Nucl. Sci. and Tech., Vol.11, No. 3 (2021), pp. 34-43

Nuclear Science and Technology

Journal homepage: https://jnst.vn/index.php/nst

Quarantine treatment of hoa loc mango by electron beam irradiation

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Abstract: Using electron beam (EB) irradiation as quarantine treatment for fresh fruits in particular and foods of plant origin in general is a growing trend of the world. Our preliminary results on EB irradiation impacts on Hoa Loc mangoes showed that EB irradiation could be a suitable quarantine treatment for the Hoa Loc mango fruits having weight from 407 to 552g and thickness from 7.3 to 8.0 cm to ensure the dose uniformity ratio (DUR) among irradiated products is within limitation (DUR $\leq$ 2.5). Main quality parameters of irradiated mangoes were insignificantly affected by exposure to EB with the dose ranging from 0.4 to 0.8 kGy, though their weight loss, the color indices L* (lightness), a* (redness to greenness), b* (yellowness to blueness) and firmness were slightly changed in compared with the control (non-irradiated). The results also revealed that vitamin C concentration of the fruits irradiated at 1 kGy much reduced and the hue angle significant increased by the end of storage. These results suggested that EB irradiation of Hoa Loc mangoes at the generic doses of 0.4 kGy is a feasible quarantine treatment that maintains the main the fruit quality.

Keywords: *Hoa Loc mango, irradiation, electron beam, dose uniformity ratio*

I. INTRODUCTION

Mango is one of the most favored and consumed tropical fruits in the United States and Australia due to its unique taste, attractive fragrance, and excellent nutritional value. However, its high water content and the rich in carbohydrates, proteins, and sugars makes mangoes, especially ripen fruits, more vulnerable to the effects of spoilage microorganisms and harmful insects. Therefore, their shelf life and marketability will be quickly deteriorated if they are not preserved by suitable ways. In addition, several invasive pests and insects may spread to new regions during their transportation and trade, affecting to the ecosystems of these new regions. For example, the pest called mango seed weevil (*Sternochetus olivieri*) can penetrate into mango seed and spread in Asia, Africa, and Oceania (including Australia) [1]. This mango seed weevil is a quarantined pest that prevents the importation of mangos to the United States from producing countries [1]. Irradiation is the most effective quarantine treatment, which can sterilize or even kill all pests and insects in packaged fruits without any undesired impacts [2]. The radiation dose of 300 Gy has been

https://doi.org/10.53747/nst.v11i3.370
Received 07 October 2021, accepted 15 December 2021

approved for control of mango seed weevil in mangoes exported from Hawaii to the continental USA. Also, the Vietnam mangoes must be quarantine by a proper measure to ensure there are no pests inside before exportation to USA and other countries.

Recently, EB irradiation has been proven as a potential intervention to treat fresh produce, especially are plant origin products [3, 4]. EB can easily penetrate to product at a limited depth depending on the density and product characteristics and its direction can be placed. Therefore, the absorbed dose at each point in a product exposed to electrons is affected by the density, shape and thickness of irradiated object because electrons are gradually attenuated and scattered when passing through material. Not similar to processed products, the complex-shaped fruits produced large differences in density within the fruit boxes and irradiation containers, so then different fruits will be received different absorbed doses during the same irradiation process. It is very important that ensuring all portions of the irradiated product received the minimum dose required for radiation quarantine treatment, dose uniformity (the Dmax / Dmin ratio) was within limitation, and acceptable processing efficiencies. In fact, a vast majority of the food items will receive the absorbed doses greater than the required minimum dose [5]. Consequently, the color, texture, flavor, and even nutritional compositions of fresh produce may be deteriorated if the product was exposed to EB with an excessive dose. Thus, the maximum absorbed dose must be under limitation of 1000 Gy as requirements of FDA, and the uniformity dose ratio (Dmax/Dmin) should not higher than 2.5 as APHIS/USDA recommendation [6].

In the present study, the Hoa Loc mangoes were irradiated by EB (10 MeV energy) at Research and Development Center for Radiation Technology (Vinagamma) with the generic dose of 400 Gy, and uniformity dose ratios inside mangoes and among the fruit boxes were determined to ensure the requirements of Australian and USA for radiation quarantine treatment. The effects of radiation dose on main quality parameters of mango also investigated with storage time.

II. MATERIAL AND METHOD

A. Materials

Hoa Loc mangoes were purchased from Chanh Thu Export and Import Fruit Company located in Ben Tre province and immediately transferred to Vinagamma, Ho Chi Minh City, Vietnam in the night before experiment. The fruits with weight from 407 to 552g and the thickness from 73 to 80 mm were packed in size 10 carton boxes (10 fruits packed in a box) for EB irradiation.

B3 WINdose dosimeters supplied by GEX Corp., USA were used in the experiments.

B. Method

Monte Carlo simulation: Monte Carlo simulations have been performed using the MCNP5 code to investigation of electron absorbed dose distribution inside fruits will be irradiated under 10 MeV electron beam with double-sided mode. Generally, Monte Carlo simulation results represent an average of the contribution from many histories sampled during the course of the problem [7]. Therefore, a total of 10^6 –10^7 histories were used in our simulation to reduce the statistical uncertainty to about 5% or less.

The highest thickness mango was chosen and a simple ellipsoidal shape of the fruit was assumed for dose calculation (Fig.1).The ellipsoidal shape, along the mutually perpendicular axes, consists of length (L), width

(W), and thickness (T) (Fig. 1). The length, width, and thickness were 16.9, 8.6, and 8.0 cm for flesh, and 11.2, 4.9, and 2.0 cm for seed, respectively. The average densities were 1.0 g/cm^3 and 1.05 g/cm^3 for flesh and seed, respectively. Nutrient values for mango flesh and seed were taken from USDA National Nutrient Database for Standard Reference as reported by Eromosele et al. [8]. Those data were used to calculate both atomic compositions based on the elemental composition ratio in tissue [9] (Table I).

Table I. The elemental composition and density of an actual mango flesh and seed (percent by mass)

Material	**Elemental composition (%)**					**Density (g/cm^3)**
	C	**H**	**O**	**N**	**Others**	
Flesh	7.01	10.18	82.4	0.13	Ca: 0.02; Mg: 0.01; P: 0.02; K: 0.23	1.0
Seed	30.1	9.41	59.85	0.64		1.05

Irradiation experiment: Electron beam (EB) irradiation was conducted at the Vinagamma , Ho Chi Minh City, Vietnam) using a 10 MeV and 15 kW linear accelerator (UERL-10-15S2, Corad Services Ltd, Russia). The system consists of double-sided EBs from upper and lower sides. The irradiated products are transported by a conveyor system. The irradiation dose for specific purposes can be controlled by setting up the operation parameters. In particular, to produce the irradiation dose of 400 Gy of each beam, the system was set up at pulse beam frequency of 37.8 Hz, scan width of 500 mm, conveyor speed of 0.85 m/min and time duration for each pulse of 4 s. In order to produce the irradiation dose of 1.0 kGy of each beam, the system frequency was increased to 87.5 Hz, while other parameters were kept the same. The mango fruits were placed in carton packed (length x width x height: 42 x 31.5 x 12 (cm)) and treated with target absorbed doses of 0.4, 0.6, 0.8 and 1.0 kGy. All experiments were performed at room temperature with at least three replications.

To determine the applied dose, B3 WINdose dosimeters were placed evenly at the surface of the mangoes as presented in Fig. 2. To measured the absorbed doses on the surface of and inside mango, the dosimeters were placed on the surface of the fruit, and inside the fruits as in Fig. 3. After irradiation, fruits were stored at 16ºC to determine color, firmness, vitamin C, weight loss in storage duration. Un-irradiated sample was used as the control. For each treatment, 3 packeds (10 fruits/ packed) were used for three replications.

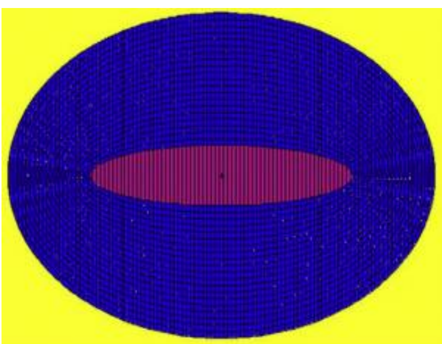


Fig.1. Cross-section of the mango along the major axis for simulation.

Fig.2. Carton boxes of Hoa Loc mango with the positions of B3 film dosimeters

Fig.3. The position of B3 film dosimeters at surface (a) and inside (b) the Hoa Loc mango

Analysis of major quality indicator after EB irradiation:

Weight loss (WL) for each treatment was determined by monitoring the fresh weight change during the storage period and calculated the WL as in equation (1)

$$WL\ (\%) = \frac{Fresh\ weight - Weight\ at\ storage\ interval}{Fresh\ weigth} x\ 100 \quad (1)$$

Color measurement: The surface color of mangoes was measures using Minolta Chroma Meter (ModelCR400, Konica Minolta Co., Japan) in L*a*b* system and illuminant D65, 2° standard white standard tile. In this system, L* represents lightness, a* (redness to greenness), and b* (yellowness to blueness) were recorded for each sample. The hue angle (ho) values were calculated (McGuire, 1992) [10]. Measurements were taken on 3 different points of each fruit, and the mean value was calculated.

Ascorbic acid content was determined according to the method of AOAC 67.21 [11].

C. Statistical analysis

All experiments were conducted in triplicate with untreated samples used as controls. Analysis of variance (ANOVA) using a statistical analysis package (SPSS 11.0) with mean separation by Ducan test at $P < 0.05$ was used to analyze the data.

III. RESULTS AND DISCUSSION

A. Absorbed dose distribution in the carton boxes

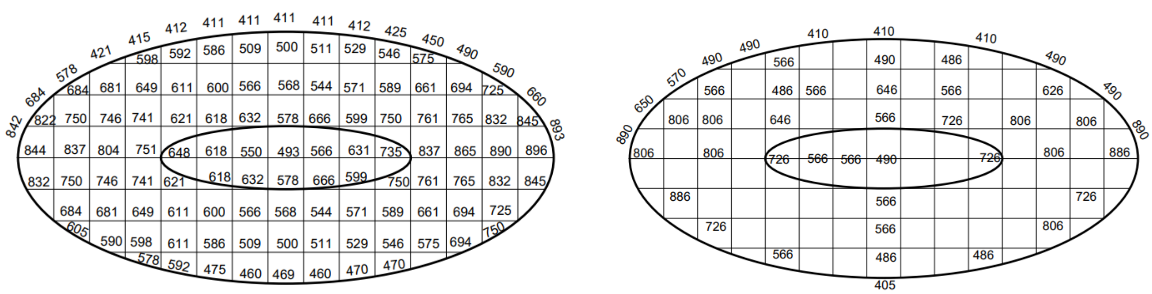
Figure 2 shows the carton boxes of the 10 size Hoa Loc mango with the positions where the B3 WINdose dosimeters attached for measuring the absorbed doses and dose mapping inside the fruit boxes. Five B3 WINdose dosimeters were placed in the box. Table II shows the absorbed dose measured by the dosimeters in the boxes. The values were taken as the averages of the measurements with three different carton boxes for each case. The results indicate that the dose distributions within boxes are relatively uniform. The absorbed doses are within the range of 405–646 Gy corresponds to the DUR of 1.59 ± 0.08. These results confirm that the carton box with dimension of 42 x 31.5 x 12 (cm) is useful for Hoa Loc mango size 10 with the fruits having weight from 407 to 552g and the thickness from 73 to 80 mm, respectively at trading process.

B. Absorbed doses inside of fruits

To calculate the dose along the major axis, we divided the mango by 1.0 ± 0.02 cm. Fig. 4 shows the dose distribution inside of the fruit obtained from the simulation and measurement. It can be seen that the absorbed dose distribution inside and outside of the Hoa Loc mango with thickness is 8.0 cm was rather similar to the simulated dose distribution, which provides more details than the one obtained with the experiment. Using double-beam the dose values increased at both ends, but decrease at the middle of seed. The DURs obtained from the experiment is 2.2. The result meets quarantine requirement (DUR $\leq$ 2.5). The results can be explained that the receiving with higher dose at the both ends of Hoa Loc Mango fruit because electrons lost insignificant amount of their energy in air before hitting the fruits and interference between double beam (top and bottom) so energy build-up in the product. At the start point, the dose is increase from skin to seed and then decrease in the middle of seed. Kim et al. (2008) reported that for most biological materials, 2 cm of entrance distance for a 10 MeV electron beam is still in the dose build-up region [12].

Table II. Absorbed doses at various positions in the carton boxes of Hoa Loc mango measured by B3 film dosimeters

Positions	1	2	3	4	5
Dose (Gy)	646±4	546±8	405±8	566±17	486±13
DUR			1.59±0.08		



a b

Fig.4. Simulated (a) and measured (b) absorbed doses inside the Hoa Loc mango fruit

C. Quality of Hoa Loc mango

Firmness is related to the ability of the fruit to withstand a load before it breaks or impact during handling; it is an indication of how difficult it is to deform the fruit [13]. The firmness of mangoes significantly reduced by EB irradiation (Table III). The smallest value of firmness recorded with the fruit exposed to EB irradiation at 1.0 kGy after 21 days of storage. The firmness of irradiated fruits quickly reduced after 3 days of storage for the fruits exposed to EB at dose below 0,6 kGy, and after 9 days of storage for the fruits treated at 0.8 to 1.0 kGy. These can be explained because mango is climacteric fruit that can ripen during storage, irradiation treatment somewhat delays its ripening. Similar findings have been reported by Lacroix and others (1992) where mango samples irradiated (gamma rays) at 0.60 and 0.90 kGy showed a significant difference in the loss of texture when compared with non-irradiated fruits [14]. El-Samahy and others (2000) also found a reduction of firmness of mango when exposed to gamma irradiation at dose levels between 0.5 and 1.5 kGy [15].

Table III. Effect of EB irradiation on firmness of Hoa Loc mango fruits during storage time

Dose (Gy)	Firmness (N)				
	0 d	**3 d**	**9d**	**15d**	**21d**
0	37.21±1.57ax	30.25±0.18dx	35.73±0.56bx	32.03±0.20cx	26.23±0.10ex
400	39.03±0.97ax	29.1±1.05bx	34.22±1.59cx	30.52±0.12bx	25.9±2.06dx
600	30.62±6.87ay	29.05±0.71abx	34.38±0.17ax	29.77±1.89aby	26.02±0.49bx
800	30.43±0.81ay	28.84±3.12abx	22.5±2.60by	25.52±1.63aby	26.38±1.36abx
1000	30.70±0.10ay	28.26±0.57bx	20.53±1.65dy	22.22±1.26cz	23.12±0.70cy

a-e Means values within a row (storage day) followed by different letters are significantly different (P < 0.05). x-y Means values within a column (dose) followed by different letters are significantly different (P < 0.05).

Weight loss of mangoes was measured at certain storage time during experimental process (Table IV). The results showed that weight loss (%) of mango during storage remarkably increased with the increase of storage time. At the same period of storage, there was no significant difference between irradiated mangoes and the control in weight loss after 9 days. The weight loss in mangoes treated at 1.0 kGy was significantly higher than those of the fruits irradiated at the lower doses after 15 and 21 days of storage (Table IV). The results can be conclusion that at low dose was not effect on the weight loss of the mangoes.

Table IV. Effect of EB irradiation on weight loss of Hoa Loc mango fruits during storage

Dose (Gy)	Weight loss (%)				
	0d	**3d**	**9d**	**15d**	**21d**
0	0.02^{ax}	0.09 ± 0.01^{bx}	0.15 ± 0.01^{cx}	0.20 ± 0.01^{dx}	0.22 ± 0.01^{ex}
400	0.02^{ax}	0.09 ± 0.01^{bx}	0.15 ± 0.01^{cx}	0.20 ± 0.01^{dx}	0.23 ± 0.01^{ex}
600	0.02^{ax}	0.10 ± 0.01^{bx}	0.16 ± 0.02^{cx}	0.20 ± 0.02^{dx}	0.23 ± 0.02^{ex}
800	0.02^{ax}	0.10 ± 0.01^{bx}	0.16 ± 0.01^{cx}	0.21 ± 0.01^{dxy}	0.24 ± 0.01^{exy}
1000	0.02^{ax}	0.10 ± 0.01^{bx}	0.17 ± 0.01^{cx}	0.22 ± 0.01^{dy}	0.25 ± 0.01^{ey}

a-e Means values within a row (storage day) followed by different letters are significantly different (P < 0.05). x-y Means values within a column (dose) followed by different letters are significantly different (P < 0.05).

The color of fruits is a very important characteristic for acceptance from consumers and the most evident indicator of their quality [16]. Visual changes in the color of the Hoa Loc mango fruits were noticeable throughout the storage time. The outer skin of the mangoes in all irradiation treatments was significantly more pitting (scars and holes) than in the control treatment (Figure 5). The fruits were browned by irradiation and the browning levels of the fruits irradiated at 0.8 to 1.0 kGy were higher than those of the fruits irradiated at the lower doses. Which suggest a higher absorbed dose in these areas that may have increased the activity of enzymes such as polyphenol oxidase and phenylalanine ammonia - lyase (PAL) [17]. On the control sample, the surface skin appeared black round or irregular spots at the end of storage time (Figure 5). The symptoms first appeared in the form of small, dark brown colour spots generally at fruit shoulder, which gradually coalesced to form bigger lesions ultimately resulting in fruit rots. The symptoms of this disease are similar to those of anthracnose on mangoes described by Uddin and Afroz (2018) [18]. The numbers of the spots were reduced with increasing irradiation doses up to 1000 Gy. These results are in agreement with those of Cia et al. (2007) reported that at a dose of 0.75 kGy and 1.0 kGy reduced anthracnose incidence and severity on papaya fruits [19]. This change in the external color was monitored by measuring lightness (L*), redness (a*), and yellowness (b*) (Table 5). Irradiation affected the L* values (P < 0.05) of mango skin as they became darker (reduced L values) in all the irradiated fruits during the storage time (Table 5). Particular at dose of 1.0 kGy (P<0.05) was significant difference with the control samples.

No immediate visual differences between control and low dose (0.4–1 kGy) treated fruit were noticeable at before treatment. However, the differences became apparent during storage and was significantly (P<0.05) higher than the control after 15 days storage for the redness (a* value). The b* value for the samples exposed EB irradiation at dose to 0.6 kGy increased with the increasing storage time and significant difference after 29 days storage. However, treated at dose from 0.8 to 1.0 kGy the value was not significant difference during time storage. Irradiation did affect (P < 0.05) the hue angle values with irradiated samples having higher values than the controls. However, only the samples treated with high dose (0.8-1 kGy) showed a significant (P < 0.05) increase in hue angle throughout the storage period. These results are in agreement with the results from Lacroix and others (1992) who reported that irradiated mangoes exposed to gamma irradiation at dose levels between 0.6 and 0.9 kGy had significantly higher hue angle values than the control [14].

Control 0.4 kGy 0.6 kGy 0.8 kGy 1.0 kGy

Fig.5. Effect of EB irradiation on outer skin of Hoa Loc mangoes after 29 days treatment

Table 5. Effect of EB irradiation on colour of Hoa Loc mango during storage time.

Parameter	Dose (kGy)	Storage time (day)					
		0	3	9	15	21	29
L*	0	56.72±1.36ay	57.27±1.99abx	56.76±2.41ax	59.03±1.67bx	58.42±2.27abx	58.77±2.57abx
	0.4	55.82±2.75axy	55.80±2.36ax	55.24±1.07axy	55.67±3.12ay	55.03±3.18ay	55.77±4.33ax
	0.6	54.39±1.87ay	54.62±2.01ay	54.14±1.27ayz	54.07±1.76ay	54.12±2.87ayz	53.41±1.86ay
	0.8	53.58±2.65ay	53.17±3.21ay	52.91±1.82abyz	50.95±3.28abz	51.98±2.87aby	49.69±15.76bz
	1.0	53.72±2.26ay	53.45±3.31ay	51.96±3.70abz	50.79±3.15abz	49.29±2.54bt	49.13±2.48bz
a*	0	-14.69±0.68ax	-14.68±0.34ax	-13.92±0.29bx	-13.25±0.34cx	-12.25±0.63dx	-11.53±0.73ex
	0.4	-13.35±0.68ay	-12.70±1.10ay	-12.18±0.87bcy	-11.28±1.42cy	-10.04±3.46cy	-9.93±1.34dy
	0.6	-13.09±0.41ay	-12.78±0.32aby	-12.13±0..55by	-10.55±0.78cy	-9.91±0.86cy	-9.17±1.21dy

	0.8	-12.40±0.54az	-11.29±0.84abz	-10.23±1.23bz	-8.64±2.14cz	-8.55±1.93cy	-8.23±3.60dy
	1.0	-12.45±0.82az	-11.29±1.08bz	-10.46±1.29bz	-9.10±1.30cz	-7.63±0.89dz	-6.81±1.59dz
b*	0	23.36±1.02ax	23.76±0.99ax	23.53±1.03abx	24.68±0.98bx	24.76±1.01bx	26.14±1.06cx
	0.4	23.40±1.14ax	23.48±1.31ax	23.41±0.80ax	23.18±1.69ax	24.59±1.37abx	25.27±1.76bx
	0.6	23.00±1.47ax	23.59±1.02abx	23.51±1.07abx	23.77±1.89abx	24.09±1.02abx	24.27±1.52bx
	0.8	22.51±2.52ax	±22.34±2.34ax	22.48±1.79ax	21.76±1.89ay	23.71±2.09axy	20.65±7.12ay
	1.0	23.06±1.81ax	22.53±2.67ax	21.92±3.21ax	21.23±2.52az	20.40±2.27ay	21.38±1.61ay
ho	0	-57.82±0.99ax	-58.28±0.86abx	-59.37±1.02bx	-61.74±0.85cx	-63.65±1.69dx	-66.16±1.89ex
	0.4	-60.27±1.43ay	-61.59±2.21ay	-62.53±1.55ay	-64.10±2.53ax	-68.12±7.51by	-68.61±1.87bx
	0.6	-60.31±1.39ay	-61.52±1.11aby	-62.69±1.17by	-66.08±1.43cy	-67.61±2.36cyz	-66.55±2.75cx
	0.8	-60.96±2.51ay	-63.01±3.49aby	5.36±4.26bcz	-66.39±5.20cy	-69.39±4.69cyz	-72.74±2.20dy
	1.0	-61.57±2.17ay	-63.29±1.76aby	-64.39±1.76by	-68.73±2.68bz	-69.43±2.18cz	-73.49±2.74dz

a-e Means values within a row (storage day) followed by different letters are significantly different (P < 0.05). x-z Means values within a column (dose) followed by different letters are significantly different (P < 0.05).

Irradiation had a significant (P>0.05) effect on the ascorbic acid content of mangoes. All irradiated samples had lower ascorbic acid content than that of the control (Table VI). At the end of the storage time, this content decreased to 46.7, 49.05, 48.79, and 50.79% in samples treated with 0.4. 0.6. 0.8 and 1.0 kGy respectively compare to 35.39% in control samples. The samples exposed to higher dose had lower concentrations than the samples treated with lower doses. This suggests that the higher the dose the higher the decrease of the acid concentrations. Similar findings were reported by Youssef et al. (2002) who found a marked decrease in ascorbic acid values of mango pulp upon gamma irradiation at doses between 0.5 and 2.0 kGy [20]. In addition, Mitchell et al. (1992) observed that the application of gamma irradiation at 0.6 kGy on mangoes produced a significant reduction on total vitamin C (ascorbic acid) [21]. The reduction of ascorbic acid could be associated with the role that this organic acid plays as a substrate in the respiration rate, which increased in the irradiated samples evaluated in this experiment. All irradiated and non-irradiated mangoes had significant (P>0.05) decreased ascorbic acid content with time. Normally, the ascorbic acid decreases during ripening of the fruit [22] thus, reduction upon storage may be due to the ripening process.

Table VI. Effect of EB irradiation on vitamin C of Hoa Loc mango fruits during storage time

Dose (Gy)	**Vitamin C (mg/100 g)**				
	0d	**3d**	**9d**	**15d**	**21d**
0	19.72 ± 0.17ax	17.94 ± 0.20bx	15.21 ± 0.28cx	13.87 ± 0.17dx	10.74 ± 0.20ex
400	18.5 ± 0.23ay	17.03 ± 0.15by	14.77 ± 0.07cy	12.88 ± 0dy	9.86 ± 0.12ey
600	17.86 ± 0.11az	16.52 ± 0.51by	13.70 ± 0.21cz	11.69 ± 0.20dz	9.10 ± 0.07ez
800	16.09 ± 0.05at	14.13 ± 0.37bz	12.18 ± 0ct	10.87 ± 0.12dt	8.24 ± 0.20et
1000	14.55 ± 0.28au	12.37 ± 0.07bt	10.87 ± 0.07cu	9.84 ± 0.12du	7.16 ± 0.21eu

a-e Means values within a row (storage day) followed by different letters are significantly different (P < 0.05). z-u Means values within a column (dose) followed by different letters are significantly different (P < 0.05).

IV. CONCLUSIONS

Our findings demonstrate that exposure of Hoa Loc mango fruits to EB irradiation at the generic dose of 0.4 kGy will retain the fruits firmness, weight loss, color when stored at 16°C up to 21 days. Irradiation at 1.0 kGy induced firmness, weight loss, ho value and vitamin C of the mangoes especially by the end the storage time. In a two-side irradiation, the dose uniformity ratio was 2.2 for Hoa Loc mangoes, which is an acceptable commercial situation (the limited ≤ 2.5). Thus, EB irradiation can effectively control dose uniformity ratio in the Hoa Loc mangoes at the thickness of 8.0 cm, while minimize quality changes and the study provides invaluable information for planning phytosanitary irradiation treatment for mangoes by EB irradiation.

ACKNOWLEDGMENT

This work was supported by Ministry of Science and Technology under Research Project number “ĐTCB.02/21/TTNCTK” in the period 2021–2022. The authors would like to thank VINATOM and VINAGAMMA for providing the favorable conditions during project implementation.

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