

Accepted Manuscript

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PII: S0023-6438(18)30901-0

DOI: <https://doi.org/10.1016/j.lwt.2018.10.055>

Reference: YFSTL 7521

To appear in: *LWT - Food Science and Technology*

Received Date: 2 August 2018

Revised Date: 18 October 2018

Accepted Date: 19 October 2018

Please cite this article as: Thakur, R., Pristijono, P., Bowyer, M., Singh, S.P., Scarlett, C.J., Stathopoulos, C.E., Vuong, Q.V., A starch edible surface coating delays banana fruit ripening, *LWT - Food Science and Technology* (2018), doi: <https://doi.org/10.1016/j.lwt.2018.10.055>.

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1 **A Starch Edible Surface Coating Delays Banana Fruit Ripening**

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22 Abstract

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

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

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44 **1. Introduction**

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

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

68 have shown that rice starch-t-carrageenan formulations enable successful modulation of the
69 gas diffusion rates (e.g., gaseous and water vapour permeability) in fruit (R. Thakur et al.,
70 2018), resulting in improved mechanical and physicochemical properties (Rahul Thakur et
71 al., 2017a; Rahul Thakur et al., 2017b; R. Thakur et al., 2016) in the edible films.

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

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90 2. Materials and methods

91 2.1 Plant material and experimental procedure

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

97 2.2 Design of experiment

98 Banana, without any visual defects, carefully were handled and prepared in small uniform
99 hands (two fingers each with similar size). A randomized experimental design, comprising 60
100 homogeneous lots (based on maturity size) of 8 fruit each were assembled randomly. Four
101 lots were used to measure the fruit properties at harvest (0 day) and the remaining 56 lots (8
102 fruit per lot) were divided into two groups. From both groups, every single lot was assigned
103 as one replication and four replications per treatment was used for assessment on each
104 removal day. Two treatments, T-I (rice starch- ι -carrageenan-fatty acid ester of sucrose
105 (FAEs), and T-II (control, treated with water) were used in the experiment. The optimized
106 coating formulation (Rice starch (3%, w/w), ι -car (1.5%, w/w), FAEs (2%, w/w) and glycerol
107 (1 %, w/w)) was prepared as previously reported by Rahul Thakur et al. (2018). Control and
108 treated fruit were respectively treated with water or coating using the sprayer for 10 seconds.
109 The overloaded coating material was spread uniformly using gloved hands before being
110 removed and air dried for 2 minutes using a hair dryer ($<35^{\circ}\text{C}$) held at a distance of 60 cm.
111 The fruit were left at room temperature for 25 minutes to dry completely. After coating, the
112 fruit were moved to an ethylene chamber (20 ppm, $20 \pm 2^{\circ}\text{C}$) where they were treated for 24
113 hours to ripening. Post-treatment, the control and coated fruit were weighed and stored at 20

114 $\pm 2^{\circ}\text{C}$; RH $52\pm 3\%$ for sampling. A range of quality parameters (including weight loss,
115 respiration, ethylene production, TA, SSC, starch content, chlorophyll level and ion leakage)
116 were assessed every second day.

117

118 **2.3 Total soluble solids (TSS) and titratable acidity (TA)**

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

125 **2.4 Colour measurement**

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

135

136 **2.5 Ethylene and respiration rate**

137 For the ethylene and respiration rate, banana samples, (n=2) were placed in a 1 L hermetic
138 glass jar with a septum and a lid for sampling gas after 1h at $20 \pm 2^\circ\text{C}$. The jars were stored at
139 ambient temperature ($20 \pm 2^\circ\text{C}$) and gas sampling was carried out using a needle probe. For
140 ethylene measurement, a 1 mL gas sample was withdrawn from the jar and injected into
141 flame ionization gas chromatograph (Varian Star CX-3400, Walnut Creek, CA) fitted with a
142 stainless steel column ($2\text{ m} \times 3.2\text{ mm OD} \times 2.2\text{ mm ID}$) packed with Porapak Q (80–100
143 mesh) (Altech, Sydney). The ethylene production rate was calculated as $\mu\text{L C}_2\text{H}_4/\text{kg h}$. For
144 respiration rate, a 5 mL gas sample was injected into a thermal conductivity gas
145 chromatograph (Gow-Mac 580, Bridgewater, NJ) fitted with a stainless steel Haysep N (80–
146 100 mesh) column ($60\text{ cm} \times 1\text{ mm ID}$, Altech, Sydney) and the respiration rate was
147 calculated (as mL CO_2 produced / Kg hr).

148

149 **2.6 Weight loss and firmness**

150 Weight loss was determined by weighing each banana fruit (n=8) before and after the storage
151 period and expressed as a percentage of the initial weight. The firmness of individual
152 uncoated and coated banana (n=8) from each replication was measured at $20 \pm 2^\circ\text{C}$ according
153 to the method of Soradech et al., (Soradech, Nunthanid, Limmatvapirat, & Luangtana-anan,
154 2017) with some modification. Briefly, 3 mm thick discs were cut from the centre of each
155 fruit using a double-headed knife. A 5 mm diameter stainless steel probe was then inserted
156 into the fruit manually and the penetration force (N) was recorded. The maximum penetration
157 force is defined as the force required pushing the probe into the banana surface to a depth of
158 3 mm at a uniform cross-head speed.

159 **2.7 Total chlorophyll content estimation**

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

$$167 \quad \text{Chlorophyll } a = 12.7 \times A_{663} - 2.995 \times A_{645}$$

$$168 \quad \text{Chlorophyll } b = 22.95 \times A_{645} - 4.67 \times A_{663}$$

$$169 \quad \text{Total chlorophyll (mg.L}^{-1}\text{)} = \text{Chlorophyll a} + \text{Chlorophyll b}$$

$$170 \quad \text{Total chlorophyll (mg.g}^{-1}\text{)} = \frac{\text{Total chlorophyll (mg L}^{-1}\text{)} \times 25 \text{ ml}}{\text{Sample weight} \times 1000}$$

171

172 **2.8 Leakage of ions from the peel**

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

183

184 **2.9 Starch content**

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

193 **2.11 Statistical analysis**

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

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209 3. Results and discussion

210 3.1 Weight loss

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

229

230 3.2 Respiration rate and ethylene production

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

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

242

243 **3.3 TA & SSC**

244 A reduction of acidity in the fruit during ripening is accompanied by a reduction in the
245 organic acids. Malic acid is the major organic acid in the banana fruit (Turner & Fortescue,
246 2012). Coating of the fruit produced no discernible effect on titratable acidity. At day 0, TA
247 was 0.15% (malic acid), which subsequently peaked at 0.37 % (malic acid) on Day 4 and
248 declined steadily thereafter (Figure 3). The increase in the TA values of Control and coated
249 fruit was recorded during the first week of storage. The increase in the titratable acidity
250 during the initial storage period has been ascribed to increased activity of malate synthase and
251 phosphoenolpyruvate carboxylase (John and Marchal (1995).

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

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

264

265 **3.4 Firmness**

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

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

280

281 **3.5 Ion leakage**

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

294

295 **3.6 Effect of coating on the appearance, chlorophyll degradation and colour of fruit** 296 **during storage**

297 Consumer perception of fruit quality and acceptability is closely aligned with skin appearance
298 (Iglesias, Echeverría, & Lopez, 2012). Surface colour of individual fruit in the treatment and
299 control groups were monitored on each sampling day at ambient temperature ($20 \pm 2^\circ\text{C}$) over
300 the course of the experiment to assess changes in appearance. The skin colour in bananas

301 transitions from green to yellow during ripening as a consequence of chlorophyll degradation,
302 which makes skin carotenoids more visible (Fig: graphical abstract) (Gol & Ramana Rao,
303 2011). A standard reference chart consisting of seven distinct visual colour change stages was
304 used to identify the progress of senescence (Fig 6d) (Nannyonga, Bakalis, Andrews,
305 Mugampoza, & Gkatzionis, 2016).

306 In our experiments, the rate of colour development was found to be significantly different
307 between the uncoated and coated treatment groups ($p < 0.05$) from the first week of storage.
308 We observed, in the case of the coated fruit, the slower emergence of browning and spotting
309 on the skin surface, in comparison to the control over the course of the experiment indicating
310 delayed maturity and ripening (Fig: graphical abstract). The lack of uniformity in the ripening
311 of coated fruit was observed during the assessment days which can be attributed to the fact
312 that coating material was applied manually. The hue angle combines both a^* and b^* values
313 from the colourimeter (Table 1), where the hue angle decreased more slowly. The narrower
314 range in hue angle of the coated fruit reflected degradation of chlorophyll in the skin of
315 coated fruit as a consequence of reduced gas transfer rates brought about by the presence of
316 the surface coating. The observation was in agreement with previous findings by Deng et al.
317 (2017) who reported that changes in the internal gas composition of the fruit significantly
318 delayed the chlorophyll degradation of banana fruit (Deng et al., 2017; Momen, Tatsumi, &
319 Shimokawa, 1997). In addition to that, it is important to mention that coating appear to be
320 transparent and has not imparted any glossiness to the banana fruit as observed during the
321 storage period.

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

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

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

337 **3.7 Starch content**

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

350 rate was significantly higher in control fruit ($p < 0.05$) where $>65\%$ starch degradation was
351 observed at the end of day 10. However, the rate was 25% in case of control fruit at the same
352 storage time and start increasing thereafter. The differential rates of starch degradation
353 between the control and treatment groups are supported by the TSS data (Fig 3), which
354 showed a more rapid rise in the sugar content of the control fruit (Cordenunsi & Lajolo,
355 1995). The delay in starch conversion in the coated fruit is attributed to the reduced exposure
356 of the starch-degrading enzyme alpha-amylase to atmospheric oxygen due to its sensitivity to
357 oxygen. The role of alpha-amylase in the conversion of starch to sugar has been extensively
358 studied (Agravante, Matsui, & Kitagawa, 1990; Tomasik & Horton, 2012) hence, current
359 study concludes that semi-anaerobic atmosphere created by surface coating slow down the
360 activity of starch degrading enzyme, therefore, starch hydrolysis occur at different time in
361 control and coated fruit.

362

363 **Conclusion**

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

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

376

377 **Acknowledgements**

378 This work was supported by the University of Newcastle, Australian Research Council
379 (ARC) Training Centre for Food and Beverage Supply Chain and Optimisation
380 (IC140100032). NSW Department of Primary Industries is a partner organisation in the
381 Training Centre.

382

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488

1 **Table 1:** Ion leakage and hue angle of banana fruit (Control and coated) during storage at
 2 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 ^b
4D	32.85±0.6 ^c	26.00±1.6 ^b	95.73±0.3 ^c	115.09±1.6 ^c
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

14

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

ACCEPTED MANUSCRIPT

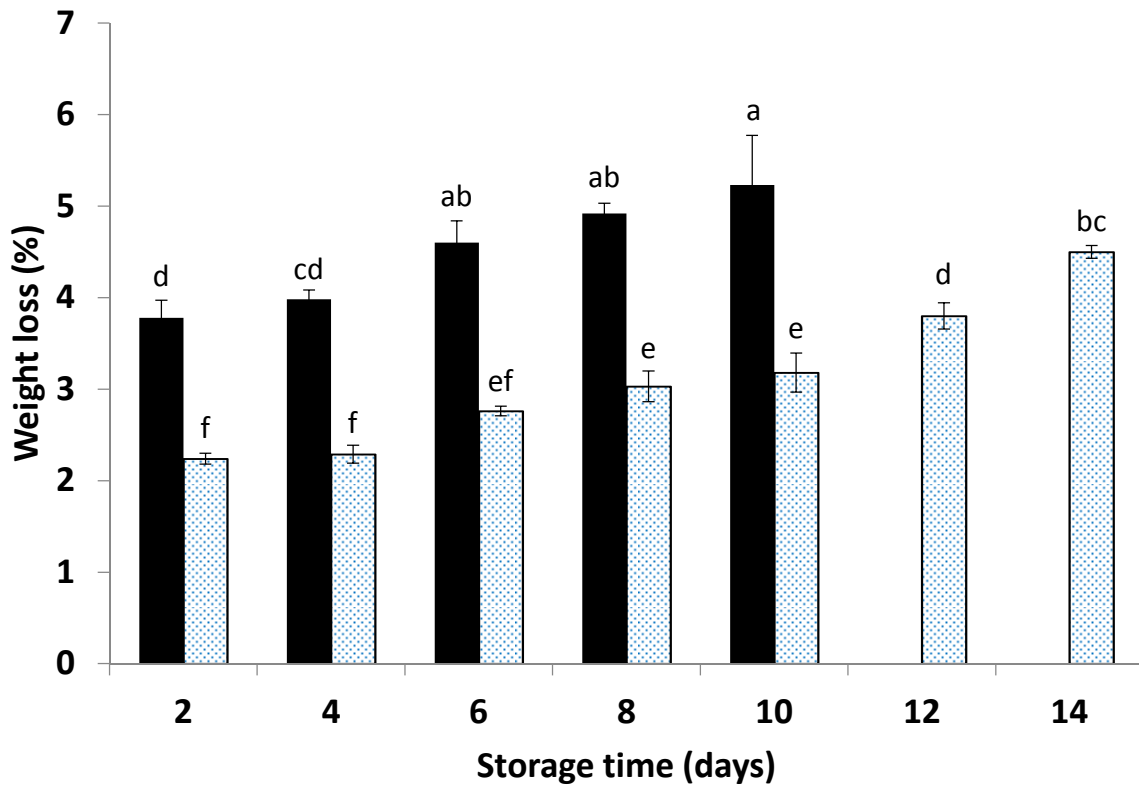


Fig 1: Weight loss for the control and coated fruit. The values are means \pm SE. Data in the columns sharing the same letter are not significantly different ($p < 0.05$). In the figure, black and white colour column represent control and coated samples respectively.

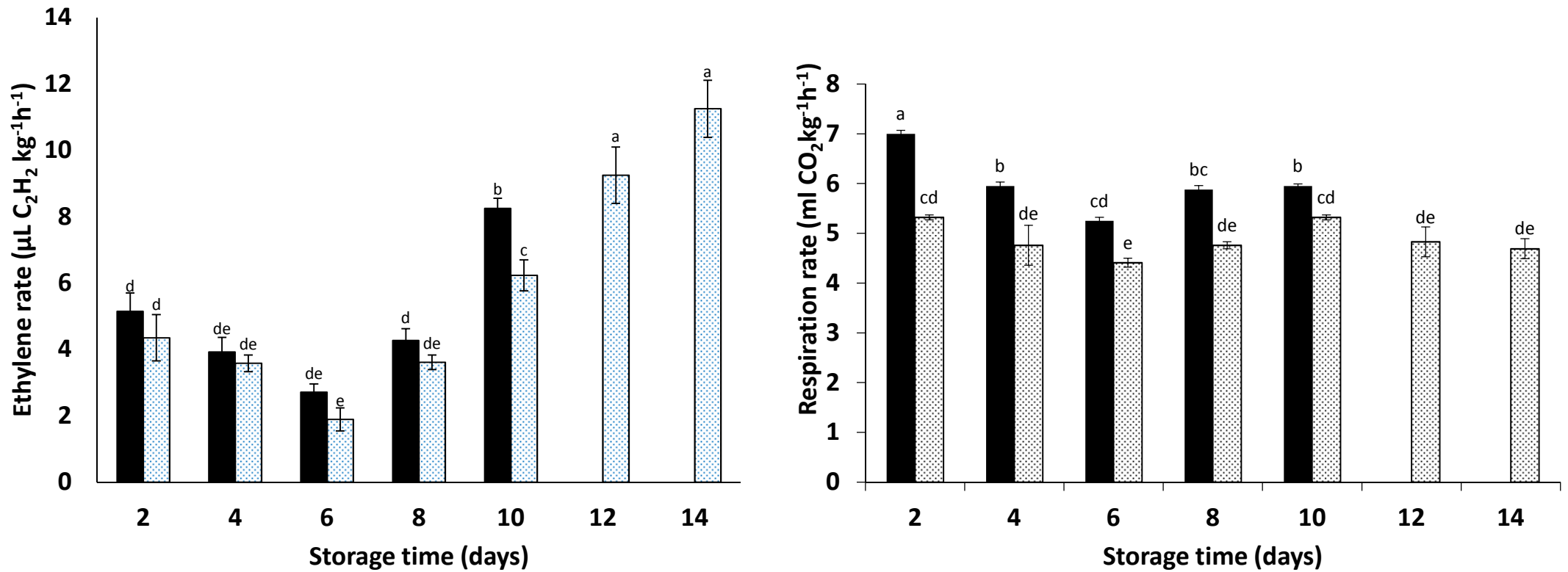


Fig 2: Graphs showing endogenous ethylene production and respiration rates of the coated and uncoated fruit stored at 20°C and $52 \pm 5\%$ RH for a period of 14 days. Control fruit were treated with water and coated fruit with a starch-carrageenan-FAEs mixture. The values are the means \pm SE. Data 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.

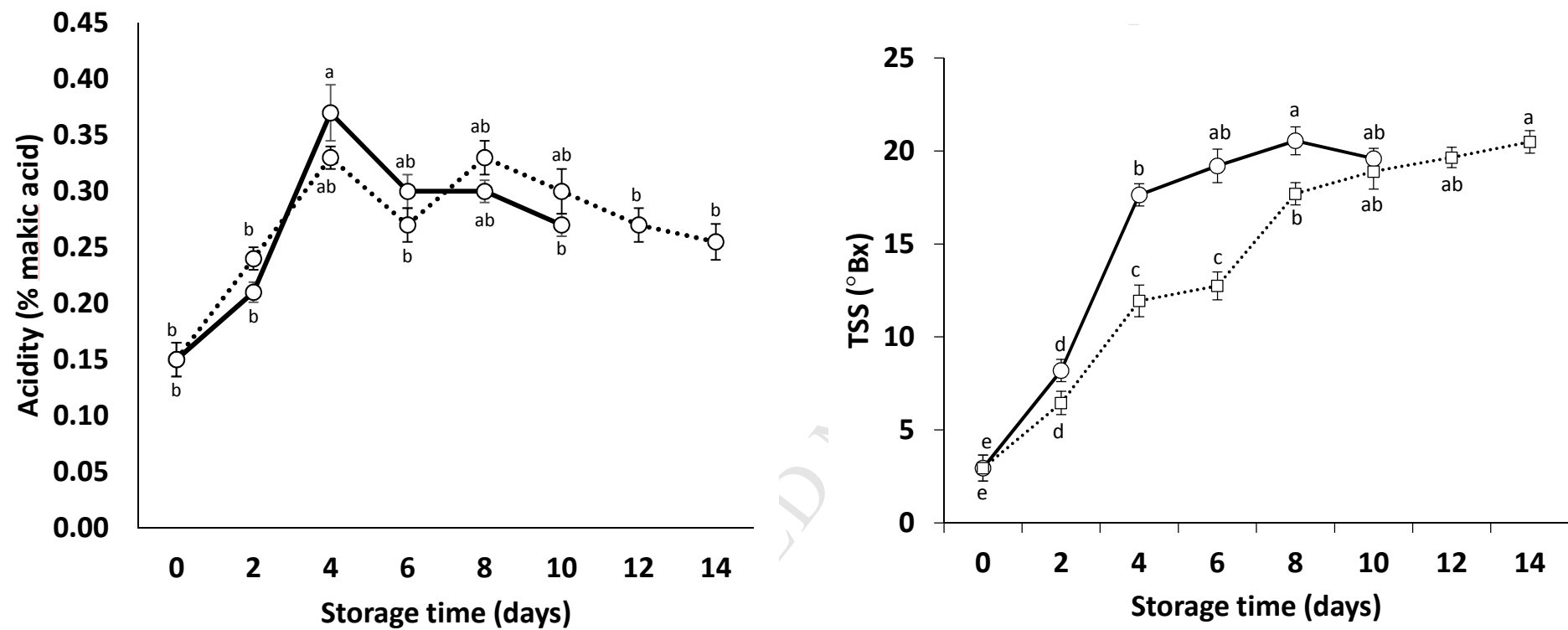


Fig 3: Titratable acidity (TA) (left) and TSS (right) for control and coated fruit during storage. The values are the means \pm SE. Data with error bars with different letters are significantly different at $p < 0.05$. In the figure, black and dotted lines represent control and coated samples respectively.

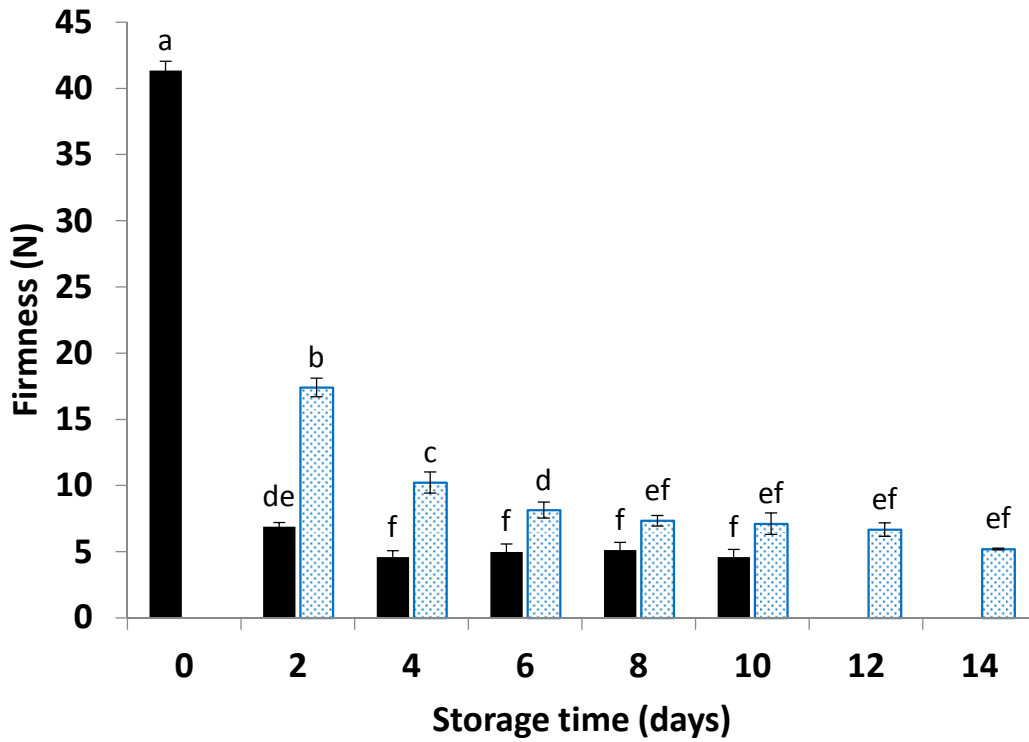
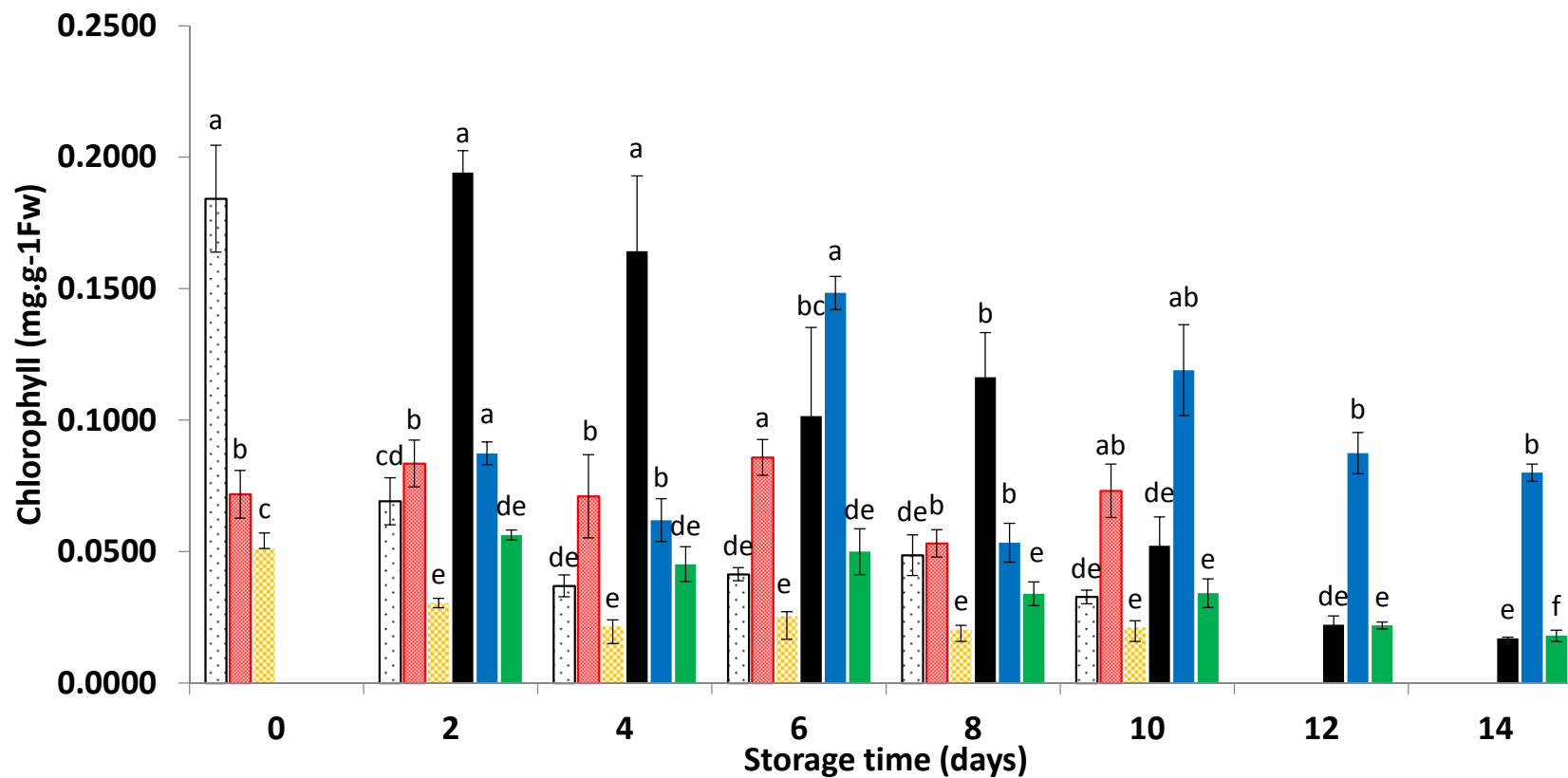


Fig 4: Changes in the fruit firmness for control and coated fruit (n=8) during storage. The values are the means \pm SE. Data with error bars with different letters are significantly different at $p < 0.05$. In the figure, black and white colour column represent control and coated samples.



1

2 **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

3 temperature (20°C). The values are the means \pm SE. Data with error bars with different letters are significantly different at $p < 0.05$. In fig,

4 different colour represents different sample codes, control Chl a, control Chl b, control total, coated Chl a, coated Chl b, coated total

5 respectively.

6

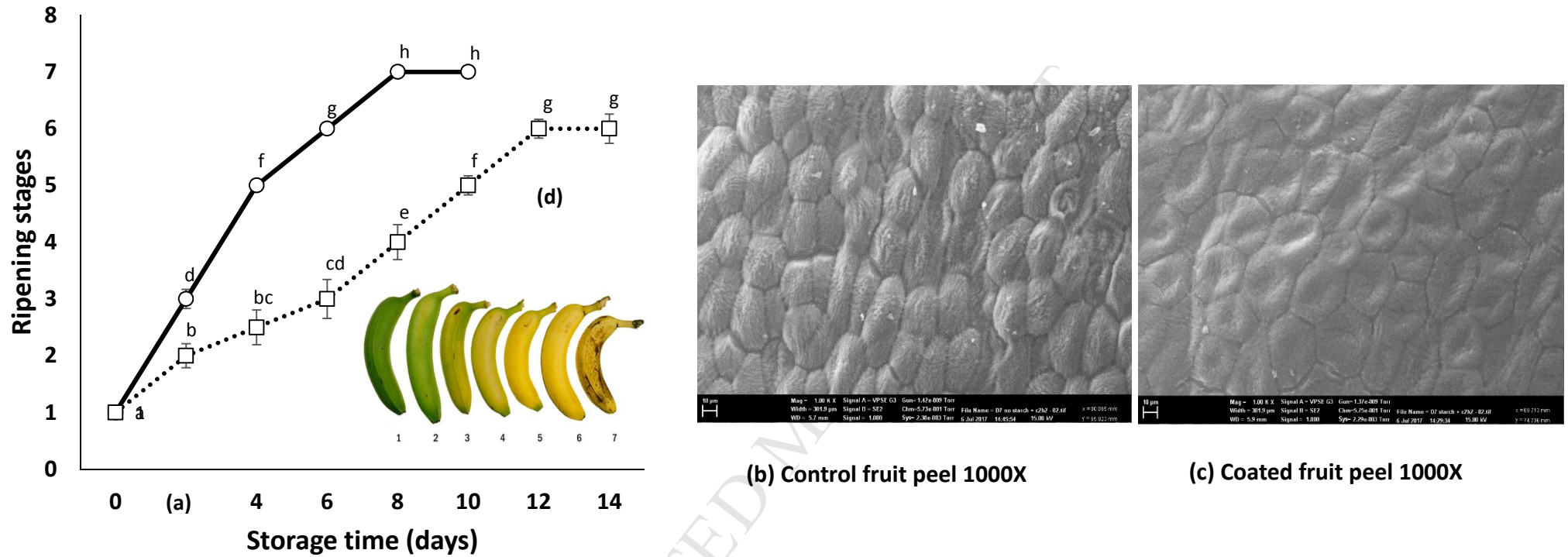


Fig 6: (a) Time course of de-greening of banana during different stages of ripening for control and coated fruits stored at 20°C. Banana fruit were spray coated and treated with 20ppm ethylene gas for 24h and stored and used for quality evaluation. Same fruit were used to study the colour changes on 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).

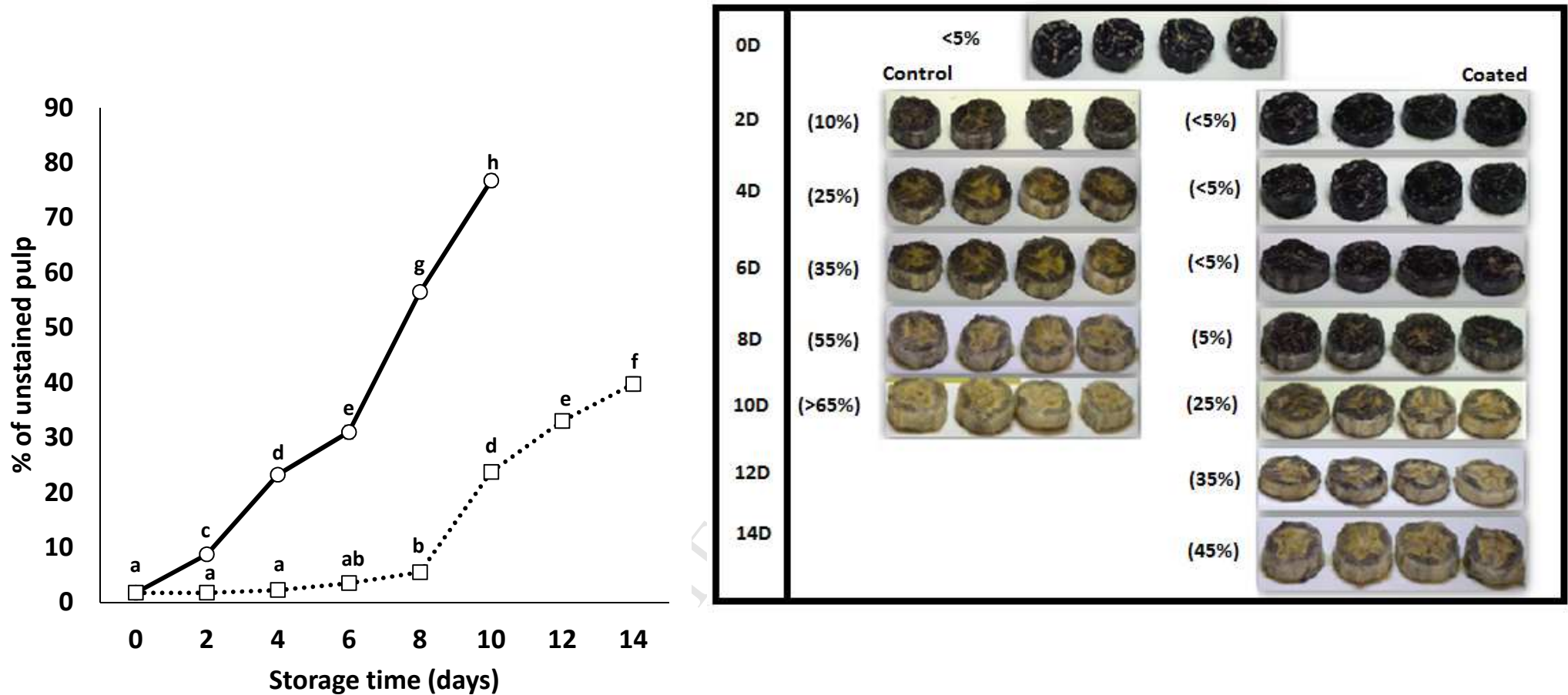


Fig 7: Starch content pattern of ripening banana (control and coated) stained with iodine solution % represents the area of unstained pulp. In the figure, black and white dotted line represent control and coated samples.

Highlights

1. A rice starch- κ -carrageenan coating blended with sucrose ester was developed
2. A 40% extension in the postharvest life was recorded at room temperature (20°C)
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.