

QUALITY OF RIPE TREE-DROPPED “MUSANG KING” DURIAN AS AFFECTED BY LOW OXYGEN STORAGE

Wan Mohd Reza Ikwana, W.H.*, Mohamad Fikkri, A.H., Tham, S.L.
Horticulture Research Centre MARDI,
MARDI Headquarters,
Persiaran MARDI-UPM, 43400 Serdang, Selangor, Malaysia.
Email: wanreza@mardi.gov.my

ABSTRACT

Controlled atmosphere (CA) storage technique involves keeping fresh produce especially fruits in atmospheric composition that is different from air composition, typically by reducing oxygen (O₂) and increasing carbon dioxide (CO₂). The present study was carried out to evaluate the effects of low-O₂ atmosphere on storage life and quality of tree-dropped ripe Musang King durian (D197). Tree-dropped ripe Musang King durian has a short storage and shelf life; it only can last for two weeks when stored at 7°C and only a couple of days at ambient temperature. Longer storage life is needed to allow sufficient time for marketing of the fruit to distant market. Tree-dropped Musang King durian fruits were subjected to storage under five different O₂ level, namely 21% (control), 1%, 2%, 3%, or 4%, whereas CO₂ was set at 0.03 % in all treatments. Storage was done at 7°C for up to 4 weeks. Parameters measured were total soluble solid (TSS), total titratable acidity (TTA), pulp colour, disease expression as well as fermentative volatiles compound (ethanol, acetaldehyde and ethyl acetate) content. In general, there were significant differences in fruits stored under low-O₂ atmosphere (1% to 4% O₂) and regular air (21% O₂) storage, particularly in disease incidence and physical appearance. Low-O₂ atmosphere completely suppressed disease incidence and fruit dehiscence throughout storage period. On the other hand, storage under regular air resulted in a severe disease on the entire external husk upon 3 weeks of storage. Judging from both external and internal quality, fruits stored under 1-4% O₂ can be kept up to 3 weeks, compared to only 2 weeks for 21% O₂-stored fruits. In spite of that, the lowest O₂ level (1%) prompted a considerable increase in ethyl acetate content which left a slight inferior taste in the aril after 2 weeks of storage, suggesting an anaerobic fermentation taking place. This suggests that 2% is the lowest tolerable O₂ level for tree-dropped Musang King durian. On the other hand, there were no significant difference in TSS, TTA and colour of the aril between low-O₂ atmosphere and regular air storage. Taken together, storage under low-O₂ atmosphere, particularly 2-4% could extend storage life of tree-dropped ripe Musang King durian a week longer than that of regular air (21% + 0.03%) by suppressing disease incidence and maintaining a good external appearance. Nevertheless, it appears that low-O₂ atmosphere was unable to exert considerable effects on the fruits' internal quality attributes, likely due to the fact that the ripening process has already progressed in the tree-dropped fruit. Hence, this warrant another investigation on early maturity stages of Musang King durian in response to low-O₂ storage.

Key words: controlled atmosphere, anaerobic, storage life, postharvest, carbon dioxide

INTRODUCTION

Malaysia is one of the top global producer and exporter of durian with ± 350,000 MT production and USD 43,251,841 export value. Malaysian durian has been exported to 18 countries, whereby the traditional markets are Singapore (49%), China (36%) and Hong Kong (12%) (Safari et al., 2018).

A total of 204 registered durian clones has been registered in Malaysia (Department of Agriculture Malaysia, 2019). Currently, one of the leading clone especially for export market is D197 or commercially known as “Musang King”. Malaysia was granted full market access for fresh and processed durian products to Singapore and Hong Kong. However, only frozen whole fruit, pulp and paste durian are allowed for the China market (Safari et al., 2018). The sales are projected to increase if China allows Malaysia to export durian in the fresh fruit form (Malaysia Quarantine and Inspection Services, 2018). Typically, in Malaysia durian is harvested when it naturally fall off the tree upon ripening. Tree-dropped ripe Musang King durian has inherent short shelf life; it can only last for 2-3 days at ambient temperature. On the other hand, its optimum storage temperature was found to be 7°C, whereby it can be stored for 14 days (Nur Azlin et al., 2019). While shelf life is not an issue when the tree-dropped ripe fruits are processed into frozen whole fruits, it has been a major challenge for fresh durian for distribution to distant market and long storage during fruit glut. One of the effective postharvest techniques to prolong shelf life and storage life of fruits is through storage atmosphere manipulation, as a supplemental treatment for cold storage.

Controlled atmosphere (CA) storage technique involves keeping fresh produce especially fruits in atmospheric composition that is different from air composition, typically by reducing oxygen (O₂) and increasing carbon dioxide (CO₂) (Thompson, 2010). In general, storage within optimum range of low O₂ atmosphere reduce respiration rate, reduce ethylene production and delay disease expression, and delay ripening in fruits, thus extend their storage life (Kader, 1986). On the other hand, outside this range respiration and ethylene production rates can be stimulated indicating a stress response, which can contribute to incidence of physiological disorders and increased susceptibility to decay (Kader, 2003b). The effects of low oxygen and/or elevated CO₂ on the physiology of fruit and vegetables have been extensively researched and demonstrated (Kader, 2003b; Brecht, 1980; Thompson, 2010).

Tropical fruits such as banana, mango, avocado, and papaya have been reported to respond to CA to a varying degree (Spalding, 1974; Kader, A.A., 1977). For durian, only a few researches on CA have been reported. Kader, (2003a) reported that optimum gas combination for durian is 3-5% O₂ + 5-15% CO₂ under storage at 12-20°C. Khunprom, (2007) reported that durian var Monthong stored at 15°C under 5-7.5 percent O₂ atmosphere prolonged the storage life of durian by 21 days longer than that in normal air (14 days). Virtually all research on low O₂ CA storage has been focusing on fruits harvested at pre-climacteric phase, and durian is no exception. The response of the ripe durian fruits which are naturally fall off the tree towards low O₂ storage is unknown. Therefore, the present investigation examines the effects of low O₂ storage on physiology, quality and sensory attributes of Musang King durian

MATERIALS AND METHOD

Sample preparation

Ripe "Musang King" durian fruits which are naturally fall off the tree were harvested from a commercial farm in Batu Pahat Johor. In this farm, each tree was equipped with a net underneath the tree to prevent fruits from falling directly to the ground. The collected fruits were immediately delivered to MARDI Postharvest Complex in Serdang Selangor where treatments and experimental procedures were conducted, which took 3 hours by using an open-air truck. Upon arrival, fruits were immediately precooled in cold room at 7°C. After overnight, fruits were sorted for uniform size and freedom from visual defect, and they were placed in corrugated fibre box prior to experimental treatment.

Experimental treatment

The boxes containing the fruit samples were placed in gas-tight cabinets, in which 3 boxes were allocated for each cabinet. They were subjected to 5 different level of O₂ up to 4 weeks namely 21% O₂ + 0.03% CO₂ (Control); 1% O₂ + 0.03% CO₂; 2% O₂ + 0.03% CO₂; 3% O₂ + 0.03% CO₂; 4% O₂ + 0.03% CO₂. The experiment was laid out in a complete randomized design (CRD) with three replications. Each replicate was represented by a box which consists of 4 fruits.

Evaluation of physical, physiological and chemical changes

Evaluations were done at weekly interval, immediately upon fruits removal from storage. Parameters measured were respiration rate, ethylene production rate, total soluble solid (TSS), total titratable acidity (TTA), pulp colour, disease expression, ethanol, acetaldehyde and ethyl acetate content.

Total soluble solids and total titratable acidity

Samples for these analyses were blended using a kitchen blender. 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 °Brix. For total titratable acidity, 5g of blended pulp samples were mixed with 20 ml distilled water and then titrated against 0.1 M Sodium Hydroxide NaOH as titrametric indicator until pH reading by pH meter (Microprocessor pH meter pH 2112/HANNA, USA) reach up to pH 8.1. The results were expressed as % citric acid as this acid is one of the most important organic acids in durian in along with malic, citric, tartaric and succinic acids (Voon et al., 2006)

Pulp colour determination

Pulp colour of individual fruit was determined by using reflectance colorimeter (model CR-400, Minolta, Japan). Data were presented in terms of colour space L*, a*, b*, hue angle (H°) and chroma (C*) values. Generally, L* indicates lightness, where 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 amounts of greenness and yellowness, in which 90° tells the colour is more to yellow and 180° indicates the colour is more to green. On the other hand, Chroma [C* = (a*² + b*²)^{1/2}] defines saturation or intensity of color (McGuire 1992).

Husk dehiscence score

Husk dehiscence was assessed by estimating the proportion of each locule open. Generally 0, 1, 2, 3, and 4 = no dehiscence, 25%, 50%, 75%, and 100%, respectively)

Disease development score

Disease development was determined by estimating the proportion of disease spread on fruits. Generally 0, 1, 2, 3, and 4 = no disease symptom, 25%, 50%, 75%, and 100%, respectively)

Ethanol, acetaldehyde and ethyl acetate content

Ethanol, acetaldehyde and ethyl acetate content in the pulp were measured by gas chromatography using the headspace technique according to method by Davis and Chase (1969). An approximately 5 g of blended pulp were deposited in 25 mL glass vials and were incubated in a water bath at 60°C for 1 hour. A headspace sample was taken with a 1 ml glass syringe for measurement of ethanol and acetaldehyde concentrations using an 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).

Respiration and ethylene production

Respiration and ethylene production rate of fruit were measured by using a gas chromatography (GC) Perkin Elmer Autosystem. Fruits were weighed and placed in an airtight jar (15L) at ambient temperature. They were capped for 1 hour to accumulate any emitted gas. Subsequently, 1 ml gas samples were withdrawn from the headspace of 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,

Statistical analysis

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

RESULTS AND DISCUSSION

Low O₂ suppressed disease expression and husk dehiscence, but did not affect other physical appearance

Most postharvest diseases in fruits are associated with fungi, either as primary invaders or secondary infection by infecting through wounds and cracks caused by insect, injuries and natural dehiscence of the fruit surface (Warrington, 2020). Mostly, important and common postharvest disease in Malaysian durian are caused by *Rhizopus artocarpus* Racib (Johnston, 1960), *Phytophthora palmivora* Butler (Lim and Chan 1986) and *Sclerotium rolfsii* (Lim & Sijam, 1989). In this present study, low-O₂ atmosphere completely suppressed disease incidence up to 4 weeks of storage indicated by no disease symptom observed on fruits stored under 1-4% O₂ (Table 1). On the other hand, storage under 21% O₂ resulted in a severe disease symptom characterized by white thick mycelial strands of the fungus, which likely caused by *Sclerotium rolfsii* (Figure 1). According to Lim and Sijam (1989), *Sclerotium rolfsii* is not a natural host of *S. rolfsii*. However, once its fruits became detached and fell on the ground where the fungus was present, infection of the fruit occurred especially under warm and moist conditions. Since the fruit samples in this study fell on the net and did not directly touch the ground, verification is needed to determine the causal agent of this disease. The disease symptom was first appeared during 3 weeks of storage specifically on the abscised surface of peduncle, which further spread to the entire external husk at the end of storage which rendered the fruits stored in air (21% O₂) could only last for 3 weeks. The effects of low O₂ on retardation of fungus growth are well documented. The O₂ and CO₂ can provide possibility either by affecting the metabolism of microorganism in storage or affecting metabolism of fruit and vegetable and can therefore be a factor in controlling them (Thompson, 2010).

Fruits stored in 21% O₂ were also found to be prone to husk dehiscence more than low-O₂ stored fruits (Table 1). The dehiscence score was significantly highest in the 21% O₂-stored fruits indicating 2 to 3 locules dehisced from the styler end progress about a quarter through to the stem end. This could be a result of high endogenous ethylene and CO₂ production in the husk of fruits stored under normal air (Booncherm and Siripinach, 1991; Wongs-aree & Noichinda, 2014). Apart from internal gas composition factor, water loss and subsequent shrinkage, may also induce husk dehiscence by providing a natural force to pull the fruit open (Sriyook et al., 1994). However, considering the fact that all fruits regardless of treatments were stored in gas-tight cabinet with 99% RH without weight loss, the water loss effects on the husk dehiscence can be ruled out in this present study. Furthermore, ethylene was found to have a greater effect than water loss on fruit dehiscence (Sriyook et al., 1994).

There was no significant difference in the pulp colour of fruits stored under different O₂ level, indicated by negligible difference in b* value. b* indicates yellowness on the hue-circle (McGuire 1992). Dark yellow and orange colour of durian pulp is a result of the carotenoids accumulation, mainly in the form of β -carotene (Wisutiamonkul et al., 2017; Barreto et al., 2011). Musang King was reportedly to have second highest carotenoid content after "Black Thorn", followed by "Red Prawn" and "IOI" durian (Tan et al., 2020). In mature durian, ripening process resulted in 30% increase in carotenoid throughout storage (Wisutiamonkul et al., 2017). However, in full ripe durian, the increase in carotenoid is not anticipated. The pulp colour remain unchanged even after they reached the storage life limit.

Judging from physical appearance of external husk, internal husk and pulp, it can be suggested that fruits stored under 1-4% O₂ can be kept up to 3 weeks, compared to only 2 weeks for 21% O₂-stored fruits. At maximum storage life (3 weeks), fruits stored under 1-4% O₂ still exhibited acceptable internal quality but tremendous quality deterioration was observed when compared with their initial quality at harvest (Figure 1). Beyond their respective storage life limit, fruits stored in 21% O₂ as well as in low O₂ exhibited senescence symptoms characterized such as red lesion on the internal husk starting from stem-end; browning at the base of the pulp that attach to the fruit axis; and pulp become watery (Figure 1). It appears that low-O₂ atmosphere was unable to exert considerable effects on the fruits' internal quality attributes, likely due to the fact that the ripening process has already progressed in the tree-dropped fruit.

Low O₂ reduce respiration rate but did not affect ethylene production

It has been well documented that reduced O₂ level can substantially lower down respiration and ethylene production rates of fruits and vegetables (Kader, 1986). This can be clearly seen in Figure 2 which illustrates the effect of different low O₂ levels on respiration rate during storage. In this study, gas analysis for respiration and ethylene production rate was done one-off upon removal of fruits from cold storage weekly, without holding them at ambient temperature for subsequent daily gas sampling during shelf life, because the fruits are fully ripe and would not be able to last for extra days after storage. Overall, fruits stored under low O₂ regardless of level had significantly lower respiration rate; about 2-fold lower than that of storage in air (21% O₂). This is in agreement with Tongdee et al. (1990) who reported that respiration and ethylene production rate of Monthong durian fruit stored under reduced O₂ at 2%, 5%, and 7.5% did not change much and remained at a pre-climacteric rate. For ethylene production, no significant difference was observed among all treatments. This might be due to the fact that the fruits in this study are at full ripe stage when they fall off the tree, and only produced ethylene at very minimum level. In addition, ethylene gas sampling was done one-off upon removal and the gas might have been given off at different time for different individual fruits, thus resulting in high deviation among replicates. Despite being a climacteric fruit (Tongdee et al. 1990), no characteristic climacteric pattern in respiration and ethylene production was exhibited in all durian in this present study, even in the fruits stored in air (21% O₂), suggesting the climacteric phase in tree-dropped ripe durian fruit has already passed. In addition, respiration rate and climacteric peak of durian is dependent on fruit maturity; they increase with maturity and decline when fruits start to ripen (Tongdee and Suwanagul, 1988).

Low O₂ level did not affect total soluble solid and total titratable acidity

Low O₂ generally resulted in inhibition of expression of senescence related genes, which in turn delaying loss of chlorophyll, slow down activity of cell wall degrading enzymes that cause fruit softening, slow down starch conversion to sugar reduce loss of acidity, as well as enhance retention of ascorbic acid (Kader, 1986). However, this does not necessarily apply to fruits harvested at fully ripe stage under similar storage condition. The effects of low O₂ level on total soluble solid (TSS) and total titratable acidity (TTA) were shown in the Figure 3. It was found that there was no significant difference in TSS throughout storage. The TSS value at harvest was 43% and it shows slight decreasing trend during storage irrespective of treatments. This could be due to increase in moisture content in pulp that diluted the water and soluble solid solution. TSS is refractometric index that indicates the proportion (%) of dissolved solids in a solution mainly sugar (Beckles, 2012). Sucrose is the predominant sugar in durian pulp, followed by glucose, fructose and maltose (Voon et al., 2006)

TTA also did not differ among treatments despite significant difference in respiration as discussed above. TTA is typically correlated with respiration rate as fruits use organic acid as energy substrate (Moreau and Romani, 1982). Malic, citric, tartaric and succinic acids are found to be most important organic acid in durian (Voon et al., 2006). No difference in TTA despite large difference in respiration between fruits stored in air and fruits stored under reduced O₂ may be explained by the fact that mostly metabolic process in durian is taking place in the husk not in the pulp (Booncherm and Siripanich, 1991) and TTA was only measured in the pulp. In general, there was no difference in pH value among treatment, but there was slight difference during 3rd week of storage whereby fruits stored in 1% and 4% O₂ had higher pH than the air (Figure 3). However, the difference could be negligible since it is still in the range.

1% O₂ induce higher accumulation of ethyl acetate

Lowering O₂ below its threshold point could induce anaerobic respiration in order to maintain the fruit's energy supply (Kader, 1986), prompting an increase in compounds such as acetaldehyde, ethanol and ethyl acetate, which is indicative of fermentative metabolism are toxic substances, causing physiological disorders and could result in off-flavours (Pedreschi et al., 2009). Figure 4 presents the accumulation of three compounds related to anaerobic respiration namely ethanol, acetaldehyde and ethyl acetate. The lowest O₂ level (1%) prompted a considerable increase in ethyl acetate content. They recorded the highest ethyl acetate level after 2 weeks of storage (17.65 ppm). The level remained constant until the end of storage. Other low O₂ level treatments resulted half as much (6-9%) of the former and did not differ much with air (21% O₂) storage. This is supportive of sensory evaluation finding (Table 2) which found that the panelists did not prefer fruits stored in 1% O₂ due to a slight inferior taste in pulp after 2 weeks of storage, suggesting an anaerobic fermentation took place. Based on the remarks by panelists, the inferior taste was characterized by gassy and alcoholic taste which is not favourable. Therefore, this suggests that 2% is the lowest tolerable O₂ level for tree-dropped Musang King durian. According to Chawengkijwanich et al. (2008), ethyl acetate along with ethyl propanoate and ethanol were the most abundant compounds emitted by mature durian "Monthong" pulp, but it present only in small amount when fruits ripen. The rise in ethyl acetate in ripe durian during storage in this present study, suggest a fermentative metabolism stress. For ethanol and acetaldehyde, no significant difference was observed among the treatments. This is in agreement with Voon et al. (2007) that ethanol and 1-butanol which are initially present in durian did not change significantly throughout storage of minimally processed D24 durian. Alcohols typically make a small contribution to flavour unless they present in relatively high concentration or if they are unsaturated (Heath and Reineccius, 1986). This may explain why ethanol compounds present in this study did not affect flavor perception in sensory evaluation (Table 2). Instead, inferior taste characterized by alcohol note was most probably due to the high content of ethyl acetate as reported by Voon et al. (2007)

CONCLUSION

Storage under low- O₂ atmosphere, particularly 2-4% could extend storage life of tree-dropped ripe Musang King durian a week longer than that of regular air (21% + 0.03%) by suppressing disease expression, delaying husk dehiscence and maintaining a good physical appearance, without risk of anaerobic respiration. Nevertheless, it appears that low- O₂ atmosphere was unable to exert maximum effects on the fruits' internal quality attributes, likely due to the fact that the ripening process has already progressed in the tree-dropped fruit. Hence, this warrant another investigation on early maturity stages of Musang King durian in response to low- O₂ storage

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FIGURES AND TABLES

Figure 1. Physical changes after 3 and 4 weeks of storage under different O₂ levels

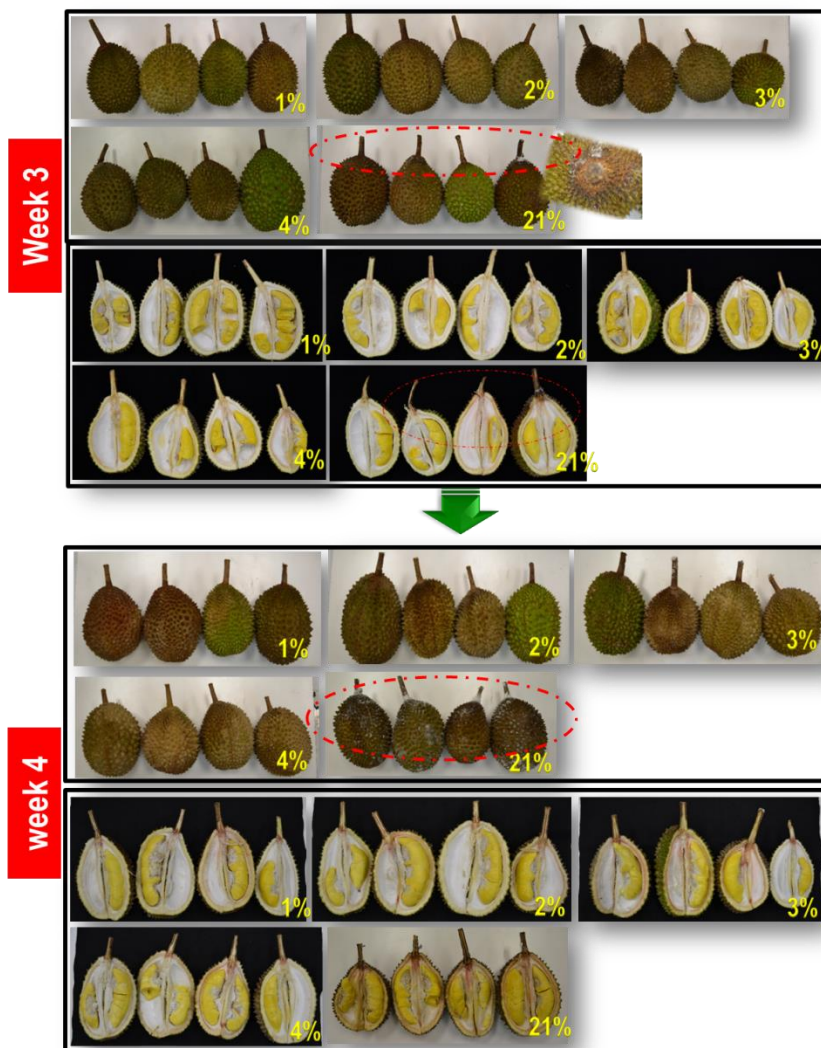


Figure 2. Respiration rate (mg CO₂ /kg-h) after storage under different O₂ level. Bars represent standard error

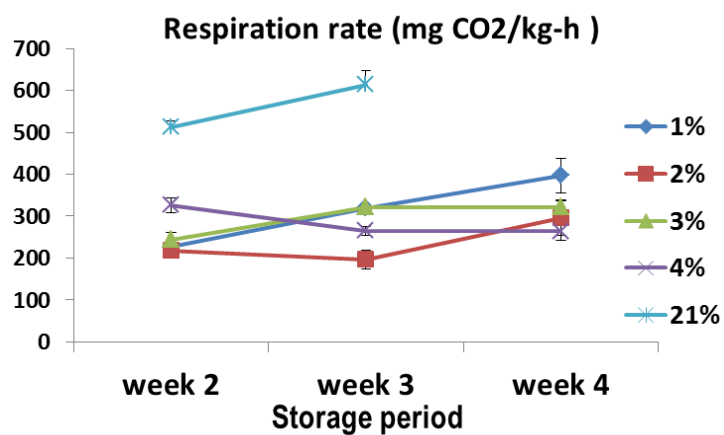


Figure 3. TSS, TTA and pH of pulp after storage under different O₂ level. Means followed by different letters within respective storage period are significantly different (p < 0.05).

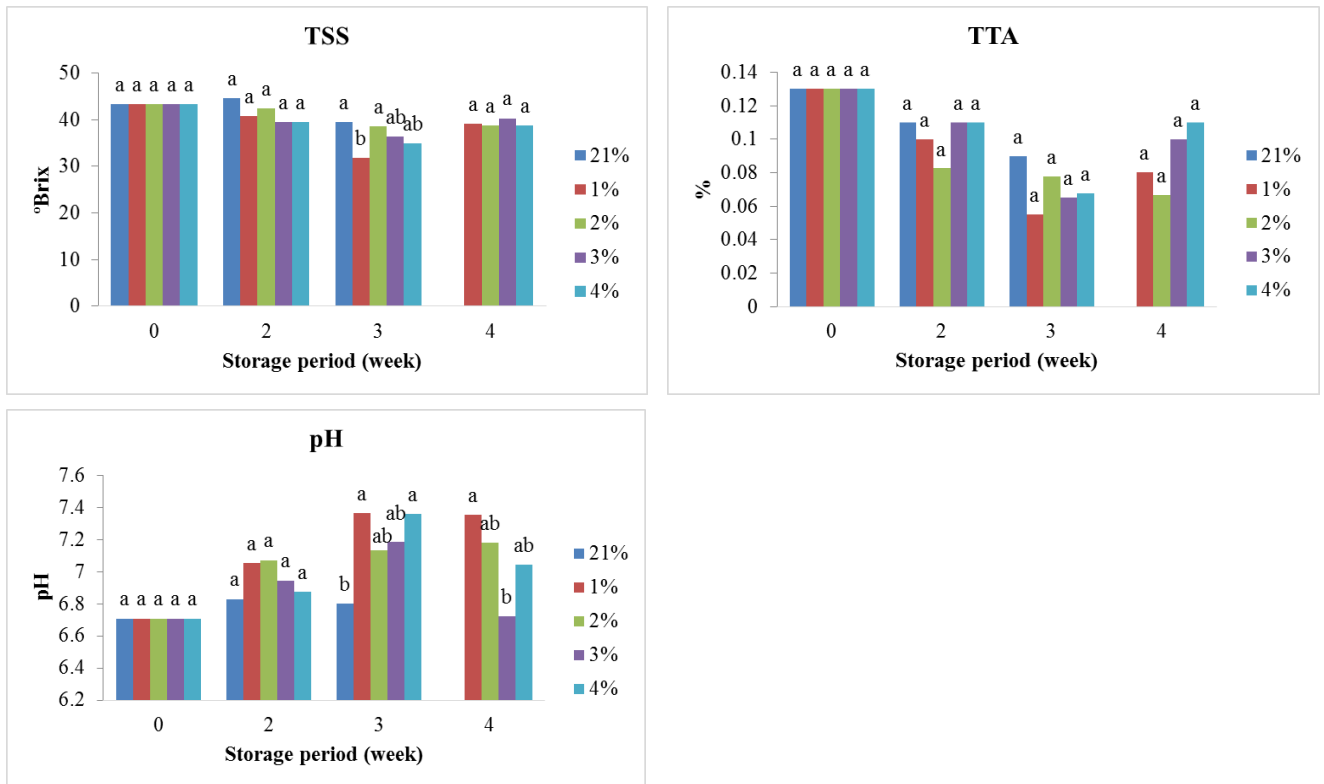


Figure 4. Production of ethanol, acetaldehyde and ethyl acetate after storage under different O₂ level. Means followed by different letters within respective storage period are significantly different (p < 0.05).

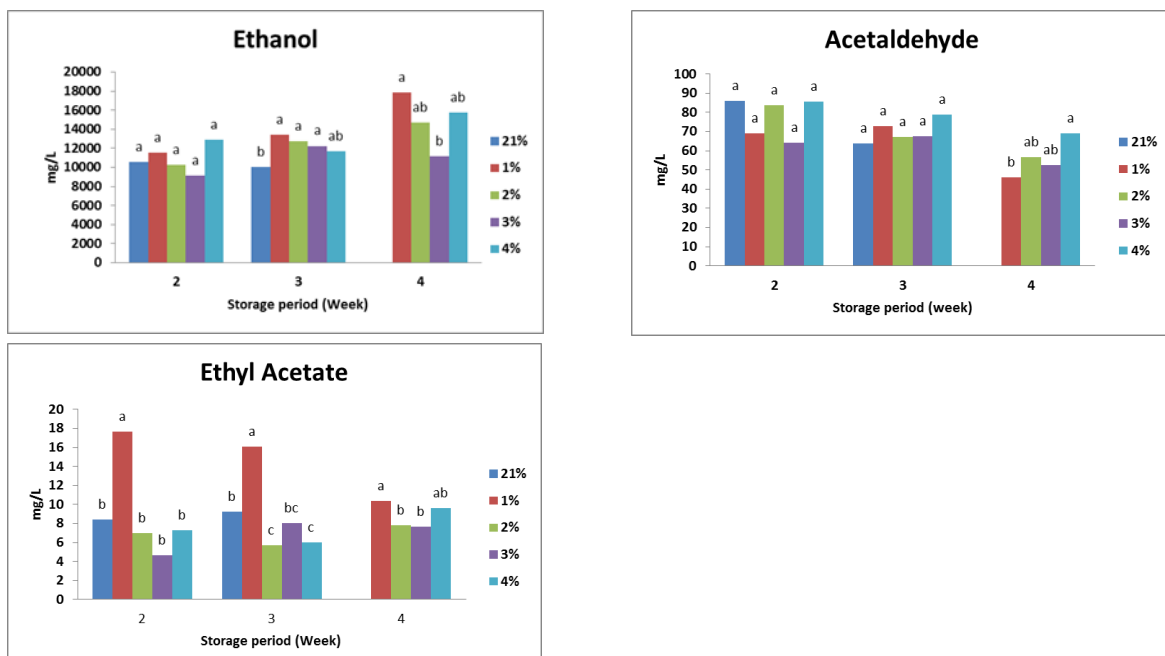


Table 1. Physical evaluation of durian (disease expression and husk dehiscence of the external husk and b* value of pulp colour) after storage under different O₂ level. Means followed by different letters within respective storage period are significantly different (p < 0.05).

Parameters	Treatments	Storage Period			
		Week 0	Week 2	Week 3	Week 4
Disease expression (Score)	21% O ₂	1.00 a	1.00 a	2.00 a	4.00 a
	1% O ₂	1.00 a	1.00 a	1.00 b	1.00 b
	2% O ₂	1.00 a	1.00 a	1.00 b	1.00 b
	3% O ₂	1.00 a	1.00 a	1.00 b	1.00 b
	4% O ₂	1.00 a	1.00 a	1.00 b	1.00 b
Husk dehiscence (score)	21% O ₂	1.00 a	1.00 a	2.25 a	3.33 a
	1% O ₂	1.00 a	1.00 a	1.00 b	1.33 b
	2% O ₂	1.00 a	1.00 a	1.00 b	1.33 b
	3% O ₂	1.00 a	1.00 a	1.00 b	1.33 b
	4% O ₂	1.00 a	1.00 a	1.00 b	1.50 b
b* value	21% O ₂	59.021 a	57.32 a	55.29 a	53.04 a
	1% O ₂	59.021 a	58.86 a	55.74 a	54.96 a
	2% O ₂	59.021 a	57.42 a	57.96 a	53.33 a
	3% O ₂	59.021 a	56.99 a	54.23 a	52.25 a
	4% O ₂	59.021 a	59.15 a	56.20 a	55.10 a

Table 2. Sensory evaluation of pulp after storage for 2 weeks under different O₂ level. Means followed by different letters within respective storage period are significantly different (p < 0.05).

Treatments (O ₂ level)	Freshness	Colour	Texture	Taste	Aroma	Overall acceptability
21%	4.53 b	4.64 a	4.28 a	4.28 a	4.28 a	4.10 a
1%	4.75 a	4.65 a	4.27 a	3.59 b	3.96 b	3.52 b
2%	4.72 a	4.53 a	4.34 a	4.52 a	4.22 a	4.21 a
3%	4.61 a	4.61 a	4.51 a	4.44 a	4.39 a	4.29 a
4%	4.81 a	4.55 a	4.31 a	4.79 a	4.37 a	4.38 a

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