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Full Paper

Extending the Storage Life of Fresh Turmeric (*Curcuma longa* L.) Rhizomes Through Light and Temperature Manipulation

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Turmeric (*Curcuma longa* L.) is becoming an important underutilized crop because of its use as a natural food colorant and its varied pharmacological properties. It is subject to dehydration, sprouting, and chemical degradation of curcuminoids, the major antioxidant, when exposed to light and high temperature. This study was conducted to determine the storage life of fresh turmeric rhizomes at 12-14°C and at ambient condition of 27-30°C either continuously exposed to light or covered with jute sack (without light). Regardless of light exposure, storage at 12-14°C reduced weight loss hence none to very slight shriveling, prevented sprouting thus the high visual quality rating of the rhizomes for 20 wk, retarded the decline in the intensity of yellow-orange color of the flesh, and maintained the acceptability of the extract (juice) to the sensory panelists. On the other hand, turmeric stored at 27-30°C resulted in high weight loss manifested as shriveling and early onset of sprouting on the 8th week of storage. Firmness of the rhizomes however, did not change markedly during storage even when sprouting had occurred. Likewise, respiration rate and ethylene production of the rhizomes did not vary between storage temperature and light exposure. Total phenolic content and antioxidant activity did not change markedly during storage regardless of the treatment. The study showed that turmeric rhizomes can be stored for 20 wk at 12-14°C without significantly affecting the quality and antioxidant property of the rhizomes.

Keywords: antioxidant activity, *Curcuma longa*, quality, storage, total phenolic content, turmeric

INTRODUCTION

Turmeric is the rhizome obtained from the plant *Curcuma longa* L. that belongs to the family Zingiberaceae (Jaggi 2012). It is used in a wide variety of food and cuisines as a native spice crop in south Asia. It is consumed either fresh or in dried form and a major ingredient in curry powder that imparts the characteristic flavor and yellow-orange color to food (Cousins et al. 2007). It has attracted much attention due to its curcuminoid content, the major antioxidant responsible for its distinct yellow-orange color and varied medicinal uses such as anti-inflammatory, anticancer, and antimicrobial agent (Nasri et al. 2014; Laokuldilok et al. 2015).

Turmeric production is not possible throughout the year hence the need for postharvest technologies to provide consumers with stable supply in fresh and processed forms. The quality of turmeric, however, depends on the initial quality of the rhizome and on-farm processing which affect the curcuminoid content, organoleptic characteristics, and general appearance of the rhizomes. The recommended storage condition is cool, dry place to prevent moisture absorption and should be protected from light to prevent chemical degradation (Weiss 2002; Jayashree et al. 2015). The curcuminoids are readily decomposed when exposed to light (Schieffer 2007), high temperature or oxidative conditions (Buescher and Yang 2000).

Curcuma species, like turmeric, contain many functional compounds such as phenolics, flavonoids, and antioxidant enzymes (Sahu and Saxena 2013). Stability of phenolic compound is an important consideration in achieving its desirable properties and maintenance of activity under varying storage conditions like exposure to light and at different temperatures (Volf et al. 2014). Rhizomes are also subject to sprouting and dehydration due to weight loss.

This study determined the effect of light and temperature manipulation on the storage life of fresh turmeric rhizomes. The study was also aimed at assessing the physico-chemical and physiological changes of the rhizomes during storage at 12-14°C and at ambient condition either continuously exposed to light or covered with jute sack (without light).

MATERIALS AND METHODS

Mature, defect-free, and small to medium-sized (30–60 g) turmeric rhizomes were bought from a wholesale market in Tanauan City, Batangas, Philippines. The rhizomes were harvested from a nearby farm at least 7-10 months after planting and cured by air-drying under ambient condition for 24 hr before selling in the market. Rhizomes were packed

in plastic crates, transported to the Postharvest Horticulture Training and Research Center (PHTRC) laboratory at UP Los Baños, and sorted without physical and insect damage.

Turmeric rhizomes were stored under four conditions: 27-30°C with light, 27-30°C without light, 12-14°C with light, and 12-14°C without light. Light exposure and temperature were manipulated by enclosing rhizomes with jute sack (without light) and then storing at 12-14°C, the recommended storage condition of ginger (Paull and Chen 2015) which is of the same family as turmeric. The control consisted of storing rhizomes exposed to light at 27-30°C.

Upon removal of turmeric rhizomes from storage at 12 -14°C and at 27-30°C at 2-wk interval, visual quality, shriveling incidence, and weight loss were gathered. For visual quality assessment, defects such as sprouting and shriveling were considered and the following rating was used: 9-8 = excellent, field fresh, 7-6 = good with minor defects, 5-4 = fair with moderate defects, 3 = poor with serious defects and at the limit of marketability, 2 = limit of edibility, and 1 = non-edible under usual conditions. Shriveling incidence was rated based on the severity of drying of rhizomes as follows: 1 = none, 2 = 10% of surface area shriveled, 3 = 25% of surface area shriveled, 4 = 50% of surface area shriveled, 5 = 75% of surface area shriveled, and 6 = 100% of surface area shriveled.

Similarly, firmness and chroma (a+ values) were determined every 2 wk. Firmness was measured at the left, middle, and right portions of the unpeeled rhizomes using a fruit pressure tester (Imada Co., Ltd.). For chroma, three rhizomes were cut into half to determine the intensity of yellow-orange color (a+ values) using a color meter (Konica Minolta Optics, Inc.).

Respiration rate and ethylene production were also determined using the static system. Three pieces of rhizome per treatment were placed separately in respiration jars and sealed for 2 hr after duplicate gas samples of 1 mL each were withdrawn from the jar. CO_2 production was measured using a gas chromatograph (GC; Shimadzu GC 8A) equipped with a thermal conductivity detector (TCD) and for ethylene production, a GC (Shimadzu GC 2014) equipped with a flame ionization detector (FID).

Determination of total phenolic content (TPC) was based on the modified method of Turnos (1993). Five grams of rhizomes were sliced thinly, extracted by boiling it with 50 mL 70% ethanol, homogenized for 2 min, and centrifuged for 10 min. Distilled water (0.9 mL) and 0.25N Folin-Ciocalteau reagent (2.0 mL) was added to a 0.1 mL extract from the homogenate. The resulting solution was allowed to stand for 5 min followed by the addition of 2 mL saturated sodium carbonate with slight agitation. After an hour, absorbance was measured at 640nm using a Secomam UV spectrophotometer. TPC was standardized against gallic acid and expressed in microgram per gram of gallic acid equivalent (GAE).

The turmeric extracts were also analyzed for free-radical scavenging activity using a modified method described by Khamsah et al. (2006 as cited by Nurliyana et al. 2010). A volume of 0.1 mL extract was added with 0.9 mL distilled water and 3.0 mL of 2,2-diphenyl-1-picrylhydrazide (DPPH) reagent and then mixed thoroughly. After 30 min of dark incubation, absorbance was measured against 90% ethanol at 517 nm using a Secomam UV spectrophotometer. Free radical scavenging activity was expressed as % inhibition.

Sensory evaluation was done monthly by only five sensory panelists due to limited number of staff at PHTRC that drink fresh turmeric extract. Rhizomes were peeled and cut into pieces. Twenty grams of rhizomes were boiled in 500 mL distilled water for 2 min to extract the juice, cooled, and presented to the panelists for flavor acceptability.

Experimental Design

The experiment was laid out in CRD with 4 treatments in triplicate per withdrawal period. Each replicate consisted of 2.0 kg rhizomes. The data was subjected to ANOVA using SAS version 9.0. Differences between treatment means were compared using LSD at 5% level of significance.

RESULTS

Cumulative Weight Loss

Weight loss progressively increased as rhizomes were stored longer at either temperature with or without exposure to light (Figure 1). There was no significant effect of light and temperature until the 18th wk. The rhizomes stored at 12-14°C without exposure to light exhibited the lowest weight loss and the highest was on rhizomes stored at 27-30°C.

Slight shriveling of the rhizomes was already evident when weight loss of about 10-15% on the 4th wk of storage at 27-30°C was obtained. On the other hand, in the case of rhizomes stored at 12-14°C, shriveling was negligible even with recorded weight loss. Differences between treatments on the severity of shriveling, however, were not significant (data not shown).

Sprouting

Storage at 12-14°C for 18 wk prevented sprouting of rhizomes regardless of light exposure (Table 1). On the other hand, light was a factor in the sprouting of rhizomes at 27-30°C. Rhizomes exposed to light sprouted on the 8th wk while those kept away from light (with jute sack) sprouted on the 12th wk. Exposure to light, likewise, resulted in faster growth of the sprouts than when kept in jute sack. Sprout length of rhizomes on the 18th wk at 27-30°C with light was 61.00 mm while it was only 29.44 mm when stored without light.

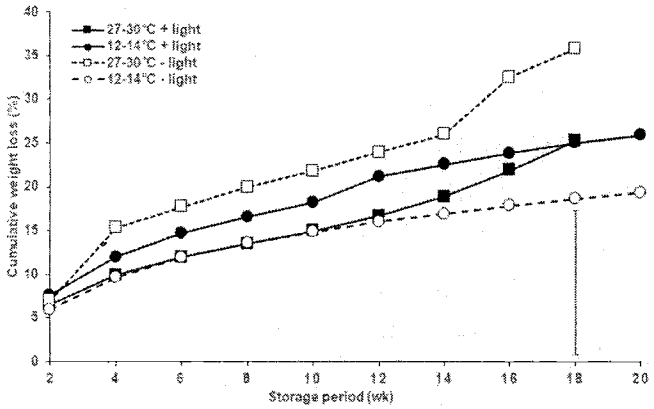

Figure 1. Percent weight loss of fresh turmeric rhizomes during 20-week storage at 27-30°C and 12-14°C, vertical bar represents LSD values

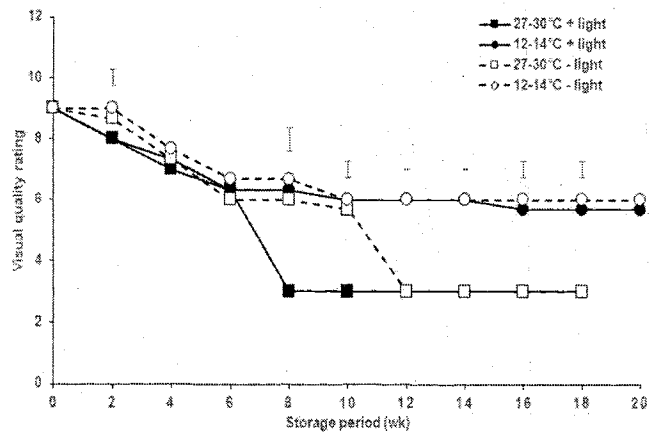

Figure 2. Change in the Visual Quality Rating (VQR) of fresh turmeric during 20-week storage at 27-30°C and 12-14°C. VQR scale: 9,8 = excellent, field fresh, 7,6 = good, defects minor, 5,4 = fair, defects moderate, 3 = poor, defects serious, limit of marketability, 2 = limit of edibility, 1 = non-edible under usual conditions, vertical bars represent LSD values

Table 1. Length of sprouts (mm) of fresh turmeric during storage at 27-30°C and 12-14°C.[1]

Storage period (wk)	27-30°C + light	27-30°C - light	12-14°C + light	12-14°C - light
8	8.33a	0b	0b	0b
10	13.11a	0b	0b	0b
12	21.56a	11.11b	0c	0c
14	30.22a	21.33b	0c	0c
16	43.44a	27.22b	0c	0c
18	61.00a	29.44b	0c	0c

[1]Means in a row followed by the same letter are not significantly different at 5% level, LSD

Table 2. Firmness (kg-force) of fresh turmeric during 20-week at 27-30°C and 12-14°C.[1]

Storage period (wk)	27-30°C + light	27-30°C - light	12-14°C + light	12-14°C – light
0	1.63a	1.74a	1.81a	1.77a
2	1.58a	1.48a	1.65a	1.68a
4	2.04a	1.97a	1.99a	2.01a
6	1.69ab	1.55b	1.78ab	1.86a
8	2.26a	2.34a	2.08a	2.34a
10	2.37a	2.13b	2.25a	2.44a
12	1.79a	1.81a	1.59a	1.71a
14	1.69a	1.52ab	1.36b	1.70a
16	1.76a	1.64a	1.80a	1.78a
18	1.69a	1.48a	1.48a	1.56a
20	-	2.01a	-	1.97b

[1]Means in a row followed by the same letter are not significantly different at 5% level, LSD. No values were indicated on the 20th week at 27-30 °C since the experiment was already terminated due to severe sprouting.

Visual Quality

Generally, turmeric rhizomes exhibited a slow decline in visual quality during the first 6 wk of storage regardless of temperature and light exposure (Figure 2). On the 8th wk of storage, there was a sudden decline in visual quality of rhizomes stored at 27-30°C in the presence of light which was attributed mainly to sprouting thereby affecting the marketability of the rhizomes. On the other hand, enclosed rhizomes with jute sack at 27-30°C had a sudden decline on the 12th wk of storage. Rhizomes stored at 12-14°C with or without light maintained their high visual quality rating of 6-7 (good with minor defects) and were still highly marketable until the last week of storage.

Firmness

Firmness increased on the 8th and 10th wk with values reaching 2.08 to 2.44 kg-force followed by a decline with extended storage (Table 2). Rhizomes enclosed in jute sack then stored at 12-14°C had the highest firmness value of 2.44 kg-force on the 10th wk of storage wherein shriveling did not occur.

Respiration Rate

Storage temperature and light exposure had no distinct effect on the respiratory pattern of fresh turmeric rhizomes. Respiration rates of fresh turmeric range 3.34 to 29.74 mg CO_2 kg^{-1} h^{-1} at 27-30°C and 1.21 to 18.63 mg CO_2 kg^{-1} h^{-1} at 12-14°C.

The effect of temperature and light exposure on the rate of respiration was evident only after 24 h of storage at different conditions. Initially, rhizomes kept at 27-30°C exhibited higher rates of respiration than those stored at 12-14°C (Figure 3). Rhizomes stored at low temperature not exposed to light had the lowest rate. This initial high rate of respiration was followed by a decrease on the 1st wk of storage which continuously decreased until the 4th week except for rhizomes exposed to light at 27-3°C wherein the decrease on the 1st wk was followed by an increase then a gradual decrease. A marked increase in respiration rate in all treatments was again observed on the 6th wk of storage followed by a decrease.

Table 3. Chroma (a+ values) of fresh turmeric during 20-week storage at 27-30°C and 12-14°C.[1]

Storage period (wk)	27-30°C + light	27-30°C - light	12-14°C + light	12-14°C - light
0	45.47a	45.23a	44.27a	44.10a
2	41.70a	43.47a	42.43a	45.17a
4	41.07a	40.97a	42.43a	37.20b
6	43.93a	44.47a	42.70a	42.40a
8	46.60a	47.17a	43.90b	46.30a
10	44.13a	45.30a	44.03a	46.27a
12	44.97a	45.37a	43.27a	43.57a
14	43.57a	43.70a	39.13a	44.57a
16	46.03a	45.00a	42.97a	45.23a
18	41.10a	42.77a	40.83a	43.27a
20	-	44.37a	-	42.90a

[1]Means in a row followed by the same letter are not significantly different at 5% level, LSD

Table 4. Sensory rating of fresh turmeric (juice) extracts during 16-week storage at 12-14°C and 27-30°C.[1]

Storage period (wk)	27-30°C + light	27-30°C - light	12-14°C + light	12-14°C - light
4	4.40a	5.00a	2.80b	2.60b
8	4.20ab	3.20b	3.60ab	4.60a
12	3.40a	2.00a	2.80a	3.20a
16	3.80a	3.80a	3.80a	3.20a

[1]Fresh turmeric extracts were rated from 1 (dull/pale yellow color, not perceptible aroma/flavor) to 5 (bright yellow, highly perceptible aroma/flavor). Means in a row followed by the same letter are not significantly different at 5% level, LSD

Ethylene Production

In this study, the observed ethylene production values were 0.06 nL kg^{-1} h^{-1} to 3.11 nL kg^{-1} h^{-1} at 27-30°C while 0.16 to 1.90 nL kg^{-1} h^{-1} at 12-14°C. Ethylene production increased slightly during the first 12 wk of storage at both storage temperatures regardless of whether the rhizomes were exposed to light or not (Figure 4). On the 16th wk, rhizomes exposed to light regardless of storage temperature exhibited a drastic increase in ethylene production with those stored at 27-30°C having the highest value. Ethylene production of rhizomes kept away from light (with jute sack enclosure) remained low during this period.

Chroma *(a+ value)*

The a+ value indicates the intensity of yellow-orange color. It was relatively stable during the 20-wk storage at 27-30°C and 12-14°C (Table 3). Exposed rhizomes at 27-30°C had the lowest a+ values while those stored at 12-14°C had the highest a+ values indicating a relatively more stable yellow-orange color.

Total Phenolic Content and Free-Radical Scavenging Activity

The observed total phenolic content (TPC) values ranged from 7.9 to 19.83 µg g^{-1}. TPC of turmeric rhizomes was relatively stable during the 20-wk storage at 27-30°C and 12-14°C and differences among treatments were not significant (Figure 5).

Similar to TPC, the antioxidant activity of rhizomes remained relatively stable until the 14th wk of storage regardless of storage temperature and light exposure (Figure 6). The percent inhibition values ranged 30-40% during the first 6 wk of storage then declined to almost 20-30% on the 8th wk in all treatments except for rhizomes stored at 12-14°C without light that retained its high DPPH activity. The decrease in activity was followed by an increase on the 10th wk with the rhizomes stored at 12-14°C and exposed to light exhibited a continuous increase until the 16th wk. During this period, all treatments exhibited the highest free-radical scavenging activity which increased to more than 50%.

Sensory Rating

The intensity of yellow to orange color and distinct aroma of rhizomes were maintained during storage (Table 4). The turmeric flavor became slightly perceptible as duration of storage progressed regardless of the treatments.

DISCUSSION

The marketability of fresh turmeric rhizomes is affected by its external and internal appearance characterized by freedom from shriveling and sprouting, firm texture, and intense yellow-orange flesh which is a rough indication of its high curcuminoid content, the compound responsible for its various pharmacological properties (Nasri et al. 2014; Laokuldilok et al. 2015). Conditions during storage affect the changes in these desirable quality attributes. In this study, both temperature and light exposure influenced the storage potential of fresh turmeric rhizomes. During the first 4 wk of storage, visual quality declined at a slow rate in all treatments and the rhizomes were still highly marketable because of the absence of sprouting. Slight shriveling was also evident during this period when weight loss reached 10-15% but this did not detract from the visual appeal of the rhizomes. As storage duration increased, those stored at 27-30°C and exposed to light exhibited a drastic decline in visual quality with the rhizomes already reaching the limit of marketability on the 8th wk when sprouting was evident. At this stage, sprouting did not lead to high weight loss since the value obtained (about 13%) was lower than those not exposed to light (about 20%) but without sprouting. However, with extended storage, sprouts continuously elongated contributing to weight loss as also reported by Akamine (1962) in fresh ginger rhizomes.

On the other hand, when the rhizomes were not exposed to light and stored at 27-30°C, the limit of marketability was reached on the 12th wk with the occurrence of sprouting. The higher weight loss (about 24%) of rhizomes stored at high temperature without

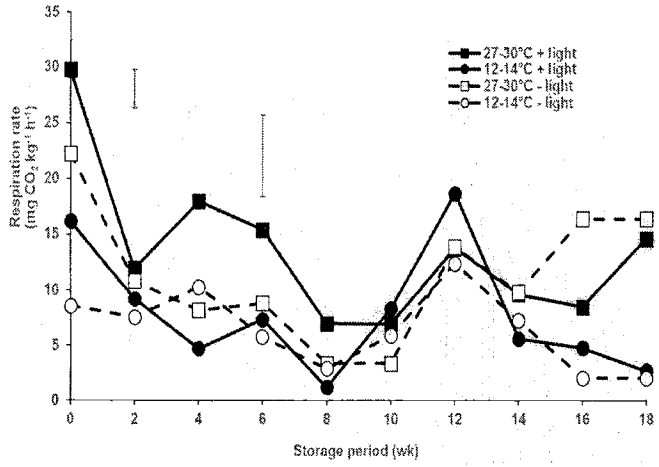

Figure 3. Respiration rate (mg CO_2 kg^{-1} h^{-1}) of fresh turmeric during 18-week storage at 27-30°C and 12-14°C, vertical bars represent LSD value

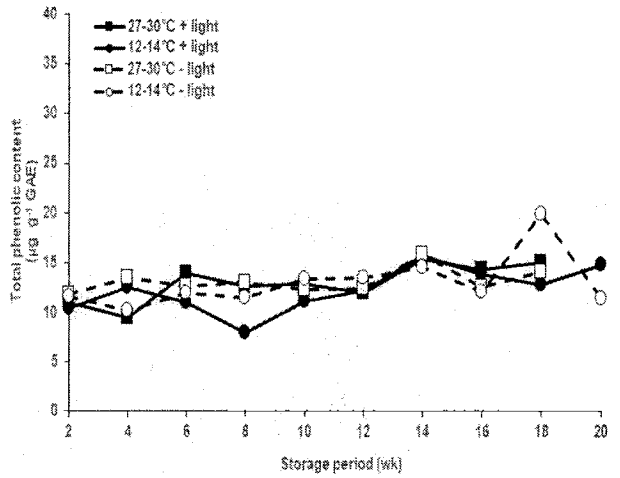

Figure 5. Total phenolic content (µg g^{-1} gallic acid equivalent) of fresh turmeric during 20-wk storage at 27-30°C and 12-14°C, vertical bars represent LSD values

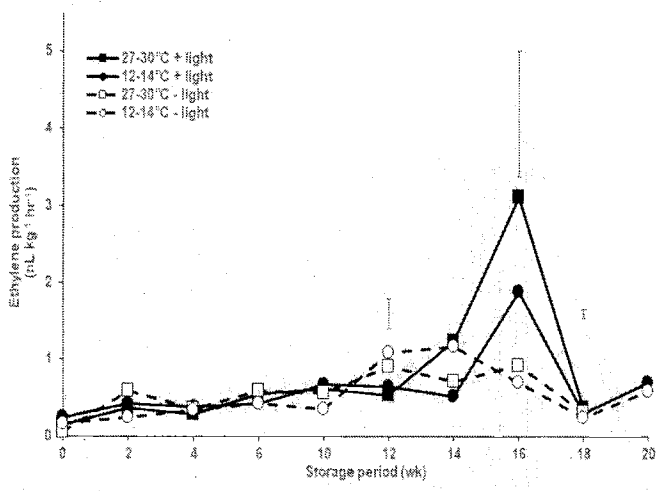

Figure 4. Ethylene production (nL kg^{-1} h^{-1}) of fresh turmeric rhizomes during 20-wk storage at 27-30°C and 12-14°C, vertical bars represent LSD values

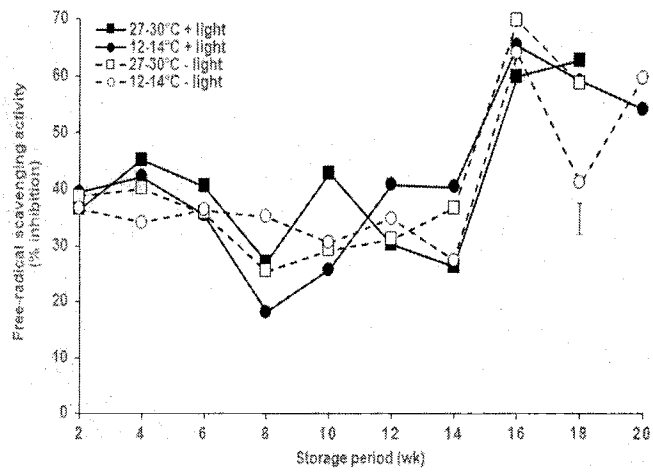

Figure 6. DPPH free-radical scavenging activity (% inhibition) of fresh turmeric during 20-wk storage at 27-30°C and 12-14°C, vertical bars represent LSD values

light than those with light (16%) did not contribute to the decline in quality because shriveling was hardly apparent. This indicated that sprouting is the main contributory factor to the decline in visual quality. Moreover, it was apparent that at high temperature, light is a factor in the early onset of sprouting but not at low temperature since sprouting did not occur at 12-14°C during the 18-wk observation period regardless of light exposure thus the rhizomes were still highly marketable. The dormancy of the rhizomes was extended during low temperature storage similar to that of ginger (Paull and Chen 2015).

Storage temperature and light exposure generally did not influence the change in firmness of the rhizomes. Even though weight loss reached 30% on the later period of storage, and with the onset of sprouting, the rhizomes remained firm and even increased on the 8th and 10th wk of storage.

The maximum respiration rates at both storage temperatures were close to the values reported by Ress et al. (2012) of 28 mg CO_2 kg^{-1} h^{-1} and 17 mg CO_2 kg^{-1} h^{-1} at 20°C and at 10°C, respectively. There was no distinct pattern of respiration during storage. The increase in respiration rate on the 12th wk at both temperatures can be attributed to the onset of sprouting during this period. On the other hand, ethylene production remained relatively stable in all treatments until the 14th wk of storage. Even with the onset of sprouting on the 8th and 12th wk of storage at 27-30°C with light and without light, respectively, ethylene production did not increase. Faster growth of sprouts during the later part of storage at 27-30°C resulted in high ethylene production.

High a+ value of rhizome enclosed in jute sack indicated a relatively more stable yellow-orange color as degradation of curcuminoid was retarded by

preventing the exposure of rhizomes to light. Accordingly, the curcuminoids are readily decomposed when exposed to light (Schieffer 2007). The sensory panelists also rated the rhizomes as having maintained yellow-orange color and distinct aroma.

Total phenolic compounds have health-promoting effects and directly indicate the antioxidant activity (Nisar et al. 2015). In this study, the observed TPC values ranged from 7.9 to 19.83 μg g^{-1} which was lower than the reported value of 1.72-7.46 g GAE $100g^{-1}$ (Kaur and Kapoor 2002). The difference in the observed values can be attributed to cultivar and growing conditions. Total phenolic content of rhizomes was relatively stable during storage regardless of holding temperature and light exposure. The change in the antioxidant activity on the other hand, exhibited no distinct pattern particularly with regard the effect of light exposure. When not exposed to light, antioxidant activity remained relatively stable until the 14^{th} wk similar to TPC. On the 16^{th} wk, activity increased to about 60% in all treatments which corroborated with the report of Kaur and Kappor (2002) that ethanolic extracts of turmeric had 62.45% antioxidant potential. On the 18^{th} week of storage, the decrease in antioxidant capacity of rhizomes stored at 14°C without light and the increase in TPC can be attributed to the type of phenolic compound and amount of individual phenolic present in turmeric rhizomes especially towards the end of storage period (Del-Toro -Sanchez et al. 2015).

CONCLUSION AND RECOMMENDATION

The desired quality attributes of turmeric like absence of shriveling and sprouting, and intense yellow-orange flesh were best maintained when the rhizomes were stored for 20 wk at 12-14°C even without protection from light. Storage at 27-30°C resulted in earlier onset of sprouting (8^{th} wk) particularly if the rhizomes are not protected from light thus the decline in visual quality and marketability. Enclosure of rhizome in jute sack (without light) prevented the degradation of phenolic compounds responsible for the antioxidant properties since total phenolic content did not change markedly during storage similar to that of the antioxidant activity. There was no change in the intensity of yellow-orange color of rhizomes which can be an indication of retarded degradation of curcuminoid.

Turmeric growers and traders can opt to use jute sack as cover or packaging material of rhizomes during ambient storage especially if there is an oversupply in order to maintain the desired quality attributes of the rhizomes in terms of intensity of color and high phenolic content and antioxidant activity. If long-term storage is desired, it is recommended to adopt cold storage and also to protect the rhizomes from light.

The change in the level of curcuminoid responsible for the various pharmacological properties of the rhizomes was not analyzed in this experiment hence further studies on this aspect needs to be done. Other storage techniques likewise need to be explored since low temperature storage cannot be readily adapted by farmers.

ACKNOWLEDGEMENT

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