Asian Journal of Plant Sciences

ISSN 1682-3974

OPEN ACCESS Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2019.1.8

Review Article
Ethylene Inhibition Using 1-Methylcyclopropene and Future Perspective for Tropical Ornamental Plants

[1]Syariful Mubarok, [1]Erni Suminar and [2]Nadia Nuraniya Kamaluddin

[1]Department of Agronomy, Faculty of Agriculture, Universitas Padjadjaran, Jalan Raya Bandung, Sumedang KM 21, Jatinangor, 45363 West Java, Indonesia
[2]Department of Soil Science, Faculty of Agriculture, Universitas Padjadjaran, Jalan Raya Bandung, Sumedang KM 21, Jatinangor, 45363 West Java, Indonesia

Abstract
Ethylene regulates many aspects of plant growth and development. During the post-harvest handling of ornamental plants, ethylene presence must be minimized to prevent quality decrease of post-harvest life, such as petal abscission and leaf senescence. To minimize the ethylene effect, several prevention strategies were developed, such as inhibition of ethylene biosynthesis and ethylene perception. This review described the inhibition of ethylene perception through chemical compounds application. Inhibition of ethylene perception is a more effective technique compared to ethylene biosynthesis in preventing ethylene effect. This was due to both endogenous and exogenous ethylene can be blocked. 1-Methylcyclopropene (MCP) is one of the common chemical compound used as ethylene inhibitor. Two formulations of 1-MCP had been developed in the recent years, gas-released powder (volatile 1-MCP) and water-soluble powder (sprayable 1-MCP). Despite having the same active ingredient, the two formulations had different affinity in ethylene effect prevention. The effectiveness of 1-MCP had been widely investigated on several ornamental plants such as Chrysanthemum, Pelargonium, Kalanchoe, Grevillea. Recently, 1-MCP had been used to improve other plants such as and Phalaenopsis, Curcuma and Ginger.

Key words: 1-Methylcyclopropene (MCP), ethylene biosynthesis, ethylene perception, ornamental plant, postharvest

Citation: Syariful Mubarok, Erni Suminar and Nadia Nuraniya Kamaluddin, 2019. Ethylene inhibition using 1-methylcyclopropene and future perspective for tropical ornamental plants. Asian J. Plant Sci., 18: 1-8.

Corresponding Author: Syariful Mubarok, Department of Agronomy, Faculty of Agriculture, University of Padjadjaran, Jalan Raya Bandung, Sumedang km 21, Jatinangor, 45363 West Java, Indonesia Tel: +62-81-3221-80800

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Ethylene is a gaseous plant hormone with a sweet and ether-like odour. The compound is a symmetrical-two carbon compound and has a molecular weight[1] of 28.05. Ethylene is easily released from plant tissue and diffused in the gas phase through the intercellular space and sides. The concentration of ethylene can be measured by two methods, gas chromatography with flame or photoionization detector and laser-acoustic technique[2]. The concentration of ethylene in water is 4.4×10^{-9} M equal to 1 µL L^{-1} in the gas phase[3] at 25°C.

Ethylene triggered various responses in plant. It releases seed dormancy, hastens shoot and root growth of dormant iris, tulip, freesia and gladiolus, promotes fruit development and ripening, induces lateral cell expansion, promotes the elongation growth of submerged aquatic species, induces roots and root hair formation, promotes the senescence and abscission process of leaf and flower and regulates the ratio of male to female flower in Cucurbitaceae[3,4].

Ethylene release causes quality loss in postharvest life of ornamental plants. In most species, ethylene hastens petal wilting. But in some, it exhibits little to no effect. In highly sensitive plant such as Pelargonium[5], ethylene immediately causes petal abscission. Plant responses vary depending on the temperature, concentration, stage of plant development, duration of exposure. Generally the ethylene responsiveness increases along with organ aging[6].

Senescence is a combination of physiological process in living organism that follows physiological maturity and enhances the programmed cells, tissues and organs death[7]. In monocarpic plants, senescence lead to the death of entire plants after reproductive development finished. Whereas in polycarpic plants, it does not lead to the death of entire plants but is limited to parts of flower, fruit and old leaf and the plant continues to develop[8].

The most visible symptom of flower senescence are wilting or withering[9], whereas the visible symptom of leaf senescence is yellowing. Flower wilting or withering is caused by the loss of plant turgor from water stress and liquid logging of the tissue in the entire cut flowering stem. Flower wilting is usually followed by color change, slow dehydration and desiccation[5,9]. Leaf yellowing due to chlorophyll degradation usually starts from the leaf margin and spreads to the lamina[10]. Chlorophyll breakdown decreases photosynthesis activity, inhibiting rooting process of the cutting and promotes susceptibility to Botrytis[11,12]. Reports regarding the improvement of post-harvest shelf life of ornamental plants through ethylene perception techniques were reviewed in this article. Ethylene promotes the senescence and abscission of leaf and flower, which characterized by wilting, premature rooting and chlorophyll loss[13]. The application of exogenous ethylene 1 µL L^{-1} caused complete petal abscission of several Pelargonium flower[14-16] within 2 h.

ENDOGENOUS AND EXOGENOUS ETHYLENE SOURCES

The ethylene production rate depend on the type of tissue and the stage of plant development. Production of endogenous ethylene in flowers was commonly proceeded in three phase at the stage of flower development: low production in young flowers, strong acceleration during senescence and rapid decrease at the end of senescence. In *Ecballium elaterium* and digitalis, ethylene production increased during flower and petal abscission[17,18], whereas in carnation, it occurs several days or several hours after the full flower opening or pollination[19-22]. In petunia and carnation, the increase of ethylene production occurred during the first 30 min after pollination[22-24]. Ethylene production raised during pollination correlated with the increasing capacity of 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase (ACO)[21,25]. The production of endogenous ethylene was also affected by environmental conditions. Darkness or shady conditions increased ethylene production and caused flower abscission[26]. The production of endogenous ethylene of *Capsicum annuum* increased when the plant was placed in 80% shade[27].

Ethylene was also found in the transit or storage containers of a post-harvest handling environment. Ethylene from ripening fruits, senescing flowers, dying or decaying plant material, the smoke of the combustion car engines and cigarette smoke were sources of exogenous ethylene. The exposure of illumining gas and tobacco smoke increased the petal abscission of geranium flower and other members, indicating the presence of ethylene in the illuminating gas and tobacco smoke[28].

CHEMICAL COMPOUNDS AS AN ETHYLENE INHIBITOR

Ethylene response could be inhibited by inhibition of ethylene biosynthesis and/or action[29]. Ethylene biosynthesis could be inhibited through the conversion of S-adenosyl L-methionine (AdoMet) to ACC or the conversion of ACC to ethylene. Some chemical compounds and environmental manipulation such as Aminoethoxyvinylglycine (AVG) and amino-oxyacetic acid (AOA) could be applied to inhibit the formation of ACC from AdoMet, whereas, Co^{2+}, alpha-aminoisobutyric acid and low O_2 concentration could be used to inhibit ethylene formation from ACC. The second method ethylene action inhibition or prevention of ethylene binding using compounds such as Diazocyclopentadine (DACP), 2,5-norbornadine (2,5-NBD), 1-MCP and silver thiosulfate (STS)[29].

Inhibition of ethylene action by inhibiting the binding process of ethylene to the receptor was more effective than preventing the synthesis of exogenous or endogenous ethylene[29,30]. The inhibition of ethylene action prevented both exogenous and endogenous ethylene effects. While the inhibition of ethylene synthesis only prevented the production of endogenous ethylene and exogenous ethylene will still bind to the receptor and caused response in plants. The AVG application followed by continuous ethylene exposure (1 μL L^{-1}) was less effective than STS to inhibit buds drop of "White Christmas" *Schlumbergera truncata* (Haw.) and also prevented petal abscission of potted *Pelargonium x hortorum*[30,31]. In tropical ornamental plants, the application of AOA reported to delay the onset of flower abscission, decreased ovary growth, delay senescence and block pollination-induced ethylene production in orchid flowers[32-34].

The quality loss during post-harvest from ethylene could be reduced or eliminated by pre-treating plants with inhibitors. In the 1970s, silver thiosulfate (STS) was discovered as an effective inhibitor in increasing the post-harvest live on ornamental plants. The STS suppress ethylene action[35], it binded to ethylene receptor, leading to the suppression of endogenous and exogenous ethylene effect. STS prevented chlorophyll loss[36], decreased petal abscission, increased postharvest quality of *Pelargonium hortonum* and other ornamental crops[16] but also inhibited rooting and decreased rooting quality[37]. Despite of the STS efficacy, silver was toxic in plant cells and a potential metal pollutant, contaminating ground water[38]. Therefore, STS application had been restricted in some countries, such as in the Netherlands[39].

A series of cyclopropene, such as cyclopropene (CP), 1-MCP, 3-MCP and 3,3-dimethylcyclopropene (3,3-DMCP) were shown as an effective chemical compound to block ethylene binding site. The 3-MCP and 3,3-DMCP were effective in higher concentration than CP and 1-MCP. Unfortunately, CP was unstable in the form of liquid or dilute gas even at -78°C, because the compound seemed to polymerize at room temperature[40]. Therefore, amongst all the substituted CPs, 1-MCP was one of the most useful and more effective in higher temperatures.

1-Methylcyclopropene (1-MCP) was developed in the early 1990s as an environmental friendly, non-toxic and effective ethylene blocker. 1-MCP quickly became a popular alternative chemical to treat and minimize post-harvest loss in horticultural crops. Effectivity of 1-MCP depends on exposure duration, cultivars, temperature, concentration, stage of development and plant maturity[6,41].

1-MCP marketed in a powder form that will form gas (volatile 1-MCP) after water or buffer addition. In order to achieve maximum efficacy, 1-MCP must be applied in closed area to prevent loss. New formulation of 1-MCP was water soluble powder (sprayable 1-MCP) and was intended for widespread application. DeEll[42] reported that this formulation was effective in maintaining 'Barlett' Pear quality and comparable to 1-MCP. The pre-harvest application 100-150 μL L^{-1} a water soluble powder of 1-MCP on apples at 7 and 14 days before harvest could reduce advance maturity in the fruit, delay color development and reduced ethylene production[43,44]. The effect of 1-MCP significantly influenced post-harvest life of several ornamental plants. 1-MCP delayed petal abscission on phlox flowers, *P. peltatum, P. zonale* and *P. x hortonum*[14,16,45,46], prevents bud, flowers and leaves abscission from Begonia, Rosa 'Royal' and 'Sunset', Lilium 'Stargazer', *Kalanchoe blossfeldiana* 'Tropicana'[47-51], reduced fresh weight loss of *Lupinus havardii* 'Texas Sapphire'[52] and increased flower longevity Gravillea and Dianthus[53,54].

APPLICATION OF 1-MCP

1-MCP could be applied in several horticultural crops to prevent ethylene negative effect on ornamental cuttings or flowers (Table 1). Mostly, 1-MCP was used as volatile application in an enclosed area. Recently, the new formulation and application of sprayable type with similar capability as volatile 1-MCP were developed. Nevertheless, in several crops such as Pelargonium, sprayable 1-MCP was less effective than volatile 1-MCP in improving the post-harvest quality of cuttings and flower. Sprayable 1-MCP required a much longer time to diffuse into the tissue compared to the volatile type. Moreover, the application of sprayable 1-MCP at low concentration in open space was not effective in preventing the deteriorative effects of ethylene. Seemingly, due to evaporation of the sprayed solution and some molecules of 1-MCP in the solution were lost during the gassing phase, which caused insufficient time for the compound to diffuse into plant cell and inactivate ethylene receptor. Therefore, in open-space application, higher concentration of sprayable 1-MCP was required. The application of sprayable 1-MCP with

Table 1: Application of 1-MCP on ornamental plants

Species	Optimum concentration	Application temperature	Duration of application	Effects
Dianthus caryophyllus L.	0.1 µL L^{-1}	20°C	6 h	Improve flower shelf life[56]
Eustoma grandiflorum (Raf.) Shinn	0.1 µL L^{-1}	20°C	6 h	Improve flower shelf life[56]
Pelargonium hortotum	0.1 µL L^{-1}	-	1 h	Reduce petal abscission after ethylene treatment[14]
Pelargonium hortotum 'Kardino'	700 nL L^{-1}	-	4 h	Reduce leaves abscission in cuttings and did not[57] effect on rooting quality
Chrysanthemum morifolium	0.25 µL L^{-1}	-	6 h	Delay the color change in flower and improve flower shelf life[58]
Chrysanthemum morifolium	0.7 µL L^{-1}	-	6 h	Improve flower shelf life[59]
Chrysanthemum morifolium 'Coral Charm'	200 nL L^{-1}	20°C	6 h	Inhibit root formation in cuttings[37]
Chrysanthemum morifolium	700 nL L^{-1}	-	4 h	Inhibit chlorophyll degradation and root formation in cuttings[60]
Epipremnum pinnatum	200 nL L^{-1}	20°C	6 h	Inhibit chlorophyll degradation in cuttings[61]
Begonia hibrida 'Miss Murry'	700 nL L^{-1}	-	4 h	Reduces the root formation[57]
Hibiscus rosa-sinensis	200 nL L^{-1}	20°C	6 h	Inhibit chlorophyll degradation in cuttings[37]
Antirrhinum majus L.	20 nL L^{-1}	20°C	6 h	Preventing the effects of exogenous ethylene and improve flower longevity[62]
Pelargonium peltatum "Pink Blizzard"	1 µL L^{-1}	22°C	2h	Effective inhibitor of thylene-induced petal abscission and reduce petal abscission after ehylene treatment[16]
Lupinus havardii "Texas Sapphire"	160 nL L^{-1}	20°C	24 h	Inhibit fresh weight loss until 6 d, increase flower retention, and increase vase life longevity[63]
Chymbidium orchid "Trump"	500 nL L^{-1}	15°C	6 h	Improve vase life and delay the senescence in flower[64]
Phlox aniculata cv. Rembrandt	25 nL L^{-1}	22°C	6 h	Inhibit flower abscission and hence the reduction in the number of open flowers on the stems[46]
Lilium x 'MonaLisa' and 'Stargazer'	500 nL L^{-1}	25°C	18 h	Inhibit the ethylene response include normal senescence, wilting, and abscission of the open flowers[49]
Dendronium 'Karen'	500 nL L^{-1}	25°C	4 h	Inhibit abscission of flower buds and open flower[65]
Chamelaucium uncinatum Schauer 'Wendy'	200 nL L^{-1}	21°C	6 h	Reduce bud, flower, and leaf abscission caused by stresses associated with dry storage[66]
Dianthus caryophyllus L. 'Idra di Muraglia', white flower	0,25 µL L^{-1}	20°C	24 h	Prevented flower wilting and preventing pigment degradation in petals[67]
Schlumbergera truncata Dark Blue and Blue Clips	100 nL L^{-1}	21°C	6 h	Improve flower longevity, extend lant display life, and improve flower opening[68]

the concentration up to 25 times volatile 1-MCP reported to be ineffective in improving postharvest life of *Pelargonium zonale*[55].

The application of sprayable 1-MCP with 1 µL L^{-1} exposure of 1-MCP for 4-6 h was effective in reducing petal abscission of *Pelargonium x hortonum*[14,69] and in reducing the loss of quality in storage cuttings of Pelargonium such as leaf yellowing but did not improve rooting ability[13,37]. In cut rosses, 1-MCP and also combination with vase solution were effective in maintaining post-harvest life of roses and chrysanthemum[58,70,71]. The application of 1-MCP on young flowers was more effective than older flowers in increasing the post-harvest life of Pelargonium[15,16]. In the case of near-senescence flower, e.g. Pelargonium, 1-MCP did not improve the flower longevity[70], suggesting the differences of response in each cultivars. Treatment with 0.1 µL L^{-1} of 1-MCP for 1 h on *P. xhortonum* 'Kim', 'Veronica' and 'Cotton Candy', that were less sensitive to ethylene, was enough to reduce petal abscission. However in the case a more sensitive *P. xhortonum* 'Fox', 12-24 h of exposure was required to reduce petal abscission[14].

The efficacy and the optimum concentration of sprayable 1-MCP were very cultivar-dependent. The response of 1-MCP did not completely inhibit petal abscission in two ethylene sensitive zonal and regal Pelargonium cultivars, such as *Pelargonium x hortonum* Bailey and Pelargonium x domesticum Bailey[14,69]. Application of sprayable 1-MCP in enclosed and open space were effective in reducing number of senescence leaves exhibited by leaf yellowing or browning. Ethylene-induced leaf yellowing was caused by chlorophyll degradation. Matile *et al.*[72], reported that ethylene accelerated chlorophyll degradation by enhancing the activation of chlorophyllase in conversion chlorophyll a and b to chlorophyllide and phytol. Generally, leaf hue and chroma were used for color change quantification from green to the initiation of yellowing[11,73]. High leaf chroma and low leaf hue indicates leaves yellowing, meanwhile the low chroma indicates that the leaves remain green[11]. Nevertheless, at the end phase senescence, the chroma decreased, leaving brown to yellow appearance in leaves. Therefore, the low value of leaf chroma may indicated not only green but also brown leaves. In general, consequence of 1-MCP application in cuttings was the increase of endogenous ethylene production. Reported by Kadner and Druege[13] showed that endogenous ethylene in Pelargonium cuttings increased as a response to the 1-MCP application. Another report also reported the increase of endogenous ethylene in citrus and coriander after 1-MCP application[74,75]. In vegetative tissue, 1-MCP application can act as a negative feedback control of ethylene production. The non-activation of the ethylene receptor would inhibit the down regulating action of ethylene and allow for uncontrolled ethylene synthesis[13]. In contrast, the application of 1-MCP in floret clearly decreases the production of endogenous ethylene. Seglie *et al.*[76] reported that the treatments 1-MCP and DPCA reduced the endogenous ethylene production in carnation[76]. So far, there was no clear explanation for these phenomenon but it was suggested that several factors such as flower maturity and the ratio of peduncle, sepal and petal may contributed to the production of endogenous ethylene as a response to 1-MCP application. Wue *et al.*[77] reported that the application of 1-MCP decreased endogenous ethylene production in petals but it increased endogenous ethylene production in sepal.

Recently, 1-MCP had been widely used for several tropical ornamental plants. 1-MCP prevents ethylene production during pollination and prevented senescence of the *Phalaenopsis* 'Herbert Hager' flower[46], promoted the quality characteristics of the highest water uptake, the best retention of anthocyanin content and the lowest browning appearance in *Curcuma aeruqinosa* and improved inflorescence longevity of the torch ginger *Etlingera elatior*[78]. Since 1-MCP was effective in improving post-harvest life of tropical ornamental plants it could be one of the potential compound to be applied as a post-harvest life quality preservation techniques of tropical ornamental plants.

CONCLUSION AND FUTURE PERSPECTIVE

Inhibition of ethylene biosynthesis and inhibition of ethylene perception are two methods to inhibit ethylene response. Volatile 1-MCP is one of the potential chemical compounds but the application was not simple. New 1-MCP formulation, sprayable1-MCP was more simple because it can be used in the field as a pre-harvest treatment. Therefore, sprayable 1-MCP is recommended as a more reliable compound to be used for ornamental plant especially for ornamental plant industry in the tropics.

SIGNIFICANCE STATEMENT

Ethylene is a plant hormone released to regulate physiological effect on ornamental plants. The presence of ethylene accelerate quality reduction in ornamental plants. Despite being one of the most effective ethylene-inhibiting compounds, 1-MCP has not been used widely for tropical ornamental plants. This review covers the potential application of 1-MCP recorded by researchers as a positive approach to minimize the obstacles that occurs in tropical ornamental plant industry.

REFERENCES

1. Abeles, F.B., P.W. Morgan and M.E. Saltveit, 1992. Ethylene in Plant Biology. 2nd Edn., Academic Press, Sandiego, CA., pp: 83-103.
2. Voesenek, L.A.C.J., M. Banga, J.H.G.M. Rijnders, E.J.W. Visser and F.J.M. Harren *et al*., 1997. Laser-driven photoacoustic spectroscopy: What we can do with it in flooding research. Ann. Bot., 79: 57-65.
3. Taiz, L. and E. Zeiger, 2002. Plant Physiology. 3rd Edn., Sinaur Associate, USA., pp: 520-525.
4. Campbell, N.A., J.B. Reece, L.A. Urry, M.L. Chain, S.A. Wasserman, P.V. Minorsky and R.P. Jackson, 2008. Biology. 8th Edn., The Benjamin/Cumming Publishing Company, USA., pp: 832-834.
5. Van Doorn, W.G., 2001. Categories of petal senescence and abscission: A re-evaluation. Ann. Bot., 87: 447-456.
6. Dole, J.M. and H.F. Wilkins, 2005. Floriculture: Principle and Species. 2nd Edn., Pearson/PrenticeHall, New Jersey, USA pp: 726-739.
7. Reid, M.S. and M.J. Wu, 1992. Ethylene and flower senescence. Plant Growth Regul., 11: 37-43.
8. Borochov, A. and W.R. Woodson, 1989. Physiology and biochemistry of flower petal senescence. Hortic. Rev., 11: 15-43.
9. Van Doorn, W.G. and E.J. Woltering, 2008. Physiology and molecular biology of petal senescence. J. Exp. Bot., 59: 453-480.
10. Rapaka, V.K., J.F. Faust, J.M. Dole and E.S. Runkle, 2008. Endogenous carbohydrate status affects postharvest ethylene sensitivity in relation to leaf senescence and adventitious root formation in *Pelargonium cuttings*. Postharvest Biol. Technol., 48: 272-282.
11. Mutui, T., H. Mibus and M. Serek, 2005. Effects of thidiazuron, ethylene, abscisic acid and dark storage on leaf yellowing and rooting of *Pelargonium* cuttings. J. Horticult. Sci. Biotechnol., 80: 543-550.
12. Carow, B. and K. Bahnemann, 1980. Einfluß von silbernitrat, kinetin und benzylaminopurin auf das vergilben von pelargonium-zonale-stecklingen/influence of silver nitrate, kinetin and benzylaminopurine on yellowing of pelargonium zonale cuttings. Die Gartenbauwissenschaft, 45: 273-278.
13. Kadner, R. and U. Druege, 2004. Role of ethylene action in ethylene production and poststorage leaf senescence and survival of pelargonium cuttings. Plant Growth Regul., 43: 187-196.
14. Jones, M.L., E.S. Kim and S.E. Newman, 2001. Role of ethylene and 1-MCP in flower development and petal abscission in zonal geraniums. HortScience, 36: 1305-1309.
15. Evensen, K.B., 1991. Ethylene responsiveness changes in *Pelargonium* x *domesticum* florets. Physiol. Plantarum, 82: 409-412.

16. Cameron, A.C. and M.S. Reid, 2001. 1-MCP blocks ethylene-induced petal abscission of *Pelargonium peltatum* but the effect is transient. Postharvest Biol. Technol., 22: 169-177.
17. Jackson, M.B., I.B. Morrow and D.J. Osborne, 1992. Abscission and dehiscence in the squirting cucumber, *Ecballium elaterium*. Regulation by ethylene. Canad. J. Bot., 50: 1465-1471.
18. Stead, A.D. and K.G. Moore, 1983. Studies on flower longevity in *Digitalis*. Planta, 157: 15-21.
19. Manning, K., 1985. The Ethylene Forming Enzyme System in Carnation owers. In: Ethylene and Plant Development, Roberts, J.A. and G.A. Tucker (Eds.)., Butterworths, Boston, pp: 83-92.
20. Peiser, G., 1986. Levels of 1-Aminocyclopropane-1-Carboxylic Acid (Acc) synthase activity, ACC and Acc-conjugate in cut carnation flowers during senescence. Acta Horticult., 181: 99-104.
21. Woodson, W.R., K.Y. Park, A. Drory, P.B. Larsen and H. Wang, 1992. Expression of ethylene biosynthetic pathway transcripts in senescing carnation flowers. Plant Physiol., 99: 526-532.
22. Larsen, P.B., E.N. Ashworth, M.L. Jones and W.R. Woodson, 1995. Pollination-induced ethylene in carnation (role of pollen tube growth and sexual compatibility). Plant Physiol., 108: 1405-1412.
23. Tang, X. and W.R. Woodson, 1996. Temporal and spatial expression of 1-aminocyclopropane-1-carboxylate oxidase mRNA following pollination of immature and mature petunia flowers. Plant Physiol., 112: 503-511.
24. Jones, M.L. and W.R. Woodson, 1999. Interorgan signaling following pollination in carnations. J. Am. Soc. Horticult. Sci., 124: 598-604.
25. Nooden, L.D., J.J. Guiamet and I. John, 1997. Senescence mechanisms. Physiol. Plant, 101: 746-753.
26. Jiang, H. and D.B. Egli, 1993. Shade induced changes in flower and pod number and flower and fruit abscission in soybean. Agron. J., 85: 221-225.
27. Wien, H.C., A.D. Turner and S.F. Yang, 1989. Hormonal basis for low light intensity-induced flower bud abscission of pepper. J. Am. Soc. Horticult. Sci. (USA), 114: 981-985.
28. Van Doorn, W.G. and A.D. Stead, 1997. Abscission of flowers and floral parts. J. Exp. Bot., 48: 821-837.
29. Serek, M., E.J. Woltering, E.C. Sisler, S. Frello and S. Sriskandarajah, 2006. Controlling ethylene responses in flowers at the receptor level. Biotechnol. Adv., 24: 368-381.
30. Serek, M. and M.S. Reid, 1993. Anti-ethylene treatments for potted *Christmas cactus*-efficacy of inhibitors of ethylene action and biosynthesis. HortScience, 28: 1180-1181.
31. Miranda, R.M. and W.H. Carlson, 1982. Chemical control of petal abscission in hybrids of Pelargonium x hortorum Baily 'Sprinter Scarlet'. Proceedings of the Tropical Region-American Society for Horticultural Science, Volume 25, October 3-9, 1982, American Society for Horticultural Science, pp: 241-252.
32. Furutani, S.C., E. Johnston and M. Nagao, 1989. Anthesis and abscission of blue jade vine flowers treated with ethephon and AOA. HortScience, 24: 1042-1042.
33. Dostal, D.L., N.H. Agnew, R.J. Gladon and J.L. Weigle, 1991. Ethylene, simulated shipping, STS and AOA affect corolla abscission of New Guinea impatiens. HortScience, 26: 47-49.
34. Ketsa, S. and A. Rugkong, 2000. Ethylene production, senescence and ethylene sensitivity of Dendrobium 'Pompadour' flowers following pollination. J. Horticult. Sci. Biotechnol., 75: 149-153.
35. Veen, H., 1983. Silver thiosulphate: An experimental tool in plant science. Scientia Horticult., 20: 211-224.
36. Purer, O. and S. Mayak, 1988. Postharvest treatments for improvement of the quality of pelargonium cuttings. Acta Horticult., 226: 591-596.
37. Serek, M., A. Prabucki, E.C. Sisler and A.S. Andersen, 1998. Inhibitors of ethylene action affect final quality and rooting of cuttings before and after storage. HortScience, 33: 153-155.
38. Davies, P.J., 2007. Plant Hormones Biosynthesis, Signal Transduction, Action. Kluwer Academic Publisher, London, UK., pp: 386-388.
39. Chapman, K.D. and S.A. Brown, 2007. Methods for extending the freshness of cut flowers, ornamental trees and plant cuttings. US Patent No. US 7,199,082 B1. USA.
40. Buanong, M., H. Mibus, E.C. Sisler and M. Serek, 2005. Efficacy of new inhibitors of ethylene perception in improvement of display quality of miniature potted roses (*Rosa hybrida* L.). Plant Growth Regul., 47: 29-38.
41. Blankenship, S.M. and J.M. Dole, 2003. 1-Methylcyclopropene: A review. Postharvest Biol. Technol., 28: 1-25.
42. DeEll, J., 2007. 1-MCP applied preharvestor posthar vestim proves the quality of 'Barlett' Pears. A news letter for commercial fruit grower. Ministry of Agriculture Food and Rural Affair Ontario, pp: 1-10.
43. Fuentes, M.J., 2008. Efecto de aplicaciones de 1-metilciclopropeno (1-MCP) en pre y postcosecha, sobre la madurez y desarrollo de Pardeamiento interno enmanzanas cv. Pinklady™. Universdad de Talca. http://dspace. utalca.cl/retrieve/16150/fuentes_fuentes.pdf
44. Mogia, C. and M. Pereria, 2008. Application of Harvista™ technology in apple. Pomaceas Tech. Bull., 8: 1-4.
45. Mubarok, S., M. Serek and V. Mussmann, 2011. Efficacy of new formulation of 1-methylcyclopropene for improving postharvest quality of pelargonium flower. Proceedings of the International Conference on Sustainable Agriculture and Food Security, September 27-28, 2011, Bandung, pp: 395-400.
46. Porat, R., A.H. Halevy, M. Serek and A. Borochov, 1995. An increase in ethylene sensitivity following pollination is the initial event triggering an increase in ethylene production and enhanced senescence of *Phalaenopsis orchid* flowers. Physiol. Plantarum, 93: 778-784.
47. Serek, M., E.C. Sisler and M.S. Reid, 1994. Novel gaseous ethylene binding inhibitor prevents ethylene effects in potted flowering plants. J. Am. Soc. Horticult. Sci., 119: 1230-1233.

48. Serek, M., E.C. Sisler and M.S. Reid, 1995. Ethylene and the postharvest performance of miniature roses. Acta Horticult., 424: 145-150.
49. Celikel, F.G., L.L. Dodge and M.S. Reid, 2002. Efficacy of 1-MCP (1-methylcyclopropene) and Promalin for extending the post-harvest life of Oriental lilies (*Lilium* X *Mona Lisa* and *Stargazer*). Sci. Hort., 93: 149-155.
50. Serek, M., E.C. Sisler and M.S. Reid, 1995. 1-Methylcyclopropene, a novel gaseous inhibitor of ethylene action, improves the life of fruits, cut flowers and potted plants. Acta Hort., 394: 337-346.
51. Serek, M. and M.S. Reid, 2000. Ethylene and postharvest performance of potted kalanchoe. Postharvest Biol. Technol., 18: 43-48.
52. Picchioni, G.A., M. Valenzuela-Vazquez and L.W. Murray, 2002. Calcium and 1-methylcyclopropene delay desiccation of *Lupinus havardii* cut racemes. HortScience, 37: 122-125.
53. Macnish, A.J., P.J. Hofman, D.C. Joyce, D.H. Simons and M.S. Reid, 2000. 1-Methylcyclopropene treatment efficacy in preventing ethylene perception in banana fruit and grevillea and waxflower flowers. Aust. J. Exp. Agric., 40: 471-481.
54. In, B.C., J. Strable and S.E. Patterson, 2015. Effects of 1-methylcyclopropene on flower senescence and petal abscission in *Dianthus caryophyllus* L. Horticult. Environ. Biotechnol., 56: 786-792.
55. Mubarok, S., 2011. 1-Methylcyclopropene for improving postharvest life of three hybrid cultivars of *Pelargonium zonale*. Proceeding of the National Seminar of Floriculture, (NSF'11), Indonesia, pp: 261-269.
56. Burana, C., T. Kurokura and K. Yamane, 2015. Short-term controlled atmosphere and 1-MCP effects on the vase life of cut flowers. Acta Hortic., 1071: 635-639.
57. Leatherwood, W.R., J.M. Dole, B.A. Bergmann and J.E. Faust, 2016. 1-Methylcyclopropene improves ethylene tolerance of unrooted herbaceous cuttings but delays adventitious root development in *Angelonia*, *Calibrachoa*, impatiens, *Portulaca*, *Sutera* and *Verbena* cultivars. HortScience, 51: 164-170.
58. Mubarok, 2012. Quality of cut flower of yellow Fiji as a respons of 1-Methylcyclopropene application. J. Agrivigor, 11: 244-250, (In Indonesian).
59. Hassan, F., 2005. Postharvest studies on some important flower crops. Ph.D. Thesis, Faculty of Horticultural Sciences, Corvinus University of Budapest, Hungary.
60. Leatherwood, W.R. and J. Dole, 2007. Ethylene sensitivity of unrooted cuttings from 28 genera and effectiveness of 1-MCP to prevent ethylene damage. American Floral Endowment, Special Research Report No. 433, Postharvest Physiology, USA.
61. Muller, R., M. Serek, E.C. Sisler and A.S. Andersen, 1997. Poststorage quality and rooting ability of *Epipremnum pinnatum* cuttings after treatment with ethylene action inhibitors. J. Horticult. Sci., 72: 445-452.
62. Serek, M., E.C. Sisler and M.S. Reid, 1995. Effects of 1-MCP on the vase life and ethylene response of cut flowers. Plant Growth Regul., 16: 93-97.
63. Valenzuela-Vazquez, M., G.A. Picchioni, L.W. Murray and W.A. Mackay, 2007. Beneficial role of 1-methylcyclopropene for cut *Lupinus havardii* racemes exposed to ethephon. HortScience, 42: 113-119.
64. Heyes, J.A. and J.W. Johnston, 1998. 1 methylcyclopropene extends *Cymbidium* orchid vaselife and prevents damaged pollinia from accelerating senescence. N. Zealand Crop Horticult. Sci., 26: 319-324.
65. Uthaichay, N., S. Ketsa and W.G. van Doorn, 2007. 1-MCP pretreatment prevents bud and flower abscission in *Dendrobium* orchids. Postharvest Biol. Technol., 43: 374-380.
66. Serek, M., E.C. Sisler, T. Tirosh and S. Mayak, 1995. 1-Methylcyclopropene prevents bud, flower and leaf abscission of Geraldton waxflower. Hort. Sci., 30: 1310-1310.
67. Seglie, L., K. Martina, M. Devecchi, C. Roggero, F. Trotta and V. Scariot, 2011. The effects of 1-MCP in cyclodextrin-based nanosponges to improve the vase life of *Dianthus caryophyllus* cut flowers. Postharvest Biol. Technol., 59: 200-205.
68. Serek, M. and E.C. Sisler, 2001. Efficacy of inhibitors of ethylene binding in improvement of the postharvest characteristics of potted flowering plants. Postharvest Biol. Technol., 23: 161-166.
69. Kim, H.J., R. Craig and K.M. Brown, 2007. Ethylene resistance of regal pelargonium is complemented but not replaced by 1-MCP. Postharvest Biol. Technol., 45: 66-72.
70. Afiifah, D., W. Sutari, Kusumiyati, E. Suminar and S. Mubarok, 2017. The effectiveness of 1-Methylcyclopropene (1-MCP) on the flower longevity of cut rose (*Rosa hybrid* Hort.). J. Kultivasi, 16: 293-297.
71. Mubarok, S., Nursuhud, E. Sumiar and V.R. Viola, 2018. Inhibition of ethylene effect on cut roses by modification of vase solution, 1-MCP and cytokinin. J. Iimu Pertanian indonesia, 23: 60-66.
72. Matile, P., S. Hortensteiner, H. Thomas and B. Krautler, 1996. Chlorophyll breakdown in senescent leaves. Plant Physiol., 112: 1403-1409.
73. Steet, J.A. and C.H. Tong, 1996. Degradation kinetics of green color and chlorophylls in peas by colorimetry and HPLC. J. Food Sci., 61: 924-928.
74. Zhong, G., M. Huberman, X.Q. Feng, E.C. Sisler, D. Holland and R. Goren, 2001. Effect of 1-methylcyclopropene on ethylene induced abscission in citrus. Physiol. Plant., 113: 134-141.

75. Jiang, W.B., Q. Sheng, X.J. Zhou, M.J. Zhang and X.J. Liu, 2002. Regulation of detached coriander leaf senescence by 1-methylcyclopropene and ethylene. Postharvest Biol. Technol., 26: 339-345.
76. Seglie, L., E.C. Sisler, H. Mibus and M. Serek, 2010. Use of a non-volatile 1-MCP formulation, N,N-dipropyl(1-cyclopropenylmethyl) amine, for improvement of postharvest quality of ornamental crops. Postharvest Biol. Technol., 56: 117-122.
77. Xue, J., L. Yunhui, H. Tan, F. Yang, N. Ma and J. Gao, 2008. Expression of ethylene biosynthetic and receptor genes in rose floral tissues during ethylene-enhanced flower opening. J. Exp. Bot., 59: 2161-2169.
78. Chutichudet, P., B. Chutichudet and K. Boontiang, 2010. Effect of 1-MCP fumigation on vase life and other postharvest qualities of siam tulip (*Curcuma aeruqinosa* Roxb.) cv. laddawan. Int. J. Agric. Res., 5: 1-10.