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Effect of modified atmosphere packaging on storability and quality attributes of fresh-cut cowpea (*Vigna unguiculata* [L.] *Walp*)

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ABSTRACT

Purpose: Increasing demand for pre-packaged fresh-cut cowpea based on nutritional content, convenience and ready-to–use attributes is limited due to its highly perishable nature. **Research method:** Two experiments were conducted to investigate the shelf life and storability of fresh-cut cowpea. Fresh-cut cowpea (cv. Local Green) subjected to hydro-cooling with or without sodium hypochlorite was sealed-packaged in LDPE bags and stored at 4-5°C and 20-22°C up to 12 days. The second experiment focused on the occurrence and alleviation of chilling injury (CI) on fresh-cut cowpea (cv. Local Green and cv. Local Pink), stored at 4-5°C and 20-22°C in sealed LDPE bags after 3 and 6 days and upon transfer after 6 days at 4-5°C plus 1, 2 and 3 days at 20-22°C. **Findings:** Fresh-cut cowpea (Local Green cv.) was 100% marketable after 6 days in sealed LDPE bags at 4-5°C, then decreased to 70% after 12 days. At 20-22°C marketable quality ratings were 87.3% after 3 days, declined to 30% after 6 days and eventually to 100% after 12 days. Absence of chilling injury for both fresh-cut cowpea cultivars, were obtained within the initial 6 days of storage at both temperatures. After 6 days at 4-5°C plus 1, 2 and 3 days at 20-22°C, resulted in progressive increases in CI development which was higher for the Local Pink versus Local Green cultivar. **Limitations:** Wider range of postharvest dips required. **Originality/Value:** Temperature control combined with MAP prolonged shelf-life of fresh-cut cowpea and reduced incidence of chilling injury.

INTRODUCTION

Cowpea (*Vigna unguiculata* [L.] Walp) (Fabaceae), also referred to as bodie, black-eye pea, crowder pea, yardlong bean or asparagus bean is a versatile annual crop adapted to semiarid conditions of heat and drought areas. Cowpea is an excellent source of many essential nutrients, including proteins and amino acids, complex carbohydrates, minerals, fiber, vitamins, and other bioactive compounds and notably low in calories and fat (Bouchenak & Lamri-Senhadji, 2013; Singh et al., 2017). Although dried cowpea grains are the most widely used for human food, other parts of the plant including leaves and immature seeds and pods are also consumed based on cultural preferences and location (Xu & Chang, 2012). Moreover, cowpea has potential in solving food insecurity challenges due to climate change, environmental stress and the realities of current threats to human health and livelihood inflicted on a global scale by the novel COVID-19 pandemic virus. Accordingly, the hunger crisis imposed by these challenges are further accentuated as a result of the deficiency in proteins, minerals and microelements in large segments of the world population, emphasizing the urgent need for a sustainable supply of both quality and quantity of food. Currently, leguminous crops have been identified as an affordable and sustainable source of essential nutrients and low cost proteins for a balanced human diet (Avanza et al., 2013). The rich source of phytonutrients in cowpea makes it one of the most suitable crops for providing a healthy, balanced diet to solve malnutrition crisis among the resource-constrained households (Okonya & Maass, 2014). Inclusion of cowpea in the diets as implemented to some extent in Trinidad and Tobago, Suriname and Guyana and more extensively in African-Asian countries would therefore, not only solve problems with hunger but help in reducing the risk of chronic health conditions. Cowpea has several agronomic, economic and environmental advantages, hence, it remains as one of the most suitable and highly cultivated legume crop across the Caribbean and more so in Africa, Asia and South America (Linguya et al., 2015).

There are numerous publications on the morphometric and physiological seed quality traits (Kamara et al., 2019), agronomy and germination indices (Iqbal, 2015), genetics (Toppo & Sahu, 2020) and phytochemical composition (Teka et al., 2020; Collado et al., 2019) of various parts of the cowpea plant and to a large extent on the dried seeds for human and livestock consumption. However, there is an overall paucity of information on the shelf life of fresh whole and fresh-cut ready to cook green tender pods with optimum snapping quality during storage under refrigerated and non-refrigerated conditions. In the Caribbean and elsewhere, the demand for pre-packaged fresh-cut cowpea is evident, based on the frequency of sales under ambient conditions at municipal markets as well as upon display on refrigerated shelves in supermarkets. However, at both market outlets the quality of fresh-cut cowpea is compromised due to limited knowledge and adherence among stakeholders related to optimum storage temperatures after harvest and the consequent impact on metabolic activity. Unfavorable storage conditions and prolonged storage durations of fresh-cut cowpea would promote degradation of chlorophyll, carotenoids, ascorbic acid, antioxidants and carbohydrates similar to that reported for snap bean (Spinardi et al., 2016). The degree of perishability is enhanced when pods selected at the green-tender stage of maturity with high moisture content and snapping quality characteristics are preferred prior to cooking at the household level.

Quality of the fresh whole or fresh-cut green cowpea pods is determined by the genotype of the parent material, as it determines the response of the plant to abiotic and biotic stresses and ultimately determines the yield potential. Furthermore, establishment of optimum crop stand could directly affect yields and therefore many aspects in its production such as seed source, production practices and management, cropping systems, methods of harvesting, and postharvest handling would compromise pod quality. Green tender cowpea pods with high quality are straight, tender, fleshy, bright green, with light green seeds. Mature pods that are unharvested and allowed to remain on plants become fibrous, less tender, less green in color and have hardened seeds. Loss of quality in pods begins immediately after harvest and increases throughout the supply chain. Unacceptable quality in green pods is often related to shriveling due to moisture loss, decay due to microbial growth, fiber development due to over-maturity, injured pods due to mechanical harvest or rough handling, browning due to injuries caused during harvest, and chilling injury (CI) due to storage at lower than the recommended temperatures (Mohammed, 2010). The high respiration rate of tender immature pods coupled with the rapid rate of transpiration and the limited wax on the cuticle promote wilting and pod deterioration. This becomes more pronounced when pods are packed in large containers where the respiratory heat is not adequately dissipated. Harvested green cowpea pods produce large amounts of respiratory heat. Therefore, immediate and thorough postharvest cooling aids should be undertaken to maintain quality and substantially prolong shelf life. Hydro-cooling is considered the most effective method of pre-cooling cowpea (Mohammed, 2010). In addition, prompt and thorough cooling can reduce the effects of dehydration and lessen damage caused by decay-producing organisms (Avanza et al., 2013).

The demand for fresh-cut cowpea has increased rapidly as it offers consumers highly nutritious, convenient and ready-to-cook options (Ramos-Villarroel et al., 2011). It is well known that fresh-cut processing which includes slicing and/or cutting of fresh vegetables promotes faster physiological deterioration, biochemical changes and microbial degradation which often results in changes in color, texture and flavor (O'Beirne & Francis, 2003). Moreover, fresh-cut operations may cause proliferation of pathogenic microorganism over the cut surfaces leading to food borne diseases (Ramos-Villarroel et al., 2011).

In response with the increasing demand for ready-to-use pre-packaged fresh-cut cowpea, potential shelf life need to be investigated. This study examined the combined effects of modified atmosphere packaging (MAP) and hydro-cooling on the postharvest quality and shelf life of fresh-cut cowpea. Determination of the susceptibility of different local cultivars of fresh-cut cowpea to chilling injury and alleviation using modified atmosphere packaging also warranted further investigation and is hereby reported.

MATERIALS AND METHODS

Experiment 1

Nine bundles equivalent to 12 kg of cowpea pods (cv. Local Green) at the tender green snap stage of maturity, were purchased from a municipal market located in the East-West corridor in Trinidad. Pod length ranging from 30-75cm were packed into a shallow light colored, well-ventilated plastic crate and transported in an air conditioned vehicle to the Professor Lawrence Wilson Food Laboratory, University of the West Indies, within one hour of purchase. The cowpea pods were sorted to ensure wholesomeness, uniformity in size, freshness in appearance, readiness to snap, freedom from residues including traces of chemicals and foreign smell and absence of defects as described by Mohammed (2010).

All sorted cowpea samples were washed with tap water for the removal of extraneous material then dipped for 3 minutes in 300 μg/ml, sodium hypochlorite solution to control surface pathogens and left in a holding room (20°C, 70-75 % relative humidity) until surface moisture had evaporated, approximately 15 minutes later. After each pod at the opposite ends was trimmed 1cm and removed, the remaining samples were uniformly placed on a sanitized plastic cutting board and cut into 3cm pieces using a sanitized stainless steel knife then transferred into a stainless steel basin and weighed. The total weight obtained was divided evenly into 3 portions. One portion of fresh-cut pods was hydro-cooled in a water bath at 4°C for 15 minutes and designated as H1, the second portion was also hydro-cooled for 15 minutes at 4C plus 500ppm sodium hypochlorite (H2) and the third untreated portion (H3) constituted the control. Fresh-cut cowpea pods weighing 40gm each were selected from H1, H2 and H3 and seal-packaged in low density polyethylene bags with a density of 0.941-0.965 g/cm3, 1 mil or 25.4µm thick (gas transmission rates at 22°C, 630 ml m-2h-1 CO_2, 109m/ m-2h-1 O_2) and stored in refrigerated incubators at 4-5°C and 20-22°C, over 12 days and evaluated at 3 day intervals for fresh weight losses (%), marketable quality (%), decay (%) color, firmness, pH, total soluble solids (TSS).

Fresh weight loss

The weight of each package of fresh-cut cowpea was taken before and after each storage interval for calculation of percentage fresh weight losses.

Percentage marketable quality

Each treatment was examined for marketable quality on a scale of 1-9 based on a method of Sherman et al. (1982) with 1= unusable, 3= unsalable, 5= fair, 7= good and 9= excellent. Following this, each sample was examined for severity of decay and classified into two broad categories: (a) marketable and (b) unmarketable. The marketable produce for each treatment was weighed and percentage marketable quality calculated against the original weight of produce.

Percentage decay

The unmarketable produce was designated as the postharvest loss due to decay incidence, weighed and the percentage decay calculated against the original weight of pods.

Color

Skin color was determined with a portable Tristimulus Minolta Chromameter (Model CR-200, Minolta Corp, Ramsey, N.J.). The meter was calibrated with a white standard tile (Minolta calibration plate CR-A43). The pod chromaticity was expressed as L*, a**,** b* coordinates (CIE, 1976). The L* color component represented the lightness of color and it was greater for lighter colors. The a***** values were negative for green and positive for red while the b* values were negative for blue and positive for yellow. Color was measured at two evenly spaced points along the equatorial region of each pod sample.

Firmness

Firmness was determined with a Koehler digital penetrometer (Model # K 19550, Koehler Instrument Company, Bohemia, N.Y.) using a K20500 brass probe with a hardened stainless steel tip which was used to measure penetration depth as pods were penetrated at both sides of their equatorial axes. The probe had a mass of 2.5g and the standard plunger used was 47.5g in mass.

pH

pH was determined with an Orion Research digital pH meter (EA 920, Orion Research Inc. Boston, MA) standardized with two buffer solutions of pH 7.41 and 4.01. The extract was obtained by macerating 25g of pulp with 100 ml deionized water for one minute in a Waring commercial laboratory blender (Model 34 BL97, Waring Products Corp, Hartford, CT).

Total soluble solids

Total soluble solids concentration (TTS) was determined on the juice expressed from a pod section using a hand-held Leica refractometer with a measuring range of 0-50°Brix (Model #10431, Leica Inc. Buffalo, N.Y.).

Experiment 2

Two cultivars of cowpea (cv. Local Green and cv. Local Purple cv.) were purchased at the same market outlet and subjected to similar pre-storage sanitizers, sorting and fresh-cut preparation as outlined in Experiment 1. However, for each cultivar an equal portion of fresh-cut pieces was sealed-packaged in low density polyethylene bags and stored continuously up to 6 days at 4-5°C and 20-22°C and subsequently transferred to 20-22°C for 1, 2 and 3 days respectively to determine the incidence of chilling injury.

Chilling injury index was measured using a rating scale on the basis of the proportion of chilling injured lesion area to the total surface area on each slice of fresh-cut cowpea categorized as follow: 1= no damage; 2 =slight damage; 3=medium damage; 4=severe damage; 5= very severe damage. The CI index was calculated according to the formula (1) used by Pesis et al. (1994).

$$\text{CI Index} = \sum_0^5 \frac{(\text{Injury level})\times(\text{number of pod slices at this level})}{\text{Total number of pod slices}} \quad (1)$$

Each experiment consisted of a completely randomized design with a factorial arrangement of variables. Each treatment was replicated 3 times with each replicate consisting of ten slices or pieces per storage period. Significance of the data was tested by the F-test. Comparison of means and calculations of least significant differences (LSD) were also performed on the data.

RESULTS AND DISCUSSION

Experiment 1

Fresh-cut cowpea attained 100% marketable quality ratings after 6 days and therefore benefitted from the modified atmosphere created in the sealed LDPE bags when combined with storage at 4-5°C. However, after 12 days under similar storage conditions, marketable quality ratings decreased to 70% (Table 1). Compared to samples stored at 20-22°C, fresh-cut cowpea marketable quality ratings were 87.3% after 3 days followed with a dramatic decline to 30% at day 6 and upon prolonged storage for 9 and 12 days succumbed to complete breakdown and 100% decay. Similar findings were reported for fresh-cut lettuce (Teka et al., 2020). Furthermore, the data presented in Table 1, emphasized how quality loss is a function of time, temperature and packaging consistent with previous research (Kader, 2002; Collado et al., 2019). Perhaps the modified atmosphere within the sealed packages at 4-5°C generated a higher bacteriostatic environment against the proliferation of fungi and bacteria responsible for deterioration compared to samples stored at 20-22°C which illustrated the importance of temperature controlled logistics during cold chain management for fresh-cut perishables and the direct effect on their metabolism (Spinardi & Ferrante, 2016).

The occurrence of decay in MAP fresh-cut cowpea after 9 days at 4-5°C, but even at an earlier interval, that is, 3 days at 20-22°C, was noticeable at cut ends of samples and characterized with a mushy texture and light brown color. While the inner epidermal region remained visibly unaffected for fresh-cut cowpea stored at the lower temperature, at the higher temperature decay initiated at the cut ends invaded the entire sample surface, resulting in complete breakdown upon prolonged storage (Table 1). Ramos-Villarreal et al. (2011)

indicated that slicing or cutting vegetables could encourage transmission of pathogenic microorganisms over the cut surface which may result in food safety issues such as food borne diseases. Notwithstanding claims by Kitinoja and Thompson (2010) that pre-cooling of fresh-cut produce would result in better maintenance of quality, such as lower losses due to decay and fresh weight, in this study pre-storage hydro-cooling with or without sodium hypochlorite did not curtail decay of fresh-cut cowpea after prolonged storage. However, both authors did caution that hydro-cooling could spread decay organisms and they recommended the inclusion of other bactericides to circumvent this from occurring.

Reduced efficacy of hydro-cooling even with sodium hypochlorite in this investigation could be caused by traces of organic matter in the hydro-cooling medium, insufficient cooling or low concentrations of sodium hypochlorite. At the same time, in accordance to Sun et al. (2012), it can be argued that excessive amounts of sodium hypochlorite could effectuate tainting of fresh-cut cowpea slices and leave deposits of sodium residues on samples thereby accentuating damages. Furthermore, chlorine could react with organic matter in the hydro-cooling medium to form potential carcinogenic compounds (Parish et al., 2003). Due to environmental and health risks the use of chlorine is forbidden in European countries and therefore for export purposes alternative sanitizers such as ozonized water is recommended for fresh-cut cowpea and other vegetables (Olmez et al., 2007) or the use of pulse light non-thermal treatment as advocated by Nor-Hasni et al. (2016).

The modified atmosphere created within the sealed fresh-cut cowpea packages and resultant high relative humidity, contributed to minimal fresh weight losses (Table 1). At 4-5°C, fresh weight losses ranged from 0.19% to 1.44% over the entire 12 days of storage probably due to reduced physiological metabolism. At 20-22°C, where higher respiratory metabolism was more than likely augmented, fresh weight losses escalated from 0.82% after 3 days to 2.43% after 6 days, almost three-folds more, followed by severe decay incidence (Table 1). The induction of wounding during fresh-cut operations could enhance metabolic activities at higher compared to lower temperatures (Esguerra & Rolle, 2018) to account for the differences in fresh weight losses and decay (Table 1). This further highlighted the significance of applying MAP in achieving a desirable atmosphere within a specific temperature regime. Moreover, this investigation pinpointed that adherence to strict low temperature control following fresh-cut operations are necessary to reduce the likelihood of wound-induced metabolism. The differences in fresh weight losses at both temperatures could be related to the resistance exerted at both cut ends and movement of water vapor due to transpiration.

Table 1. Interaction of temperature × storage duration upon percentages marketable quality, decay and fresh weight loss of fresh-cut cowpea (cv. Local Green)

Storage interval (days)	Marketable quality (%)		Decay (%)		Fresh weight loss (%)	
	4-5°C	20-22°C	4-5°C	20-22°C	4-5°C	20-22°C
3	100.0e[y]	82.7d	0.0a	17.3b	0.19a	0.82ab
6	100.0e	30.0b	0.0a	70.0d	0.58ab	2.43c
9	70.0c	0.0a	30.0c	100.0e	1.32b	nd[z]
12	70.0c	0.0a	30.0c	100.0e	1.44b	nd
$LSD_{(0.05)}$	12.5		12.2		0.9	

[z]nd: no data due to decay. [y]Mean separation in each column for each treatment by LSD $_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

Consumers generally select pre-packaged fresh-cut cowpea based on appearance and an important index of optimum quality during display for sale is color which is often used to determine the pigment chlorophyll and freshness. The significant interaction between temperature, time and hydro-cooling treatments for L*color values shown in Table 2, could be used as an aging criterion and as an indicator of physiological and pathological factors on fresh-cut perishables (Kader, 2002). Fresh-cut cowpea subjected to hydro-cooling plus sodium hypochlorite had a darker green color L* value compared to hydro-cooled samples and the control not hydro-cooled at all after 3 days at 4-5°C (Table 2). However, at 20-22°C the opposite effect was obtained. Upon prolonged storage at 4-5°C after 12 days, the L* value of 34.2 for hydro-cooled samples inferred a lighter green color compared to the other pre-cooling treatments. The L* value of 29.6 after 12 days at 4-5°C for samples that were not hydro-cooled had an intense green color and this could be attributed to the development of water-soaked areas randomly located at the distal ends of fresh-cut cowpea samples and probably symptomatic of chilling injury, a physiological disorder which required further investigation and subsequently reported in Experiment 2. At 20-22°C, the L* values marked the initiation of senescence, with hydro-cooled samples after 3 days securing a faded green color compared to samples kept for 6 days. Moreover, the pale green color of control samples that were not hydro-cooled after 6 days as opposed to 3 days at 20-22°C could also be senescence-related.

The significant storage time by temperature interaction for color value a* representative of green intensity is reflected in Table 3. The maintenance of color a* value of -6.1 to – 6.3 after 3 days at both temperatures was different after 6 days with samples having a more intense green color at the lower temperature than at the higher temperature. Green color retention of fresh-cut cowpea is associated with the presence of chlorophyll and the data in Table 3 confirmed that over prolonged storage chlorophyll degradation proceeded faster with time at the higher temperature, consistent with that published by Chandra et al. (2008), and Guanasekharan et al. (1992) for lettuce and broccoli. These findings signified that green color retention as an important quality index which should be preserved until ready-to-use by all stakeholders in the fresh-cut industry. Accordingly, Ferrante et al. (2004) reported that color changes are the first visible symptom of senescence which could compromise the economic value of a commodity. Thus in this research, the modified atmosphere created within the sealed LDPE bags at a low temperature successfully reduced the occurrence of degenerative processes associated with senescence.

Table 2. Interaction of temperature × storage duration × hydro-cooling upon L* color value of fresh-cut cowpea (cv. Local Green)

Storage interval (days)	Color (L*)					
	4-5°C			20-22°C		
	H1[x]	H2	H3	H1	H2	H3
3	32.6g[y]	30.3def	33.1gh	31.5fg	34.7ijk	28.4bc
6	30.1def	27.0b	22.8a	28.8c	35.3jk	36.1k
9	35.3jk	33.4hi	31.1ef	nd[z]	nd	nd
12	34.2hij	30.1def	29.6cde	nd	nd	nd
$LSD_{(0.05)}$	1.5					

[z]nd: no data due to decay. [y]Mean separation in each column for each treatment by $LSD_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level. [x]H1: Hydrocooled at 4^0C for 15 minutes; H2: Hydrocooled for 15 minutes at 4^0C plus 500ppm sodium hypochlorite; H3: Control.

Table 3. Interaction between temperature × storage time for color value a* and firmness of fresh-cut cowpea (cv. Local Green)

Storage interval	Color a*		Firmness (g/force)	
(days)	4-5°C	20-22°C	4-5°C	20-22°C
3	-6.1d[y]	-6.3d	549.6e	554.4e
6	-2.9b	- 21a	481.9c	368.6a
9	-4.3c	nd[z]	524.1d	nd
12	-3.5b	nd	450.4b	nd
$LSD_{(0.05)}$	0.6		21.8	

[z]nd: no data due to decay. [y]Mean separation in each column for each treatment by LSD $_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

Table 4. Interaction between temperature × storage time for pH and total soluble solids (TSS) of fresh-cut cowpea (cv. Local Green)

Storage interval	pH		TSS (%)	
(days)	4-5°C	20-22°C	4-5°C	20-22°C
3	6.0a[y]	6.1b	1.0a	1.1b
6	6.0a	6.1b	1.1b	1.2c
9	6.1b	nd[z]	1.1b	nd
12	6.2c	nd	1.0a	nd
$LSD_{(0.05)}$	0.03		0.09	

[z]nd: no data due to decay. [y]Mean separation in each column for each treatment by LSD $_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

The decline in marketable quality and increase in decay of fresh-cut cowpea was also linked to tissue deterioration which could influence textural quality or firmness. Although fresh-cut cowpea benefited from the high relative humidity within sealed LDPE bags with minimal fresh weight losses, firmness declined from 549.6 g/force after 3 days at 4-5°C to 450.4 g/force after 12 days (Table 3). A similar but more abrupt decrease in firmness was obtained at 20-22°C between day 3 and day 6 followed by complete tissue collapse thereafter. These findings corroborated with Toivonen and Brummell (2008) that firmness may be determined by the physical anatomy of the fresh-cut cowpea tissue as well as cell size, cell shape and packing, cell wall thickness and strength, the extent of cell to cell adhesion together with turgor pressure. Moreover, cell wall thickness and strength contributed to firmness, characteristic of a cultivar and largely determined by genetic factors and could be attributable to data presented in Table 3.

The pH obtained for fresh-cut cowpea as shown in Table 4 had minor differences among treatments which ranged from 6.0 to 6.2 and therefore could be characterized as low-acid. The pH at 4-5°C after 3 and 6 days was marginally lower than samples kept after 9 and 12 days. Also, fresh-cut cowpea stored at 20-22°C recorded pH values slightly higher after 3 and 6 days compared to their counterparts stored at 4-5°C. The results are inconsistent with that reported by Bahram-Paryar and Loon-Tak (2018) for fresh-cut onions where higher temperatures accounted for lower pH due to accelerated metabolism and wound-induced stress.

Generally, cowpea has a bland taste due to low total soluble solids (TSS). Regardless of the treatments, TSS of fresh-cut cowpea showed minimal changes which ranged from 1.0 to 1.2 (Table 4). This is not unusual since the maturity selected for fresh-cut purposes in this study was at the tender green stage. The baseline readings for TSS taken prior to storage at day zero before cutting was 2.5. TSS then decreased to 1.0 at 4-5°C and 1.1 at 20-22°C on day 3 after cutting and could be due to the process of respiration. Slight increases in TSS at both temperatures were obtained as storage time advanced. Similarly, minor increases in TSS were noted after 3 and 6 days at 20-22°C than at 4-5°C. These increases in TSS could be related to moisture loss as described by Nunes et al. (2004) on their research with green snap beans.

Kleinhenz and Bumgarner (2013) indicated that TSS in vegetables could be influenced by variety, stage of maturity at harvest, metabolic activity as well as major abiotic factors such as environmental conditions during growth and development**.**

Experiment 2

As shown in Table 5, an overall absence of chilling injury (CI) for the cv. Local Green and cv. Local Pink fresh-cut cowpea cultivars, was obtained within the initial 6 days of storage at both temperatures. However, after 6 days at 4-5°C and upon subsequent transfer to a non-chilling temperature at 20-22°C for 1, 2 or 3 days, there were progressive increases in CI symptom development, which were consistently higher for the Local Pink cultivar compared to the Local Green cultivar (Table 5). The hastening of CI incidence confirmed that the sensitivity and severity hereby manifested is genetically regulated and based on cultivar, the duration of exposure to a warmer temperature at the time incipient CI injury occurred as articulated extensively in previous studies (Mohammed & Wickham, 2016; Pan et al., 2018). For the Local Green cultivar, dark-green water-soaked lesions dominated, eventually succumbing to secondary decay upon prolonged exposure to the non-chilling temperature. Fresh-cut cowpea samples from the more CI susceptible Local Pink cultivar had numerous scattered rusty-brown spots accompanied with pronounced decay upon transfer from continuous storage for 6 days plus 2 and 3 days at 20-22°C, leading to a more severe decline in pod quality and reduced marketability than the Local Green cultivar (Table 5).

Nevertheless, for both cultivars following incipient CI damage, an advancement of secondary decay dominated and even surpassed any evidence of pitting. Although the application of modified atmosphere packaging of fresh-cut cowpea was tested in this experiment to attenuate CI, there is still an urgent need to explore more valid treatments and techniques to inhibit or ameliorate CI of fresh-cut cowpea.

Table 5. Interaction of temperature × time × cultivar upon chilling injury incidence of fresh-cut cowpea (cv. Local Green and cv. Local Pink).

Storage intervals	Chilling injury[x] 4-5°C		20-22°C	
	Local Green cv.	Local Pink cv.	Local Green cv.	Local Pink cv.
3 days	1.0a[y]	1.1a	1.0a	1.0a
6 days	1.4ab	1.7ab	1.0a	1.0a
6 days @ 4-5°C + 1 day @ 20-22°	1.9b	2.9c	nd[z]	nd
6 days @ 4-5°C + 2 days @ 20-22°C	3.9d	4.8e	nd	nd
6 days @ 4-5°C + 3 days @ 20-22°C	5.0e	5.0e	nd	nd
$LSD_{(O.O5)}$	0.7			

[z]nd: no data due to decay. [y]Mean separation in each column for each treatment by LSD $_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level. [x]Chilling injury: 1= no damage; 2 =slight damage; 3=medium damage; 4=severe damage; 5= very severe damage.

CONCLUSION

Refrigerated storage of fresh-cut cowpea at 4-5°C in sealed LDPE bags was more effective in maintaining marketable quality compared to samples stored at 20-22°C. Chilling injury symptoms not evident during continuous storage at 4-5°C after 6 days were visibly apparent with incremental increases in severity upon transfer for 1, 2 or 3 days at 20-22°C. The Local Pink cultivar was consistently more susceptible to the development of chilling injury symptoms compared to the Local Green cultivar.

Conflict of interest
The authors declare no conflict of interest.

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