



Application of 1-Methylcyclopropene (1-MCP) for Delaying the Ripening of Banana: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author WMCBW designed the study and wrote the first draft of the manuscript. Authors CKB and GDKK managed to collect and included important literature to the manuscript. In addition, authors KHS and CAKD managed to improve the quality of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

1- Methylcyclopropene (1-MCP) has been identified as a safe chemical tested successfully in extending shelf life while maintaining quality of plant products. 1-MCP, at very low concentrations, usually blocks ethylene receptors and then inhibits the action of ethylene delaying further ripening and senescence. Several studies have been conducted elsewhere for delaying ripening of different banana cultivars such as *Cavendish*, *Prata*, *Tella Chakkerakeli*, *Beragan* and *Kolikuttu*. Physiological reactions related with ripening of banana are delayed by inhibition of ethylene perception, while ethylene synthesis of banana fruit can be regulated at suppressed levels of ACS and ACO by 1-MCP. The effectiveness of 1-MCP on bananas varies with the maturity of the fruit.

Fumigation, the conventional application method, has some limitations, particularly long exposure duration, uneven ripening and green ripening in bananas. Application of 1-MCP in aqueous form is recently developed to minimize these limitations. Micro-bubbling and controlled release packaging technologies are effective tools of application of 1-MCP on bananas. This review compiles and critically analyses the existing knowledge on the technological use of 1-MCP, clarifies inconsistencies in different publications.

Keywords: 1-methylcyclopropene; banana; ethylene; ripening; shelf life.

1. INTRODUCTION

Banana (*Musa acuminata* Colla) is a climacteric fruit crop and widely grown in tropical countries having a high consumer demand throughout the world. A major problem found in banana industry is high postharvest losses owing to its short postharvest life [1]. Ripening of banana is initiated either by endogenous ethylene which is evolved naturally when banana fruit reaches its full maturity stage or by using commercially available products which release ethylene gas.

Hence, altering ethylene production level and inhibitors for ethylene sensitivity are influential tools to elucidate the ethylene action in banana fruit ripening [2]. 1-methylcyclopropene (1-MCP) is found to be able to delay the ripening process of mature-green fruits. Use of 1-MCP is widely demonstrated in ripening of *Cavendish*, harvested at pre-climacteric stage [3]. As an ethylene blocker, 1-MCP hinders the ethylene effect on a wide variety of vegetables, fruits and ornamentals. It is stable at room temperature, active at very low levels of concentrations (2.5 nL/L–1µL/L), non-toxic as Generally Recognized As Safe (GRAS) compound recommended by United States Department of Agriculture (USDA). 1-MCP can regulate the ethylene synthesis of banana fruits at suppressed record levels of Aminocyclopropane-1-carboxylic acid synthase (ACS) and Aminocyclopropane carboxylate oxidase (ACO) genes. Simultaneously, it inhibits the ethylene sensitivity resulting delayed physiological changes of ripening [2].

Furthermore, the effect of 1-MCP on respiration, chlorophyll degradation, softness, diseases, disorders, acidity and sugar content has been studied in 16 horticultural produce [4]. Many research studies as mentioned in the paper have been carried out to prolong the banana shelf life around the world which has been conducted under diverse conditions for variety of cultivars. Further, different modes of application are used for 1-MCP treatment such as fumigation and aqueous form. The effect of 1-MCP on fruits

depends upon cultivar, maturity, concentration, temperature, duration and application technique, exposure and storage environment [5]. This article presents a critical review on application of 1-MCP in delaying the ripening of banana and its related postharvest qualities.

2. METHYLCYCLOPROPENE (1-MCP): GENERAL USE

Three generations of ethylene antagonists (2, 5-norbornadiene and its analogs, diazocyclopentadiene and cyclopropenes) that can effect on fruit ripening and senescence have been developed by Edward Sisler and coworkers [6]. Here, 1-Methylcyclopropene (1-MCP) among these cyclopropenes is so far the most effective ethylene inhibitor [7]. Buanong et al, [8] and Kebenei et al, [9] had also mentioned that although other cyclopropenes employ more inhibition of ethylene action than the methyl derivative, 1-MCP remains the cyclopropene of choice for suppressing ethylene responses for ease of use in case of easiness. 1-MCP is very effective odourless ethylene antagonist with 54.09 molecular weight, stable at room temperature and has a non-toxic mode of action, with low (< 0.1 ppm) measurable residues in fruits. Its chemical formula is C₄H₆. Several characteristics of 1-MCP such as, active at very low concentrations such as at levels of parts per billion, easily applicable gaseous molecule, a clear safety profile and not leaving residues in treated produce are reported in getting rapid approval from regulatory authorities around the world [10]. 1-MCP is currently used for sixteen horticulture products to extend the shelf life around the world [11].

1-MCP usually blocks ethylene receptors, thereby inhibits the ethylene reaction. When 1-MCP molecules bind to ethylene receptor sites, they do not allow the receptor to “unlock” like the ethylene molecule does. Therefore, further ripening action gets delayed because signal cannot be sent for a chemical reaction [12]. Approximately 100 µl/l or more of ethylene

concentration is needed to compete effectively due to greater attraction of 1-MCP for the ethylene receptor in fruits and rapid diffusion [4]. Yan et al, [13] also noted that, expression of genes related with the ethylene-signaling pathway of fruit ripening is blocked by the application of 1-MCP. Early research works conducted on 1-MCP with applied ethylene and/or endogenous ethylene have resulted that 1-MCP can protect the plant parts from any form of ethylene either endogenous or exogenous. But responses vary with commodity types. Sozzi and Beaudry, [14] have further elaborated that the efficacy of 1-MCP treatment on plant products depends on six main factors; genotype (species and cultivar) and ripening physiology, pre-harvest environmental conditions and practices, harvest maturity, treatment conditions, effect on susceptibility to pathological disorders, and the postharvest storage conditions.

1-MCP usually gives better results when applied at room temperature compared to cooling conditions for many fruit crops and it is applied at 20-25°C in most experiments. 1-MCP does not perform well at low temperature (5-10°C). This might be due to reduction of sensitivity to ethylene [15]. Golding et al, [16] mentioned that treatment with 1-MCP two days after initiation of ripening where autocatalytic ethylene production rises is effective in suppressing the ripening process. Jiang et al, [17] and Sisler & Serek, [7] also noted that if 1-MCP is applied within 24 h of ethylene treatment, ripening would be extended. The reduced ability of 1-MCP to contest for the receptors or availability of little amount of ethylene binding sites is the reason for this result. According to the USEPA, [18] the safety of usage, toxicity levels and environmental profiles of 1-MCP are extremely favorable with reference to both humans and animals and even with the environment. In addition, 1-MCP is applied at low rates. It's mode of action is non-toxic and similar in chemically to naturally occurring substances [19] and [20].

2.1 Commercial Application of 1-MCP on Plant Products

1-MCP is available in an encapsulated form in α -cyclodextrin (CD) and it is a highly volatile gas. Encapsulated 1-MCP gas molecules are usually released mixing in appropriate amount of water or KOH buffer [11] and [21]. 1-MCP is commercially available for applying to edible crops under the trade names of EthylBloc® and SmartFresh® which are approved for use in the

United States [22]. SmartFresh™ has been developed as two delivery systems; tablets (SmartTabs) or sachets containing the SmartFresh™ cyclodextrin powder [23]. EthylBloc® powder takes approximately 20–30 min to release 1-MCP at standard temperature and pressure and it might take a longer duration at low temperatures. Further, 1-MCP gas concentration in an air tight container filled with plant material drops with time and also around one third of the initial amount of gas leftovers in the container after 24 hrs at 5°C [24]. In addition to the application as fumigant, 1-MCP is also applied to plant products in aqueous form [25]. Early efforts to stop the premature fruit-drop by pre-harvest application of 1-MCP in a way of spraying or in gaseous form were not effective [26]. However, the 1-MCP formulation registered as Harvista™ which was developed by AgroFresh for pre harvest application has been allowed to be used in Chile, New Zealand, South Africa, and United States since 2014 [10].

2.2 Effective Concentrations of 1-MCP and Treatment Duration

The effect of 1-MCP concentrations varies with commodity type, exposure time, temperature and mode of application. Higher concentrations of 1-MCP normally result more effect on plant materials [24]. The degree of response on banana fruit to treatments of 1-MCP varies heavily on the interaction between 1-MCP concentration and exposure time. According to previous research, exposure time to 1-MCP varied from 12 to 24h, to be sufficient to obtain a complete response. Six hours of exposure time at 0.45 $\mu\text{l l}^{-1}$ concentration was not sufficient for inducing changes in respiration or in ethylene production [27]. A time/temperature relationship was also observed in broccoli as well as banana, where high concentrations of 1-MCP were required for reducing the treatment durations. Cultivar also needs to be considered [28]. According to Hagan et al, [25], 1-MCP can be applied in aqueous solutions too in the form of direct application on to the fruit. This will eliminate the requirement of having prolonged exposure of fruits in sealed environments, which is essential in gaseous treatments. This direct application needs only one minute of immersion in aqueous solution of 1-MCP in contrast to an exposure for 6 to 24 h in gaseous application.

3. APPLICATION of 1-MCP FOR BANANA

Table 1 presents details on previous studies conducted to determine the effect of 1-MCP on

banana. Golding et al, [29] mentioned that 1-MCP is an effective compound for preventing banana from ethylene effect. According to Silva et al, [30], 1-MCP is usually applied as a gaseous compound. 1-MCP inhibits the ethylene action and the ripening process through competitive inhibition of ethylene receptors in the plant tissues. Therefore, 1-MCP is considered as a potential compound to be used in controlling the ripening process and senescence of harvested banana fruits at commercial scale.

The fact that 1-MCP is able to delay the ripening process of banana which are mature-green and at pre-climacteric stage is clearly proven. Furthermore, the effect of exposure time, concentration levels and temperature dependency of the response are already being established [3]. Jiang et al, [17] mentioned that an exposure time of a 24 hrs duration to concentrations of either 500 or 1000 nL L⁻¹ of 1-MCP at 20°C has extended the green life of *Cavendish* bananas 16 to 31 days. Blankenship and Dole, [4] have mentioned that exposure time and concentrations of 1-MCP applied for banana are subsequently between 6 and 24 hours and ranging from 5 to 1000 nLL⁻¹. Nanthachai et al, [31] studied on absorption of 1-MCP for a range of produce including banana and discovered that the initial sorption rate correlated with fresh weight of fruit, dry matter content and insoluble dry matter content, and not with the soluble dry matter content. Silva et al, [32] have assured the fact that the changes in respiratory profile and color development linked with ripening of banana variety, *Prata* might be depending upon the functioning ethylene receptors. When treated with 1-MCP, certain interruptions have been identified in the biochemical changes which take place during normal ripening process of banana.

Some of these changes are uneven peel de-greening and reduced respiration rates. This might be due to the disruptions that takes place in the usual regulation of production of ethylene. Jiang et al, [17] further revealed that ethylene treatment on ripening of banana fruits treated with 1-MCP was enhanced with increasing time between 1-MCP and ethylene treatments due to synthesis of new ethylene-binding sites with time. In addition, associated shelf life extension of fruits can only be predicted at the earliest phase of ripening. Otherwise, there may be alternative ethylene binding sites, which may react differently with 1-MCP. Silva et al, [31] confirmed that 1-MCP had delayed the onset of the respiratory peak and inhibited the rate of carbon

dioxide production of *Prata* Banana. When 1-MCP had been applied at early maturity stage of banana fruit, it irreversibly had occupied the ethylene receptors.

Mainardi et al, [32] showed that banana ripening was clearly affected by the 1-MCP treatments. The climacteric rise in respiration was anticipated when banana fruits were exposed to exogenous ethylene, but when fruits were treated with 1-MCP, they did not show any increase in respiration, although an ethylene peak could be seen after 24 days. Kumar et al, [33] have studied the effect of 1-methylcyclopropane on economic shelf life of *Tella Chakkerakeli* banana fruits at ambient conditions (32 ± 2°C and 78 ± 2% RH). 1-MCP concentration of 400 ppb resulted minimum ethylene evolution rate, physiological loss in weight, pulp to peel ratio and maximum fruit firmness retention. Maximum shelf life of 16 days was recorded in *Tella Chakkerakeli* banana treated. Balasuriya et al, [34] had stated that shelf life can be extended by application of 1-MCP more than 6 days in unripe *Kolikuttu* bananas. Banana which were treated with 300 ppb 1-MCP for 24 h, achieved the shelf life of 14 days.

3.1 Effect of 1-MCP on Physico-Chemical Properties of Banana

Physiological changes that take place during ripening of banana fruits can be delayed by inhibiting ethylene perception. Simultaneously, ethylene synthesis can be regulated by 1-MCP at suppressed transcript levels of ACS and ACO genes [2]. 1-Methylcyclopropene can lengthen the postharvest quality of banana fruit by suspending the expression of ripening characteristics and senescence through surpassing the binding of ethylene to receptors followed by inhibiting ethylene signal transduction and downstream action [46]. The strongest effect of 1-MCP is on ethylene production. The rate of respiration was the least affected process in banana fruits. Further, the process of softening the tissues and the color changes in skin from green to yellow are considered as in between [3].

Sisler and Serek, [7] have noted that treatment of 1-MCP done before exposing into ethylene, inhibits changes associated with ripening showing the association of ethylene in fruit ripening. Pelayo et al, [49] also stated that 1-MCP binds with ethylene receptors irreversibly in order to hinder the ethylene-induced ripening.

Pathak et al, [50] also had reported on 1-MCP to have considerable effects on expression as well as on the enzymes involved in biosynthesis of ethylene during ripening of banana. Physiological changes related with ripening of banana can be delayed due to inhibition of ethylene sensitivity. Simultaneously, synthesis of ethylene in the fruit itself is able to be regulated by 1-MCP [2].

According to Jiang et al, [17], softening of green-mature banana fruit treated with 1-MCP is not activated by exogenous ethylene treatment, although fruits treated with 1-MCP depend upon synthesis of new ethylene binding sites. Lohani et al, [51] revealed that 1-MCP strongly limits inducing the Pectin Methyl Esterase (PME) activity of banana with ethylene when the fruits are treated with 1-MCP before applying ethylene due to inhibition of PME. Vilas-Boas and Kader, [36] observed that the fact when 1-MCP was applied to fresh cut bananas at low temperatures before storage, it is effective in controlling the softening induced by ethylene.

According to a study conducted by Abdalnoor, [24] 1-MCP treatment at 250 ppb significantly postponed the onset of the climacteric peak up to 20 days while untreated fruits reached the climacteric peak after 8 days at $18\pm 1^\circ\text{C}$ and 85-90% relative humidity. It was further reported that 1-MCP retarded the development of colour of peel and accumulation of total soluble solids (TSS), reduced softening of flesh and weight loss, and maintained ascorbic acid content during storage of banana fruits. Mubarok et al, [45] have observed that the application of 1-MCP prevents the change of TSS until 12 days of storage in mature green fruit, but the change of TSS occurred in mature fruits. The experiment, therefore suggest that TSS increased due to the initiation of fruit ripening in mature stage of banana. Because of inhibition of ethylene sensitivity in the receptor, 1-MCP suppress sugar accumulation, therefore the ripening of banana fruit was delayed. Unal et al, [43] as well as Pelayo et al, [3] had mentioned on the inconsistency of the effect of 1-MCP on activities of Polyphenol Oxidase (PPO) upon flesh part of the fruit. Although the activity of PPO on fruit peel increased within the whole period of storage

regardless of the fact of treating or not treating with 1-MCP, it was more than in control fruits compared to 1-MCP treated fruit peel. PPO causes enzymatic browning. 1-MCP treatment inhibited the total volatile production of fruit, and quantitatively, indicated lower ester concentrations [11].

3.2 Effect of 1-MCP on Pathway of Ethylene Biosynthesis of Banana

1-aminocyclopropane-1-carboxylic acid (ACC) plays a major role in the pathway of ethylene biosynthesis. In addition, synthesis of ethylene is determined by Aminocyclopropane-1-carboxylic acid synthase (ACS) and Aminocyclopropane carboxylate oxidase (ACO). These are the two main enzymes involved in the process of ethylene biosynthesis [52]. The ACS activity in pulp elevates to a higher level showing that ethylene production in banana fruit pulp activates banana ripening. The ACO mRNA also increases significantly in the peel at climacteric and post-climacteric stages [53]. The ethylene normally induces the ethylene climacteric in bananas by increasing ACO of banana fruits and further expressed that application of 1-MCP inhibits the ACO and ethylene synthesis. This inhibition suggests that 1-MCP also reduced the stimulatory influence of exogenous ethylene on ripening [54] and [55]. As banana ripening is from the inside out of fruit, the ACS activity first normally increases in pulp and then in the peel. Golding et al, [29] reported similar results suggesting that ethylene synthesis regulated by normal feedback might get blocked by 1-MCP and that the transcription of ACS in bananas may possibly be greater. An experiment conducted by Xu et al, [56] resulted that, once banana fruits are treated by 1-MCP with a concentration of $1.2 \mu\text{L l}^{-1}$, ACC content progressively raised while in storage within 15 days, but the value at peak was 1.88 times lower than the levels observed in fruits which were non-treated. Additionally, the peak value of ACO activity of 1-MCP treated banana fruits was 1.36 times lower than the levels observed in the fruits which were non-treated.

Table 1. Application of 1-MCP on different cultivars of banana

Reference	Cultivar	1-MCP treatment			Storage conditions	Shelf life
		Concentration	Exposure period	Mode of treatment		
[16]	Williams (<i>Musa spp</i> , AAA)	450 µL/L	6 h	Gas	20°C	34 days
[17]	Cavendish	0.5 or 1.0 µL/L	24 h	Gas	20°C and in sealed polyethylene	58 days
[35]	Williams (<i>Musa spp</i> , AAA) fruits harvested 71 days after bunch emerged	500nL/L	24 h	Gas	20°C	56 days
[3]	Cavendish (Partially ripe fruits)	1000 nL/L	6 or 24 h	Gas	14°C	6 days
[36]	Grand Nain banana (fresh cut)	1 µL/L	6 h	Gas	5°C	7 days
[2]	Zhonggang (<i>Musa spp</i> , AAA)	200 nL/L	24 h	Gas	20°C, 80-90% RH	20 days
[37]	Khai	250 ppb	24 h	Gas	20°C	20 days
[24]	Grand Nain	250 ppb	24 h	Gas	18±1°C	20 days
[38]	Cavendish (Partially ripe fruits)	0.63 ppm	6 h	Gas	Ambient	8 days
[39]	Bari Kola (<i>Musa spp</i> , AAA)	0.08 ppm/day	6 h			6 days
[39]	Bari Kola (<i>Musa spp</i> , AAA)	100 µL/L	5 min	Aqueous	20±2°C, 75-80% RH	35 days
[40]	Homthong, Khai	500	-	Aqueous	21±2°C	-
[41]	Rasthali (AAB), partially ripe banana fruits	1000 ppb	24 h	Gas	27±2°C, 65-75% RH	9 days
[34]	Kolikuttu	300 ppb	24 h	gas	Ambient	14 days
[42]	Cavendish	0.5g/30ml	24 h	Gas	28±1°C	15 days
[42]	Cavendish	0.5g/30ml 1-MCP and 2.5% Chitosan	24 h	Gas	28±1°C	20 days
[43]	Anamur	312.5 ppb	24 h	Gas	20°C	8 days
[25]	Falsehorn (<i>Musa paradisiacal</i> , AAB)	100 µL/L	1 min	Aqueous	15°C, 75% RH	21 days
[44]	Gros Michel	300 ppb	15 min	Aqueous	30°C, 75% RH	14 days
[33]	TellaChakkerakeli (<i>Musa paradisiaca</i> L.)	400 ppb	24 h	Gas	25°C, 75±2%	10 days
[33]	TellaChakkerakeli (<i>Musa paradisiaca</i> L.)	400 ppb	24 h	Gas	32±2°C, 78±2% RH	16 days
[45]	Muli	0.25 µL/L	6 h	Gas	20±2°C , 80% RH	12 days

Reference	Cultivar	1-MCP treatment			Storage conditions	Shelf life
		Concentration	Exposure period	Mode of treatment		
[46]	Lakatan	400 nL/L	20 h	Gas	26-28°C, 78-86% RH	16 days
[47]	Kandula	0.5 ppm	6 h	Gas	14±1°C, 85-90% RH	29 days
[48]	Ambul	1 ppm	18 h	Gas	29±5°C, 66±7% RH	19 days

3.3 Use of Modified Atmosphere (MA) Packaging for 1-MCP Treated Banana

Modified atmosphere (MA) packaging is a useful technology adaptable to a variety of fruits and vegetables, as well as banana. Commercially, in MA packaging, clusters or hands of banana fruit are packed in to a corrugated box which contains a polyethylene liner in the shape of a bag. The ethylene absorbent is also kept inside this bag [17]. The shelf life of banana was reported to have extended by 58 days when the fruits were packed and sealed in the polyethylene bags including 0.5 or 1.0 1/1 1- MCP. Golding et al, [16] have reported that fruits stored in polyethylene bags after 1-MCP treatment are able to ripen as in normal pathway with no ethephon treatment given thereafter and have the capacity to produce some aroma volatiles as well. According to Silva et al, [30], the postharvest life of fruits stored under refrigerated conditions is able to be attained even under ambient conditions when fruits are packed under modified atmospheric conditions. But, generally what is expected as benefits of MA packaging with ethylene scrubbers are restricted by the fact of rising of temperature within the packaging which will adversely effect on quality and shelf life of fruits. In addition, too low O₂ levels result anaerobic respiration situation. However, this limitation can be eliminated with 1-MCP.

3.4 Problems Associated with Banana Treated with 1-MCP

Uneven skin degreening on treated 1-MCP fruits and early stage of fruit ripening have been reported because of variations in the rate of synthesizing new ethylene binding sites at different locations of the fruit. The tissues in peel and pulp areas of the fruit perform differently in evolving ethylene as well as in responding to ethylene [57]. According to Golding et al, [16] and by Jiang et al, [17], *Cavendish* banana showed delays in peel colour development and unevenness in ripening when the fruits were treated with 1-MCP at the stage of matured green. However, the same was not reported with bananas of *Berangan* cultivar. Harris et al, [35] had reported that differences in maturity of fruit were the reason for this unevenness in ripening observed in *Cavendish* banana. The effect of 1-MCP application on bananas is greatly influenced by different factors. Some of them are type of cultivar, the stage of fruit maturity, previous exposures to ethylene, conditions in cultivations and the capacity of the fruit to

ultimately ripen. When 1-MCP treated banana are stored in polyethylene bags, fruits will become ripe due to generation of new ethylene receptors under this condition [17]. Even though 1-MCP application on banana has been proved for delaying the ripening and maintaining the fruit quality, varying responses for its effects in limiting the commercialization of 1-MCP application for bananas have been observed [38].

3.5 Factors Affecting Application of 1-MCP on Banana at Commercial Scale

According to Golding et al, [16], the partially interrupted ripening actions in treated bananas may limit the use of 1-MCP commercially that indicates the combined role of ethylene in ripening. Furthermore, Harris et al, [35] had reported that due to the uneven color development, 1-MCP had limited potential in commercial level and this issue was aggravated due to the fact of having different maturities in fruits in open market. According to Bagnato et al. [58] although high 1- MCP concentrations inhibit banana ripening, fruit decay increased. Ripening can be delayed by reduced concentrations of 300nl l⁻¹ but changing of firmness, color, soluble solid content and aroma profiles showed similar to untreated fruits. According to Pelayo et al, [17], unevenness of the reactions of banana fruits which are partially ripe makes it less potential to be used commercially. In addition, the color and volatile production can be inhibited, when fruits are treated with 1-MCP. But inception of ethylene as well as rate of respiration are not affected. All the processes are inhibited by treating 1-MCP to pre-climacteric fruits [16].

3.6 Effect of Banana Fruit Maturity on 1-MCP Treatment

Maturity of banana fruit is one of major consideration in determining the behavior towards 1-MCP. When applying 1-MCP, developmental stage of fruits should be considered as effect varies with maturity [35]. Presence of a strong interaction of 1-MCP and its effectiveness with varying fruit maturity was also reported by [17]. When fruits were harvested at progressing stages of maturity from 71 to 156 - 173 days after emerging the banana bunch, ripening was more effectively delayed by a 1-MCP treatment with 500 nL l⁻¹ concentration at 20°C with an exposure time of 24 hrs duration. And the exact time for ripening of banana

subjected to a continuous flowing air current with ethylene at $0.1 \mu\text{l}^{-1}$ concentration and at 20°C had reduced from 40 to 28 days. Harris et al, [35] revealed that the green life of banana fruits of least mature bunch showed significantly higher levels of 56 days than banana fruits treated with 1-MCP. This is due to varying effectiveness of 1-MCP with different fruit maturity levels. At commercial applications mixed maturity among fruit bunches is very common. Furthermore, the less matured fruits which were continuously exposed to air free of either ethylene nor 1-MCP took an extended time to ripen than highly matured bunches. It further demonstrated the effect of 1-MCP in extending the postharvest life of banana to significantly differ with varying fruit maturity. Banana fruits harvested at late stage generally show a lower response to 1-MCP applications. When 1-MCP is applied during the climacteric period of banana, 1-MCP incompletely forms bonds with the ethylene receptors and does not act inhibitory to endogenous production of ethylene [59].

According to the Mubarok et al, [45], the effect of 1-MCP is usually determined upon the stage of fruit maturity. After climacteric stage, ethylene biosynthesis process come to the peak and also the ethylene is bound to receptor. Hence, 1-MCP application to mature fruits cannot totally inhibit the ethylene action. Different responses to 1-MCP treatment have been showed by banana hands obtained from upper, middle and bottom of the bunch. This is in agreement with Moradinezhad et al, [60] who exhibited that different variation in responses to 1-MCP depend on placement of fruits in the bunch itself as well. Furthermore, according to [7], Young banana hands consist of low number of receptors saturated with minute concentrations of 1-MCP which cause to inhibit the ripening process. Due to this saturation and less number of receptors, any ethylene exogenously applied is unable to bind further more. As stated by Bagnato et al, [58] when 1-MCP is applied to fruits which are immature, ripening will completely get inhibited.

4. MICROBUBBLE (MB) TECHNOLOGY FOR 1-MCP TREATMENTS

According to Golding et al, [7], confirmed by Harris et al, [35], fumigation of banana with 1-MCP, the conventional application method, is having many drawbacks, particularly, long exposure time durations, uneven ripening patterns, less or no peel colour development leaving green unchanged even after ripening.

The main reason for this was to have less and varying contacts of 1-MCP with the fruit surface. Thus, the application of an aqueous solution of 1-MCP was observed in minimizing limitations of fumigation which is the conventional method. As mentioned by Choi and Huber [61], studies have revealed that 1-MCP in aqueous form exhibited an increased capacities to be used in controlling the fruit ripening process of climacteric fruit. Under normal conditions, 1-MCP has limited solubility in water. Therefore, a relatively higher concentration should be used when aqueous form of 1-MCP is applied. Pongprasert and Srilaong, [62] revealed that application of 1-MCP using MB is an easy and rapid technology of inhibiting banana fruit ripening. It might have the potential to be applied for other fruits as well when fumigation facility is less available.

5. CONTROLLED RELEASE PACKAGING TECHNOLOGY

Controlled release packaging (CRP) is a new technology that is known to be used to transfer antioxidants and antimicrobials from the active packaging layer. This technology can be further used for delivery of ethylene antagonist to delay the banana ripening. CRP system is a very effective tool to maintain the yellow life of bananas when they are delivered in packaging to non-banana producing countries. Then, 1-MCP can work as an active compound for delaying ethylene induced fruit ripening [38]. Study conducted by Lee et al, [63] has reported on package sachets that can release 1-MCP. Hotchkiss et al, [64] have also stated about release of 1-MCP from different heat pressed polymer films.

6. CONCLUSION

The finding and application of 1-MCP have developed into a turning point in horticulture postharvest sector of fruit and vegetables to inhibit the primary activities that comprise in fruit ripening and senescence. 1-MCP has been found as an effective chemical for avoiding banana from the effects of ethylene. Scientists have performed experiments of 1-MCP application on more than 20 banana cultivars. The efficacy of 1-MCP treatment on banana fruits is determined by different factors such as concentration, exposure time, cultivar harvest maturity and postharvest storage conditions. Although 1-MCP is mainly applied as a fumigant, treatment can be performed in aqueous to plant products form. 1-MCP is able to regulate at levels

of ACS and ACO in ethylene biosynthesis pathway of banana. This delays many physiological reactions and alterations related to ripening of banana. Uneven skin degreening of banana fruits was seen with 1-MCP treatment and early stage of fruit ripening have been reported in commercial applications. Microbubbling technology and controlled release packaging are used to enhance the efficacy of 1-MCP and avoid some problems associate with treatments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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