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Dynamic controlled atmosphere storage technique by means of chlorophyll fluorescence extends storage life of Chokanan mango

(Teknik penyimpanan atmosfera terkawal dinamik secara klorofil floresens memanjangkan hayat simpanan mangga Chokanan)

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Abstract

Dynamic controlled atmosphere (DCA) storage technique is a new variation of controlled atmosphere (CA) technique, allowing more extreme O_2 setting through the application of a non-destructive monitoring system to assess low-oxygen stress. One of the commercial monitoring systems used for this purpose is by utilizing chlorophyll fluorescence. The present study was carried out to evaluate the effects of DCA on storage life and quality of Chokanan mango in comparison with conventional or static CA (SCA) and air (control). In general, there were statistically significant differences in all parameters measured from all storage conditions, with DCA exerting the most distinctive effects. DCA has resulted in significantly decreased respiration rate during storage, consequently delaying the ripening process as well as disease development. Therefore, there was a longer storage life; DCA-stored fruits could be kept up to 7 weeks without risking losses due to anaerobic conditions compared to only 5 and 3 weeks for SCA and air-stored fruits, respectively. Nevertheless, a slight acidity retention after ripening warranted a fine-tuning of this technique to ensure that the storage life extension by DCA would not come at the expense of the flavour profile of Chokanan mango.

Keywords: anaerobic compensation point, low oxygen limit, climacteric, ripening, stress

Introduction

Controlled atmosphere (CA) storage technique involves keeping fresh produce, especially fruits in an atmospheric composition that is different from air composition, typically by reducing oxygen (O_2) and increasing carbon dioxide (CO_2) (Thompson, 2010). CA storage has been long used to prolong storage life of fruits by lowering their respiration rate since storage life increases when respiration rate decreases. In the conventional static CA (SCA), O_2 is maintained at a pre-determined safe level throughout a storage period, far above the anaerobic compensation point (ACP) where O_2 consumption and CO_2 production is minimal (Boersig et al. 1988).

The need for the lowest possible O_2 levels tolerated by fruit to maximize the CA benefits has resulted in the development of dynamic controlled atmosphere (DCA). In DCA, the O_2 level is set at the lowest safe

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level by monitoring the lowest oxygen limit (LOL) tolerated by fruits during the entire storage period. LOL is closely associated with ACP. Currently, LOL during storage can be monitored by using chlorophyll fluorescence (CF), respiration quotient (RQ) and ethanol (ET) (Mditshwa et al. 2018). The most successful approach to date is based on monitoring the chlorophyll fluorescence changes (Stephens and Tenner 2005; Mditshwa et al. 2018). As the O_2 level in the storage decreases below LOL, the chlorophylls in the fruit skin emit a fluorescence, which then is captured by the sensors as a signal that O_2 is below LOL. In response, the O_2 level can be increased to just above the stress point. Hence, the atmosphere in DCA changes (dynamic) according to the fruit metabolism rather than being static throughout storage as in conventional CA (Prange et al. 2012; Raffo et al. 2009). Commercial application of chlorophyll fluorescence based-DCA has been limited to apple and pear storage. Likewise, most of the published DCA research has been done on these fruits (Prange et al. 2012). Collective finding on DCA research and application on apple has been recently reviewed by Mditshwa et al. (2018). To the best of our knowledge, there is yet published DCA research on tropical fruits. To this end, the present study was carried out to evaluate the possible application of chlorophyll fluorescence based-DCA in extending the storage life and maintaining the quality of one of the most popular tropical fruits, mango.

In Malaysia, Chokanan is one of the widely grown mango cultivars. Nevertheless, Chokanan mango has inherently short storage and shelf life; it can only last for three weeks when stored at 13 ºC and only a few days at ambient temperature (Wan Reza et al. 2007; Ahmad Tarmizi et al. 1996). Longer storage life is needed to allow sufficient time for transporting and marketing the fruits to distant markets; and to ensure a prolonged availability even during the off-season as mangoes are seasonal.

Chokanan mangoes showed a positive response to storage under low O_2 atmosphere as reported by Shukor et al. (2000) and Wimonwat et al. (2003); they can extend their storage life by about 1 week longer in conventional CA than those stored in air. Further longer storage life is needed to make sure that the benefits obtained from the CA application outweigh the costs which are relatively high. In this paper, the effects of DCA via chlorophyll fluorescence on storage life and quality of Chokanan mango are discussed.

Materials and methods

Sample preparation

Chokanan mangoes at the mature green stage were purchased from a commercial farm in Bidor, Perak and were brought to postharvest laboratory in MARDI Serdang on the same day. The mature green fruits were picked out based on the fruit shape (fullness of the cheeks), which indicated the age of the fruit: an estimation of 11 weeks after fruit set (Ahmad Tarmizi and Pauziah 2005). After an overnight precooling in cold room at 13 °C, the fruits were sorted for uniform size, shape and maturity. The fruits were washed in tap water without sanitation treatment, air-dried and packed in corrugated fibre board prior to experimental treatment.

Experimental treatment

The boxes containing the fruit samples were placed in gas-tight cabinets, in which three boxes were allocated for each cabinet. They were subjected to three different atmosphere compositions at a temperature of 13 °C for up to eight weeks: air (control), static CA (SCA), and dynamic CA (DCA). The setting and control of different combination of gases (O_2, CO_2 and N_2) were done by using an automatic CA control system (ICA Storage Ltd, UK). The air and SCA composition were set at 21% O_2 + 0.03% CO_2 and 2% O_2 + 5% CO_2 respectively. The combination of O_2 and CO_2 for the SCA treatment was

selected according to a previous study by Shukor et al. (2000) which identified the optimum atmosphere composition for the SCA storage of Chokanan mango.

The DCA composition was set according to the fruit's fluorescence response to low oxygen stress, implemented by using HarvestWatch System™ (Satlantic Inc., Halifax, N.S., Canada). For LOL monitoring by chlorophyll fluorescence (F-α), a sample of six fruits was placed in a small container equipped with Fluorescence Interactive Response Monitor (FIRM) sensors on its upper side. The containers were put inside the CA cabinet. The real-time monitoring was done at hourly basis throughout the entire storage period, and the oxygen level was changed according to the method recommended by Prange et al. (2007).

The experiment was laid out in a completely random design (CRD) with three replications. Each replicate was represented by a box which contained 18 fruits. Each fruit weighed approximately 250 – 300 g. In order to promote uniform ripening, the fruits were subjected to ethylene treatment at 200 mg/L upon removal from the storage, and subsequently transferred to ambient temperature (25 °C) to simulate the commercial shelf life.

Evaluation of physical, physiological and chemical changes

The evaluations were done on one-week interval, immediately upon fruits removal from storage, and when the fruits ripened under ambient conditions. The parameters measured were respiration rate, ethylene production rate, total soluble solid (TSS), total titratable acidity (TTA), ascorbic acid, flesh firmness, skin and flesh colour, disease development, and ethanol, acetaldehyde and ethyl acetate content.

Respiration and ethylene production

The respiration and ethylene production rate of fruit was measured by using a gas chromatography (GC) Perkin Elmer Autosystem. The fruits were weighed and placed in an airtight jar (1 L) at ambient temperature. They were capped for one hour to accumulate any emitted gas. Subsequently, 1 mL gas samples were withdrawn from the headspace of the jar by inserting a syringe through a fitted septum into the GC. The respiration rate was expressed as mL/kg/hr whereas the ethylene production rate was expressed as μl/kg/hr.

Total soluble solids, total titratable acidity and ascorbic acid content

The samples for these analyses were blended using a kitchen blender. The total soluble solids (TSS) of the pulp were determined directly from the puree of fresh fruit samples using a digital refractometer (Atago Model DBX -55, Japan). The results were recorded in ^{o}Brix. For the total titratable acidity, 5 g of blended pulp samples were mixed with 20 mL distilled water and then titrated against 0.1 M NaOH as the titrametric indicator until the pH reading by a pH meter (Microprocessor pH meter pH 2112/HANNA, USA) reached pH 8.1. The results were expressed as % citric acid using the following equation: (Titre (mL) × citric acid multiplication factor × 100)/20 mL. The multiplication factor for citric acid was 0.0064, where 1 mL 0.1 M NaOH was equivalent to 0.0064 g citric acid. The citric acid level plays a significant role in determining the acidity of a mango (Medlicott and Thompson 1985). The ascorbic acid was determined by extracting 10 g of blended pulp sample in 100 mL metaphosphoric acid (HPO_3), and the extract was filtered through a Whatman no. 1 filter paper. A 10 mL volume from the filtered solution was determined volumetrically with the 2 – 6 dichlorophenol-indophenol (DCPIP) reagent until a slightly pink colouration was observed and persisted for 15 s (Ranganna 1977). The results were expressed in mg/100 g fruit sample using the following equation: Titre (mL) × DCPIP standard factor × dilution (100/5) × 100%.

Flesh Firmness determination
The fruits were cut into half and the firmness was measured on the top, middle and bottom region of the fruit flesh for each fruit. A texture analyzer machine (Stable Micro Systems, UK) with 5 mm diameter stainless steel probe was used for measurement. The flesh firmness was expressed in Newton (N), indicated by the maximum value recorded by the probe while penetrating the flesh to a 10 mm depth.

Skin and flesh colour determination
The skin and flesh colour of the individual fruit was determined by using reflectance colorimeter (model CR-400, Minolta, Japan). The reading was taken at each point from the top to bottom of each fruit. The data were presented in terms of colour space L*, a*, b*, hue angle (Hº) and chroma (C*) values. Generally, L* indicates lightness, where the values range from completely opaque (0) to completely transparent (100); a* indicates greenness and b* indicates yellowness on the hue-circle. The hue angle [H° = arctan (b*/a*)] describes the relative amount of greenness and yellowness, of which 90° indicates that the colour is more to yellow and 180° indicates that the colour is more to green. On the other hand, chroma [C* = (a*2 + b*2)1/2] defines the saturation or intensity of colour (McGuire 1992; Voss 1992).

Disease development
Disease development was determined by counting the fruit that showed anthracnose symptoms in relation to the total amount of fruits from each sample. Anthracnose, caused by Colletotrichum gloeosporioides, is one of the most serious postharvest diseases of mango fruits (Onyeani and Amusa, 2013). The assessment was done on each fruit using a 1 – 4 severity scale; 1 = No symptom; 2 = Slight; 3 = Moderate; 4 = Severe, as defined by Nor Hanis Aifaa and Suhanna (2015) with some modifications.

Ethanol and acetaldehyde content
Ethanol and acetaldehyde content in the pulp was measured by gas chromatography using the headspace technique outlined by Davis and Chase (1969). Approximately 5 g of blended pulp were deposited in 25 mL glass vials and incubated in a water bath at 60 °C for one hour. A headspace sample was taken with a 1 mL glass syringe to measure the ethanol and acetaldehyde concentrations using the HP5890A gas chromatograph equipped with a flame ionization detector (at 250 °C) and a glass column (2 mm × 1.0 m) containing 5% Carbowax on 60/80 Carbopack as a stationary phase (at 85 °C).

Statistical analysis
The data were subjected to one-way analysis of variance (ANOVA) using GLM (General Linear Models) procedures. The mean separation was done by using Duncan Multiple Range Analysis (DMRT) for the minimum significant difference at $p \leq 0.05$ (SAS Institute Inc. 1994).

Results and discussion
Chlorophyll fluorescence changes
The chlorophyll fluorescence signal indicating the fruits' response to low O_2 stress as well as the subsequent stress-release conditions is represented in *Figure 1*. A spike in F-α value was observed once the fruits were exposed to O_2 below the critical value (0.6%). The F-α spike could be associated with acidosis taking place in the chloroplast as a result of insufficient ATP production due the low O_2 stress condition (Prange et al. 2005). When the stress was reduced by increasing the O_2 concentration to 0.7%, the F-α value was restored to its previous base level. Therefore, the O_2 level at 0.7% was used in the DCA composition. On the other hand, the CO_2 level was set at 1.4%, which was twice as much O_2 level based on the findings from a preliminary experiment in which the ratio of 1 O_2 : 2 CO_2 was the best DCA composition for Chokanan mango (Data not shown).

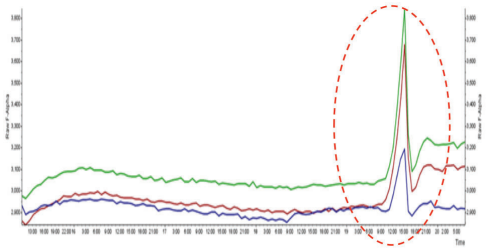

Figure 1. Chlorophyll fluorescence signal (Fα) increased (in circle) indicating that the fruit is under low O_2 stress

Respiration and ethylene production rate

It has been well documented that reduced O_2 and/or elevated CO_2 promote substantial reduction in respiration and ethylene production rates of fruits and vegetables (Kader 1986). As anticipated, similar result was obtained in the present study. The extremely low O_2 level in DCA storage resulted in lower respiration rate in fruits (*Figure 2*). In *Figure 2*, the Day 0 at shelf life referred to the fruits upon removal from three weeks of storage whereas Day one to four referred to the subsequent days at ambient temperature. Upon removal, the DCA-stored fruits showed the significantly lowest respiration rate whereas the CA-stored fruits showed an intermediate, and air-stored fruits showed the highest respiration rate, with about two-fold difference between each storage condition. Regardless of the storage condition, all fruits had a notable increase in respiration rate after one day being withdrawn from the cold storage, suggesting a climacteric rise since mango is a climacteric fruit characterized by an increased respiration and ethylene production during ripening (Sivakumar et al. 2011). Among the treatments, air-stored fruits showed the greatest magnitude of increase in respiration rate. On the other hand, a post-storage suppression in respiration rate was observed in both SCA and DCA-stored fruit. This suppression suggested the presence of a residual inhibitory effect as a consequence of prior exposure to low O_2; similar observation was also reported by Shukor et al. (2000) on Chokanan mangoes stored in 2, 5 and 10% O_2.

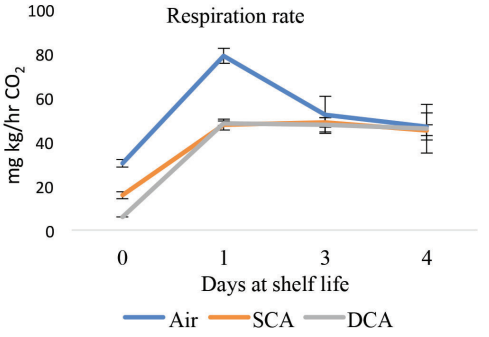

Figure 2. Respiration rate (ml kg/hr CO_2) of Chokanan mango after 3 weeks of storage and subsequent ripening at ambient temperature. Bars represent standard error

No significant ethylene burst was observed in the fruits irrespective to the storage condition since there was high deviation in ethylene production within the same group (*Table 1*). Since the ethylene gas sampling was done only once a day throughout the shelf life, and that the gas might have been released at different time for different individual fruits, there was a high deviation among replicates. Nevertheless, it is noteworthy that ethylene was not detected from the fruits removed from the DCA storage until three days of shelf life, suggesting that the ethylene production was also suppressed by the extremely low O_2 in DCA.

Table 1. Ethylene production rate (μl kg/hr CO_2) of Chokanan mango after three weeks of storage and subsequent ripening at ambient temperature. Means followed by letters within respective storage period are significantly different (p <0.05).

Storage condition	Days at ambient			
	0	1	3	4
Air	0.24 a	0.56 a	0.91 a	0.91 a
SCA	1.01 a	0.00 a	0.77 a	0.58 a
DCA	0.00 a	0.00 a	1.74 a	1.68 a

Ethanol and acetaldehyde

Lowering O_2 below its threshold point could induce the anaerobic respiration to maintain the fruit's energy supply (Kader 1986; Weichmann 1987), prompting an increase in CO2 production and accumulation of ethanol and acateldehyde, and eventually resulting in off-flavours and tissue breakdown (Kubo et al. 1996; Golias et al. 2008). Ethanol is produced in mangoes not only under anaerobic metabolism, but also during ripening process (Bender et al. 2000). Our result showed that there was a considerably high accumulation of acetaldehyde and ethanol production in the flesh of DCA-stored fruit (*Table 2A*). Whether this accumulation is caused by anaerobic respiration may not be known at this time. However, it was likely that a transient accumulation occurred after the fruits were kept in the gas-tight cabinet for several weeks. These products declined to the level similar to that of the air-stored fruits when the fruits ripened at ambient condition (*Table 2B*). In addition to that, the CO_2 level remained at a very minimal level in DCA throughout the storage period, and there was no indication of skin discoloration, greyish flesh and abnormal flavor development, all of which was a typical condition of mangoes affected by anaerobic metabolism. Therefore, we ruled out the possibility that the aerobic respiration was shifted to anaerobic respiration in DCA-stored fruits.

Table 2. Chemical changes (TSS, TTA, TSS:TTA, ascorbic acid, ethanol and aldehyde content); colour changes (skin and flesh hue); firmness and disease severity of Chokanan mango fruit upon removal from storage (A) and after ripen at ambient (B). Means followed by letters within respective storage period are significantly different (p <0.05).

(A)

Storage period / Storage condition	Week 0	Week 3	Week 5	Week 7
Total Soluble Solid – TSS (Brixº)				
Air	9.16 a	13.37 a	-	-
SCA	9.16 a	14.20 a	12.3 a	-
DCA	9.16 a	12.63 a	13.4 a	16.1
Total Titratable Acidity – TTA (%)				
Air	1.02 a	0.48 b	-	-
SCA	1.02 a	0.68 b	0.30 b	
DCA	1.02 a	0.92 a	0.77 a	0.51
TSS : TTA ratio				
Air	9.08 a	28.13 a	-	-
SCA	9.08 a	21.33 ba	41.50 a	-
DCA	9.08 a	13.81 b	18.11 b	32.6
Ascorbic acid (mg/100g fresh weight)				
Air	37.02 a	28.66 a	-	-
SCA	37.02 a	30.07 a	25.4 a	-
DCA	37.02 a	29.25 a	27.29 a	28.11
Ethanol (mg/L)				
Air	1.03 a	28.6 b	-	-
SCA	1.03 a	93.6 a	83.5 a	-
DCA	1.03 a	235.5 a	112.9 a	137.6

(B)

Storage period / Storage condition	Week 0	Week 3	Week 5	Week 7
Total Soluble Solid – TSS (Brixº)				
Air	17.97 a	14.23 a	-	-
SCA	17.97 a	13.43 a	12.53 a	-
DCA	17.97 a	14.23 a	12.53 a	14.9
Total Titratable Acidity – TTA (%)				
Air	0.5 a	0.25 b	-	-
SCA	0.5 a	0.30 ba	0.22 b	-
DCA	0.5 a	0.35 a	0.37 a	0.41
TSS : TTA ratio				
Air	88.33 a	57.52 a	-	-
SCA	88.33 a	45.16 b	66.24 a	-
DCA	88.33 a	38.64 b	33.63 b	36.42
Ascorbic acid (mg/100g fresh weight)				
Air	12.38 a	10.16 ba	-	-
SCA	12.38 a	6.89 b	8.07 b	-
DCA	12.38 a	12.34 a	10.97 a	9.19
Ethanol (mg/L)				
Air	1.43 a	81.09 a	-	-
SCA	1.43 a	71.86 a	93.21 a	-
DCA	1.43 a	95.87 a	90.62 a	86.69

(Cont.)

Table 2. Cont.

Storage period / Storage condition	Week 0	Week 3	Week 5	Week 7
Acetaldehyde (mg/L)				
Air	3.07 a	1.92 b	-	-
SCA	3.07 a	1.97 b	1.07 a	-
DCA	3.07 a	5.63 a	3.79 a	3.69
Skin Colour (Hue°)[1]				
Air	116.07 a	94.28 c	-	-
SCA	116.07 a	109.87 b	92.69 b	-
DCA	116.07 a	115.58 a	111.86 a	105.85
Flesh Colour (Hue°)[1]				
Air	97.81 a	92.97 b	-	-
SCA	97.81 a	95.83 a	93.38 b	-
DCA	97.81 a	97.35 a	96.57 a	95.89
Firmness (N)				
Air	100.7 a	6.09 b	-	-
SCA	100.7 a	53.29 a	28.11 b	-
DCA	100.7 a	58.58 a	40.27 a	21.72
Disease severity score[2]				
Air	1.0 a	1.08 a	-	-
SCA	1.0 a	1.00 b	1.8 a	-
DCA2	1.0 a	1.00 b	1.3 b	1.3

Storage period / Storage condition	Week 0	Week 3	Week 5	Week 7
Acetaldehyde (mg/L)				
Air	0.95 a	1.37 a	-	-
SCA	0.95 a	1.61 a	0.74 a	-
DCA	0.95 a	1.37 a	0.55 a	0.78
Skin Colour (Hue°)[1]				
Air	81.5 a	89.51 a	-	-
SCA	81.5 a	89.61 a	86.42 b	-
DCA	81.5 a	92.26 a	86.85 b	85.55
Flesh Colour (Hue°)[1]				
Air	85.5 a	92.22 a	-	-
SCA	85.5 a	92.66 a	91.64 a	-
DCA	85.5 a	92.54 a	93.04 a	93.32
Firmness (N)				
Air	9.46 a	3.96 b	-	-
SCA	9.46 a	5.81 ba	5.23 b	-
DCA	9.46 a	6.32 a	6.51 a	5.16
Disease severity score[2]				
Air	1.0 a	2.08 a	-	-
SCA	1.0 a	1.50 b	2.23 a	-
DCA2	1.0 a	1.19 b	1.27 b	1.97

[1]Skin and Flesh Hue°: Generally, higher hue° indicates more green
[2]Disease severity score: 1 = No symptom; 2 = Slight; 3 = Moderate; 4 = Severe

Ripening and quality

In line with respiratory activity, the ripening process was most delayed in DCA-stored fruits followed by SCA and air-stored fruits. Low O_2 generally resulted in the inhibition of expression of senescence-related genes, which in turn delayed the loss of chlorophyll, slowed down the activities of cell wall degrading enzymes that caused fruit softening, slowed down starch conversion to sugar that reduced the loss of acidity, and enhanced the retention of ascorbic acid (Kader 1986). These physico-chemical changes are shown in *Table 2A*. The storage conditions significantly affected all parameters, except for TSS and ascorbic acid content. The fruits under DCA clearly retained the colour of skin and flesh the most, especially starting from three weeks until ripened as indicated by the higher H°. Likewise, the DCA-stored fruits retained its firmness better than others did. Intriguingly, at week three of storage, the firmness of air-stored fruit remarkable dropped, suggesting a ripening-induced softening. The TTA also remained higher in DCA-fruits throughout the storage. TTA is a measurement of fruit acidity based on the presence of organic acids (Medlicott and Thompson 1985), with citric and malic acids being the major acids present in mangoes and mostly other ripe fruits (Seymour et al. 1993). Considering the fact that organic acids are the substrates for fruit respiration (Fagundes et al. 2013), higher acidity retention in DCA-stored fruits could be linked to the low O_2 level that influences respiration rate.

While delaying ripening is always the main goal in storing fruits under the low O_2 storage, obtaining a good organoleptic quality upon transfer to air is of prime importance. The quality of fruits is normally attributed to the combination of good appearance, especially color, texture, flavor and nutritive value (Kader 2001), which can be achieved by a perfect ripening process. Despite the ripening suppression during storage, DCA and SCA-stored fruits were able to undergo the compositional changes upon transfer to air. Nevertheless, the changes took place at a slower pace with a smaller magnitude than that of the air-stored fruits (*Table 2B*). Note that there was still obvious acidity retention in DCA-fruits even after being transferred to air. Unlike TSS, which attained similar level with other treatments, no concomitant decrease in TTA has resulted in lower TSS:TTA ratio in DCA-stored fruit. The TSS:TTA ratio generally reflects sugar to acid ratio, suggesting that the fruits are less sweet even though they contain high TSS (Khaliq et al. 2016). TSS is correlated to the degradation of cell walls and hydrolysis of starch to sucrose whereas TTA is associated with the respiration process which uses the organic acid as a substrate, possibly contributing to declining fruit acidity (Hossain et al. 2014). The constant low respiration rate of DCA-stored fruits during the storage persisted even after ripening, possibly explaining the high retention of acidity in the fruits.

Apart from low O_2 itself, slower ripening in DCA-stored fruits can be linked to high accumulation of ethanol and acetaldehyde. According to Beaulieu et al. (1997), acetaldehyde, which is a result of conversion of ethanol, may be involved in fruit ripening delay. This was supported by Burdon et al. (1996) whom showed that acetaldehyde was capable of inhibiting the activity of ACC oxidase, an enzyme implicated in ethylene production in mango, consequently suggesting a possible mechanism for ripening delay (Burdon et al. 1996).

Disease incidence and severity

Apart from fast ripening, disease incidence is another major limiting factor of mango storage life. Anthracnose, caused by Colletotrichum gloeosporioides, is one of the most serious postharvest diseases of mango fruits (Onyeani and Amusa 2013). The pathogen infects immature fruits and remains latent until storage and ripening during which time lesions progressively appear (Dodd et al. 1989). Chokanan mangoes which were treated with 250 ppm propiconazole prior to regular air storage at 13 °C demonstrated severe anthracnose disease incidence after four weeks of storage, hence limiting its storage life to up to three weeks only (Wan Reza et al. 2007). Likewise, in the present study, severe anthracnose symptoms were observed in the air-stored fruits on week four of storage. On the other hand, the DCA-stored fruits had significantly lower incidence and severity of anthracnose disease; slight symptoms only first appeared on week seven of storage (*Table 2A*), and the disease only became severe on week eight. Meanwhile, severe anthracnose symptoms were observed in SCA-stored fruits on week six of storage. Therefore, the disease severity coupled with senescence rendered the air-stored fruits to possibly be kept to up to three weeks whereas the SCA and DCA-stored fruits could be kept up to five and seven weeks, respectively. The capability of the lower O_2 level in delaying disease incidence can be explained by the fact that pathogen respirates as fruits do; hence, lowering O_2 can suppress the pathogenic growth in the host (Makino and Hirata 1997). Another possible mechanism is that the slower ripening process in low O_2 storage result in concomitant disease symptoms suppression. This could be attributed to the fact that anthracnose is a latent infection; it is initially dormant in unripe fruits until it is triggered by the dramatic physiological changes, such as ripening, in turn inducing its reactivation of infection and eventual symptoms on the fruits (Coates and Johnson

1997). In previous studies, CA coupled with pre-storage treatment of prochloraz, benomyl or hot water suppressed disease incidence in Nam Dok Mai (Kramchote et al. 2008), Rad (Kim et al. 2007); and Tommy Atkins mangoes (Noomhorm and Tiasuwan 1995), respectively.

Conclusion

In conclusion, the Chokanan mangoes showed positive responses to storage under DCA because DCA-stored fruits could be kept up to seven weeks compared to only five and three weeks for SCA and air-stored fruits, respectively. The results were brought about by a significant reduction of respiration rate, slow ripening process and delayed disease incidence during storage, and these processes persisted even after the transfer to ambient air. However, a slow metabolic process has resulted in a residual inhibitory effect since the increase in TTS did not occur with a concomitant decrease in TTA, resulting in relatively high acidity retention in DCA-stored fruit. Consequently, the fruit flavor might be adversely affected to an extent. Further fine-tuning is necessary to optimize the DCA implementation on Chokanan mangoes to overcome such problem so that extending storage life would not come at the expense of flavour profile.

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Abstrak

Teknik penyimpanan atmosfera terkawal dinamik (DCA) merupakan satu variasi teknik kawalan atmosfera (CA) yang membolehkan paras oksigen (O_2) ekstrem rendah diaplikasi dalam penyimpanan buah-buahan. Ia dilengkapi dengan sistem pemantauan yang menilai tekanan O_2 rendah sepanjang simpanan, iaitu salah satu kaedah yang digunakan secara komersial adalah dengan menggunakan konsep *chlorophyll fluorescence*. Berbanding dengan DCA, paras O_2 dalam CA konvensional sekadar ditetapkan pada tahap minimum selamat sepanjang tempoh penyimpanan, yang ternyata lebih tinggi daripada keperluan optimum. Kajian ini dijalankan untuk menilai kesan DCA terhadap hayat simpanan dan kualiti mangga mangga Chokanan. Mangga yang dituai pada peringkat hijau matang komersial yang telah disimpan dalam tiga keadaan yang berlainan komposisi atmosferanya iaitu DCA, SCA atau udara biasa (kawalan) pada suhu 13 °C selama tujuh minggu. Komposisi DCA ditetapkan pada 0.7% O_2 + 1.4% CO_2 berdasarkan isyarat klorofil floresen cence terhadap tekanan O_2 yang rendah, manakala SCA dan penyimpanan udara biasa masing-masing ditetapkan pada paras 2% O_2 + 5% CO_2 dan 21% O_2 + 0.03% CO_2. Parameter fisiologi dan kualiti buah diukur dengan serta-merta selepas buah dikeluarkan daripada penyimpanan diikuti setelah buah masak pada suhu ambien. Secara umum, terdapat perbezaan signifikan dalam semua parameter yang diukur ke atas semua keadaan penyimpanan, iaitu DCA memberi kesan yang paling tersendiri. Tahap O_2 yang sangat rendah dalam DCA telah menyebabkan kadar respirasi menurun secara drastik semasa penyimpanan. Pada masa yang sama, ia menyebabkan peningkatan ketara dalam asetaldehid dan etanol. Walau bagaimanapun, kedua-dua sebatian tersebut kembali kepada paras normal setelah dipindahkan ke suhu ambien. Selari dengan kadar respirasi, proses pemasakan dilambatkan dalam buah-buahan yang disimpan oleh DCA, yang ditunjukkan oleh perubahan perlahan dari segi warna kulit dan isi; ketegaran isi, jumlah pepejal terlarut (TSS) dan jumlah keasidan boleh titrat (TTA) semasa penyimpanan. Selain itu, buah-buahan yang disimpan dalam DCA mempunyai tahap keterukan penyakit antraknos yang lebih rendah. Ini menyumbang kepada hayat simpanan yang lebih lama, yang mana buah-buahan yang disimpan DCA dapat bertahan sehingga tujuh minggu, berbanding dengan hanya lima dan tiga minggu untuk SCA dan buah-buahan yang disimpan dalam udara biasa. Walaupun pemasakan tertangguh

semasa penyimpanan, buah-buahan yang disimpan DCA bagaimanapun boleh masak selepas dipindahkan ke suhu ambien, tetapi pada kadar yang agak perlahan. Walau bagaimanapun, pengekalan keasidan yang lebih tinggi selepas masak dalam buah-buahan yang disimpan DCA mungkin menjejaskan kualiti pemakanannya. Secara umumnya, teknik DCA dapat memanjangkan hayat simpanan Chokanan mangga jauh lebih baik daripada teknik SCA konvensional serta simpanan dalam udara biasa; dengan melambatkan pemasakan dan kerosakan buah tanpa menyebabkan risiko keadaan anaerobik. Walau bagaimanapun, kajian lanjut diperlukan untuk memastikan bahawa hayat simpanan panjang yang diperolehi melalui aplikasi DCA tidak menjejaskan kualiti pemakanan mangga Chokanan.