ORIGINAL RESEARCH PAPER

Agriculture

Volume - 7 | Issue - 4 | April-2017 | ISSN - 2249-555X | IF : 4.894 | IC Value : 79.96

Postharvest Quality of Chilling Injured Ginger Rhizomes (Zingiber officinale Roscoe Cv. Bentong) as Affected by Maturity Stages, Storage Temperatures, and Durations

KEYWORDS: browning, colour, firmness

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ABSTRACT

Ginger (Zingiber officinale) has been identified as one of the market potential herbs which have been used as a spice and traditional medicine throughout the world. It contains phenolics, terpenes, flavonoids, which harnesses an incredible healing power proven for a host of ailments. Storage life and usage of ginger are limited as it is susceptible to chilling injury (CI). Maturity stages, varieties, storage durations and temperatures, and environment influence occurrence of CI in ginger rhizomes. Storage of rhizomes at ambient temperature leads to high moisture loss, shrivelling and sprouting, while storage below 12 ºC causes CI and browning. Improper maturity stages at harvest caused reduction of ginger quality, decrease storage life and increase fiber and sprouting of rhizomes. The objective of this study was to characterize CI of ginger rhizomes as affected by maturity stages (7, 9 and 11-months after planting), storage temperatures (5, 15 and 25 ºC) and storage durations (0, 8, 16, 24 and 32 days). Weight loss due to loss of moisture content was significantly higher in the gingers stored at ambient temperature (25 ºC) than at 5 and 15 ºC storage temperatures. Browning index at 5 ºC storage increased as storage durations increased in all maturity stages of ginger, highest at 11-months, followed by 9 and 7-months, with browning indices of 0.98, 0.95 and 0.86, respectively. As browning increased, ginger pulp colour changed from yellow to light brown with a reduction in rhizomes firmness. Ginger under 5 ºC storage showed the highest reduction in pulp firmness by 68%, 66% and 64% in 7, 9 and 11-months ginger, respectively, and rhizome turned soft and watery. As a conclusion, the 9-months ginger under 15 ºC storage was selected as optimum maturity stage and storage temperature since these ginger exhibited minimum CI and postharvest quality was maintained after 32 days of storage.

1. INTRODUCTION

Ginger (Zingiber officinale Roscoe cv. Bentong) is a modified stem known as rhizome which creeps horizontally under the soil surface. It is a herbaceous perennial herb and widely used as medicine and spices all around the world. The cultivar of the ginger determine the colour of the ginger pulps, it is either dark yellow, light yellow or yellowish orange. The size of the ginger rhizomes is also used to determine ginger cultivar, while the thickening of the brownish peel is used to determine the maturity of the ginger rhizomes, whether harvested at the young or mature stage. Local farmers tend to harvest ginger 5-6 months (young) and 9-10 months (matured) after planting. However, mature ginger was demanding more than young ginger in the domestic market, especially for culinary spices and medicines and prices for the mature ginger are higher than the young ginger. Due to the high demand for the uses of ginger locally, farmers need to produce more ginger and store the ginger at an optimum temperature in order to meet the consumer demand while maintaining the quality of the ginger for a longer period.

Temperature is the most contributing factor in losses on the crops during storage. Rhizome, root and tuber crops are highly perishable, spoil and decay easily and needs to be stored at low temperature after harvest, during transportation and storage. Storage durations are also a great factor in postharvest losses and the quality of the crops, especially for short natural shelf life crops. According to Atanda et al. (2011), low storage temperature lengthens the storage life of the horticultural crops and lowers the rate of losses as storage durations increased. Shukor et al. (1986) reported ginger rhizome can be stored up to 4 months at 10-15 °C. Ginger rhizome is susceptible to CI and storage at 4 °C or below resulted in CI which could reduce the quality and affect consumer acceptability towards ginger.

Different maturity stages, the degree of ripeness, cultivars, environmental circumstances and storage temperatures and durations influenced the occurrence of CI in rhizomes. CI is damaged to plant parts over a period of exposure to a chilling temperature below 10 °C but above the freezing point (Wang, 1990). The longer the time of exposure to chilling temperature, the higher the degree of CI in ginger, but a full manifestation of the CI symptoms on ginger become apparent upon removal of the ginger to non-chilling temperature. Chilling temperatures alter the physical properties of the ginger cellular membrane which resulted indirect injuries, dysfunctions, and secondary injuries like loss of membrane integrity, pungency, aroma, , internal breakdown, discoloration and susceptibility to decay and death. However, the most common CI symptoms in ginger rhizome are browning, pulp translucency, skin peeling and tissues softening (Wang, 1982). Thus, the objective of this study was to determine the postharvest quality of chilling injured ginger rhizomes as affected by maturity stages, storage temperatures, and durations.

2. MATERIALS AND METHODS

2.1 Sample preparation and extraction

Fresh ginger (Zingiber officinale Roscoe cv. Bentong) rhizomes were tagged and harvested at 7, 9 and 11-months after planting from a commercial farm in Bentong, Pahang, Malaysia. The ginger rhizomes were transported to the Postharvest Laboratory, Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia within 3 hours after harvest in order to maintain the quality and freshness of the rhizomes. Uniform size (200-300g) and damage-free fresh ginger rhizomes were selected, and then soil and dirt attached to the rhizomes were removed by using a brush. The clean and fresh ginger rhizomes were placed into cardboard boxes (30 cm x 25 cm x 15 cm) with 12 ventilation holes (5 cm x 2 cm) at both sides of the boxes. The ginger rhizomes were stored at three storage temperatures, 5 °C (chilling temperature), 15 °C (low temperature) and 25 °C (ambient temperature). CI incidences, browning, weight loss, pulp firmness and pulp colour were measured after 0, 8, 16, 24 and 32 days of storage. Ginger rhizomes were washed under tap water and peeled by using a peeler and air-dried at ambient temperature for 30 min. The

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ginger rhizomes were extracted by using a juicer extractor (HU-100, Korea). The resulting juice was filtered with a Whatman No.1 filter paper and centrifuged (Heraeus Megafuge 8R, Thermo Fisher Scientific, Germany) at 8,000 rpm for 20 min at 4 °C. The upper supernatant was pipetted out and used to analyze the degree of browning.

2.2 Weight loss

The weight of ginger rhizomes at initial and after 8 days interval of each storage was measured by using an electronic balance (B303, Mettler Toledo, Japan). Weight loss of the ginger in each treatment was calculated by differences between initial weight and final weight divided by initial weight and multiplies by 100. The loss in weight was expressed as percentage of the fresh weight of the ginger.

2.3 Pulp firmness

Ginger pulp firmness was measured by using an Instron Universal Testing Machine (5543P5995, Instron Corp. Minneapolis, USA) fitted with a 6 mm diameter cylindrical probe and a 5 kg load cell. Ginger rhizomes were cut into 1 cm thickness of the equatorial part for four disks. The Instron probe was punched to 3 mm depth at a crosshead speed of 20 mm/min into each rhizome disk. Each disk was punched for 3 times at equidistance and the reading was recorded in Newton (N) using the Instron Merlin Software version M12-13664-EN.

2.4 Degree of browning

The DOB of ginger pulp was determined by the method of Coesteng and Lee (1987) with modifications. Five grams of peeled ginger were extracted by a juice extractor (HU-100, Korea) and filtered through Whatman No.1 filter paper. A 10mL of the filtrate was added to15 mL of 95% ethanol, shaken and centrifuged at 8000 rpm for 15 min. Then, 300 µL of filtrate from each treatment was pipetted into a microplate and DOB was determined by measuring the absorbance of the samples at 440 nm using a spectrophotometer (1510, Multiskan Go, Fisher Thermo Scientific, United Kingdom).

2.5 Colour determination

Colour changes of ginger rhizomes were measured on a longitudinal cut on rhizomes pulp with a colorimeter (CR-300, Minolta Corp. Japan) equipped with an 8 mm diameter measuring head and calibrated with a standard white tile. The ginger rhizomes were peeled and pulp colour was taken on four random points on each ginger rhizome. The readings were expressed in L*, C* and h° colour space (CIE 1976) where L* = lightness, C* = chromaticity, and h° = hue angle. L* ranged from 0 to 100 where 0 = black and 100 = white. C* or saturation ranged from 0 at the centre of the circle where 0 is completely unsaturated (grey, black or white) and the value increased at a further distance from the centre to 60. A high value of C* indicated high saturation and colour purity. The h° was defined as starting at +a* axis where 0° = +a* (red), 90° = +b* (yellow), 180° = -a* (green) and 270° = -b* (blue).

2.6 Experimental design and analysis

The experiment was conducted using a randomized complete block design (RCBD) in a three factorial arrangement of treatments, with four replications. The treatments were three maturity stages of ginger rhizomes (7, 9 and 11-months after planting) x three different temperatures (5, 15 and 25 °C) x five storage durations (0, 8, 16, 24 and 32 days after storage). The results were analyzed using analysis of variance of SAS version 9.3 (SAS Institute, Cary, NC) and the means were compared by Tukey honestly significant differences (HSD) test at P = 0.05. When an interaction effect was found to be significant, regression analysis was conducted to determine the relationships between the dependent and independent variables. When the relationship was not significant, the effects of the variables were compared using a pooled least significant difference (LSD) test at P = 0.05.

3. Results and Discussion

3.1 Weight loss

Weight loss was significantly higher (P = 0.05) in rhizomes stored at 25 °C than at 5 and 15 °C for 7, 9 and 11-months ginger (Figure 3.1). 11-months ginger stored at 25 °C showed the highest weight loss at a rate of 0.24%/day/g FW during 8 days storage and there were positive cubic relationships between storage durations and weight loss of 11-months ginger (Figure 3.1). The ginger stored at 25 °C showed a sharp increase in weight loss

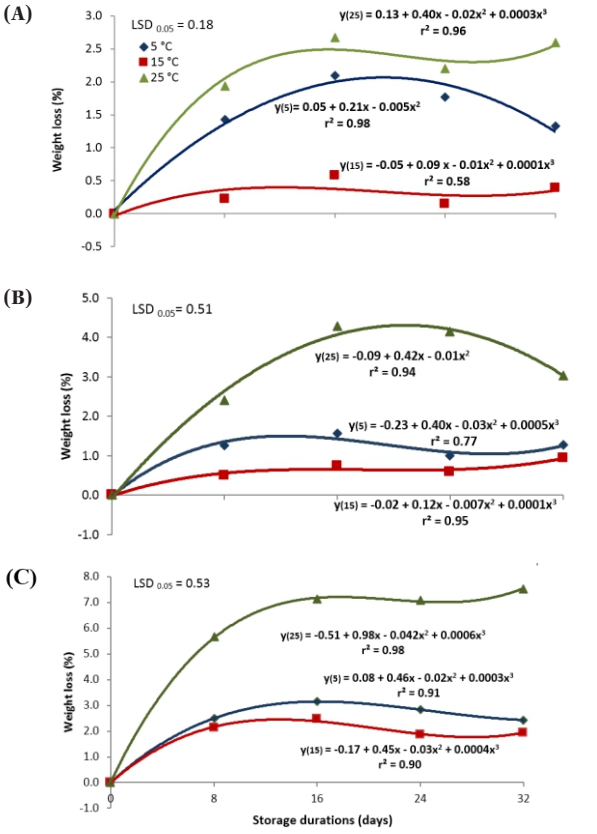

Figure 3.1. Relationships between storage durations (0, 8, 16, 24 and 32 days) and percentage of weight loss of 7 (A), 9 (B) and 11-months (C) old ginger rhizomes stored at different storage temperatures (5, 15 and 25 °C). Solid line indicates a significant regression trend at P = 0.05, (n = 12).

(5.7%) by 8 days storage, followed by gradual changes until 32 days of storage. Storage temperatures of 5 and 15 °C caused weight losses of 2.5% and 2.1%, respectively, by 8 days storage. This is supported by Policegoudra and Aradgya (2007) who reported that rhizomes stored at ambient temperature had the highest weight loss of 1%/day during initial 30 days storage. In the current study, weight losses of the 11-months ginger stored at 25 °C for 8 days, were higher (3.7% and 3.2%) than 7 and 9-months ginger, respectively. The findings of Shukor et al. (1986), and Policegoudra and Aradhya, (2007) were also in an agreement whereby ginger rhizomes stored at ambient temperature showed a higher weight loss (30%) compared to those at 5 and 15 °C storage temperatures during 30 days of storage.

Ginger rhizome is a modified underground stem with lenticels, sunken opening that originated from the stomata, that serve to regulate and minimize water loss via transpiration process when the ginger is exposed to the atmosphere (Ravindran and Babu, 2004). The 11-months ginger which was bigger in size showed a higher weight loss compared to 7 and 9-months ginger stored at 5, 15 and 25 °C. Water loss through transpiration from the skin of root crops depends on the degree of maturity, variety, and damages. Evidently, 7, 9 and 11-months old ginger stored at 5 °C showed shriveling symptoms and ginger become very dry due to less humidity and too cold tempera-

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ture. At cold temperature (5 ºC), respiration and transpiration rate of rhizomes were affected and cannot function normally. The water vapour and air move through the interstitial spaces of plant tissue and differences between the rate of water vapour pressure in the crops and surrounding affect the amount of transpiration water loss in the crops (FAO, 2016).

Ginger stored at 15 ºC showed the lowest weight loss due to the high RH which tend to limit the outflow of water and minimal the water potential from the ginger rhizome to the atmosphere (Bareja, 2013). All maturity stages ginger stored at 15 ºC were still can be commercialized and no shriveling symptoms after 32 days of storage. Paull et al. (1988) reported shelf life of ginger could be prolonged up to 28 weeks at storage temperatures of 10-12 ºC, with 90% RH. Moreover, this result was similar to the studies by Akamine (1962), and Manassokorn and Kosiyanchinda (1985), whereby the storability of fresh rhizomes at 13 and 16 ºC were 24 weeks and 18 weeks, respectively. Storage at low temperature 10-15 ºC tends to prolong the shelf life of ginger by reducing weight loss. However, the low temperature could cause other problems, such as pathogen infections and CI. Differences between temperatures of horticultural produce and surrounding become the main factor of the weight loss of the produce. Therefore, in order to minimize the water loss, the rhizomes should keep at low temperature (13-15 ºC) and the differences temperatures between rhizome and surrounding must be as low as possible. This is because rhizome is marketed on a weight basis, thus weight loss of rhizome also caused economic loss.

3.2 Pulp firmness

The results showed negative relationships between storage durations and pulp firmness for 7, 9 and 11-months ginger stored at 5, 15 and 25 ºC (Figure 3.2). The pulp firmness decreased (softening increased) as the storage durations increased in all maturity stages and also storage temperatures. The pulp firmness is an indicator of pulp physical quality, eating quality, freshness and shelf life, and also pulp softening is the result of the cell wall degradation (Thumdee et al., 2010). According to Ravi et al., (1996), the storage life of root crops varies depending on the cultivars, handlings, storage temperatures, humidity, and storage period. Sweet potato can be stored up to 2-4 months and the postharvest losses were 20%-25%. Similarly, Yun and Lee (1998) reported that firmness of ginseng roots is reduced during extended storage. During storage, the moisture content of the produce was continuously lost from the peel and then replenished by the movement of moisture from the inner core of the produce. The moisture loss due to respiration and transpiration caused shriveling on the fruits or vegetables which decreased firmness and the produce becomes unmarketable (Jayashree and Visvanathan, 2011). Sasaki et al. (2006) reported that firmness of fresh-cut pumpkin decreased due to dehydration with the appearance of wilting symptoms as storage days extended.

At 5 ºC storage, there were rapid reductions in pulp firmness, whereby firmness dropped by 68%, 66% and 63% for 7, 9 and 11-months ginger, respectively, by 32 days of storage. The results were found similar to the findings by Reihaneh and Mehdi, (2010) who reported that there were rapid losses in the firmness of tuber crops at 10 ºC with 85%-90% RH. The ginger pulp became soft and watery at 5 ºC storage, with 7-months ginger being softer by 36% and 25% than 9 and 11-months ginger, respectively, by storage day 32. The result also showed that pulp firmness decreased less rapidly for old ginger compared to young ginger. This could be attributed to the less fibrous content of young ginger (Douglas et al., 2005). The softer the rhizome pulp, the more susceptible it was to CI, mechanical damages causing reduced shelf life, reduced consumer acceptability and increased wastage. This result was similar to the findings by Bauchot et al. (1999) where they found that CI is a physiological disorder leading to extreme softening, affecting the fruits. Also, Heyes et al. (1994) reported that the decrease of firmness in a produce is directly related to the rate of degradation of pectic substances and hemicelluloses, which caused weakening of cell walls and cohesive forces that bind cells together.

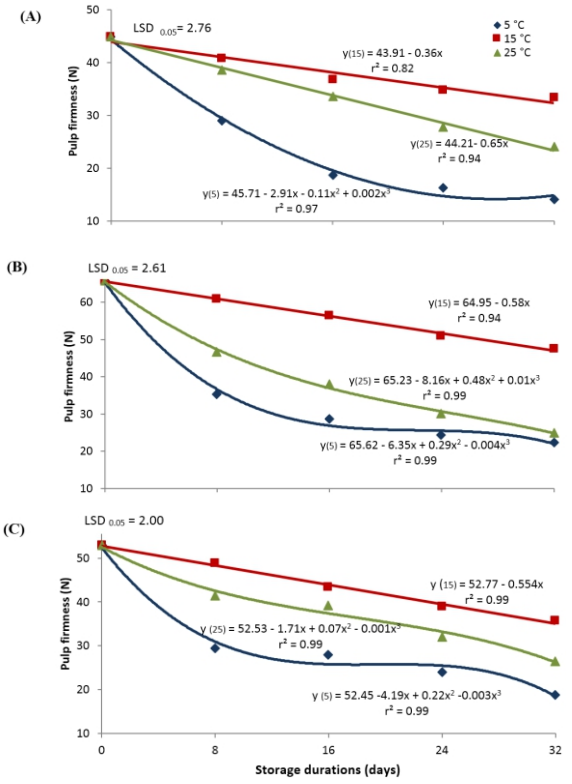

Figure 3.2. Relationships between storage durations (0, 8, 16, 24 and 32 days) and pulp firmness of 7 (A), 9 (B) and 11-months (C) old ginger rhizomes stored at different storage temperatures (5, 15 and 25 ºC). The solid line indicates a significant regression trend at P = 0.05, (n = 12).

The 7, 9 and 11-months ginger pulp firmness stored at 15 ºC decreased gradually throughout the storage periods. However, ginger stored at 15 ºC was still in firm conditions without being watery. In addition, the reduction in pulp firmness for 7, 9 and 11-months ginger stored at 25 ºC did not show any watery symptoms and ginger was still firm and maintained its consumable value even after 32 days of storage. However, the pulp firmness for ginger stored at 15 ºC was better compared to storage temperatures at 25 ºC. This result was supported by Moretti et al. (2010) where the firmness of fruits and vegetables were affected by high temperature storage. This is due to changes in the composition of the cell wall, a number of cells in the produce and cell turgor properties at different temperatures (Woolf et al., 2000). In addition, an increase of pulp softening during storage was also caused by high moisture loss in the rhizomes. In order to prolong the shelf life, maintain the freshness, texture and eating quality, ginger needs to be harvested at 9-months and store at 15 ºC to avoid softening and watery pulp.

3.3 Degree of browning

Browning is one of the CI symptoms in the ginger pulp. The DOB on 7, 9 and 11-months ginger pulp was significantly (P = 0.05) affected by storage temperatures and storage durations (Figure 3.3). The results showed increments in DOB for all maturity stages and storage temperatures as storage durations increased. The DOB for 7, 9 and 11-months ginger was severe at 5 ºC storage and ginger pulp turned yellowish brown; while at 15 and 25 ºC storage, ginger pulp showed low browning symptoms and pulp still remained initial yellow in colour. On day 32, DOB of ginger stored at 5 °C was highest in 7-months, followed by 9 and 11-months ginger, with DOB of 0.72, 0.48 and 0.56, respectively. Similar results were also found in the previous study by Policegoudra and Aradhya (2007), CI occurred on ginger stored at 4 °C and caused water-soaked lesions with browning, tissue

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softening and loss of flavor and pungency of ginger. Slight browning symptoms occurred on ginger rhizomes after 5 days of storage at 7 °C, and serious browning symptoms on ginger rhizomes after 2 weeks exposure to 7 °C and rhizomes become soft and watery (Anonymous, 2004). These findings are also supported by Nunes et al. (2007) who reported that DOB on mango depends on the time exposure to different storage temperatures. Also, potato tuber showed serious browning evidence at 4 °C storage (Sergio et al., 2012). Browning reactions are important to consider while unraveling biochemical mechanisms and the relationships between membrane stability, metabolism of oxygen free radical, and browning. Besides being limited by the availability of associated enzymes and the concentration of polyphenol substrate, browning may also be rate-controlled by membrane stability (Cantos et al., 2002).

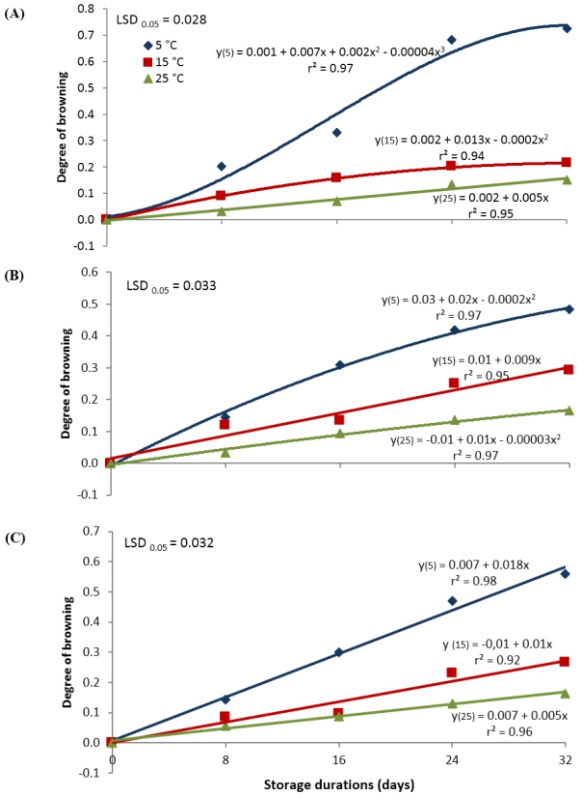

Figure 3.3. Relationships between storage durations (0, 8, 16, 24 and 32 days) and degree of browning of 7 (A), 9 (B) and 11-months (C) old ginger rhizome stored at different storage temperatures (5, 15 and 25 °C). The solid line indicates a significant regression trend at P = 0.05, (n = 12).

The browning symptoms that occurred in all maturity stages ginger stored at 5 °C could be due to the interaction between phenol and polyphenol oxidase (PPO) (Crisosto et al., 1999). Browning on the rhizome is due to phenolic oxidation and destruction of rhizome cellular compartmentation enables phenolic substances to be accessible to PPO which catalyse the phenolic oxidation (Araji et al., 2014). The initial reaction catalysed by PPO produces reddish-brown o-quinones. This process is very effective and fast, so they subsequently undergo a series of non-enzymatic reactions (Whitaker and Lee, 1995; Busch, 1999). Also, the catalytic oxidation of PPO is the main factor causing browning of lotus rhizomes during storage at low temperature (Yu et al., 2002). In addition, a browning symptom in the ginger might also relate to the tissue deterioration and senescence, which resulted in the changes of membrane permeability. The browning induction in the produce was due to decline in the degree of unsaturated fatty acids and membrane permeability. This caused the physical membranes characteristics affected by low temperature storage and an increase in lipid peroxidation during chilling which attributes to browning development (Wang, 1992).

The 7-months ginger showed the highest DOB compared to 9 and 11-months ginger under all storage temperatures. A previous study reported that DOB of tuber depends on the age, maturity, and variety of the crops (Busch, 1999). In a similar study reported by Medlicott et al. (1990), older rhizomes were more resistant to low temperature due to its fibrous content compared to the younger rhizomes. Proper storage temperatures tend to control the undesirable enzyme activities and eliminate one or more of the essential components (oxygen, enzyme, copper or substrate) from the enzymatic reaction. Browning becomes severe when storage durations were increases resulting in an internal breakdown in the ginger rhizome (Paull and Chen, 2015). Thus, rhizomes loss their sheen and the pulp changed to a yellowish brown during storage and handlings.

The results of the present study also showed that DOB at 15 °C storage increased for 7, 9 and 11-months ginger after 32 days of storage. However, DOB for all maturity stages stored at 15 °C was still below 30%, which was still under acceptable level based on the hardness scale. The ginger pulp was still with initial yellow without pulp softening and watery evidence that appeared. These results were also found to be similar in a previous study, the optimum temperature to store and transport ginger is 12 °C and storing at this temperature tend to maintain the market value of ginger for at least 3-months (Anonymous, 2004). However, rhizomes stored at temperatures below 12 °C caused flash blackening and other CI evidence like discoloration, internal breakdown and tissue softening (Anonymous, 2004).

3.4 Colour evaluation (L*, C*, h°)

Colour densities of ginger pulp at the different maturity stages were measured and expressed in values of a lightness (L*), chromaticity (C*) and a hue angle (h°). For ginger pulp L*, the three-way interaction effect between maturity stages, storage temperatures, and storage durations was not significant. However, there were significant two-way interactions between maturity stages x storage durations on pulp L*. Further examination of the interactions indicated there were positive quadratic relationships between storage durations and pulp L* for 7, 9 and 11-months ginger rhizomes (Figure 3.4). The 7, 9 and 11-months ginger pulp showed a similar reduction trend in L* value as storage durations increased within 32 days. The ginger L* value decreased during storage indicating that the ginger pulp developed a darker colour compared to the initial colour at each maturity stage. In the beginning of the experiment, the initial L* value of 11-months ginger pulp showed highest L* indicating a lighter pulp colour followed by 9 and 7-months pulp (LSD = 5.74). However, by 32 days, the 7 and 9-months pulps were not significantly different in L* value, but this L * values were significantly lower compared to 11-months pulp. The lower L* values for 7 and 9-months indicated darker pulp colour.

There were also significant two-way interactions between storage temperatures and storage durations on pulp L*. The relationships between storage durations and pulp L* were found to be positive quadratic for ginger stored at 5, 15 and 25 °C (Figure 3.5). The L* values for each storage durations for 25 °C were significantly lower compared to L* values at 15 °C. In contrast to pulp stored at 15 and 25 °C, pulp stored at 5 °C continued to show a rapid reduction of ginger pulp L* until 32 days of storage. The ginger pulp L* showed lowest at 5 °C of storage, thus indicating a darker ginger pulp compared those in the other storage temperatures. However, ginger pulp L* stored at 15 and 25 °C still maintained its initial yellow pulp after 32 days of storage. These results were supported by Mercado-Silva and Cantwell (1997), whereby L* of root was maintained or slightly changed at storage 13 and 20 °C after 3 weeks of storage. The ginger pulp L* decreased rapidly at low temperature and caused the ginger pulp to change to a darker colour indicating the browning effect on the ginger pulp. Thus, L* value is a useful indicator of browning at a cooler temperature, which showed similar findings with reports by

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Chen et al., (2008).

The results showed there were significant interaction effects (P = 0.05) between maturity stages, storage temperatures and storage durations on ginger pulp h° (Figure 3.6). Ginger exposed to 5 °C exhibited a more rapid decrease in pulp h° as compared to 15 and 25 °C for all maturity stages of ginger. Also, the ginger pulp h° decreased rapidly during storage for all maturity stages ginger. The reduction on h° for ginger stored at 5 °C caused the ginger

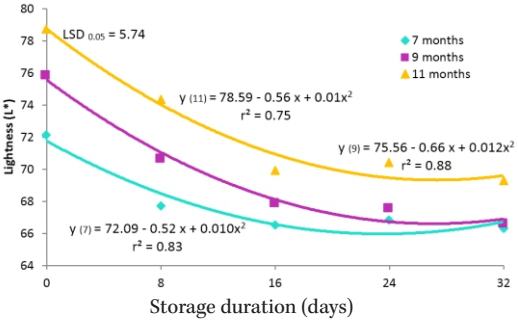


Figure 3.4. Relationships between storage durations and lightness of ginger rhizomes harvested at different maturity stages (7, 9 and 11-months). The solid line indicates a significant regression trend indicates no significant difference at P = 0.05, (n = 12).

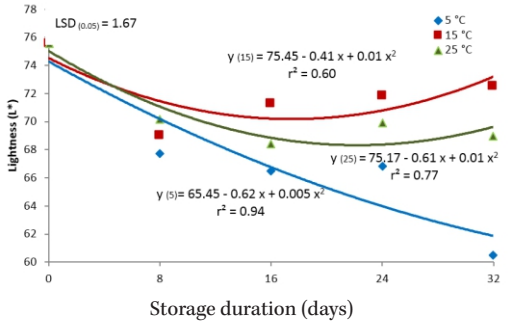
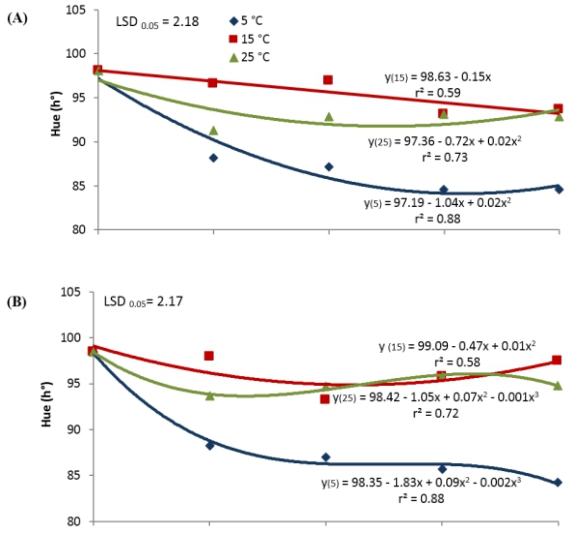


Figure 3.5. Relationships between storage durations and lightness of ginger rhizomes stored at different storage temperatures (5, 15 and 25 °C). The solid line indicates a significant regression trend indicates no significant difference at P = 0.05, (n = 12).



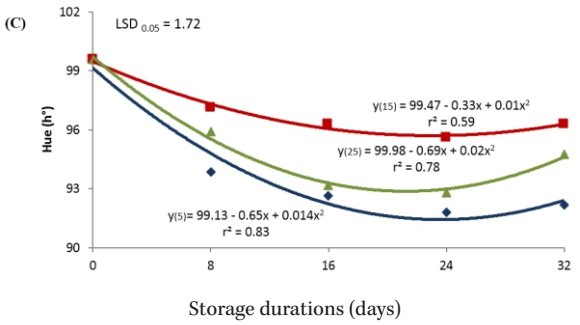


Figure 3.6. Relationships between storage durations (0, 8, 16, 24 and 32 days) and hue of 7 (A), 9 (B) and 11-months (C) old ginger rhizome stored at different storage temperatures (5, 15 and 25 °C). Solid line indicates a significant regression trend at P = 0.05, (n = 12).

pulps change to brown. But, ginger stored at 15 and 25 °C still maintained its yellow pulp and no browning symptoms occurred throughout 32 days of storage. The h° reduced when browning on the pulp increased (Samim and Banks, 1993) and the colour changed into brown. The reduction in colour intensity was apparently due to the changes in the amounts of pigments which were gradually lost during storage at low temperature (Maria et al., 2005). In addition, changes in the h° were also due to dehydration of the root crop, which tends to reduce the intensity of the yellow of the ginger. Dehydration occurred in ambient temperature and caused the ginger pulp to change brownish yellow. At 15 °C, there was only a slightly reduced on the h° of the ginger pulp, which at a range of 1%-4% per day that occurred in ginger by 32 days of storage. Temperatures influenced the storage durations of ginger and at 15 °C, ginger pulps were still yellow. Storage at 5 and 25 °C caused colour changes over the storage period, which affects the consumer acceptability and could reduce the nutritional quality of the ginger.

Figure 3.7 showed there were significant interaction effects (P = 0.05) between maturity stages, storage temperatures and storage durations on ginger pulp C*. The ginger pulp colour changed from vivid yellow at day 0 to dull grayish yellow on day 32 for all maturity stages ginger stored at 5 °C. The C* represents the saturation and colour purity, which showed that the lower the C* value for the pulp after long storage at 5 °C indicated less saturated and more grayish yellow ginger pulp than those in the beginning of the experiment. The pulp C* values were reduced slightly along 32 days of storage at 15 and 25 °C for all maturity stages of ginger. 7, 9 and 11-months ginger rhizome still in acceptable yellow pulp at storage temperatures 15 and 25 °C. The higher pulp C* illustrated that the colour of the ginger pulp was more intense and more vivid as compared to the ginger pulp stored at 5 °C. Reduction in both L* and C* on ginger pulp corresponded to the development of CI on ginger and these colour changes affect the shelf life of the ginger. While at 25 °C storage, C* showed the lowest reduction and ginger pulp were still at high C* values after 32 days of storage. The results also showed the cooler or lower temperature caused higher changes on the C* as compared to ambient temperature (25 °C). Under ambient temperature, the C* of the ginger was maintained and ginger pulp still remained vivid yellow.

Initially, ginger pulp at 7, 9 and 11-months was similar in colour, but changed during storage at 5, 15 and 25 °C. The ginger pulp L* was higher for ginger stored at 15 °C than ginger stored at 5 °C. Hardenburg et al. (1986) reported low temperature storage reduces enzymatic activities and loss of luminance in the produce which caused a reduction in the L*. Among the objective measurements of colour, the L* and h° was very important to evaluate the ginger

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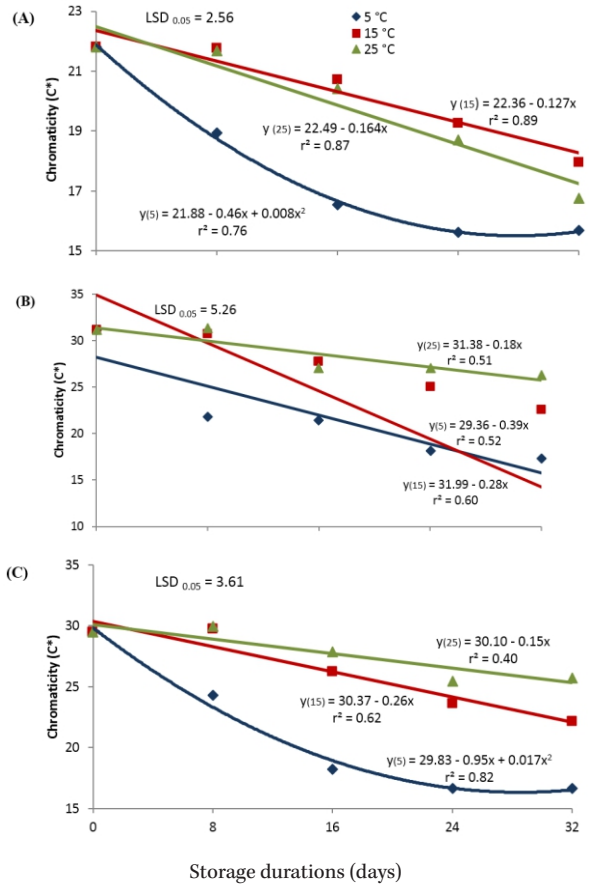

Figure 3.7. Relationships between storage durations (0, 8, 16, 24 and 32 days) and chromaticity of 7 (A), 9 (B) and 11-months (C) old ginger rhizomes stored at different storage temperatures (5, 15 and 25 °C). The solid line indicates a significant regression trend indicates no significant difference at P = 0.05, (n = 12).

colour since the pulp is in yellow colour. At 5 °C storage, the ginger pulps L* and h° values decreased as storage durations was extended with the appearance of brown discoloration (browning symptom) on the pulps. The yellowish brown and translucent appearance on the pulp stored at 5 °C reflected darker and not colourful (low L* and low C*) pulp. Lower L* and C*, and yellowish brown pulp increased membrane permeability and loss of integrity induced by the low temperature storage, with a resultant increase in water loss through the periderm (Cantwell et al., 1992; Mercado-Silva and Cantwell, 1997). Also, ginger stored at 5 °C had possible increased in the ion leakage by tissue discs, whereas, ginger stored at 15 and 25 °C showed yellow and no translucent and browning appearance. Therefore, the optimum storage temperatures for ginger would be at 15 °C which showed lighter and more vivid colour (high L* and high C* value) and possessed yellow positive h° pulp after 32 days of storage.

CONCLUSIONS

Maturity stages, storage temperatures, and storage durations affected the weight loss, pulp firmness, colour and caused CI on ginger rhizomes. The browning was also severe at 5 °C and pulp turned to yellowish brown and at 15 and 25 °C storages, ginger pulp showed low browning and pulp still remained yellow. Browning affected the physical and physiological characteristics of ginger rhizomes which lead to their reduction in the quality and shelf life. The weight loss of 11-months ginger stored at 25 °C was 1.9% and 1.5% higher compared to the weight loss for 7 and 9-months ginger after 32 days of storage. Also, 11-months ginger stored at 25 °C showed highest weight loss at a rate of 0.24%/day/g FW after 32 days of storage. Ginger pulp firmness decreased as storage durations increased under 5, 15 and 25 °C storages for all maturity stages of ginger rhizomes. Ginger stored at 5 °C showed a rapid reduction in pulp firmness by 68%, 66% and 64% in 7, 9 and 11-months ginger, respectively, after 32 days of storage. The ginger pulp becomes soft and watery with 7-months ginger being softer than the others due to fewer fiber contents. Optimum harvesting stage and proper storage conditions, temperature and humidity are needed to lengthen the storage life and lifespan, maintain the quality and appearance of the ginger rhizomes. Thus, the optimum maturity stage and storage temperatures selected from this study are 9-months ginger stored at 15 °C which resulted in minimum browning while maintaining the colour, quality and shelf life of the ginger rhizome after 32 days of storage.

ACKNOWLEDGMENTS The authors would like to express their gratitude for grants and financial support from Putra Grant and Universiti Putra Malaysia for providing the equipment and facilities to carry out the experiment.

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