compared with ethylene since it can react to the receptor at much lower concentrations. This positive point of 1-MCP increases the potential use of 1-MCP in small concentration without much harm to plants and humans. It also reduced ethylene biosynthesis in some species through biosynthesis in some species through feedback inhibition. Blankenship (2001) mentioned that the effectiveness of 1-MCP depends on many factors like concentration, exposure time and fruit maturity.

So far, 1-MCP has effectively been used for controlling the ethylene action particularly, the inhibition of flower and bud abscission in many crops, such as tuberous begonia and kalanchoe plants (Serek et al., 1995b), *Cymbidium* orchid flowers (Heyes and Johnston, 1998), Oncidium (Huang et al., 2009), *Dendrobium* (Uthaichay et al., 2007), carnation (Ichimura et al., 2002), pelargonium (Cameron and Reid, 2001) and ripening of bananas (Golding et al., 1998), apricots (Fan et al., 2000) and apples (Fan et al., 1999). Moreover, Almasi (2019) noted that maximum postharvest quality improvement was obtained by 1-MCP pretreatment in very sensitive cut Mokara orchid hybrids. The efficiency of 1-MCP as a com-

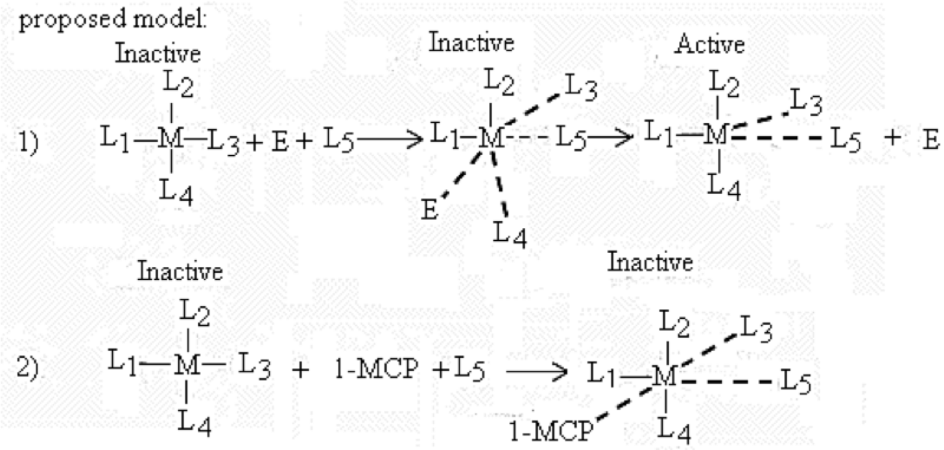

Figure 3. A proposed model for antagonist effects of 1-MCP with ethylene. From Sisler and Serek (1997)

mercial treatment to inhibit petal abscission in the pelargoniums is related to transport and storage temperatures and numbers of application (Cameron and Reid, 2001). Sisler et al. (1996) reported that 1-MCP is a suitable option to inhibit ethylene action on carnation without irradiation and can be applied successfully at a small range of concentration (0.5 nL L^{-1}), thereafter, the concentration of 1-MCP, which is effective, is equal to one tenth of diazocyclopentadiene DACP concentration required. Moreover, flowers exposed to exogenous ethylene 10 days after 1-MCP treatment did not show sensitivity to ethylene (Cameron and Reid, 2001). The effective short exposure time is required for high concentration of 1-MCP. Meanwhile, 1-MCP is the first gaseous product found to be a permanent antagonist of ethylene in the dark, and it can be applied at a very low concentration. In addition, 1-MCP controls the ethylene production too and it is capable of stopping irreversibly the autocatalytic production of ethylene, but it may not bring a direct effect on ethylene production. This conclusion is in agreement with the fact that a constant perception of ethylene is required to continue the production of ethylene. The ethylene sensitivity of flowers is increased with age of the carnations, but their ethylene binding capacity is reduced. Aging flowers need a higher concentration of 1-MCP to be conserved against exogenous ethylene than younger

3.5 Factors affecting 1-MCP effects

3.5.1 Concentration

Effective concentrations of 1-MCP differ greatly with commodity, exposure time, temperature and method of application. In carnation, the minimum concentration required was 2.5 nL L^{-1}, while in apples some studies have revealed that 1 μL/L was required to block ethylene action (Fan et al., 1999; Jiang and Joyce, 2002; Sisler et al., 1996). Furthermore, lower concentrations of 1-MCP may be as effective as higher concentration if it is applied over a long period of time. The abscission during vase life in Dendrobium inflorescences treated with 100 - 500 nL L^{-1} 1-MCP prior to simulated air transport was inhibited remarkably (Chutichudet et al., 2011). (Honghem et al., 2007) fumigated the orchid hybrid 'Mokara Jairak Gold' with 1-MCP at 250 nL L^{-1} for 0 (control), 3, 6 and 12 h at 25 °C. All inflorescences treated with 1-MCP had significantly longer span life than the control (Honghem et al., 2007). Exposure to 1-MCP for 12 h showed the longest display life of 34.2 days compared to the other treatments. Khunmuang et al. (2019) reported that exposure of the inflorescences to 0.2 μL L 1-MCP for 6 h pre-treatment in the cut ethylene-sensitive Vanda 'Sansai Blue' orchid flowers followed by 10 μL L^{-1} ethylene, recovered both inflorescence color and anthocyanin content to control levels.

With potted plants, increasing the concentration of 1-MCP from 0 to 5.8 nL L^{-1} on *Heimalis begonia* (Begonia × elatior hybrida) 'Najada' or to 10 nL L^{-1} for kalanchoe 'Tropicana' and rose 'Victory Parade' decreased the percentage of begonia buds and flowers dropped, senescence of kalanchoe flowers or rose leaf drop (Serek et al., 1995a). Minimum concentration varied with species. Increasing 1-MCP concentration from 20 to 100 nL L^{-1} increased display life of holiday cactus (Schlumbergera) (Serek and Sisler, 2001). However, only 20 nL L^{-1} was required to obtain maximum display life of campanula in the presence of exogenous ethylene (Serek and Sisler, 2001). Increasing 1-MCP concentration from 0 to 10 nL L^{-1} increased postproduction life of kalanchoe in the presence of exogenous (3μL L^{-1}) ethylene.

3.5.2 Exposure time

The treatment duration range in most studies has been effective between 12 and 24 h (Blankenship and Dole, 2003). Six hours 1-MCP fumigation with concentration of 0.45 μL L^{-1} was not sufficient to prevent ethylene production in avocado (Jeong et al., 2002). DeEll et al. (2002) noted that the cultivar also has a major effect such as 'Empire' apples required less treatment time than 'Cortland' to obtain the same effect at the same 1-MCP concentration. There was no difference in postharvest qualities of Oncidium cut flowers when they treated with 1-MCP between 2 to 12 h in temperature of 10 to 28 °C (Huang et al., 2009). Therefore, it is concluded that length of 1-MCP fumigation depends on many factors such as the commodity, concentration and temperature.

3.5.3 Temperature

In most studies, 1-MCP as an anti-ethylene agent were used at temperatures between 20-25 °C (Blankenship and Dole, 2003). There is a relationship between concentration, exposure time and temperature and use of low temperatures for some agricultural products is not effective. At a lower temperature, the affinity of 1-MCP for receptors in binding sites is low. Thus, it should be applied at longer exposure time and higher concentrations to get the same result of a high temperature exposure. In addition, ethylene sensitivity level would be probably declined at a low temperature, subsequently its effectiveness will also drop. Application of 1-MCP at low temperatures (5 - 10 °C) and (2 °C) in coriander (*Coriandrum sativum*) and penstemon 'Firebird' were not effective on postharvest quality probably due to low sensitivity to ethylene. However, the use of 1-MCP (5 or 20 nL L^{-1}) for the latter at 20 °C caused incomplete protection from exogenous ethylene (Jiang and Joyce, 2002; Serek et al., 1995b).

3.5.4 Maturity stage

Plant growth stage should be considered when 1-MCP is used because the effects vary with plant maturity. Fan et al. (2000) revealed that the effects of 1-MCP on apricot fruit (*Prunus armeniaca*) diminished with ripening stage. Reaction of a leafy brassica to 1-MCP was less than a floral brassica and probably it is because of different ages of leaves in leafy brassica or existence of inherent differences between two kinds of brassica. The reaction to 1-MCP within leafy brassica tend to be weaker than the same reaction in floral brassica, the reason to this difference could be the different ranges of the leaves ages in leafy brassica or the potential and innate differentiation of both brassicas which have caused the difference between the two types when it comes to the reaction to 1-MCP (Able et al., 2002). 1-MCP treatment may completely protect the single flowers of carnations from ethylene. But spike or spray flowers of delphinium and gypsophilia (*Gypsophilia paniculata*)] may not have complete protections, which is presumably due to variations in tissue ages (Newman et al., 1998; Sisler et al., 1996). Harris et al. (2000) noted that the response of the banana fruit to 1-MCP was correlated to the maturity stage, whereas, most of commercial bananas are not in the same stage of maturity. So, 1-MCP treatment would probably affect them variously. Baritelle et al. (2001) found that stage of ripeness in pear fruits has significant effects on the tissue mechanical properties in response to 1-MCP treatment. Müller et al. (1999) pointed out that there was a difference in the amount of ABA depending on the age of rose flowers. As for the 'Bronze' cultivar, it has more ABA in the buds compared to the newly opened flowers. The ABA content increased in the open flowers with aging. Furthermore, a close relationship existed between ethylene and ABA during senescence of *Phalaenopsis* (Sun et al., 2009) and roses (Müller et al., 1999) where 1-MCP delayed ABA-induced flower senescing.

3.5.5 Time from harvest to treatment

The significance of time from harvest to 1-MCP application changes with the crop species. Normally, the more sensitive a crop is to ethylene, it should be treated with 1-MCP as soon as possible after harvest. Broccoli and Pak Choy (*Brassica rapa*) should be treated with 1-MCP as soon as possible, otherwise their postharvest qualities will be lost rapidly (Able et al., 2002). Efficacy of 1-MCP treatment on ethylene production in apple fruit had a close relationship with the application time. Delay in the use of 1-MCP after harvest caused earlier deterioration. Manenoi et al. (2007) reported that the optimum time for 1-MCP treatment in papaya fruits is when their skin turns yellowish more than 25%. Furthermore, those fruit treated with 1-MCP with less than 25% yellow skin could not ripen normally and showed lower respiratory peak and ethylene production during ripening. Cameron and Reid (2001) noted that ethylene sensitivity of petals in *Pelargonium peltatum* 'Pink Blizzard' was greatly affected by the stage of flower development. Flowers at stages 1, 2 and 3 were more sensitive than stage 0, as their petals totally abscised within 2 h of ethylene exposure but not the latter stage.

4 Conclusions

The sensitivity of cut flowers to ethylene relies on many internal and external factors such as cultivars or hybrids, developmental stage, temperature during exposure to ethylene, concentration and duration of exposure. 1-MCP can be applied in enclosed locations to increase the shelf and storage life of cut flowers and flowers, ornamental leaves plants and harvested fruits and vegetables by preventing the harmful effects of ethylene. Fruits, vegetables and flowers are exposed to 1-MCP in confined spaces such as rooms, cold stores, greenhouses, packages, containers and transport trucks. The effect of 1-MCP on postharvest quality of commodities depends on its concentration, exposure time, temperature, maturity stage and time from harvest to treatment.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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