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A Starch Edible Surface Coating Delays Banana Fruit Ripening

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Abstract

A rice starch edible coating blended with sucrose esters was developed for controlling the postharvest physiological activity of Cavendish banana to extend postharvest quality during ripening at 20 ± 2°C. Coating effectiveness was assessed against changes in fruit physiochemical parameters such as weight loss, titratable acidity, total soluble solids, flesh fruit firmness, ion leakage, colour change, respiration, ethylene production, chlorophyll degradation and starch conversion were determined. The topography of coating material on the fruit surface was evaluated by scanning electron microscope (SEM). Surface morphology studies highlighted the binding compatibility of the coating matrix with the fruit peel character and formed a continuous uniform layer over the fruit surface. The results showed that the coating was effective in delaying ethylene biosynthesis and reducing respiration rate. Other factors impacting included delayed chlorophyll degradation, reduced weight loss and retention of fruit firmness for the first six days, all of which improved the commercial value of the fruit. The shelf life of coated fruit was prolonged for 12 days in comparison with the untreated control which ripened within seven days and lost marketability after Day 6. The pilot study demonstrates the effectiveness of a starch-based edible coating formulation for improving the ambient storage capacity of banana fruit.

Keywords: Edible Coating, Banana, Ripening, Postharvest, Shelf life.

1. Introduction

The short-shelf life of banana fruit is a continuing challenge for the banana industry worldwide, particularly in regions where refrigerated storage capability is absent (Peroni-Okita et al., 2013). Several postharvest technologies, including low temperature storage, control atmosphere storage, use of ethylene antagonists such as 1-MCP and surface coating of fruit have been investigated to delay fruit ripening (Ahmed & Palta, 2016; Deng, Jung, Simonsen, & Zhao, 2017; Jiang, Joyce, & Macnish, 1999; Pongprasert & Srilaong, 2014). Problems such as chilling injury, improper ripening and the high capital cost of some technologies, limits the use of these applications in many instances. But over 100 million tons of bananas are harvested and marketed around the world.

Like other horticulture produce, banana undergoes a series of biochemical changes after harvesting which affects the storage quality, shelf life and reduces its marketability. Bananas have a high water content, making control of water loss (through temperature and humidity control) a critical aspect of postharvest storage (Embuscado & Huber, 2009). For the marketing of bananas in large remote cities away from production areas, mature green bananas are harvested and transported to markets before ripening with ethylene and distributed to retailers. After treatment with ethylene banana go through a sequence of physiological and biochemical changes occurring inside ripening fruit are known to lead to the development of characteristics in the soft flesh tissues that impact on consumer acceptability. These include an increase in membrane permeability (ion leakage), loss of flesh firmness, decreased starch content, increased sugar levels, colour change, increased respiration rate and loss of turgor (Jiang et al., 1999). Edible coatings slow down these effects, preventing loss of water by creating a barrier between the skin and external environment (Nawab, Alam, & Hasnain, 2017). Previous studies conducted in our laboratory

have shown that rice starch-ι-carrageenan formulations enable successful modulation of the gas diffusion rates (e.g., gaseous and water vapour permeability) in fruit (R. Thakur et al., 2018), resulting in improved mechanical and physicochemical properties (Rahul Thakur et al., 2017a; Rahul Thakur et al., 2017b; R. Thakur et al., 2016) in the edible films.

Skin colour is the characteristic feature of banana ripening and an important marker of consumer acceptance. Upon turning yellow, banana lost their marketability to consumers within 1 to 3 days (Ahmed & Palta, 2016). Thus, the ability to extend shelf life, by even modest levels would significantly reduce losses within the banana supply chain. The use of 1-MCP has been shown to be effective in controlling or delaying ethylene biosynthesis in bananas (Zhu et al., 2015) which has been recently commercialized. However, some reports have shown that banana fruit treated with 1-MCP may stay green or ripen with uneven colour and may inhibit the production of total volatile compounds and aroma of fruit (Harris, Seberry, Wills, & Spohr, 2000; Zhu et al., 2015). At present no commercial product or treatment exists that can successfully extend the shelf life of banana without impacting on peel colour, flavour and aroma profile. The work presented in this manuscript outlines the formulation and application of a novel edible coating based on a starch - carrageenan matrix blended with sucrose fatty acid esters to extend the shelf life and improve the marketability of banana fruit.

2. Materials and methods

2.1 Plant material and experimental procedure

Mature green 'Cavendish' banana fruit samples were sourced from Queensland region (G + A Campagna). The fruit had not been treated with ethylene and were selected for use in the experiment based on uniformity of skin colour and is free from any defects, including any physical damage and diseases. Before treatment with the coating solution, fruit hands were dipped into chorine sanitiser (hypochlorite solution, $5gL^{-1}$) solution for 30 sec.

2.2 Design of experiment

Banana, without any visual defects, carefully were handled and prepared in small uniform hands (two fingers each with similar size). A randomized experimental design, comprising 60 homogeneous lots (based on maturity size) of 8 fruit each were assembled randomly. Four lots were used to measure the fruit properties at harvest (0 day) and the remaining 56 lots (8 fruit per lot) were divided into two groups. From both groups, every single lot was assigned as one replication and four replications per treatment was used for assessment on each removal day. Two treatments, T-I (rice starch-ι-carrageenan-fatty acid ester of sucrose (FAEs), and T-II (control, treated with water) were used in the experiment. The optimized coating formulation (Rice starch (3%, w/w), ι-car (1.5%, w/w), FAEs (2%, w/w) and glycerol (1 %, w/w)) was prepared as previously reported by Rahul Thakur et al. (2018). Control and treated fruit were respectively treated with water or coating using the sprayer for 10 seconds. The overloaded coating material was spread uniformly using gloved hands before being removed and air dried for 2 minutes using a hair dryer (<35°C) held at a distance of 60 cm. The fruit were left at room temperature for 25 minutes to dry completely. After coating, the fruit were moved to an ethylene chamber (20 ppm, 20 ± 2°C) where they were treated for 24 hours to ripening. Post-treatment, the control and coated fruit were weighed and stored at 20

± 2°C; RH 52±3% for sampling. A range of quality parameters (including weight loss, respiration, ethylene production, TA, SSC, starch content, chlorophyll level and ion leakage) were assessed every second day.

2.3 Total soluble solids (TSS) and titratable acidity (TA)

The TSS concentration of the fruit pulp was measured using a handheld refractometer (Atago PAL-1, Japan) and data was expressed in °Brix. 10 g sample of the banana pulp was prepared from the eight fruit and homogenized with 20 mL of distilled water and filtered through a cloth sheet and used for the measurement of TA and TSS. The TA of the fruit pulp was determined using the standard method of Association of Official Analytical Chemists (1990) and total acidity was expressed as the percentage of % malic acid.

2.4 Colour measurement

Eight individual fruits per replication were selected for the measurement of peel colour, which was measured around the equatorial, centre and stem regions of the fruit at three different marked points using a Chroma meter-2 reflectance colourimeter (Konica Minolta Sensing Inc. Japan) equipped with a CR-300 measuring head. Colour was recorded using the CIE a*, b* and L* scale. Skin colour was also subjectively assessed on a scale from 1 to 7 as described by CSIRO (1971) where 1 = entirely green, 2 = break green, 3 = more green than yellow, 4 = more yellow than green, 5 = yellow with green tips, 6 = entirely yellow, and 7 = entirely yellow with brown freckles. The same fruit were assessed for colour measurement each assessment time.

2.5 Ethylene and respiration rate

For the ethylene and respiration rate, banana samples, (n=2) were placed in a 1 L hermetic glass jar with a septum and a lid for sampling gas after 1h at 20 ± 2°C. The jars were stored at ambient temperature (20 ± 2°C) and gas sampling was carried out using a needle probe. For ethylene measurement, a 1 mL gas sample was withdrawn from the jar and injected into flame ionization gas chromatograph (Varian Star CX-3400, Walnut Creek, CA) fitted with a stainless steel column (2 m × 3.2 mm OD × 2.2 mm ID) packed with Porapak Q (80–100 mesh) (Altech, Sydney). The ethylene production rate was calculated as μL C_2H_4/kg h. For respiration rate, a 5 mL gas sample was injected into a thermal conductivity gas chromatograph (Gow-Mac 580, Bridgewater, NJ) fitted with a stainless steel Haysep N (80–100 mesh) column (60 cm × 1 mm ID, Altech, Sydney) and the respiration rate was calculated (as mL CO_2 produced / Kg hr).

2.6 Weight loss and firmness

Weight loss was determined by weighing each banana fruit (n=8) before and after the storage period and expressed as a percentage of the initial weight. The firmness of individual uncoated and coated banana (n=8) from each replication was measured at 20 ± 2°C according to the method of Soradech et al., (Soradech, Nunthanid, Limmatvapirat, & Luangtana-anan, 2017) with some modification. Briefly, 3 mm thick discs were cut from the centre of each fruit using a double-headed knife. A 5 mm diameter stainless steel probe was then inserted into the fruit manually and the penetration force (N) was recorded. The maximum penetration force is defined as the force required pushing the probe into the banana surface to a depth of 3 mm at a uniform cross-head speed.

2.7 Total chlorophyll content estimation

The total chlorophyll was determined according to the method of Jatoi et al. (2017) with some modifications. Briefly, four, ~0.1 g banana peel slices without pulp or fibre from eight fruit were randomly selected to add in 25 mL of aqueous acetone (80% v/v) separately for 5 minutes. The solution was then vortexed for 3 min before being filtrated through a Whatman No. 4 filter paper. Chlorophyll a and b absorbance was then recorded separately at λ = 663 nm and λ = 645 nm respectively using a Cary 50 Bio UV–vis spectrophotometer, with total chlorophyll expressed according to the equations below.

$$Chlorophyll\ a = 12.7 \times A_{663} - 2.995 \times A_{645}$$

$$Chlorophyll\ b = 22.95 \times A_{645} - 4.67 \times A_{663}$$

$$Total\ chlorophyll\ (mg.L^{-1}) = \text{Chlorophyll a} + \text{Chlorophyll b}$$

$$Total\ chlorophyll\ (mg.g^{-1}) = \frac{Total\ chlorophyll\ (mg\ L{-}1) X 25\ ml}{Sample\ weight\ x\ 1000}$$

2.8 Leakage of ions from the peel

Ion leakage within the fruit peel was measured according to a modified method of Al-Qurashi, Awad, Mohamed, and Elsayed (2017) and was expressed as membrane stability index percentage (MSI %). Briefly, three grams of peel disks per fruit from each of the four replicates were randomly sampled and placed in 30 mL of deionized water at ambient temperature for 2 h in a shaker. Solution conductivity (k_1) was then measured with an electrical conductivity digital meter (Orion 150A+, Thermo Electron Corporation, USA). The solution containing the disks was then placed in a boiling water bath (100 °C) for 30 min to release electrolytes before being cooled to room temperature (22 ± 2°C). The solution conductivity was then rerecorded (k_2) and MSI calculated according to the formula: ion leakage (%) = $(k_1/k_2) \times 100$.

2.9 Starch content

Starch content of banana was determined by iodine dip method (Blankenship, Ellsworth, & Powell, 1993) with some modifications. Briefly, a staining solution of 1% potassium iodide and 0.1% iodine in distilled water was prepared and the fruit (n=8 per replication) were cross-sectionally cut in half and dipped into the solution at a depth of 5mm for the 30s and the change in colour (blue-black colour development) was observed visually and scored. Blue-Black colour was subjectively assessed on a scale from <5% to >65%, where <5% = entirely black, 10% = onset of off-white, 25% = more black than off-white, 35% = equal black and off-white, 55% = more off-white than blue, >65% = Entire off-white with some blue edges.

2.11 Statistical analysis

ANOVA was carried out to determine the significant differences between the treated and control fruit using statistical software (SAS v 24, The SAS Institute, USA). The results were considered to be significantly different at $p<0.05$.

3. Results and discussion

3.1 Weight loss

Postharvest fruit and vegetables are susceptible to water loss, which reduces the quality and value of fresh produce (Cosme Silva et al., 2017). Coating with an edible membrane can significantly reduce moisture loss and extend shelf life. As expected, weight loss (WL) started from the 2nd day of storage, with a significant difference between the control (3.78%) and coated fruit (2.24%) recorded ($p<0.05$). WL was continuous throughout the storage period, with the control fruit experiencing weight loss of 5.23% at day 10, which was 2.05 % higher than the coated fruit at the same time point and reaches to stage 7 (Fig 1) at the end of day 10 with a significant loss of marketability hence not analysed further. Coated fruit showed a slower rate of ripening and was analysed until day 14. WL in the coated fruit showed no significant difference over the first seven days of storage ($p<0.05$) indicating that the semi-permeable nature of the starch coating was effective in reducing moisture and mass transfer from the fruit surface. Nawab et al. (2017) observed a similar reduction in weight loss in tomato fruit coated with a starch-based film. Kerdchoechuen, Laohakunjit, Tussavil, Kaisangsri, and Matta (2011) similarly demonstrated the effectiveness of starch films on citrus fruit, reporting that coated fruit showed 4.8-7.7% less weight loss relative to the control. As water play an important role in fruit shelf life, quality as well as market price (Cosme Silva, Silva et.al.2017), less loss of water is critical and our findings showed that starch coating is effective to minimize the water loss for banana during storage.

3.2 Respiration rate and ethylene production

Ripening in climacteric fruit such as banana is characterised by a significant and rapid increase in respiration rate which is accompanied by intensive metabolic change (Wills & Golding, 2016). Respiration rate and endogenous ethylene production rates tracked similarly across the storage period, decreasing over the first 6 days, then increase further till day 10 of the experiment (Fig 2). Respiration rate in the control fruit was significantly and consistently greater than the coated fruit across the entirety of the storage period. Importantly, the maximum respiration rate in the treated fruit was maintained below the minimum value observed for the control across the entire storage period.

There was no difference in endogenous ethylene production rates following the ripening with ethylene at the start of the experiment. The only differences in ethylene occurred after 10 days, where the control fruit were discarded as they were over-ripe.

3.3 TA & SSC

A reduction of acidity in the fruit during ripening is accompanied by a reduction in the organic acids. Malic acid is the major organic acid in the banana fruit (Turner & Fortescue, 2012). Coating of the fruit produced no discernible effect on titratable acidity. At day 0, TA was 0.15% (malic acid), which subsequently peaked at 0.37 % (malic acid) on Day 4 and declined steadily thereafter (Figure 3). The increase in the TA values of Control and coated fruit was recorded during the first week of storage. The increase in the titratable acidity during the initial storage period has been ascribed to increased activity of malate synthase and phosphoenolpyruvate carboxylase (John and Marchal (1995).

TSS content increased throughout the storage period in the banana fruit. However, both control and coated fruit reach to their maximum content at a different time during storage. In

control fruit maximum TSS value recorded was around 20.5°Bx, observed on day 8 of storage and for treated fruit, it was 20.5 on day 14. Significant differences ($p<0.05\%$) occur between control and coated fruit between day 3 to day 8 with greater acceleration in TSS accumulation in control. The higher increase in the TSS of the control fruit may be associated with the degradation of starch and dehydration of fruit during storage. Moreover, the similar explanation for the increase in TSS during storage has been provided by (Dave, Ramana Rao, & Nandane, 2017) in the pear fruit. The delay in TSS in coated fruit may most likely have occurred due to the slower metabolic activities of fruit occur due to controlled gaseous exchange. Similar results in the slower increase in TSS were found in the previous study on fruit coated with biopolymer coatings (Al-Qurashi et al., 2017; Soradech et al., 2017).

3.4 Firmness

A continuous and gradual loss in the fruit firmness was observed in both the control and coated fruit during ripening. Firmness loss, expressed as fruit softening, are related to dehydration and loss of integrity in cell wall structures during the course of fruit ripening (Deng et al., 2017). The higher firmness on the 0 day (41.32 N) indicates the compact tissues and firm nature of banana fruit (Fig 4). The treated fruit showed a lower rate of loss of firmness compared to the control across the storage time ($p<0.05$) to day 10 but were not significantly different beyond this point. Similarly, control fruit undergoes rapid fruit softening (>80%) within the first two days of ripening and remained relatively constant in the subsequent sampling times. Banana fruit, treated with starch edible coating showed the highest firmness of 17.39 N on day 2, 10.23 N on day 4 and 8.14 N on day 6 respectively. However, it remained less than 6.89 N in untreated fruit in all the sampling days. Better retention of firmness in case of coated fruit indicated that starch coating was effective in

slowing down the metabolic and enzymatic activities in fruit, resulted into the slower degradation of pulp tissues.

3.5 Ion leakage

Ion leakage is an indicator of plasma membrane integrity and used to assess cell membrane damage or viability (Ahmed & Palta, 2016). Banana peel from the control and coated fruit lost integrity during ripening, resulting in 64% and 58% ion leakage respectively at the end of day 10. At this time point, however, the control was deemed to have reached full maturity (stage 7), while the coated fruit had progressed only to stage 5 on the maturation scale. The results show that ion leakage was significantly delayed ($p<0.05$) in the peel tissues of the treated fruit with the greatest point of the difference occurring between day 4 and day 8 ($p<0.05$) (Table 1). Loss of cell wall integrity is also closely linked to the leakage of Ca^{2+} and Mg^{+} ions, which are important cofactors in many enzymatic processes including nuclease and protease activity. (Ramirez-Sanchez, Huber, Vallejos, & Kelley, 2018). These findings are consistent with the previous reports showing that the coating of fruit can reduce the ion leakage from the banana peel (Ahmed & Palta, 2016).

3.6 Effect of coating on the appearance, chlorophyll degradation and colour of fruit during storage

Consumer perception of fruit quality and acceptability is closely aligned with skin appearance (Iglesias, Echeverría, & Lopez, 2012). Surface colour of individual fruit in the treatment and control groups were monitored on each sampling day at ambient temperature (20 ± 2°C) over the course of the experiment to assess changes in appearance. The skin colour in bananas

transitions from green to yellow during ripening as a consequence of chlorophyll degradation, which makes skin carotenoids more visible (Fig: graphical abstract) (Gol & Ramana Rao, 2011). A standard reference chart consisting of seven distinct visual colour change stages was used to identify the progress of senescence (Fig 6d) (Nannyonga, Bakalis, Andrews, Mugampoza, & Gkatzionis, 2016).

In our experiments, the rate of colour development was found to be significantly different between the uncoated and coated treatment groups ($p<0.05$) from the first week of storage. We observed, in the case of the coated fruit, the slower emergence of browning and spotting on the skin surface, in comparison to the control over the course of the experiment indicating delayed maturity and ripening (Fig: graphical abstract). The lack of uniformity in the ripening of coated fruit was observed during the assessment days which can be attributed to the fact that coating material was applied manually. The hue angle combines both a* and b* values from the colourimeter (Table 1), where the hue angle decreased more slowly. The narrower range in hue angle of the coated fruit reflected degradation of chlorophyll in the skin of coated fruit as a consequence of reduced gas transfer rates brought about by the presence of the surface coating. The observation was in agreement with previous findings by Deng et al. (2017) who reported that changes in the internal gas composition of the fruit significantly delayed the chlorophyll degradation of banana fruit (Deng et al., 2017; Momen, Tatsumi, & Shimokawa, 1997). In addition to that, it is important to mention that coating appear to be transparent and has not imparted any glossiness to the banana fruit as observed during the storage period.

The data obtained from the chlorophyll degradation study is shown in Fig 5. The quantitative analysis of Chl a & Chl b and total chlorophyll indicates a higher concentration of these in the coated fruit than the control fruit ($p<0.05$) whereas control fruit showed weaker accumulation of these pigments. The retardation of colour in coated fruit may be attributed to

the modified atmosphere by an edible coating which has slow down the ripening process. Similar results have been observed in a previous study by Gol and Ramana Rao (2011) who reported that edible coating strongly affected the synthesis of photosynthetic pigments in banana fruit.

The influence of the coating on the fruit surface characteristics through SEM analysis is illustrated in Fig 6 (b and c). Starch coating uniformly covered the pericarp surface without cleavage among epidermal cells, however, some cracks and/or cleavage was observed between the cells in non-coated fruits. Starch coating provided more uniform coverage onto the fruit surface without any cracks thus slowing down the ripening. The lack of surface coverage might potentially accelerate the mass transfer across the fruit surface thus leads to an increased respiration rate and fungus invasion (Deng et al., 2017).

3.7 Starch content

At the pre-climacteric stage, almost all the carbohydrates in a banana are in the form of starch, which is subsequently broken down to reducing and non-reducing sugars during ripening (Thompson & Burden, 1995). Starch concentration in a banana can be qualitatively analysed by complexation with iodine solution, with starch presence denoted by blue-black colour development. Fig 7 shows the pattern of starch degradation in banana slices over the course of storage. The persistence of a blue/black colouration in the coated fruit relative to the control presents clear evidence of delayed maturation. Skin appearance and starch content correlated closely in both the treatment and control fruit, with the coated fruit reaching full maturity (stage 7) compared to the control (day 10), representing a significant extension (40%) in postharvest life at room temperature. Starch degradation pattern was scored on a scale of 1 to 10 according to Blankenship et al. (1993) reported previously. Fig 7 represents the starch degradation pattern in control and coated fruit. The starch degradation

rate was significantly higher in control fruit ($p<0.05$) where >65% starch degradation was observed at the end of day 10. However, the rate was 25% in case of control fruit at the same storage time and start increasing thereafter. The differential rates of starch degradation between the control and treatment groups are supported by the TSS data (Fig 3), which showed a more rapid rise in the sugar content of the control fruit (Cordenunsi & Lajolo, 1995). The delay in starch conversion in the coated fruit is attributed to the reduced exposure of the starch-degrading enzyme alpha-amylase to atmospheric oxygen due to its sensitivity to oxygen. The role of alpha-amylase in the conversion of starch to sugar has been extensively studied (Agravante, Matsui, & Kitagawa, 1990; Tomasik & Horton, 2012) hence, current study concludes that semi-anaerobic atmosphere created by surface coating slow down the activity of starch degrading enzyme, therefore, starch hydrolysis occur at different time in control and coated fruit.

Conclusion

The study developed a rice starch composite edible coating for significantly extending the shelf life of the banana fruit stored at 20 ± 2°C. The results presented in this study demonstrated the efficiency of coating in controlling gas transfer rates including atmospheric oxygen and ethylene production that control respiration and maturation in the fruit. Coated fruit experienced reduced weight loss, improved firmness, reduced kinetics associated with starch degradation and delays in the appearance of visual cues associated with loss of quality, relative to the control. We speculate that the presence of the coating significantly impacts on gas mass transfer across the skin which in turn affects the activity of key enzymes associated with ripening. However, further work is required to confirm this and to fully assess the impact of the coating on sensory attributes and consumer acceptance. A 40% extension is

postharvest life was recorded in the absence of refrigerated storage. This has the capacity to significantly reduced spoilage losses in the supply chain, particularly in developing countries.

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488

Table 1: Ion leakage and hue angle of banana fruit (Control and coated) during storage at 20°C.

	Ion leakage		Hue angle	
	Control	**Coated**	**Control**	**Coated**
0D	12.58±0.6 [a]	12.58±0.6[a]	117.51±0.5[a]	117.51±0.5[a]
2D	21.32±0.5[b]	18.23±0.1[b]	106.48±0.3[b]	117.51±0.3[a]
4D	32.85±0.6[c]	26.00±1.6[b]	95.73±0.3[c]	115.09±1.6[a]
6D	48.05±2.4[d]	38.35±1.0[c]	93.67±0.2[c]	110.95±0.8[ab]
8D	58.90±4.6[e]	54.34±6.0[d]	90.26±0.5[cd]	105.25±1.7[b]
10D	64.34±2.0[e]	58.23±2.5[e]	86.91±1.0[e]	98.98±1.1[bc]
12D	-	61.10±1.8[e]		95.76±0.4[c]
14D	-	62.32±1.4[e]		94.16±0.3[c]

The values are the means ± SE. Mean values with different letters are significantly different at $p<0.05$.

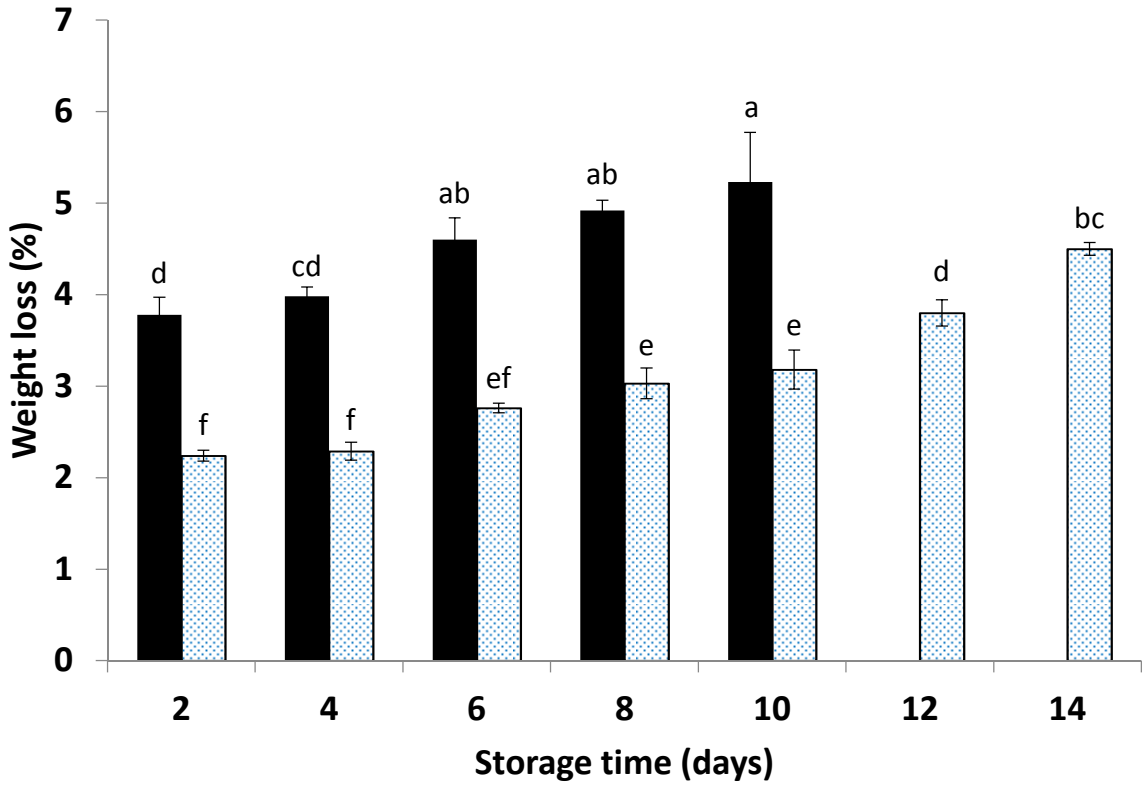


Fig 1: Weight loss for the control and coated fruit. The values are means ± SE. Data in the columns sharing the same letter are not significantly different ($p<0.05$). In the figure, black and white colour column represent control and coated samples respectively.

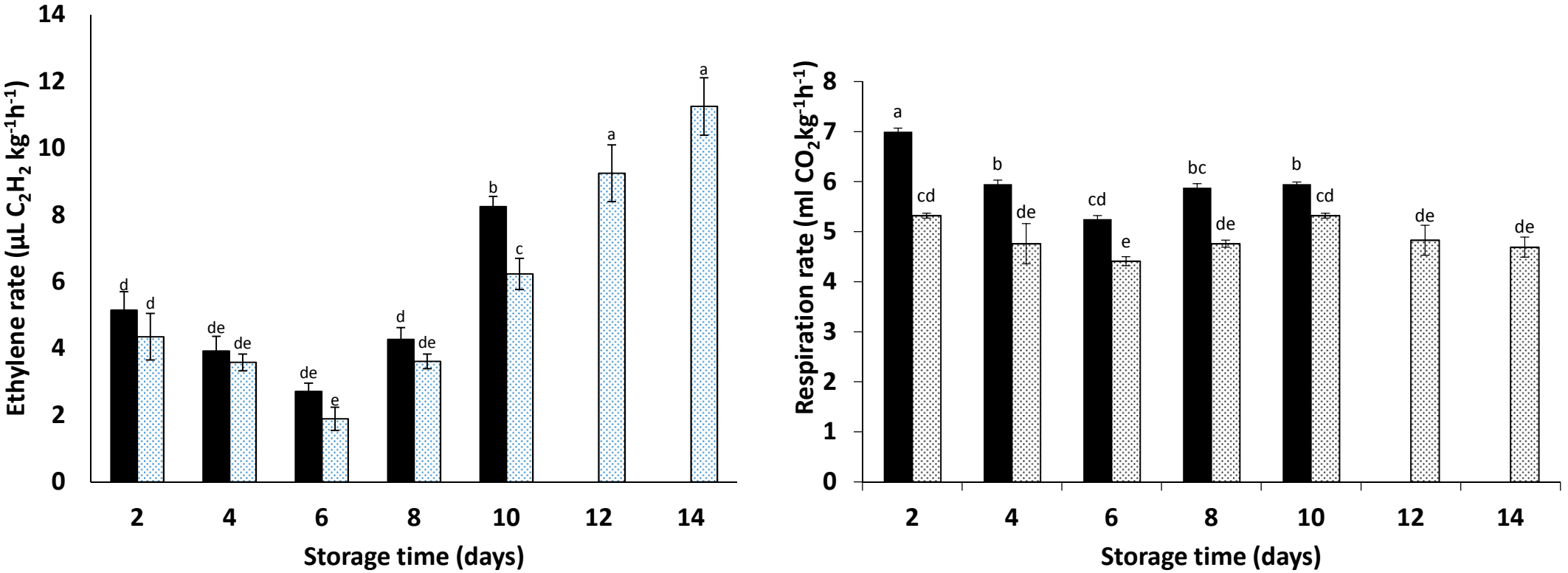


Fig 2: Graphs showing endogenous ethylene production and respiration rates of the coated and uncoated fruit stored at 20°C and 52 ± 5% RH for a period of 14 days. Control fruit were treated with water and coated fruit with a starch-carrageenan-FAEs mixture. The values are the means ± SE. Data sharing different letters on the bars and lines are significantly different at $p<0.05$. In the figure, black and white colour column represent control and coated samples.

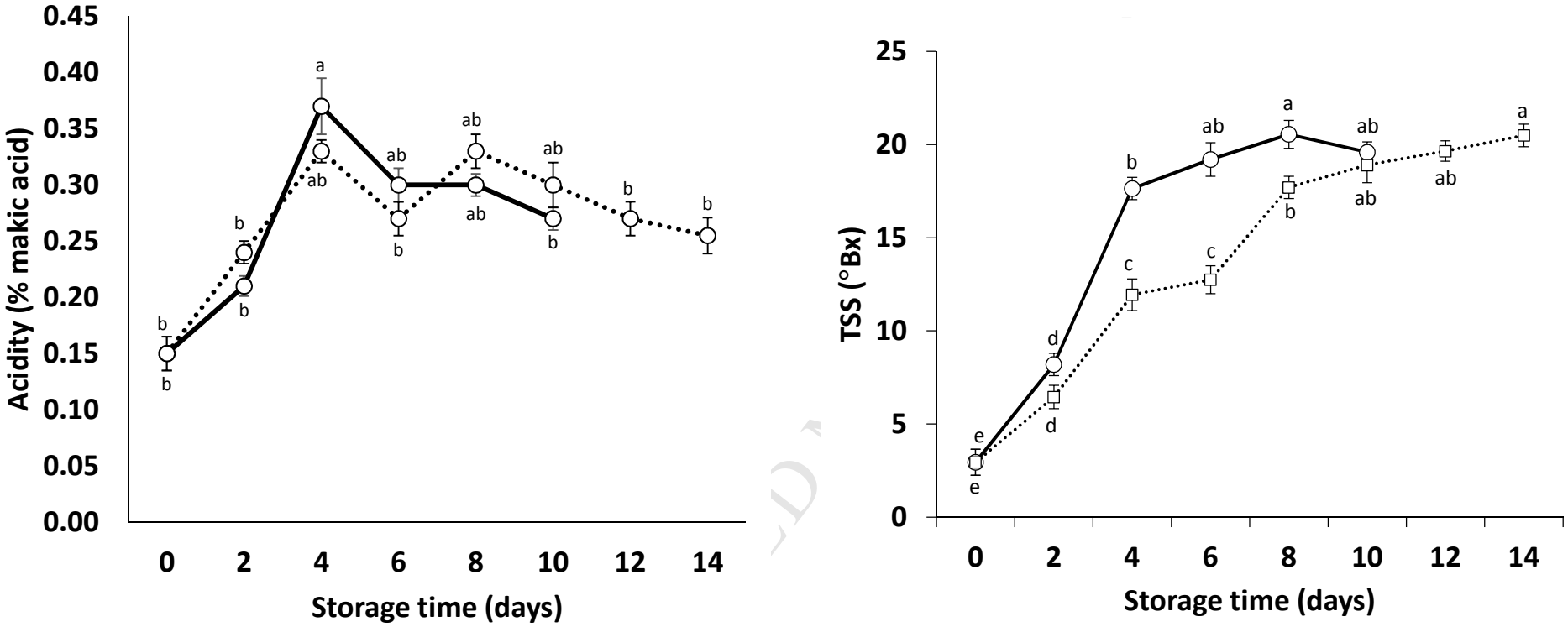


Fig 3: Titratable acidity (TA) (left) and TSS (right) for control and coated fruit during storage. The values are the means ± SE. Data with error bars with different letters are significantly different at $p<0.05$. In the figure, black and dotted lines represent control and coated samples respectively.

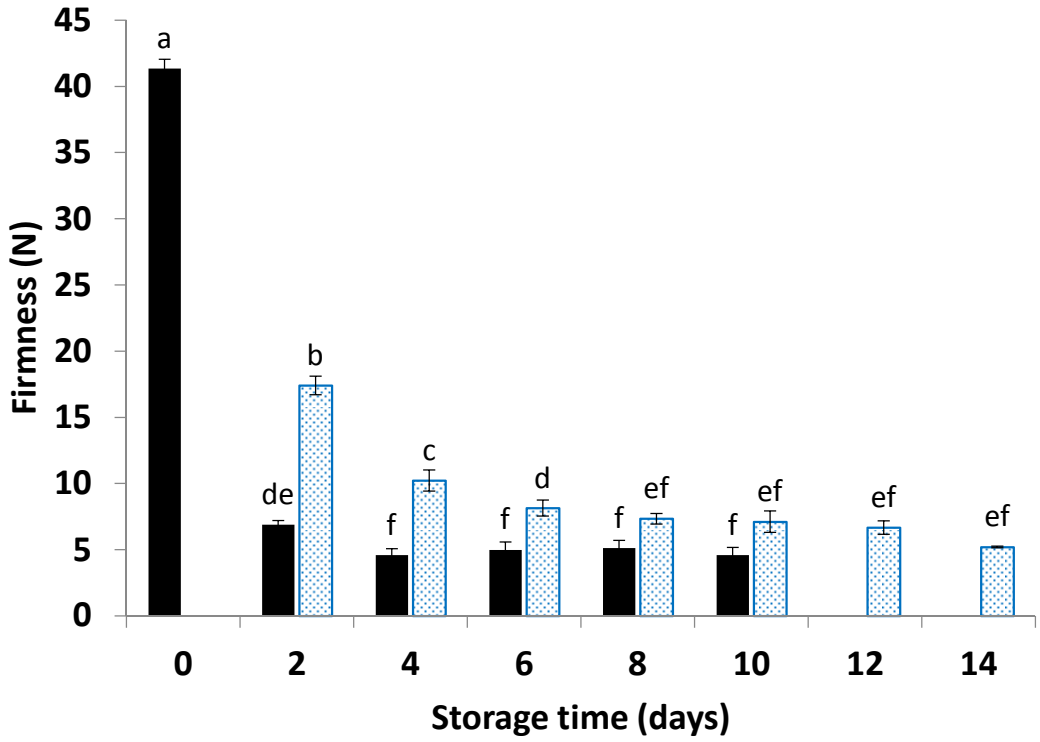


Fig 4: Changes in the fruit firmness for control and coated fruit (n=8) during storage. The values are the means ± SE. Data with error bars with different letters are significantly different at $p<0.05$. In the figure, black and white colour column represent control and coated samples.

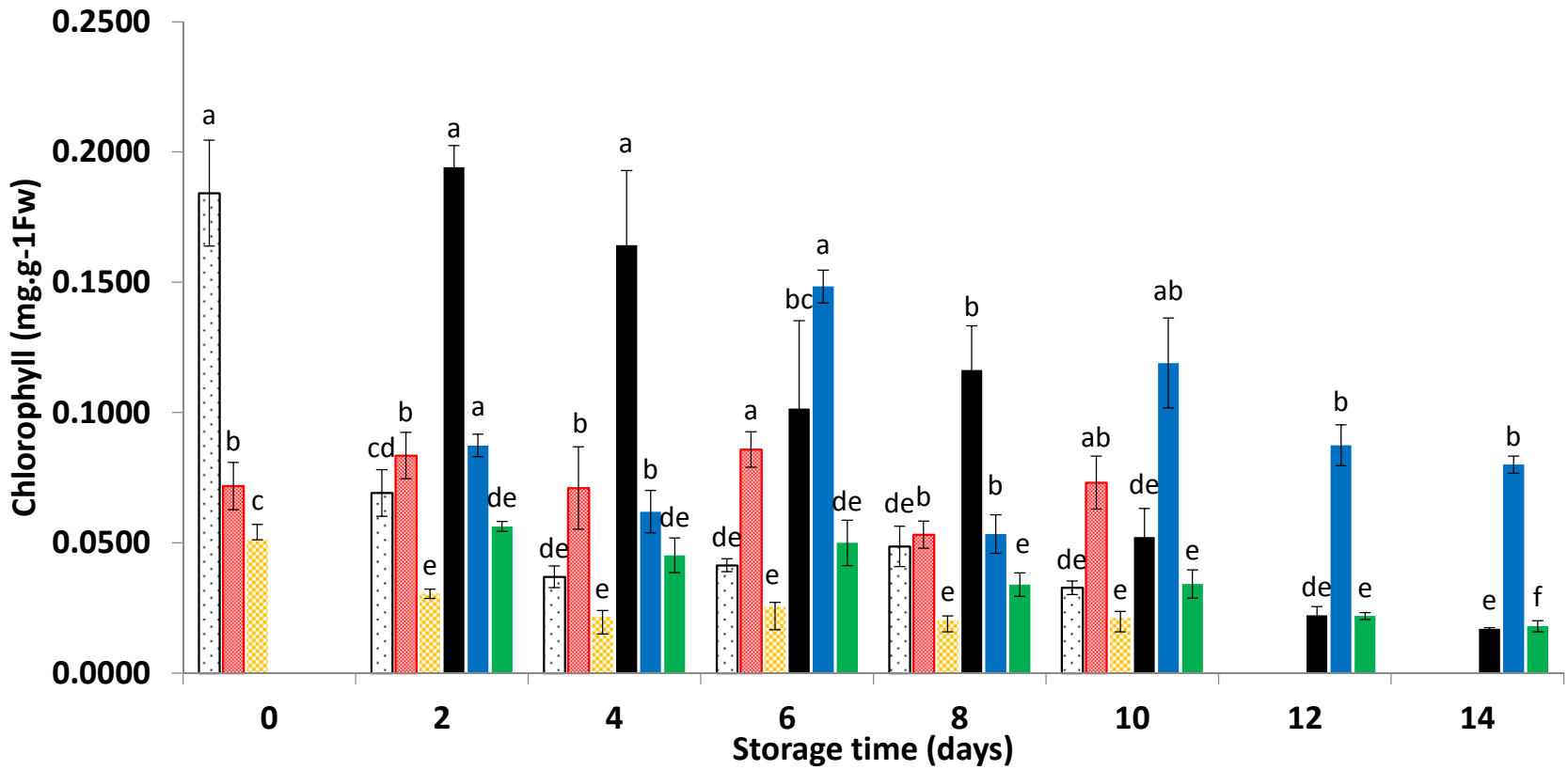
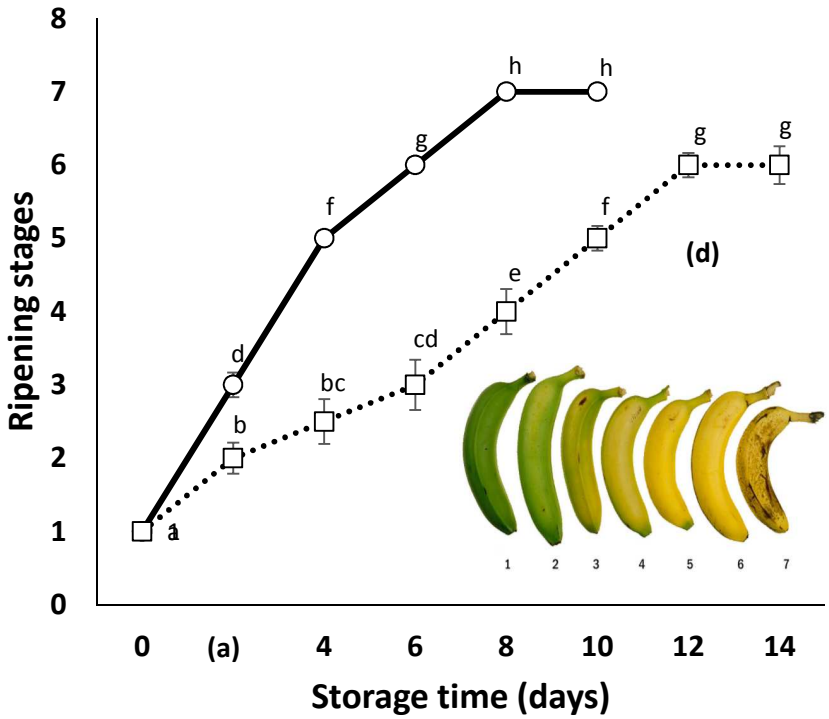
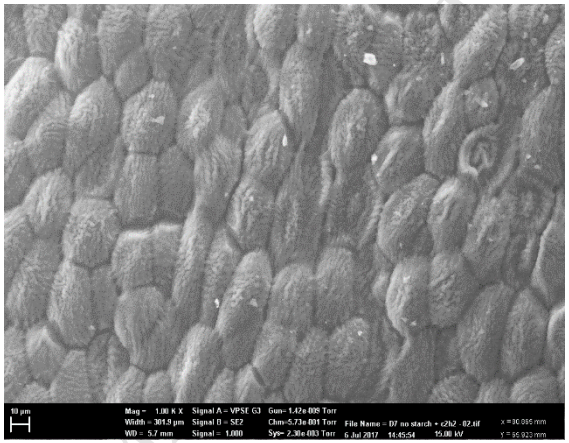
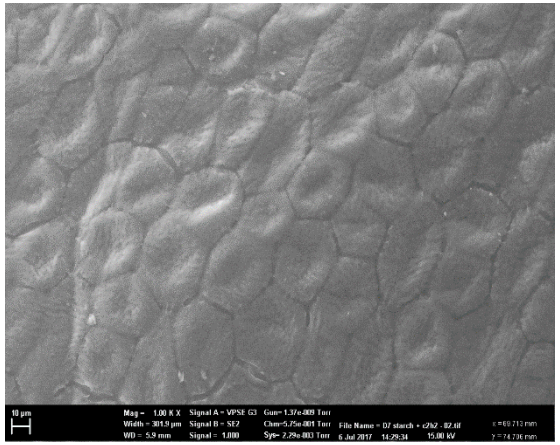


Fig 5: Effect of rice starch-ι-carrageenan edible coating on the content of total chlorophyll, Chl a, Chl b of banana fruit during storage at ambient temperature (20°C). The values are the means ± SE. Data with error bars with different letters are significantly different at $p<0.05$. In fig, different colour represents different sample codes, control Chl a, control Chl b, control total, coated Chl a, coated Chl b, coated total respectively.





(b) Control fruit peel 1000X



(c) Coated fruit peel 1000X

Fig 6: (a) Time course of de-greening of banana during different stages of ripening for control and coated fruits stored at 20°C. Banana fruit were spray coated and treated with 20ppm ethylene gas for 24h and stored and used for quality evaluation. Same fruit were used to study the colour changes on each sampling time. In the figure, black and white dotted line represent control and coated samples. **(b)** SEM micrograph for control fruit (1000x). **(c)** SEM micrograph for coated fruit (1000x). **(d)** standard ripening chart for banana fruit (Wills and Golding, 2016).

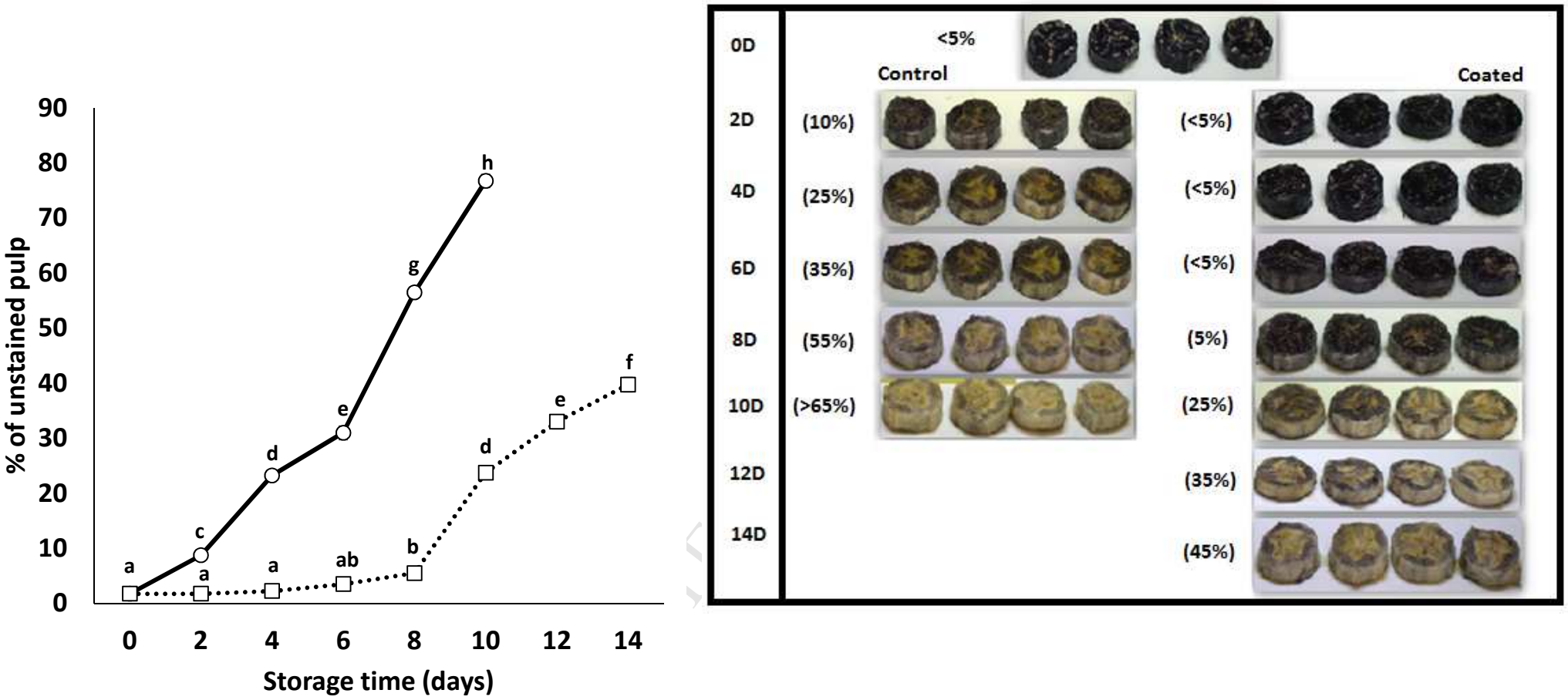


Fig 7: Starch content pattern of ripening banana (control and coated) stained with iodine solution % represents the area of unstained pulp. In the figure, black and white dotted line represent control and coated samples.

Highlights

1. A rice starch-ι-carrageenan coating blended with sucrose ester was developed
2. A 40% extension in the postharvest life was recorded at room temperature (20ºC)
3. Coating delayed the ethylene production and starch degradation rate during storage
4. The treatment reduced the fruit weight loss, firmness and chlorophyll degradation of banana fruit.