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Influence of antibrowning agents on shelf life of fresh-cut pineapple (*Ananas comosus* L.) cv. Kew

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Abstract

Food spoilage due to browning is one of the major challenges faced by the food and processing industries. In fruits and vegetables, browning due to both enzymatic and nonenzymatic reactions is a common event that renders them unattractive and unsuitable for consumption. In the last few decades, numerous studies have been conducted to slow or inhibit these undesirable physiological reactions during processing and storage. An experiment was carried out to determine the effect of different antibrowning agents on the quality and shelf life of fresh-cut pineapple from 2020-2021 in the laboratory of the Department of Horticulture at Annamalai University. The experiment consisted of 11 treatments and was replicated 3 times, *viz.*, T_1 (ascorbic acid 500 ppm), T_2 (ascorbic acid 1000 ppm), T_3 (citric acid 250 ppm), T_4 (citric acid 500 ppm), T_5 (sodium chloride 100 ppm), T_6 (sodium chloride 200 ppm), T_7 (calcium chloride 100 ppm), T_8 (calcium chloride 200 ppm), T_9 (honey 5%), T_{10} (honey 10%), and T_{11} (control). Antibrowning agents significantly and positively impacted the quality parameters of fresh-cut fruits. The minimum physiological weight loss (0.71%) and maximum scores of firmness (2.16kg/cm^2), titratable acidity (0.53%), total sugar (11.65%), nonreducing sugar (1.94%) and texture index (2.37) were recorded in T_8. However, maximum TSS (14.6 °Brix), total sugar (11.65%), and reducing sugar (9.48%) were recorded in T_{10}. The lowest browning rate was recorded in the treatment with ascorbic acid in T_2. The treatments with calcium chloride and ascorbic acid best retained the quality of fresh-cut pineapple fruit.

Key words: Anti-browning chemical, postharvest, pineapple, fresh-cut fruits, *Anana scomosus*, preservative

Introduction

In recent years, with increasing consumer preference and demand for healthy and fresh food, the supply of fresh fruits and vegetables has grown rapidly (Sanad *et al.*, 2014). The popularity of fresh-cut fruits and vegetables started in the 1980s, and it has been growing and expanding ever since, especially in developing countries (Baselice *et al.*, 2017). It provides consumers with ready-to-eat or easy-to-prepare fruits and vegetables, saving time and effort in meal preparation. However, maintaining its quality is a challenging task.

Fruits and vegetables undergo various enzymatic and nonenzymatic reactions that are responsible for their natural coloration. Enzymatic reactions, catalyzed by polyphenol oxidase enzymes (PPOs), oxidize aromatic compounds into quinones, leading to browning. This browning makes fruits and vegetables unattractive, unacceptable, and inedible, resulting in significant losses of produce worldwide (Weerawardana *et al.*, 2020). Such enzymatic reactions result in the deterioration of fruit (Shrestha *et al.*, 2020), microbial growth (Cofelice *et al.*, 2019) and tissue softening (Li *et al.*, 2017). It is an undesirable reaction (Lim and Wong, 2018), particularly for freshly cut fruits, because it not only is susceptible to deterioration or affects flavour, color, and texture but also increases the chances of microbial growth, which ultimately shortens the shelf life of fruits (Zhao *et al.*, 2021).

Thus, food browning is of major concern in food processing and storage industries (Lim and Wong, 2018), and in recent decades, researchers have put effort into developing better ways to prevent browning in freshly cut fruits and vegetables and to extend their shelf life (Liu *et al.*, 2019). Preventing browning in food and food processing industries has become a crucial and prioritized research area (Ioannou and Ghoul, 2013), as it can significantly reduce costs in the fresh produce sector. In food preservation, advanced antibrowning agents effectively inhibit polyphenol oxidase enzymes (PPOs), preventing undesirable browning. These agents enhance food aesthetics, extend shelf life, and reduce waste. Embracing these innovations benefits both the food industry and consumers alike. Numerous studies have been conducted on the potential use of calcium ascorbate, ascorbic acid (Putnik *et al.*, 2017), citric acid (Fan *et al.*, 2018) and sodium chloride (Li *et al.*, 2015) as antibrowning agents. Many such antioxidant agents are claimed to be effective in inhibiting or preventing browning and retaining the overall quality of fruits and vegetables.

The present study aimed to explore the effects of various antibrowning agents on freshly cut pineapple fruits (cv. Kew). By investigating different treatment concentrations, the research sought to identify the most effective means of extending and preserving the shelf life of the fruit.

Materials and methods

Experimental location and raw materials: The experiment was conducted in the laboratory of the Department of Horticulture, Annamalai University, Tamil Nadu, during 2020-2021. Well-matured, good-quality fruit of pineapple var. Kew with no mechanical or microbial damage was used for the experiment. The fruits were washed with deionized water. A stainless-steel pineapple corer was used for slicing the pineapple into rings. The experiment was laid out in a CRD design, with 11 treatments, and replicated 3 times. The treatment combinations were as follows: T_1: ascorbic acid (500 ppm), T_2: ascorbic acid (1000 ppm), T_3: citric acid (250 ppm), T_4: citric acid (500 ppm), T_5: sodium chloride (100 ppm), T_6: sodium chloride (200 ppm), T_7: calcium chloride (100 ppm), T_8: calcium chloride (200 ppm), T_9: honey (5%), T_{10}: honey (10%), and T_{11}: control. The sliced fruits were immediately dipped in the respective treatments for approximately five minutes. After dipping, slices of fruits were drained, weighed and immediately transferred into a transparent airtight 250 mL beaker. Each beaker consisted of 2 semirings of fruit slices. Fruit samples were kept under refrigerated conditions at 14 ±2°C. Visual observation and biochemical analysis were recorded on a daily basis.

Physiological weight loss: The physiological weight loss of fruits was measured and recorded daily as indicated below and expressed as percentage loss.

$$\text{PLW} = \frac{\text{Initial weight} - \text{Weight after storage}}{\text{Initial weight}} \times 100$$

Firmness: The firmness of the fruits was determined by using a hand penetrometer. The readings were taken at three different parts of the fruit slices, and the mean value was expressed in kg/cm^2 (Pocharski *et al.*, 2000).

Sensory evaluation: Sensory analysis was conducted on a 5-point hedonic scale. The sensory evaluation was conducted on a daily basis until the 4th day of the experiment (Lawless and Heymann, 2010).

Total soluble solids and total sugar content: The total soluble solids of the fruit slices were measured by using a hand refractrometer and expressed as ^{o}Brix (Ibdullah *et al.*, 2012). The total sugar was determined by the methods suggested by Ranganna (1986).

Titratable acidity (%): Titratable acidity was determined by diluted fruit juice titrated against 0.1 N sodium hydroxide using phenopthalin as an indicator (AOAC, 2000).

Reducing and Nonreducing sugar: Reducing and nonreducing sugars were determined by methods given by Ranganna (1986).

Browning and texture index: Browning was evaluated on a scale of 1-5 by Gonzalez-Aguilar *et al.* (2004).The texture of the slices was measured on sensations such as hardiness, crispness and juiciness in a five-point hedonic scoring technique (Table 1).

$$\text{Texture index} = \frac{G1 + G2 + G3}{3}$$

Statistical analysis: Statistical computer software was used to compute the ANOVA and LSD (Panse and Sukhatme, 1985).

Table 1. Grade scale for sensory evaluation

Grade No.	Sensory features	Grade point
G1	Hardiness: Ranges from hard and compact flesh to soft and fragile flesh.	5, 4 . . . . . 1 and 0
G2	Crispness: Very crisp and breakable flesh to flexible and loose flesh.	5, 4 . . . . . 1 and 0
G3	Juiciness: Juicy flesh with juice felt on the fingers when slightly pressed to dry flesh.	5, 4 . . . . . 1 and 0

Results and discussion

Sensory evaluation: As presented in Table 2, the maximum acceptability of fresh-cut fruit was recorded in T_2, which was at par with T_8. The lowest was observed in T_{11}, significantly lower than all other treatments. On the final day, no significant difference among the treatments was found in the sensory score. However, treatment T_2 continued to be the best treatment in terms of acceptability, followed by T_8 and T_9, and control T_{11} remained the least accepted treatment among all treatments. The study found that the highest acceptability of fresh-cut fruit was recorded in the treatment with 1000 ppm ascorbic acid (T_2), followed by calcium chloride (T_8) at 200 ppm.This was in line with Ngamchuachit *et al.* (2014), who reported maximum liking by the panelist to calcium chloride-treated fresh-cut mango fruit.

Table 2. Effect of different antibrowning agents on organoleptic (score) and texture of fresh-cut pineapple

Treat-ments	Organoleptic score (5.00 Hedonic scale)				Texture Index			
	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2	Day 3	Day 4
T_1	4.66	4.13	3.53	2.00	4.44	3.87	3.25	2.08
T_2	5.00	4.86	4.33	2.26	4.58	4.00	3.30	2.11
T_3	4.46	3.86	3.13	1.60	4.36	3.76	3.13	1.78
T_4	4.40	4.20	3.60	2.00	4.44	3.86	3.23	2.06
T_5	4.00	3.53	2.66	1.20	4.19	3.58	2.96	1.65
T_6	4.06	3.53	2.73	1.26	4.21	3.60	2.98	1.67
T_7	4.66	4.46	3.86	2.09	4.67	4.14	3.42	2.23
T_8	4.93	4.80	4.20	2.18	4.85	4.22	3.54	2.37
T_9	4.66	4.53	3.93	2.12	4.34	3.73	3.17	1.84
T_{10}	4.40	3.86	3.20	1.66	4.32	3.71	3.15	1.78
T_{11}	3.66	3.20	2.40	1.00	3.76	3.17	2.52	1.50
SE(d)	0.12	0.10	0.10	0.26	0.03	0.04	0.06	0.25
C.D.	0.25	0.22	0.21	NS	0.07	0.09	0.12	NS

T_1:Ascorbic acid 500 ppm, T_2: Ascorbic acid 1000 ppm, T_3: Citric acid 250 ppm, T_4: Citric acid 500 ppm, T_5: Sodium chloride 100 ppm, T_6: Sodium chloride 200 ppm, T_7: Calcium chloride 100 ppm, T_8: Calcium chloride 200 ppm, T_9: Honey 5%, T_{10} : Honey 10%, T_{11}: Control

Texture index: Among treatments, T_8 ($CaCl_2$ 200 ppm) had the highest texture index, significantly surpassing others. T_{11} (control) had the lowest on the first day, and over time, the texture index consistently decreased, with T_{11} experiencing the maximum reduction. On the fourth day, T_8 had the highest texture index, while T_{11} had the lowest, with no significant differences among treatments. The decline in texture may result from moisture loss due to respiration and metabolic activities. T_8's high score aligns with Zhang *et al.* (2019) findings, suggesting $CaCl_2$ treatment aids in maintaining firmness in pear cv. Nanguo.

Physiological weight loss: The data on the effect of different chemical and natural agents on the PLW of pineapple slices are given in Table 3. On the first day, T_8 ($CaCl_2$ 200 ppm) recorded the minimum PLW, which was on par with T_2 and T_7. The maximum loss of PLW was recorded in T_{11} (control), significantly different from all the treatments. At the end of the experiment, the minimum loss of PLW was recorded in T_8, which was significantly lower than that in all other treatments.

However, the maximum loss of PLW at the end of the experiment was recorded in control treatment T_{11}, which was significantly different from the other treatments. The results show that treatments with antibrowning chemicals, natural agents, and honey performed better than the control treatments in preventing PLW loss. Treatment T_8, containing 200 ppm calcium chloride, exhibited the highest inhibition percentage of physiological weight loss (PLW). Gradual decrease in PLW with storage period in all treatement was consistent with the findings of Lee *et al.* (2022) who reported similar result in cut fresh apples.

Table 3. Effect of different antibrowning agents on physiological weight loss (PLW) and firmness (kg/cm^2) of fresh-cut pineapple

Treat-ments	Physiological loss in weight (%)				Firmness (kg/cm^2)			
	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2	Day 3	Day 4
T_1	0.34	0.44	0.63	0.93	4.56	4.16	3.60	1.65
T_2	0.23	0.36	0.56	0.84	4.86	4.53	3.86	1.87
T_3	0.52	0.63	0.82	1.15	4.26	3.76	3.13	1.30
T_4	0.44	0.56	0.75	1.04	4.53	4.10	3.53	1.42
T_5	0.62	0.72	0.95	1.23	3.76	3.43	2.70	1.09
T_6	0.65	0.75	0.96	1.25	3.83	3.46	2.76	1.15
T_7	0.22	0.34	0.54	0.83	5.16	4.73	4.20	2.02
T_8	0.15	0.24	0.41	0.71	5.50	5.16	4.56	2.16
T_9	0.43	0.53	0.73	1.04	4.16	3.73	3.20	1.26
T_{10}	0.51	0.64	0.85	1.16	4.26	3.83	3.23	1.38
T_{11}	0.81	0.92	1.02	1.37	3.56	3.16	2.36	0.86
SE(d)	0.05	0.06	0.04	0.02	0.04	0.05	0.05	0.24
C.D.	0.12	0.12	0.09	0.06	0.10	0.11	0.12	NS

Firmness: The firmness of the fruit slices decreased over the period of study (Table 3). The maximum firmness in fruit slices was recorded in T_8, which was significantly higher than all other treatments. The minimum firmness was recorded in T_1, which was significantly lower than that in all other treatments. On the last day of the experiment, the firmness recorded was not significantly different among the treatments. The maximum firmness was recorded in T_8, followed by T_7 and T_2. The minimum firmness at the end of the study period was recorded in T_{11}. Additionally, treatments with both chemical and natural antibrowning agents significantly retained the firmness of the fruit slices better than the control treatment. Our finding is in agreement with Zhang *et al.* (2019), who reported that $CaCl_2$ treatment significantly reduced the softening of peeled pears and helped maintain the firmness of the fruit.

Total sugar: The total sugar content during the storage period wassignificantly different among the treatments. The maximum total sugar content was recorded in T_{10}, which was significantly higher than that in all other treatments (Table 4). The lowest total sugar content was recorded in T_8, which was on par with that in T_7. The total sugar content in the fresh fruit cut continued to increase with the period of storage, which might be due to hydrolysis of starch and other higher polysaccharides during storage, which resulted in higher total sugars.

In the study, T_8 treatment with calcium chloride (200 ppm) showed the lowest total sugar content, possibly due to the inhibition of enzymatic activity, as supported by Wijewardane *et al.* (2009), preserving starch levels. Conversely, T_{10} with 10% honey exhibited the highest total sugar content, likely influenced by the concentrated sugar in the honey solution, contributing to the overall increase in sugar content.

Total soluble solids: Among the various treatments, T_{10} had the highest TSS, significantly differing from the other treatments, followed by T_9 (Table 4). T_8 had the lowest TSS, comparable to T_7. Throughout storage, TSS increased continuously for all treatments. On the 4th day, T_{10} had the maximum TSS, significantly higher than others, while T_7 had the lowest, on par with T_8. The study indicates a significant rise in TSS during storage, potentially attributed to cellulose and hemi-cellulose solubilization or water loss, with calcium chloride-treated fresh-cut fruit experiencing reduced water loss (Shehata *et al.*, 2019; Hernández-Muñoz *et al.*, 2008).

Reducing sugar: The maximum reducing sugar on the first day of the experiment was recorded in treatment T_{10}, which was significantly different from all other treatments, while the lowest was recorded in treatment T_8 (Table 5). On the fourth day, the maximum and minimum reducing sugar contents were recorded in T_{10} and T_8, respectively. During the study, it was observed that the reducing sugar content in the fresh-cut fruit increased continuously over time.The continuous increase in reducing sugar with the experimental period was in line with Ali *et al.* (2004), who reported the same trends of increase in reducing sugar in fresh-cut fruits of different varieties of apple.

Nonreducing sugar: From Table 5, it is evident that the fresh-cut fruit treated with calcium chloride (200 ppm) T_8 had the maximum nonreducing sugar, which was at par with T_7, while the lowest was observed in the control treatment in T_{11}, which was at par with T_5 and T_6. On the fourth day, T_8 had the highest nonreducing sugar content, followed by T_7, which was statistically on par. Treatment T_{11} had the lowest nonreducing sugar content.

Among the various treatments, T_8 ($CaCl_2$ 200 ppm) had the maximum nonreducing sugar content, while the minimum content was recorded in T_{11} (control). This might be due to the ability of calcium chloride to delay the degradation and reduce respiration of fruits (Hayat *et al.*, 2003).

Titratable acidity: On the first day of storage of fresh-cut fruit of

Table 4. Effect of different antibrowning agents on total sugar and TSS (°Brix) content in fresh-cut pineapple

Treat-ments	Total sugar (%)				Total soluble solids (°Brix)			
	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2	Day 3	Day 4
T_1	11.50	11.53	11.56	11.59	12.76	12.96	13.13	13.23
T_2	11.51	11.54	11.57	11.60	12.90	13.13	13.26	13.40
T_3	11.48	11.51	11.54	11.57	12.60	12.76	12.90	13.03
T_4	11.49	11.52	11.55	11.58	12.76	13.00	13.13	13.26
T_5	11.48	11.51	11.54	11.57	12.56	12.73	12.83	13.00
T_6	11.48	11.51	11.54	11.57	12.63	12.76	12.86	13.03
T_7	11.46	11.49	11.52	11.56	12.43	12.56	12.70	12.83
T_8	11.45	11.48	11.51	11.55	12.36	12.53	12.63	12.73
T_9	11.54	11.57	11.60	11.63	13.16	13.43	13.63	13.83
T_{10}	11.56	11.59	11.62	11.65	13.33	13.56	13.83	14.06
T_{11}	11.53	11.56	11.59	11.61	13.03	13.26	13.43	13.66
SE(d)	0.005	0.005	0.005	0.005	0.04	0.03	0.05	0.04
C.D.	0.010	0.010	0.012	0.012	0.09	0.07	0.10	0.09

Table 5. Effect of different antibrowning agents on reducing sugar (%) and nonreducing sugar in fresh-cut pineapple

Treat-ments	Reducing sugar (%)				Nonreducing sugar (%)			
	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2	Day 3	Day 4
T_1	9.32	9.35	9.38	9.41	1.96	1.93	1.90	1.86
T_2	9.34	9.37	9.40	9.43	1.97	1.94	1.91	1.87
T_3	9.30	9.33	9.36	9.39	1.94	1.91	1.88	1.85
T_4	9.31	9.34	9.37	9.40	1.95	1.92	1.89	1.86
T_5	9.29	9.32	9.35	9.38	1.93	1.90	1.87	1.84
T_6	9.30	9.33	9.36	9.39	1.93	1.90	1.87	1.84
T_7	9.28	9.31	9.34	9.38	2.01	1.98	1.96	1.93
T_8	9.26	9.30	9.33	9.37	2.03	2.00	1.97	1.94
T_9	9.37	9.40	9.44	9.47	1.98	1.95	1.92	1.89
T_{10}	9.39	9.42	9.45	9.48	2.00	1.97	1.94	1.91
T_{11}	9.36	9.39	9.42	9.45	1.92	1.89	1.86	1.83
SE(d)	0.004	0.004	0.003	0.003	0.01	0.01	0.01	0.01
C.D.	0.009	0.009	0.008	0.008	0.02	0.02	0.02	0.02

pineapple slices, T_7 and T_8 recorded the maximum acidity, which was at par with T_9, T_{10}, T_4 and T_2, T_{11} recorded the lowest acidity on the first day. On the second day, T_8 had the maximum (0.56%) titratable acidity, while the control (T_{11}) had the lowest titratable acidity (Table 6). Decreasing titratable acidity was observed during the experimentation period in all the treatments, which was in line with the findings of Ngamchuachit *et al.* (2014), who reported an increase in acidity in fresh-cut mangoes treated with calcium chloride. However, our findings differ from the report by Navindra *et al.* (2009), which stated that the titratable acidity of fresh jackfruits treated with antibrowning agents declined over the experimental period. By the end of the experiment, the maximum acidity in fresh-cut fruit was recorded in T_8, which was on par with T_7, T_9, T_{10}, T_2 and T_4. Meanwhile, the lowest titratable acidity was recorded in the untreated control treatment T_{11}, which was on par with T_1, T_3, and T_5 and T_6. The titratable acidity of the fresh-cut pineapple fruit in the present study is in

Table 6. Effect of different antibrowning agents on titratable acidity (%) in fresh-cut fruit

Treat-ments	Titratable acidity (%)				Browning index			
	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2	Day 3	Day 4
T_1	0.53	0.51	0.50	0.47	1.2	1.7	2.4	3.0
T_2	0.54	0.52	0.51	0.49	1.0	1.5	2.1	2.9
T_3	0.51	0.49	0.47	0.45	1.3	1.8	2.5	3.1
T_4	0.54	0.52	0.51	0.49	1.2	1.7	2.4	3.0
T_5	0.51	0.47	0.47	0.44	1.5	2.0	2.7	3.5
T_6	0.51	0.48	0.47	0.44	1.5	2.0	2.7	3.5
T_7	0.57	0.55	0.54	0.52	1.4	1.9	2.6	3.4
T_8	0.57	0.56	0.55	0.53	1.3	1.8	2.5	3.3
T_9	0.56	0.54	0.53	0.51	1.1	1.6	2.3	3.0
T_{10}	0.55	0.54	0.53	0.50	1.3	1.8	2.5	3.2
T_{11}	0.50	0.45	0.44	0.42	1.7	2.2	2.9	3.8
SE(d)	0.01	0.02	0.02	0.02	0.04	0.05	0.07	0.22
C.D.	0.03	0.05	0.04	0.05	0.09	0.12	0.16	NS

line with the report made by Ngamchuachit *et al.* (2014), who reported 0.53, 0.58, 0.60 and 0.60% titratable acidity in fresh-cut Kent variety mango.

Browning index: Based on the sensory scores on the browning of fresh-cut pineapple slices on the first day, T_2 (ascorbic acid 1000 ppm) had the lowest browning index, which was at par with T_9, while the maximum was recorded in T_{11} (control) (Table 6 and Fig. 1). The browning of the fresh-cut fruit slice of pineapple increased with time. By the end of the experiment, the maximum browning score was recorded in the untreated group (T_{11}), while the minimum was recorded in the T_2 group. No significant difference among the treatments was noticed on the fourth day of the experiment.

The experiment found that all the antibrowning agents significantly inhibited the rate of browning in fresh fruit slices of pineapple compared to untreated T_{11}. Treatment T_2 (ascorbic acid 1000 ppm) consistently had the lowest browning index during the experiment. This was in agreement with Singh *et al.* (2015), who reported minimum browning or color change in apple slices treated with ascorbic acid (1%).

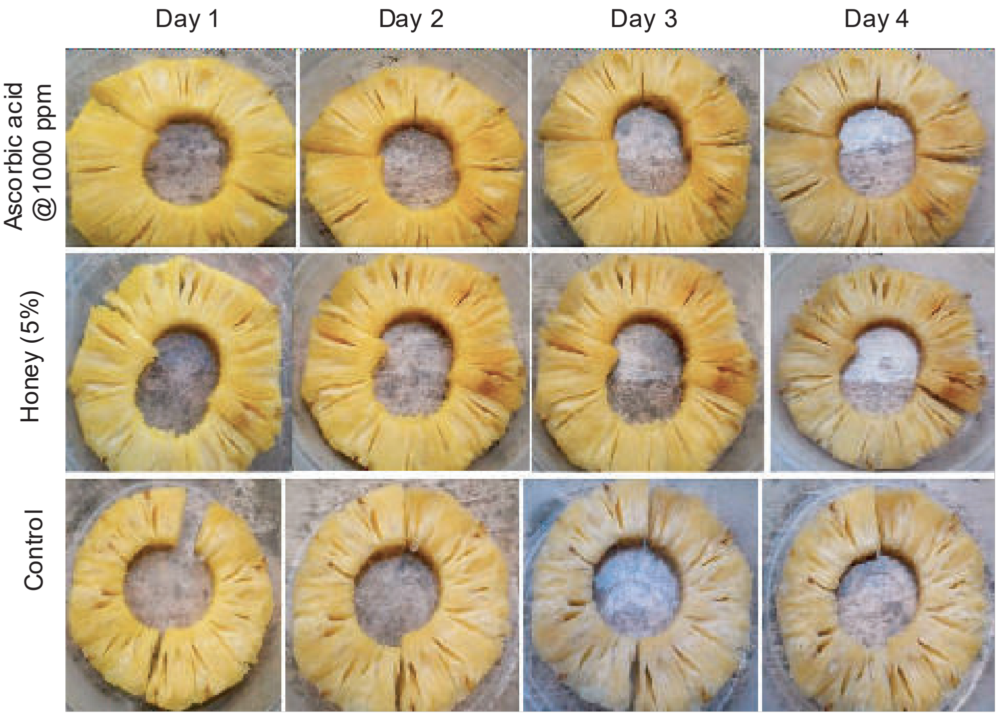

Fig. 1. Effects of different antibrowning treatments on browning of fresh-cut pineapple

From the above findings, it can be concluded that the treatments with different antibrowning agents gave better results in terms of maintaining the fruit quality and retaining their appearances than untreated fresh-cut fruits. The effectiveness of the antibrowning agents was significantly different among the treatments. It was found that treatment with calcium chloride (200 ppm) and ascorbic acid (1000 ppm) were most effective in slowing down or inhibiting the browning rate, retaining the quality of fresh-cut fruit of pineapple. Thus, antibrowning agents tested in this experiment can be used for extending the shelf life of fresh-cut fruit. That said, authors feels that more research is needed in this area for broader and clear understanding of the role of the antibrowning agents used for the study.

Conflict of interest: The authors declare no conflict of interest.

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