



Effects of chemical pre-treatment methods combined with electron beam irradiation on the quality of “Edor” longan

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Abstract: Using electron beam (EB) radiation as a phytosanitary treatment to control insect pests of quarantine concern on the exported fresh fruits is a development trend in the world. In this study, the effect of EB irradiation within the quarantine dose (400 to 1000Gy) on the quality of "Edor" longan was investigated. In addition, the chemical pre-treatments are also combined with EB irradiation to decrease the pericarp browning of longan. "Edor" longan was fumigated with SO₂ or soaked in 1.5N HCl solution for 20 minutes after EB irradiation at low quarantine dose (400Gy). Untreated and non-irradiated fruits were considered controls. Then, all treatments were stored at assumed commercial conditions (25-26°C). The results show that the treated samples delayed a decrease in the total phenolic content and had lower pericarp browning than control. Besides, chemicals pre-treatment combined with irradiation were not significantly different in weight loss, TSS, total acid content, vitamin C... compared to samples treated with chemicals only. In particular, the treated samples had delayed the degree of damage level due to rotting when shelf life was extended up to 22 days compared the control (12 days). Therefore, the method of combining SO₂ fumigation treatment with EB irradiation (400Gy) can be used for quarantine treatment of export "Edor" longan; and treatment with 1.5N HCl solution can be considered to replace the traditional SO₂ fumigation method.

Keywords: Combined treatment, dipping in HCl solution, irradiation, "Edor" longan, pre-treatments, SO₂-fumigated.

I. INTRODUCTION

Longan (*Dimocarpus longan*) is a non-climacteric subtropical fruit tree in the genus *Dimocarpus* and the family Sapindaceae. Longan is widely grown in many countries, including Vietnam [1, 2]. The longan fruit has favored in many countries due to its high value in nutrient and delicious taste. Edor longan is originated from Thailand and now grown in the Southern Vietnam. Edor longan has been

exported to China, Japan, EU, Australia and the US... However, the short shelf-life of longan somewhat limited its exportation to the distant market like the US. Therefore, some preservation methods have been developed to keep the freshness and characteristic color of longan for longer storage. At maturity, longan contains a relatively large seed covered by edible fleshy portion and a thin, leathery and indehiscent pericarp. However, this outer pericarp is easy to be browned and rotten after

harvest, which keep the fruit in good quality only in 3-5 days at 32-35°C [3]. Browning of pericarp may be related to hygroscopicity and/or heat stress, aging, cold injury, pathogens and fruit pests [4]. The spoilage of fruit is mainly due to the attacks of harmful microorganisms such as *Lasioidiplodia theobromae*, *Geotrichum candum* and *Rhizopus* spp., during storage, transportation and sale [5, 6].

Fumigation with sulfur dioxide (SO₂) has been widely used to deal with browning and rotting problems during postharvest storage of longan [7]. SO₂ can inhibit the pericarp browning, kill the spoilage bacteria and pathogens on the fruit, and act as an antioxidant [8]. In addition, SO₂ can also act as a bleaching agent, creating a bright yellow pericarp and reducing the respiratory process, so significantly prolonging the shelf-life of fruits [9]. However, it is hard to remove all SO₂ after treatment, and the residual gas may cause harmful effects to customers, especially for asthmatic patients. Therefore, it is necessary to apply other pre-treatment to replace for SO₂ fumigation [10].

Up to now, many chemicals were studied to inhibit the browning as well as prolong the shelf life of post-harvest longan by domestic and international researchers. Dipping the longan fruits in chitosan solution of 0.2% (pH=3.3) can reduce the pericarp discoloration, browning index, as well as spoilage rate and increase the acceptable fruit quality after 26 days of storage [11]. The quality of the longan fruits treated with 0.1% carbendazim solution followed by dipping in 4mM oxalic acid solution and storing at 4±1°C, 95% humidity was stable for longer time with limited browning, and microbial rotting [12]. Other chemicals like HCl, ClO₂, oxalic acid, ascorbic acid... are also studied to replace for SO₂

fumigation. According to Apai et al. (2010), treatment of longan in 1.5N HCl for 20 minutes could prolong the shelf life, reduced rotting rate and keep the fruit quality after 7 days of storage at 25°C and after 45 days of cold storage at 5°C, humidity 85% [10]. Likhitrugulung et al. (2020) reported that the fruits treated with 1.5% ClO₂ for 5 minutes could storage for 42 days at 5°C with low pericarp browning and spoilage rate [13]. Soaking "Daw" longan in 0.001–0.005% sodium chlorite for 10 minutes reduced its browning and kept the total phenol content of the fruits stored at 25±1°C, humidity 82±5% during 48 hours [14].

Together with the browning, dehiscence and post-harvest decay of the storage fruits, phytosanitary treatment to control the pests is a very important measure to facilitate the export of fresh fruit in general and longan in particular. Currently, there are some phytosanitary methods such as hot heat treatment, cold heat treatment, chemical treatment, irradiation, etc. which have been approved [15]. The minimum required quarantine dose is 400Gy and the maximum dose is 1000Gy for fresh fruits imported into Australian and the US.

To our knowledge, the combined effects of chemical pre-treatment and electron beam irradiation on the longan have not been studied yet. Therefore, the purpose of this study is to investigate the effects of chemical pretreatment (SO₂ fumigation and HCl dipping) combined with electron beam irradiation at a minimum dose of 400Gy on the quality of Edor longan to facilitate its exportation to the US and Australia.

II. MATERIALS AND METHODS

A. Plant Preparation and Treatments

"Edor" longan grown and harvested with VietGAP and GlobalGAP standards,

were purchased at Chanh Thu Fruit Import Export Co., Ltd. (Nhon Phu hamlet, Hoa Nghia commune, Cho Lach district, Ben Tre province). The fruits with similar size, bright pericarp color, indehiscent, without any injury and microbial rot were selected for sampling. Longan were packed in mesh bags (500g) and stacked in plastic trays (41.5×35.5×10cm) with a net weight of around 5kg. All longan samples were stored at 5°C and transported to VINAGAMMA by a specialized vehicle.

Chemical pre-treatment: Edor longan was pre-treated as follows: a) SO₂ fumigation; b) Dipping in 1.5 N HCl solution for 20 minutes [10]; c) Dipping in 1.5% ClO₂ for 5 minutes [13]; d) Dipping in 40 mM ascorbic acid (AA) solution for 2 minutes, then continue to dipping in 2 mM oxalic acid (AO) solution for 3 minutes [16]; and e) the untreated longan is the control sample. All sample were stored at 15-20°C, humidity of 80-90% for 3 days (conditions of transportation by plane), and continue to be stored at 25-26°C and humidity of 75-80% for 20 days.

Chemical treatment combined with EB irradiation: Edor longan was treated with SO₂ fumigation or dipped in 1.5N HCl solution for 20 minutes, followed by EB irradiation at a dose of 400Gy under an electron beam accelerator UELR-10-15S2 (10MeV, capacity 15kW, CORAD, Russian) at Vinagamma. Non-chemically treated and non-irradiated fruits were the control samples. All fruits were stored at 15-20°C, humidity of 80-90% for 3 days (conditions of transportation by plane), and continue to be stored at 25-26°C and humidity of 75-80% for 20 days.

B. Quality Measurements

Pericarp color: The pericarp color of longan was determined by using a Minolta CR400 colorimeter. The difference in pericarp color was expressed through the values of L*, Hue color angle and Chroma C, which was calculated as follows:

$$\text{Hue} = \arctan\left(\frac{b^*}{a^*}\right) \quad (1)$$

$$\text{Chroma } C^* = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

Browning Index (BI): The browning index (BI) was assessed by scoring method as reported by Khan et al. (2012) [17]. Specially, 1=no browning; 2=slightly browning (<10%); 3=browning 10-25%; 4=browning 25-50%; 5=browning 50-75% and 6=browning >75%.

Weight loss: Weight loss was calculated as percentage with respect to the initial weight of each treatment as a following equation:

$$X (\%) = \frac{M_1 - M_2}{M_1} \times 100 \quad (3)$$

Where X – the rate of weight loss (%), M1 – sample weight at the initial time (g), M2 – sample weight at the time of testing (g).

Firmness: The firmness of fruit was measured with a LUTRON FR-5120 with a 3mm diameter plunger used to puncture the fruit. The force to penetrate the pericarp and flesh is recorded in units of Newton (N).

Total soluble solids TSS (°Brix): TSS content of fruit fleshy was determined using a refractometer TI-RBX0032, Trans Instruments Pte Ltd., Singapore.

Titrateable acid (TA): The titrateable acid content of longan fleshy was determined by titration according to AOAC 22.060 (1980) [18]. 10ml of the fruit solution titrated with 0.1N NaOH solution. The results are expressed as %TA.

Ascorbic acid: Ascorbic acid content was determined by titration method with 2,6-dichlorophenol indophenol solution according to ISO 6557-2 (1984) [19]. The results are expressed as mg of ascorbic acid/100g of fruit fleshy.

Total phenolics content (TP): The total phenolics content in pericarp was determined by using Folin-Ciocalteu reagent and measured at 765nm by using a UV-Vis spectroscopy according to the method of Tang et al. (2019) [20]. The results are expressed in mg of gallic acid/100g of longan pericarp.

C. Statistical analysis

The experiments were arranged as a completely randomized design. Statistical analysis was carried out by using SPSS version 22. One-way ANOVA test (P=0.05) was performed to determine significant differences among the treatments.

III. RESULTS AND DISCUSSION

A. Effects of chemical pre-treatments on the quality of Edor longan

1. Pericarp color and BI:

The effects of chemical pre-treatments on the color and browning index (BI) of longan pericarp were shown in Table I. In general, the values of L*, C* and Hue color angle of longan pericarp decreased, while its BI value increased in all treatments.

Pericarp color is one of the important attributes affecting to the longan quality. The results from Table I showed that the values of L*, C* and Hue angle decreased with storage time in all treatments. The values of L*, C* and Hue angle of HCl and SO₂ were higher and significantly different (P<0.05) compared with DC, AA+AO and ClO₂ after treatment at the first day and after 9 days of storage. However, the difference between HCl and SO₂ samples was not statistically significant (P<0.05).

Table I. Effect of chemical pre-treatments on pericarp color and BI of Edor longan after 9 days stored at 25-26°C

Treat- ment	Pericarp color							
	L*		Chroma C*		Hue (°)		BI	
	Day 0	Day 9	Day 0	Day 9	Day 0	Day 9	Day 0	Day 9
Control	43.65 ± 0.35 ^a	34.95 ± 0.84 ^a	23.18 ± 0.30 ^a	21.46 ± 0.11 ^b	63.00 ± 0.75 ^a	62.43 ± 0.18 ^a	1.61 ± 0.15 ^a	4.53 ± 0.19 ^a
AA+AO	43.31 ± 0.17 ^a	36.21 ± 0.52 ^b	23.36 ± 0.10 ^a	21.77 ± 0.14 ^b	64.30 ± 0.14 ^b	63.77 ± 1.06 ^a	1.53 ± 0.12 ^a	4.47 ± 0.18 ^a
ClO₂	44.22 ± 0.36 ^b	38.67 ± 0.43 ^c	23.27 ± 0.09 ^a	20.88 ± 0.29 ^a	64.41 ± 0.10 ^b	63.13 ± 1.11 ^a	1.51 ± 0.14 ^a	4.35 ± 0.20 ^a
HCl	52.45 ± 0.58 ^c	51.08 ± 0.55 ^d	24.71 ± 0.16 ^b	23.43 ± 0.28 ^c	76.72 ± 0.81 ^c	70.39 ± 0.35 ^b	1.10 ± 0.87 ^b	2.03 ± 0.11 ^b
SO₂	52.52 ± 0.58 ^c	51.16 ± 0.63 ^d	24.65 ± 0.25 ^b	23.46 ± 0.29 ^c	76.90 ± 0.86 ^c	73.50 ± 0.62 ^b	1.09 ± 0.81 ^b	2.00 ± 0.16 ^b

Numbers in the same column with different letters are significantly different (p<0.05).

Besides, the browning index BI decided the color change of the pericarp and is negatively correlated with the values of L*, C* and Hue angle [10]. Table 1 showed that the BI of the fruits pre-treated with HCl and SO₂ after 9 days of storage were 2.03 and 2.00,

much smaller than control (4.53), AA+AO (4.37) and ClO₂ (4.35) at a significantly confidence of 95% (p<0.05). According to Lichter et al. (2000), polyphenol oxidase (PPO) was inactivated at the low pH under 3.0 [21]. SO₂ fumigation inhibited enzymatic

browning of longan pericarp by lowering the pH [22]. Dipping the fruits in HCl reduced browning by reducing pH of the pericarp, or forming a colorless quinine-sulfate complex that inhibited polyphenol oxidase activity [23]. This result was similar to the results of Apai et al. (2010), 'Daw' longan treated with 1.5N HCl solution for 20 minutes and SO₂

fumigation showed better appearance and brighter color with higher L*, C* values than control sample [10].

2. TP content, firmness and weight loss

The effects of chemical pre-treatments on TP content, firmness and weight loss were shown in Table II.

Table II. The effects of chemical treatments on TP content, weight loss (%) and firmness of Edor longan after treating (0 day) and 9 days stored at 25-26°C

Treatment	TP (mg GAE/100g fruit pericarp)		Weight loss (%)		Firmness (N)	
	Day 0	Day 9	Day 0	Day 9	Day 0	Day 9
Control	31.84 ± 0.34 ^a	12.71 ± 0.93 ^a	0	10.51 ± 0.47 ^a	18.56 ± 0.37 ^a	10.16 ± 0.70 ^a
AA+AO	31.98 ± 0.32 ^a	12.99 ± 0.53 ^a	0	9.32 ± 0.26 ^b	18.69 ± 0.39 ^a	12.93 ± 0.49 ^b
ClO ₂	31.88 ± 0.31 ^a	13.88 ± 0.52 ^a	0	9.54 ± 0.45 ^b	18.55 ± 0.38 ^a	12.77 ± 0.75 ^b
HCl	32.01 ± 0.38 ^a	27.08 ± 0.57 ^b	0	7.31 ± 0.24 ^c	18.93 ± 0.56 ^a	17.72 ± 0.31 ^c
SO ₂	32.02 ± 0.28 ^a	26.73 ± 0.56 ^b	0	7.21 ± 0.27 ^c	19.28 ± 0.60 ^a	17.63 ± 0.40 ^c

Numbers in the same column with different letters are significantly different ($p < 0.05$)

Phenolic compounds were the primary factors influencing the browning index, which was caused by enzymes in fruits and vegetables [12]. The results in Table II revealed that TP content of the longan was significantly reduced after 9 days of storage. Fortunately, the reductions in TP content of the fruits treated with HCl and SO₂ were 15.40 and 16.52% only, much smaller than those of the control (60.08%), the fruits treated with AA+AO (59.38%) and ClO₂ (56.48%). Therefore, pre-treatments of Edor longan with HCl and SO₂ effectively suppressed the activity of polyphenoloxidase enzymes (PPO), which is the key enzyme catalyst in phenolic oxidation reactions [24]. Tran et al. (2015) showed that the TP content in pericarp of 'Huong Chi' longan treated with 1.5N HCl solution for 5 minutes was stable and higher than the control after 35 days of storage (4°C,

95% RH) [12]. Similar results were observed with the litchi fumigated with SO₂ that TP content of treated fruits was significantly higher than non - treated ones after 21 days of storage (1°C, 95% RH) as reported by Sivakumar et al. (2005) [25].

Weight loss is one of the most important indicators that need to be controlled during storage. As it can be seen from Table II, the highest weight loss of the longan samples after 9 days of storage was 10.51%, as recorded with control, followed by ClO₂ (9.54%), AA+AO (9.32%), HCl (7.31%) and SO₂ (7.21%). However, there was no statistically significant difference in weight loss between the fruits treated with HCl and SO₂ ($p < 0.05$). It may be because the natural dehydration caused by a vapor pressure disparity between the storage

environment and the fruit's pericarp. Additionally, the respiratory process also contributes to minimizing the weight loss in fruits [26, 27].

Firmness exhibited a decline over the duration, particularly in the control, AA+AO, and ClO₂ samples as presented in Table II. However, the firmness of the fruits treated with HCl and SO₂ remained consistent after 9 days of storage, and the distinction between the two treatments was not statistically significant

($p < 0.05$). These results were similar to the results of Apai et al. (2010b), where the firmness of the fruits fumigated with SO₂ and soaked in HCl solution did not display any statistically significant variation from the 5th to the 60th day of storage [28].

3. TSS, TA and ascorbic acid

The effects of chemical pre-treatments on TSS, TA and ascorbic acid of Edor longan were presented in Table III.

Table III. The effects of chemical treatments on TSS (°Brix), TA (%) and ascorbic acid of Edor longan after 9 days stored at 25-26°C

Treat- ments	Quality of fruit flesh					
	TSS (°Brix)		TA (%)		Ascorbic acid (mg/100g)	
	Day 0	Day 9	Day 0	Day 9	Day 0	Day 9
Control	19.60 ± 0.10 ^a	18.07 ± 0.12 ^a	0.142 ± 0.006 ^a	0.109 ± 0.006 ^a	49.28 ± 2.65 ^a	25.85 ± 1.80 ^a
AA+AO	19.57 ± 0.15 ^a	18.43 ± 0.15 ^b	0.139 ± 0.011 ^a	0.110 ± 0.006 ^a	49.72 ± 2.36 ^a	32.30 ± 1.08 ^b
ClO₂	19.53 ± 0.12 ^a	18.47 ± 0.15 ^b	0.142 ± 0.006 ^a	0.100 ± 0.006 ^a	49.28 ± 1.65 ^a	33.33 ± 0.72 ^b
HCl	19.63 ± 0.15 ^a	19.13 ± 0.12 ^c	0.141 ± 0.006 ^a	0.132 ± 0.006 ^b	49.72 ± 2.36 ^a	39.98 ± 0.72 ^c
SO₂	19.67 ± 0.12 ^a	19.20 ± 0.10 ^c	0.142 ± 0.006 ^a	0.132 ± 0.006 ^b	50.15 ± 1.89 ^a	41.09 ± 1.02 ^c

Numbers in the same column with different letters are significantly different ($p < 0.05$)

The changes in TSS, TA and ascorbic acid content are the important criteria for evaluation the fruit quality during storage. After 9 days of storage, the TSS, TA and ascorbic acid of the longan treated with HCl and SO₂ were significantly higher than those of the control, AA+AO and ClO₂ samples (Table III). These results are in accordance with the research of Tran et al. (2015), where "Huong Chi" longan was immersed in a 1.5N HCl solution for 5 minutes, resulting in the preservation of higher TSS and TA content compared to the untreated samples after a 20 days storage at 4°C [12]. Apai et al. (2010) demonstrated that the total soluble solids (TSS) and titratable acidity (TA) content of the longan, which were fumigated by SO₂ or

immersed in a 1.5N HCl solution for 20 minutes were higher than those of the untreated samples after a 60-days storage at 3±1°C, 85% relative humidity [10].

The study on the storage of litchi, Jiang et al. (2004) reported that the ascorbic acid content of the litchi treated by 1% HCl was 20.3mg/100g, higher than 19.16mg/100g of the control [29]. The study conducted by Han et al. (2000) found the contents of ascorbic acid of the "Shixia" longan treated with SO₂ (10 minutes and 20 minutes), were higher than those of the control after 40 days of storage at 4°C [30].

In this experiment, some chemical pre-treatments have been applied to Edor longan,

and our results indicated that the fruits treated with 1.5N HCl solution for 20 minutes or fumigated with SO₂ kept the better quality compared to the control and other treatments. Therefore, the pre-treatments of SO₂ fumigation and HCl dipping were selected to combine with electronic beam irradiation as the phytosanitary treatment of Edor longan to quarantine and facilitate its exportation.

B. Effects of chemical pre-treatments (SO₂ and HCl) combined with electron beam (EB) irradiation on the quality of Edor longan

1. The impact of chemical pre-treatments combined with EB irradiation on the pericarp color of longan

The pre-treatments with SO₂ and HCl much improved the shelf life of longan as observed in this experiment that the treated longan could keep good quality up to 22 days, while the control sample was only preserved for 12 days. Table IV showed the changes in pericarp color of treated longan with storage time through the L*, C* and Hue angle values.

As indicated in the table, all control fruits were no longer preserved after 12 days, because they were completely damaged. Luckily, the fruits treated with HCl, SO₂, and followed by EB irradiation can store up to 22 days at the temperature of 25-26°C, humidity of 75-80%.

Table IV. The effects of chemical treatments combined with EB irradiation on pericarp color of longan after 22 days stored at 25-26°C

Value	Treatment	Time of storage						
		Day 0	Day 5	Day 8	Day 12	Day 15	Day 19	Day 22
L*	Control	43.06 ± 0.09 ^{au}	39.27 ± 0.19 ^{az}	38.69 ± 0.22 ^{ay}	37.57 ± 0.37 ^{ax}	*	*	*
	HCl	52.01 ± 0.35 ^{bz}	51.56 ± 0.20 ^{bz}	51.00 ± 0.12 ^{by}	50.80 ± 0.22 ^{by}	50.62 ± 0.43 ^{ay}	49.63 ± 0.14 ^{ax}	49.44 ± 0.36 ^{ax}
	HCl+Irr	52.03 ± 0.40 ^{bz}	51.63 ± 0.46 ^{bz}	50.83 ± 0.19 ^{by}	50.97 ± 0.05 ^{by}	50.44 ± 0.28 ^{ay}	49.71 ± 0.37 ^{ax}	49.45 ± 0.23 ^{ax}
	SO ₂	52.02 ± 0.22 ^{bz}	51.58 ± 0.35 ^{bz}	50.99 ± 0.18 ^{byz}	50.69 ± 0.18 ^{by}	50.55 ± 0.44 ^{ay}	49.73 ± 0.38 ^{ax}	49.85 ± 0.20 ^{ax}
	SO ₂ +Irr	52.08 ± 0.24 ^{bz}	51.73 ± 0.42 ^{bz}	51.08 ± 0.13 ^{by}	50.99 ± 0.11 ^{by}	50.13 ± 0.18 ^{ax}	49.85 ± 0.08 ^{ax}	49.88 ± 0.16 ^{ax}
C*	Control	21.36 ± 0.19 ^{ay}	20.97 ± 0.23 ^{axy}	20.55 ± 0.17 ^{ax}	20.50 ± 0.26 ^{ax}	*	*	*
	HCl	25.39 ± 0.47 ^{bz}	24.49 ± 0.20 ^{by}	24.46 ± 0.22 ^{by}	24.00 ± 0.35 ^{by}	23.06 ± 0.26 ^{ax}	23.01 ± 0.31 ^{ax}	22.54 ± 0.54 ^{ax}
	HCl+Irr	25.19 ± 0.54 ^{bz}	24.59 ± 0.14 ^{by}	24.40 ± 0.26 ^{by}	24.08 ± 0.19 ^{by}	23.08 ± 0.26 ^{ax}	23.27 ± 0.16 ^{ax}	22.76 ± 0.35 ^{ax}
	SO ₂	25.47 ± 0.14 ^{bz}	24.60 ± 0.11 ^{by}	24.48 ± 0.14 ^{by}	24.23 ± 0.27 ^{by}	23.35 ± 0.36 ^{ax}	23.34 ± 0.21 ^{ax}	22.98 ± 0.12 ^{ax}
	SO ₂ +Irr	25.33 ± 0.28 ^{bz}	24.57 ± 0.05 ^{by}	24.40 ± 0.17 ^{by}	24.09 ± 0.35 ^{by}	23.26 ± 0.47 ^{ax}	23.23 ± 0.14 ^{ax}	22.97 ± 0.19 ^{ax}
Hue (°)	Control	64.88 ± 0.51 ^{az}	64.42 ± 0.48 ^{ayz}	63.71 ± 0.32 ^{axy}	63.42 ± 0.33 ^{ax}	*	*	*
	HCl	78.18 ± 0.26 ^{bv}	77.55 ± 0.60 ^{buv}	77.32 ± 0.74 ^{bu}	76.12 ± 0.31 ^{bz}	74.07 ± 0.17 ^{ay}	72.73 ± 0.16 ^{ax}	72.10 ± 0.12 ^{ax}
	HCl+Irr	78.19 ± 0.30 ^{bu}	77.47 ± 0.68 ^{bu}	77.37 ± 0.92 ^{bu}	76.02 ± 0.15 ^{bz}	73.54 ± 0.71 ^{ay}	72.79 ± 0.21 ^{axy}	72.42 ± 0.36 ^{ax}
	SO ₂	78.17 ± 0.19 ^{bv}	77.55 ± 0.31 ^{buv}	77.06 ± 0.76 ^{bu}	76.02 ± 0.31 ^{bz}	75.10 ± 0.45 ^{by}	74.36 ± 0.20 ^{bx}	73.97 ± 0.41 ^{bx}
	SO ₂ +Irr	78.07 ± 0.51 ^{bu}	77.36 ± 0.46 ^{bzu}	77.42 ± 0.95 ^{bzu}	76.80 ± 0.61 ^{bz}	75.55 ± 0.25 ^{by}	74.17 ± 0.32 ^{bx}	74.08 ± 0.18 ^{bx}

Numbers with different letters in the same column (a, b, c, d, e) and in the same row (x,y,z,u,v) are significantly different (p<0.05). * Samples were completely damaged.

As presented in Table IV, the characteristic color parameters (L^* , C^* and Hue angle) of the fruits treated with HCl, HCl followed by EB irradiation (HCl+Irr), SO_2 and SO_2 followed by irradiation (SO_2 +Irr) were kept in good quality during storage up to 22 days. There were statistically significant differences ($p < 0.05$) in color parameters between the control and other treatments on the first day of storage. Our results showed that EB irradiation at 400Gy did not affect on pericarp color of longan during storage. The results were similar to the study by Follett and Sanxter (2002), that external appearance of longan treated with hot-water immersion was rated as unacceptable after 14 and 21 days of posttreatment storage, whereas irradiated and nontreatment fruit were rated as acceptable an all days [31]. Gamma irradiations at a dose of 400-600 Gy also did not affect to the skin color of dragon fruits storage after 9 days [32]. The skin color of dragon fruit irradiated by X-ray with the dose less than 800 Gy did not change after 12 days of storage at 10°C [33].

2. Effects of chemical pre-treatments combined with EB irradiation on BI and TP content of longan

In this experiment, the effects of chemical pre-treatments combined with EB irradiation on

the browning index (BI) and the reduction of phenolic content in longan pericarp were investigated and the results were presented in figure 1.

The changes in pericarp color are not only expressed through the parameters of L^* , C^* and Hue angle, but also reflected by TP content and BI of the fruit pericarp. In this study, the BI (Fig.1A) of all longan samples increased, but their TP content (Fig.1B) decreased with storage time. Figure 1A showed that the highest BI was always recorded with the control, namely that the pericarp of the control fruits was quickly browned during storage, but the treated fruit could be stored up to 22 days at the same conditions. The BI of the fruits stored 22 days was within acceptable levels for consumption ($BI < 3$). The TP content of control fruits was the lowest at all time, which suggested that the treatments prevented the reduction of titratable acid in longan during storage. The differences in values of BI and TP content between the fruits treated with HCl, SO_2 and the fruits pre-treated with HCl, SO_2 followed by irradiation were not statistically significant ($p < 0.05$). Thus, the values of BI and TP content were not be affected by electron beam irradiation at 400 Gy.

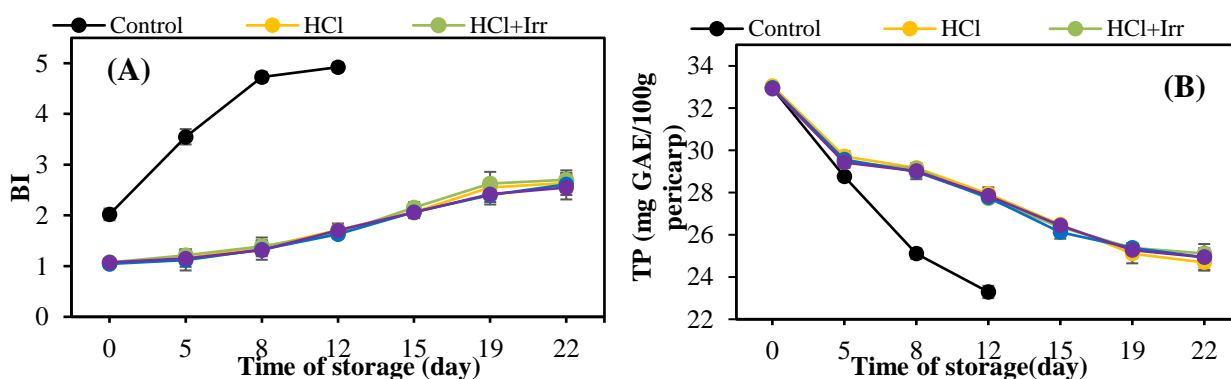


Fig. 1. Effects of chemical pre-treatment combined with EB irradiation on browning index BI (A) and total phenolic content of pericarp (B) after 22 days of storage at 25-26°C

3. Effects of chemical pre-treatments combined with EB irradiation on weight loss and firmness of longan

Figure 2 shows the effects of chemical treatment combine with or without irradiation on the fruits. As it can be seen in Fig.2A, the weight losses of all fruit samples increased with storage time and the differences were not statistically significant after 8 days of storage ($p < 0.05$). However, after 12 days, control fruits showed the highest weight loss, then were completely damaged after 15 days. The reason

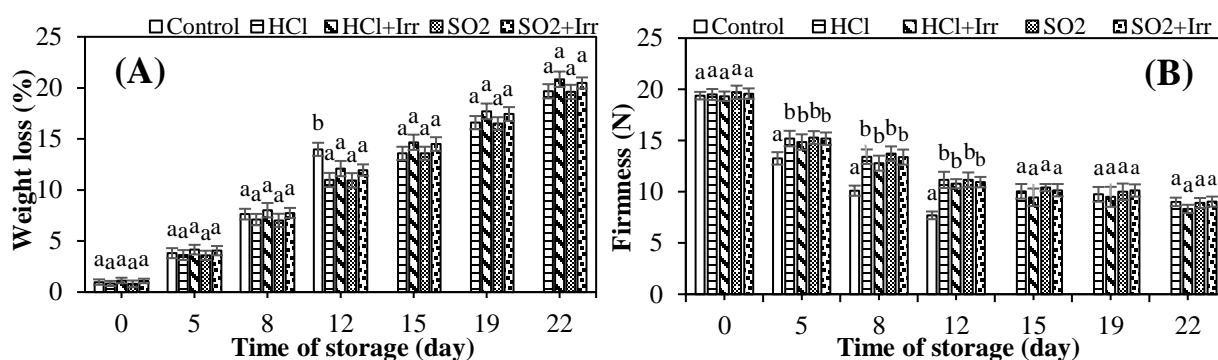


Fig. 2. Effect of chemical treatment combined with EB irradiation on weight loss (A) and firmness (B) of longan after 22 days of storage at 25-26°C

In contrast with weight loss, the firmness of the all fruits decreased with storage time as indicated in Fig.2B. The firmness of the control fruits quickly decreased with storage time, and the differences in firmness between treated and control fruits increased and reached the maximum after 12 days before the controls were completely damaged. This is also attributed to spoilage microorganisms. However, there was no significant difference in firmness between the fruits treated by chemical only and chemical combined with irradiation. Thus, EB irradiation at the dose of 400Gy did not affect the firmness of the Edor longan. Similar results were reported by A. Uthairatanakij et al. (2018) that gamma ray irradiation with the doses of 400-600Gy did not affect the firmness of dragon fruit after 9 days of storage [32].

for that is the control fruits were attacked by spoilage microorganisms and being damaged during storage. For irradiated fruits (both HCl+Irr and SO₂+Irr), their weight losses were higher than those of the fruits treated with HCl or SO₂ only, although the differences were not statistically significant ($p < 0.05$). The results were similar to the study by Marisa and Khan (2008), that the weight losses of dragon fruits irradiated by X-rays at 600 or 800Gy were greater than the control after 12 days of storage at 10°C [33].

4. Effects of chemical treatments combined with EB irradiation on TSS, TA and vitamin C (acid ascorbic) content of longan fruit

As presented in Fig.3, the TSS (Fig.3A) and TA (Fig.3B) of all longan decreased with storage time, and these values of the control were always the smallest during storage. However, the differences were not statistically significant between the fruits treated by chemical and chemical combined with EB irradiation. Similarly, another study showed that gamma irradiation at 400-600Gy did not affect TSS content of red dragon fruit. Also, Radiation quarantine of dragon fruits by X-ray with the dose of less than 800Gy did not affect the TSS and TA of the fruits [32, 33].

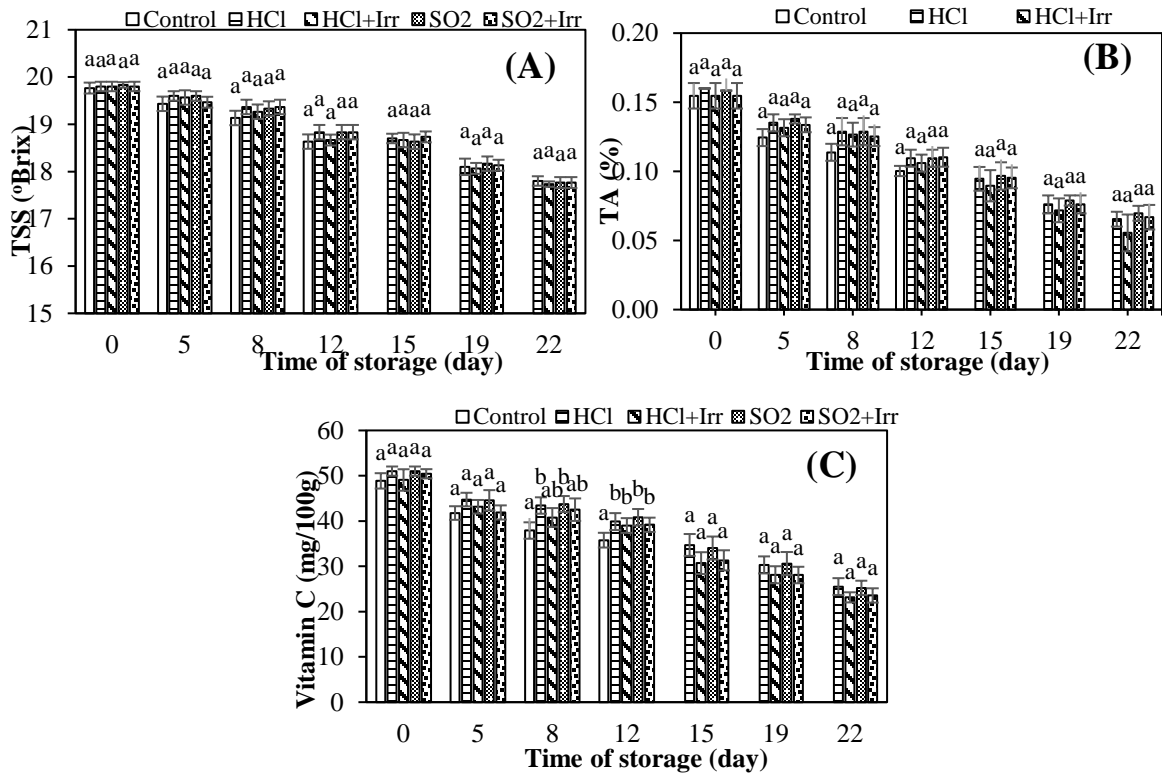


Fig. 3. Effect of chemical treatment combined with EB irradiation on TSS (A), TA (B) and ascorbic acid (C) of longan after 22 days of storage at 25-26°C

The results from Fig.3C show that the vitamin C content of the control fruits was the lowest during storage. There were many causes for this decline but mainly due to light and the presence of microorganisms [35]. Ascorbic acid (vitamin C) was one of the antioxidants in fruit and is radio-sensitive vitamin [34], and it seems not to be affected by EB irradiation at 400 Gy. Our results also revealed that the spoilage of longan during storage was the highest in the control, leading to a greater reduction in its vitamin C content. After 22 days of storage, vitamin C contents of the fruits treated by chemical combined with EB irradiation (HCl + Irr and SO₂ + Irr) were smaller than those treated by HCl or SO₂ only. This might be due to the ionizing radiation which caused partial conversion of ascorbic acid to dehydroascorbic acid [34].

However, the longan treated with HCl combined with irradiation were less attractive compared to the other samples due to their worsening in sensory quality. Therefore, it requires further study to use HCl treatment replacing the traditional SO₂ fumigation to keep the sensory quality of Edor longan.

IV. CONCLUSIONS

The present study proves that Edor longan treated with 1.5N HCl solution for 20 minutes can be preserved longer with acceptable sensory and nutrient qualities including pericarp color, browning index (BI), phenolic content, as well as the weight loss, TSS, TA, vitamin C similar to SO₂ fumigation.

Treatment with 1.5 N HCl solution for 20 minutes or SO₂ fumigation combined with

EB irradiation at 400 Gy did not affect the weight loss, firmness, TSS, TA, vitamin C content of Edor longan during storage at 25-26°C, humidity 75-80%. Also, chemical pre-treatment combined with EB irradiation limited the reduction in phenolic compounds, browning index (BI) and kept the characteristic color of the longan pericarp during storage. SO₂ fumigation combined with EB irradiation at 400 Gy can be applied to quarantine the Edor longan; and the chemical treatment with 1.5N HCl solution can be also considered to replace the traditional SO₂ fumigation to eliminate the use of this harmful gas in the future. However, further research is needed to investigate how to keep the sensory quality of longan for exportation.

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REFERENCES

- [1]. Lin, Y., Chen, M., Lin, H., Lin, M., Hung, Y.C., Lin, Y., Chen, Y., Wang, H. and Ritenour, M.A. Phomopsis longanae-induced pericarp browning and disease development of longan fruit can be alleviated or aggravated by regulation of ATP-mediated membrane lipid metabolism. *Food Chemistry*, 269, pp.644-651, 2018.
- [2]. Sun, J., Lin, H., Zhang, S., Lin, Y., Wang, H., Lin, M., Hung, Y.C. and Chen, Y. The roles of ROS production-scavenging system in Lasiodiplodia theobromae (Pat.) Griff. & Maubl. -induced pericarp browning and disease development of harvested longan fruit. *Food Chemistry*, 247, pp.16-22, 2018.
- [3]. Han, D.M., Li, J.G., Pan, X.W., Li, R., Guo, D.L., Wu, Z.X. and Shuai, L. Recent advances in postharvest research on longan fruit. *Acta Horticulturae*, 1029, pp.325-330, 2014.
- [4]. Li, H.Y. and Li, C.F. The early high quality and high production techniques for longan trees. *South China Fruits*, 28(6), pp.30-31, 1999.
- [5]. Uthairatanakij, A., P. Jitareerat, S. Photchanachai, and P. Ieamtim. "Combined treatments of sulfur dioxide and polyethylene bags on the quality and disease incidence in gamma irradiated Longan fruit'Daw'." In *VI International Postharvest Symposium 877*, pp. 1489-1494, 2009.
- [6]. Jiang, Y., Zhang, Z., Joyce, D.C. and Ketsa, S. Postharvest biology and handling of longan fruit (Dimocarpus longan Lour.). *Postharvest Biology and technology*, 26(3), pp.241-252, 2002.
- [7]. Sing, C. T. "Sulfur dioxide fumigation in postharvest handling of fresh longan and lychee for export. [Conference paper]. " *ACIAR Proceedings-Australian Centre for International Agricultural Research (Australia)* (1994).
- [8]. Lin, Hetong, Lin Yifen, Yihui Chen, Kong Xiangjia, and Zhang Junian. "Technologies of post-harvest handling and storage for longan fruits." In *2011 International conference on new technology of agricultural*, pp. 758-763. IEEE, 2011.
- [9]. Han, D.M., Wu, Z.X., Ji, Z.L. and Han, M. Effects of SO₂ treatment on the oxidation and senescence of longan fruit. *J. Fruit Sci*, 16(1), pp.24-29, 1999.
- [10]. Apai, W. Effects of fruit dipping in hydrochloric acid then rinsing in water on fruit decay and browning of longan fruit. *Crop Protection*, 29(10), pp.1184-1189, 2010.
- [11]. Man, D.L. and Phong, N.V. Effect of chitosan concentration and dipping time in acid-chitosan coating solution on quality of "tieu da bo" longan fruits during cold storage. *Van Hien*

- University Journal of Science*, 5(2), pp. 128-140, 2017.
- [12]. Tran, D.T., Hertog, M. and Nicolai, B.M. Multi-response optimization of postharvest treatments to maintain quality of longan'Huong Chi'during cold storage. *European Journal of Horticultural Science*, 84(4), pp.226-236, 2019.
- [13]. Likhitrugulrung, S., Pankasemsuk, T., Whangchai, K., Apai, W. and Pattanapo, W. Study on the effects of longan fruit dipping in chlorine dioxide on pericarp browning and quality during cold storage. *Geomate Journal*, 18(68), pp.41-46, 2020.
- [14]. Khunpon, B., Uthaibutra, J., Faiyue, B. and Saengnil, K. Reduction of enzymatic browning of harvested 'Daw'longan exocarp by sodium chlorite. *ScienceAsia*, 37(3), pp.234-239, 2011.
- [15]. Hallman, G.J. Phytosanitary measures to prevent the introduction of invasive species. *Biological invasions*, pp.367-384, 2007.
- [16]. Ali, S., Khan, A.S., Malik, A.U., Anwar, R., Anjum, M.A., Nawaz, A., Shafique, M. and Naz, S. Combined application of ascorbic and oxalic acids delays postharvest browning of litchi fruits under controlled atmosphere conditions. *Food Chemistry*, 350, p.129277, 2021.
- [17]. Khan, A.S., Ahmad, N., Md, A.U. and Amjad, M. Cold Storage Influences the Postharvest Pericarp Browning and Quality of Litchi. *International Journal of Agriculture & Biology*, 14(3), pp.389-394, 2012.
- [18]. AOAC. Titratable Acidity in Official Methods of Analysis, 13th edn. Washington, DC: Association of Official Agricultural Chemists. (1980).
- [19]. ISO 6557/2. Fruits, vegetables and derived products. Determination of ascorbic acid content. Part 2. Routine methods. ISO, 1984.
- [20]. Tang, Y.Y., He, X.M., Sun, J., Li, C.B., Li, L., Sheng, J.F., Xin, M., Li, Z.C., Zheng, F.J., Liu, G.M. and Li, J.M., 2019. Polyphenols and alkaloids in byproducts of longan fruits (Dimocarpus Longan Lour.) and their bioactivities. *Molecules*, 24(6), p.1186, 2019.
- [21]. Lichter, A., Dvir, O., Rot, I., Akerman, M., Regev, R., Wiesblum, A., Fallik, E., Zauberman, G. and Fuchs, Y. Hot water brushing: an alternative method to SO₂ fumigation for color retention of litchi fruits. *Postharvest Biology and Technology*, 18(3), pp.235-244, 2000.
- [22]. Wu, Z., Han, D., Ji, Z. and Chen, W. Effect of sulphur dioxide treatment on enzymatic browning of longan pericarp during storage. *Acta Horticulturae Sinica*, 26, pp.91-95, 1999.
- [23]. Fleuriot, A. and Billot, J. Fruit phenolics. *CRC Press, Boca Raton*, 378, 1990.
- [24]. Queiroz, C., Mendes Lopes, M.L., Fialho, E. and Valente-Mesquita, V.L. Polyphenol oxidase: characteristics and mechanisms of browning control. *Food reviews international*, 24(4), pp.361-375, 2008.
- [25]. Sivakumar, D., Regnier, T., Demoz, B. and Korsten, L. Effect of different post-harvest treatments on overall quality retention in litchi fruit during low temperature storage. *The Journal of Horticultural Science and Biotechnology*, 80(1), pp.32-38, 2005.
- [26]. Yaman, Ö. and Bayındırlı, L. Effects of an edible coating and cold storage on shelf-life and quality of cherries. *LWT-Food science and Technology*, 35(2), pp.146-150, 2002.
- [27]. Bhowmik, S.R. and Pan, J.C. Shelf life of mature green tomatoes stored in controlled atmosphere and high humidity. *Journal of Food Science*, 57(4), pp.948-953, 1992.
- [28]. Apai, W., M. Huntavee, and S. Likhitrugulrung. "Effects of Acid Dips on Pericarp Browning and Fruit Quality of Longan Fruits during Cold Storage." In *Southeast Asia Symposium on Quality and Safety of Fresh and Fresh-Cut Produce* 875, pp. 213-222, 2009.
- [29]. Jiang, Y., Li, Y. and Li, J. Browning control, shelf life extension and quality maintenance of

- frozen litchi fruit by hydrochloric acid. *Journal of Food Engineering*, 63(2), pp.147-151, 2004.
- [30]. Han, D., Luo, T., Zhang, L., Wu, J., Wu, H., Wu, Z., Li, J., Wang, J. and Pan, X. Optimized precooling combined with SO₂-released paper treatment improves the storability of longan (*Dimocarpus longan* Lour.) fruits stored at room temperature. *Food Science & Nutrition*, 8(6), pp.2827-2838, 2020.
- [31]. Follett, P.A. and Sanxter, S.S. Longan quality after hot-water immersion and X-ray irradiation quarantine treatments. *HortScience*, 37(3), pp.571-574, 2002.
- [32]. Uthairatanakij, A., Cholmaitri, C., Aiamla-or, S. and Jitareerat, P. Gamma irradiation as phytosanitary treatment for red flesh dragon fruit. In *IV Asia Symposium on Quality Management in Postharvest Systems 1210*, pp.145-150, 2017.
- [33]. Wall, M.M. and Khan, S.A. Postharvest quality of dragon fruit (*Hylocereus* spp.) after X-ray irradiation quarantine treatment. *HortScience*, 43(7), pp.2115-2119, 2008.
- [34]. Kilcast, D. Effect of irradiation on vitamins. *Food chemistry*, 49(2), pp.157-164, 1994.
- [35]. Ajibola, V.O., Babatunde, O.A. and Suleiman, S. The effect of storage method on the vitamin C content in some tropical fruit juices. *Trends in Applied Sciences Research*, 4(2), pp.79-84, 2009.