HAYATI
Journal of Biosciences

Vol. 30 No. 4, July 2023 612-620
DOI:10.4308/hjb.30.4.612-620
ISSN: 1978-3019
EISSN: 2086-4094

New Proposed Dose of Irradiation to Control Fruit Flies (Diptera:Tephritidae) and its Influence to Super Red Pittaya (*Hylocereus costaricensis*) Quality

Hendra Adi Prasetia[1*], Slamet Budiawan[1], Salbiah[1], Ade Syahputra[2], Murni Indarwatmi[3], Wayan Murdita[4]

[1]The Applied Research Institute of Agricultural Quarantine, Indonesia Agricultural Quarantine Agency, Ministry of Agriculture, Cikarang Barat, Bekasi 17520, Indonesia
[2]Tanjung Priok Agricultural Quarantine Major Service, Indonesia Agricultural Quarantine Agency, Ministry of Agriculture, Jakarta 14310, Indonesia
[3]Research Center for Radiation Process Technology, Research Organization for Nuclear Energy, National Research and Innovation Agency, Jakarta 12440, Indonesia
[4]The Pest Forecasting Institute, Directorate General of Food Crops, Ministry of Agriculture, Jatisari, Karawang 41374, Indonesia

ARTICLE INFO

Article history:
Received January 12, 2020
Received in revised form November 13, 2022
Accepted February 20, 2023

KEYWORDS:
Hylocereus costaricensis,
gamma irradiation,
Tephritidae,
physical attributes

ABSTRACT

As one of the important pests, fruit flies derived from Tephritidae family have caused the worst consequences in losing the economic value of fresh horticultural commodity including on the dragon fruits. As a prospective quarantine treatment, gamma irradiation has been thrived to eliminate totally the appearance of those adults' flies with less impact on the fruit quality degradation. In this study, a series of irradiation dosages were examined to both the third instar larvae (subsequently from *Bactrocera papayae*, *B. cucurbitae* and *B. carambolae*) infesting fruits and the non-infested ones afterwards at 0, 50, 100, 150, 200, 250, 300, 350 and 400 Gy. For a number of the infested fruits, a series of observations were persisted in at room temperature (27±1°C) until two weeks of the post-treatment period. Whereas the non-infested fruits were stored at 11±1°C for 17 days of the storage. Results showed that *B. papayae* required the highest recommended dosages (the effective dose = 248.4 Gy; the minimum dose = 225.1 Gy; the maximum dose = 279.6 Gy) for achieving $LD_{0.99}$ rather than the other tested spesies. There were also no significant differences among each of the non-infested fruits in terms of altering of the observed physical attributes. This result has become a distinct indication that a higher dose value than the generic one is mostly recommended both for phytosanitary irradiation and stabilization of fruit quality.

1. Introduction

Pittaya also recognized as dragon fruit, is one kind of exotic horticultural plants firstly cultivated in several locations both in Central and South America (Mizrahi *et al.* 1997; Perween *et al.* 2018) and known as its magnificent ornamental value due to numerous spacious flowers blooming in late-night (Pushpakumara *et al.* 2006). One of the most attractive species of this fruit is recognized as Hylocereus costaricensis with distinctly distinguished through its red flesh with pink skin (Nerd *et al.* 1999). This fruit has also classified as the premium ones since it contains many antioxidant substances (Mahattanatawee *et al.* 2006), a significant amount of bioactive compounds and a certain number of micro essential mineral substantially needed by human's body (Bellec *et al.* 2006).

However, several quarantine pests appearances have caused several serious consequences dealing with loss of economics potencies and trade values. McQuate (2010) reported certain patterns of *Bactrocera cucurbitae* and *B. dorsalis* infestation to white flesh dragon fruit on a local orchard in Hawaii island. Other important species are *B. papayae* and *B. carambolae* greatly impacting on several reported cases of severe tropical fruits deterioration (Salomon *et al.* 2018). Another previous study conducted by Drew *et al.* (2001) found several cases of fruit flies infestation on a number of the white flesh of dragon

* Corresponding Author
E-mail Address: hendra.buttmkp@gmail.com

fruits traded in Vietnam. Several species of *Bactrocera* spp. such as *B. dorsalis*, *B. correcta* and *B. cucurbitae* have frequently infested on this commodity and therefore need further treatment to disinfest for fulfilling the requirement of the phyto-sanitary measures implemented on several trade partnership countries (Hoa *et al.* 2006).

At least, three reasons such as the appearance of converted sugars as the main source of energy and the protein source not only for achieving the optimum maturity but also together with lipids for determining the next generation, have previously proposed in supporting why several kinds of flesh fruits are preferably chosen as hosts (Fletcher 1987; Koswanudin *et al.* 2018). Learning from this case, an appropriate applying of the proper quarantine treatment shall be taken as a main priority in preventing the cross-contamination risks possibly occurred (Follet and Sanxter 2000). One of the technical schemes for minimalizing the fruit flies contamination on several kinds of horticultural commodities is through gamma irradiation.

Irradiation is one of the established quarantine treatments having auspicious prospects not only on eliminating the pests but also on allowing the minimum impacts of fruit degradation (Moy and Wong 2002; Follet and Sanxter 2003). Other benefits offered by this treatment are tangible to all process of fresh horticultural packaging and no remained residue (Hallman 2011). As a recognized treatment, irradiation has been conducted to prevent normal adults appearance and not subjected to total elimination of larvae of those tephritids (Hallman 2012). The first recommendations formulated by the International Consultative Group on Food Irradiation (ICGFI) firmly stated two generic doses in achieving those previous goals namely 150 Gy for fruit flies and 300 Gy for other insects (ICGFI 1991).

Unfortunately, previous studies describing the role of irradiation on risks mitigation of flies contamination to dragon fruits have been relatively rare to be published. This study has a crucial role since it would briefly describe whether the previous generic dose of fruit flies was sufficient or not and how its impacts on critically altering the attributes of the physical fruits.

2. Materials and Methods

2.1. Dose-response Tests

This study was conducted from January to December 2018. There were three kinds of tropical fruit flies species–*Bactrocera papayae*, and *Bactrocera carambolae* classified into *Bactrocera dorsalis* species complex (Schutze *et al.* 2015), and also *Bactrocera cucurbitae*–originated from Laboratory of Vapour Heat Treatment, Pest Forecasting Institute, Karawang Regency, West Java Province. While, red dragon fruits, mature index = 4, were supplied from a local market in Cibitung-Bekasi Regency, West Java Province. Those entire eggs were obtained in mid-day through an hour and half of nesting. Each of 150 pieces eggs were counted under stereo microscope (BOE 3500, Boeco, Germany) artificially inserted into a fruit through a square cut of windows located on the surface of peel sizing in 2 cm × 2 cm × 1 cm (expressed as length, width, depth), then those windows were tightly sealed. There were totally 45 eggs-infested fruits containing 6,750 pieces eggs, then a half of those eggs converting into mature larvae as the targeted life stage for this study.

All of infested fruits were stored at ambient temperature (27±1°C) for almost 5 days on giving sufficient period in growing the eggs into mature larvae (L-3) known as the most radio-tolerant stage (Balock *et al.* 1963; Follet *et al.* 2011; Follett and Amstrong 2004; Hallman 1999). Irradiation was then carried on Centre for Irradiation Application, National Atomic Agency, South Jakarta, Special Region of Jakarta Province using irradiation facility (Panoramic Gamma Irradiators, IAEA, Vienna, Austria). A series of irradiation treatment were conducted at a range of 50 (stated minimum and maximum doses, 50.40-58.93), 100 (100.79-117.87), 150 (159.17-187.50), 200 (212.22-249.99), 250 (256.94-272.22), 300 (308.13-326.67), 350 (357.37-443.95) and 400 (408.42-507.37) Gy to both infested and uninfested fruits. Un-irradiated ones (0 Gy) were used a control for observing natural response mortality of the insect.

Gamma irradiation was generated from a Co-60 energy source owning a counted activity until 100 kCi with a minimum dose rate at 2.5 kGy/h and a measured radiating spectrum was 1.33 meV.

Each of dragon fruit was individually positioned on a cylindrical plastic container (diameter = 20 cm; height = 30 cm). Those filled containers were then placed on a-four of compass directions. At least two dosimeters (Gafchromic™ Dosimetry Media Type HD-V2, Bridgewater, NJ, USA) in each of compass positions were attached into a series of represented container for quantifying the absorbed doses on the four-different directions. The dose uniformity ratio for all of replicates was ≤1.24 (maximum/minimum ratio).

After irradiation, entire infested fruits were stored on ambient temperature (27±1°C) for almost 3 days on allowing those infested mature larvae in transforming into pupae. All of collected pupae gained from fruit's dissections were moved into a number of cube-shaped confinements having 27 liter in volume for 14 days for further observation of adult's appearances. On the other hand, overall non-infested fruits were then placed into a commercial showcase (POLYTRON SCP-18A, Japan) at 11±1°C until 17 days.

2.2. Physical Fruit Quality Properties

Color alteration occurred to post-irradiated and uninfested fruits was observed after a half-month storage period using a Konica Minolta Color Reader (CR-10 Plus, Osaka-Japan). Internal calibration was carried on before color's testing to all of those fruits. The observed values (L,a and b ones) then subsequently converted into chroma values, hue angles and pericarb index using several kinds of mathematical formulas developed by Carreno *et al.* (1995).

In a different approach, the pulp's strength was also measured utilizing a fruit hardness tester (Cat. No. 9300, Tokyo-Japan) according to a method described by Prasetia *et al.* (2018). While for analyzing of total dissolved solid to all juices fruits, a pocket refractometer (PAL-1, Atago, Tokyo-Japan) was employed during the entire tests. A proposed method developed by Rosman *et al.* (2018) was mainly selected for this analysis.

2.3. Data analysis

Data obtained from a series of dose-response tests were converted into certain proportioned values of no adult's emergence through modified forms of Leibniz series giving a wide range of flexibility terms, expressed as follows:

$$A_{(n)} = \frac{\left(1-\frac{n_{ls}}{n_{ts}}\right)+\left(1-\frac{n_{ps}}{n_{ls}}\right)}{(n_{ts}+n_{ls})} x100 \quad \text{.............................(1)}$$

$$A_{t(n)} = 1- \left(\frac{n_{ls}}{n_{ps}} x100\right) \quad \text{...(2)}$$

Where $A_{(n)}$ and $A_{t(n)}$ subsequently were proportion of no adults emerge from the entire inoculating stages and the final fraction of dead pupae. While nts, nls, and nps afterwards refer to total amount of inoculated eggs, a number of observed thirds instar larvae and the whole of noticed pupae. All of the previous proportioned values were then analyzed through a linier regression model.

Analysis of variance (ANOVA) has been conducted to evaluate whether slope and intercept values were significantly affected to a series of trial doses, means were compared by Duncan's multiple range tests (DMRT). For obtaining a certain limit of trial dosages on achieving LD_{99} values, the dosage-mortality data were further analyzed using a probit model at confidence level of 95%. The statistical approaches using ANOVA and DMRT was also operated for analyzing physical fruit attributes.

3. Results

3.1. Determination of the Most Tolerant Species of Fruit Flies

All of three species fruit flies were well-developed until pupae stadium at each of tried dosages. However, there was a strong correlation in reducing populations of observed adult fruit flies appearance caused by the rising of gamma irradiation dosages observed during the entire trials (Figure 1). The entire three regression linear model described relations between those doses of irradiation and mortalities of observed pupae were significant ($P<0.05$).

There were similar flat-patterns in terms of the peak value of dead pupae percentage observed after treated with irradiation applied at a range of dose 250 to 400 Gy (data not shown). There were no significant differences among each of three species of tested fruit flies observed on entire of trial dosages ($F = 3.6$; $df = 2$; $P = 0.09$). In contrast with the previous findings, *B. carambolae* had the least tolerant against gamma-irradiation exposures ($F = 5.6$; $df = 2$; $P = 0.04$) than two others tested fruit flies (Table 1). The

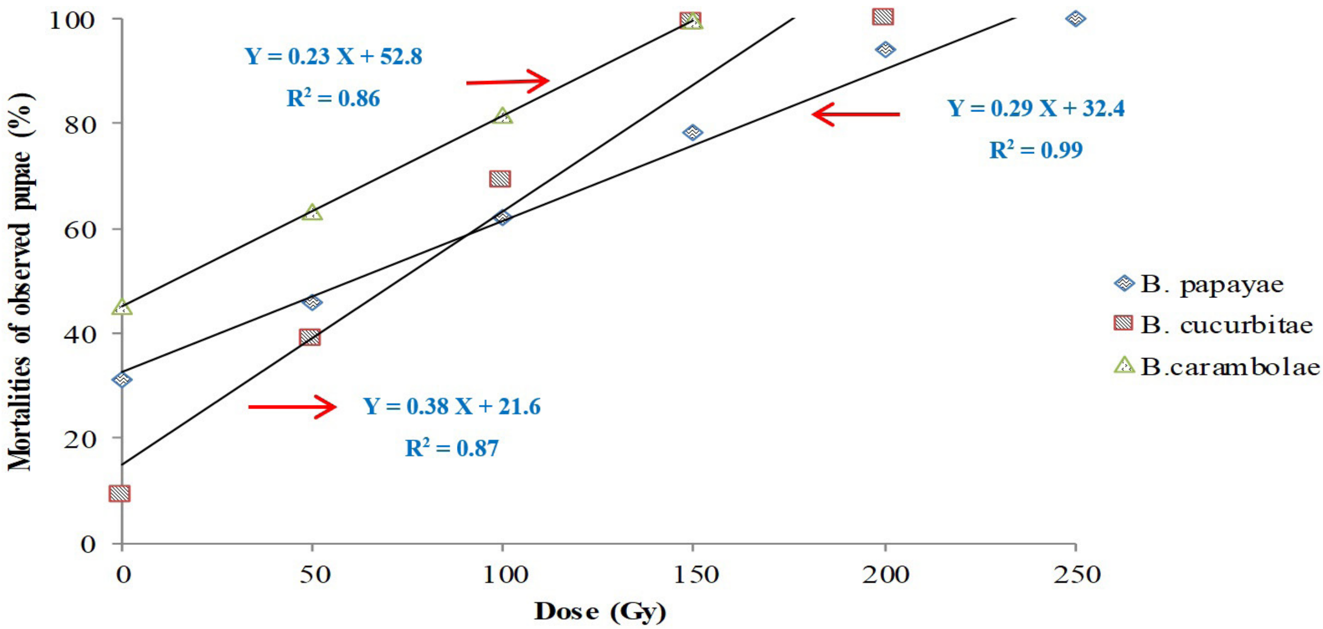


Figure 1. The response of raising dead pupae (preventing adults emergence) due to adding of irradiation dose tested on mature larvae instar artificially reared on dragon fruits. *B. papayae* was the most tolerant species among three species of tested fruit flies

altering of R^2-values was significant ($P<0.05$) in terms of describing intimate relations between each value of applied dosages and obtained relative percentages of dead pupae.

However, those predicted doses for total preventing adults appearance were different where adults papaya fly emergence was avoided by applying the biggest values of irradiation dosages. Consequently, *B. papayae* was needed higher values of applied dosages compared than those of two others kind of tested fruit flies (Table 1). Another a unique finding was *B. carambolae* had slight wider values than that of *B. cucurbitae* in terms of a range of needed dosages for avoiding adult fly appearance.

There was a significant difference observed on means value of the recommended dose for causing dead pupae on *B. papayae* than those of both *B. cucurbitae* and *B. carambolae* ($P<0.05$). Another that, there was no significant difference observed in means of recommended dose between *B. cucurbitae* and *B. carambolae*. Only *B. papayae* required the highest predicted value of dosage in dealing with achieving a total inhibition of their adults' appearance.

3.2. Effects of Irradiation to Physical Attributes Changes of Fruit

For non-infested fruits, several observations were carried on to study further about irradiation's effect on physical fruit characteristics. The first observations were conducted to investigate the irradiation treatment to color attributes of fruit's pulp (Table 2). Those results indicated there were no significant differences among each of irradiated and non-irradiated fruits ($p>0.05$) in relating with observed chroma, hue angle, and pericarp color indexes.

At the end of storage periods, overall fruits color seemed not to be developed anymore. Most of the fruits were seemed into dark red indicating the saturated color conditions were reached at this time. This fact was also confirmed with the hue angle and pericarp color index showing the relatively same tendencies of color transitions into real red and strong intensities of red spectrum observed on the pulp.

Another of our findings confirmed there were relatively similar influences relating to irradiation effect to both of pulp hardness and sugar brix observed after the end of storage periods (Figure 2). These findings also strengthened the previous ones meaning all of irradiated dosages were not significantly impacted on lowering pulp hardness and sugar brix index in a drastic pattern.

In another word, irradiation treatment was not drastically altering the integrity of pulp structure. The same pattern was also strongly confirmed to the narrow changes of brix values indicating degradation of sugar was not completely occurred yet. Therefore,

Table 1. Linear regression of percentage dead pupae (inhibiting of adult emergence) against dose (Gy) practiced to third instar larvae of three fruit fly species artificially reared on dragon fruits

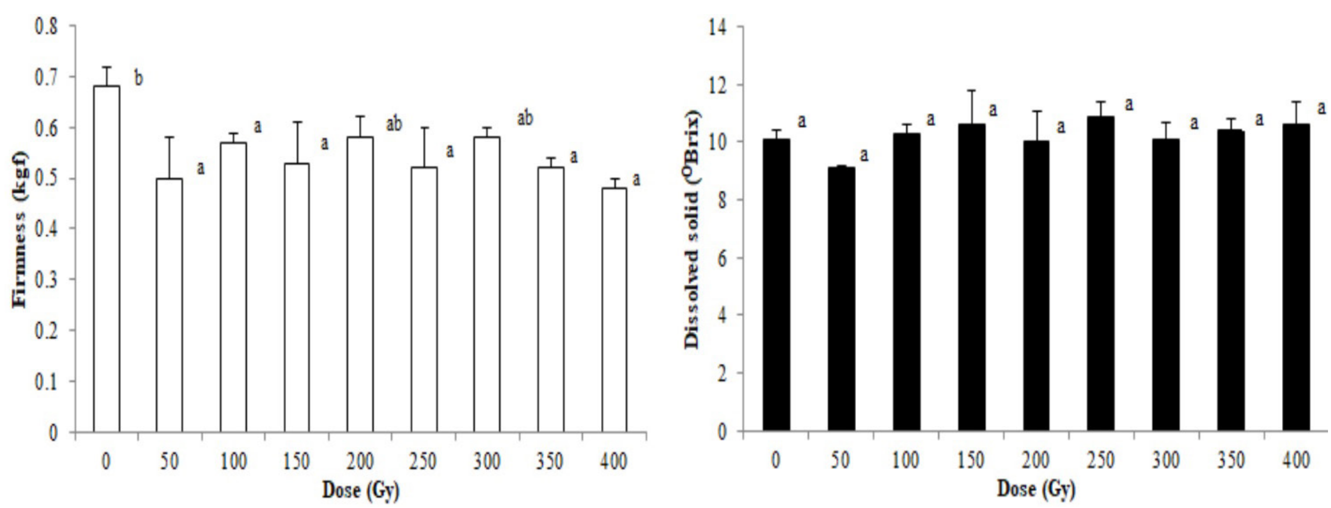
Species	N	Slope ± SE	Intercept ± SE	R^2	Forecasted dose (95% CL) for 100 % mortality (Gy)
B. papayae	4468	$0.29±0.02^{ab}$	$32.4±2.4^{a}$	0.99	248.4 (225.1–279.6)
B. cucurbitae	4123	$0.38±0.07^{b}$	$21.6±11.1^{a}$	0.87	170.0 (156.0–188.1)
B.carambolae	4902	$0.23±0.05^{a}$	$52.8±7^{b}$	0.86	167.8 (145.8–200.3)

Linear regression expressed as y = ax + b where a is the slope, b is the intercept, x is the irradiation dose (Gy) and y is the percentage of mortality. Means within columns for each comparison followed by the same letters are not significantly different (P>0.05; DMRT)

Table 2. Color characteristics of post-irradiation fruits observed after 17 days of storage at 11±1°C

Dose (Gy)	Chroma	Hue angle	Pericarp color index
0	$14.2±2.9^{a}$	$23.3±3.4^{a}$	$8.5±1.2^{a}$
50	$13.8±3.5^{a}$	$21.4±1.5^{a}$	$10.1±2.7^{a}$
100	$14.4±3.9^{a}$	$23.1±1.4^{a}$	$9.6±1.8^{a}$
150	$11.4±2.4^{a}$	$21.5±5.8^{a}$	$10.7±1.1^{a}$
200	$11.8±3.6^{a}$	$22.3±3.9^{a}$	$12.4±3.0^{a}$
250	$14.2±6.1^{a}$	$27.4±9.6^{a}$	$13.3±6.4^{a}$
300	$12.0±3.3^{a}$	$21.9±4.4^{a}$	$11.6±2.6^{a}$
350	$13.2±5.2^{a}$	$27.4±12.2^{a}$	$12.7±5.1^{a}$
400	$11.5±5.0^{a}$	$30.2±15.5^{a}$	$15.7±7.1^{a}$

Mean values followed by the same letter within a row indicate no significant differences (P>0.05; DMRT)



A B

Figure 2. Alterations the two physical quality of fruits namely, (A) fruit firmness and (B) total dissolved solid, after 17 days of storage at 11±1°C. Values were expressed as means ± standard errors. Values followed by the same letter indicated no significant differences (p≤0.05; DMRT)

the fruits had still juicy characteristics during the storage periods.

4. Discussion

Tropical fruit flies-*B. papayae*, and *B. carambolae* grouped into *Bactrocera dorsalis* species complex (Schutze *et al.* 2015), and also *B. cucurbitae* - have been considered as important pests infesting important horticultural commodities in South East ASIAN countries (Indonesia, Malaysia, Cambodia, Myanmar, Brunei Darussalam, Laos and Thailand) (Hu *et al.* 2010; Prabhakar *et al.* 2009; Zhan *et al.* 2015). The minimum dose for sterilizing those flies has remained varies compared other Tephritid flies, as follows 30 Gy for *B. correcta* (Puanmee *et al.* 2010), 75 Gy for *B. invadens* (Ogaugwu *et al.* 2012), 70-90 Gy for *B. dorsalis* (Nasution *et al.* 2018), 90 Gy for *B. zonata* (Mahmoud and Barta 2011), and 200-250 Gy for *B. tau* (Cai *et al.* 2018). While for preventing adult flies appearance, the third instar larvae have been previously irradiated on medium doses ranging from 85 Gy for *B. tau* (Zhan *et al.* 2015) to 125 Gy for *B. dorsalis* (Follett and Amstrong 2004). Our result confirmed that a series of regression linear trends have strongly correlated on achieving total sterility with gradual gamma irradiation doses, even though the final-values gained in this study were on higher ranges.

Previous studies demonstrated that performing low level of irradiating dose was not properly fit for insect sterilization as well as poor performance of mating after irradiated with the high dose (Parker and Mehta 2007). Therefore, in this case gamma-irradiation has formed a new character of fly-tolerant ability during their developmental stages (Zhan *et al.* 2015). A surprise result gained from another research showed irradiation at 400 Gy to the newly appeared male-imago did not modify their competitiveness on mating reflecting on producing their offspring (Cai *et al.* 2018). This phenomenon is quite interesting to be observed further, particularly in relating to the different variations of both of behaviors appeared from (Cai *et al.* 2018; Hansen *et al.* 2014; Kheirallah *et al.* 2017) and also determining which of developmental stages are essentially critical for managing the sterile insects populations (Bakri *et al.* 2005; Costa *et al.* 2020; Lopez-Guillen *et al.* 2008).

Meanwhile, difficulties on practicing the irradiating scheme often cause inaccuracies results leading some fundamental issues closely relating to determine the generic dose for the complete sterile ones. In this case, the rearing circumstances as well as their quality controls (Costa *et al.* 2020) should be assured through fulfilling basic requirements for implementation of the sterile insect technique regulated by FAO/IAEA (2014). Therefore, the gained result will be statistically satisfied and it is also well-understood to be reproduced for another case-experimental studies.

Improving life adaptation to the changes in solar radiation distribution, particularly on tropical area, is a key factor in understanding which approaches are suitable for fruit flies control management. As a part of the integrative post-harvest management system, irradiation aimed to prevent adults emergence of those flies has critically played on determining phytosanitary status of fresh horticultural commodities. Previous studies mentioned *B. dorsalis* have relatively higher dose until 250 Gy for fulfilling that purpose (Seo *et al.* 1973), while Follet and Amstrong (2004) reported at least needed three doses – 210, 225 and 250 Gy – subsequently for avoiding imago appearance of Melon, Mediterranean and Oriental flies. Furthermore, Follet and Weinert (2009) and also Hallman *et al.* (2010) informed that the maximum dose applied on commercial facilities shall not exceed 1.5 until 2 times the minimum dose applied.

On many different studies observing irradiating effects in preserving the quality of fruits, it has revealed that there was not any significant differences on physics-chemistry and sensory attributes in between untreated control oranges and irradiated ones exposed at 200 to 400 Gy after cold-storing for almost a half month (Mc Donald *et al.* 2013). A slight difference finding was performed on mandarin's pulp becoming smoother after irradiated at 450 Gy (Miller *et al.* 2000). A distinct deviation observed on fruits physiological development was carried on soon after irradiated in a range of doses 600–800 Gy marked by darkening color and visual defect seen on the fruit surface (Mc Donald *et al.* 2012; O'Mahony *et al.* 1985) as well as off-flavor appearance as a result of coating combination treatment (Obenland *et al.* 2011, 2012). Our result confirmed that the overall irradiating doses did not drastically alter the fruit properties into more sensitive ones, therefore the whole fruits attributes were not degraded yet until the end of storage.

As previously informed, IPPC has allowed the usage of irradiation treatment under low-oxygen concentrations only for Grapholita molesta (IPPC 2010; Zhan *et al.* 2020). Therefore, the pest management studies through gamma-irradiation combined modified atmosphere storage should be further prioritized for decreasing flies resistant strongly related with severe hypoxia phenomenon (Dias *et al.* 2020; Zhan *et al.* 2020) as well as extending the shelf of life of fresh fruits directly related to slowing down of respiration rate (Barkai-Golan and Follett 2017; Lacroix and Follett 2015; Srimartpirom *et al.* 2018).

Conficts of Interest

The authors stated there is no conflicts of interest.

Acknowledgements

The authors would like to highly appreciate to a team from Centre of Isotope and Radiation' Applications, National Atomic Agency lead by Mr. Bonang Sigit Trenggono for its fully support in a whole of irradiating experiments and to the Applied Research Institute of Agricultural Quarantine, Indonesia Agricultural Quarantine Agency, Ministry of Agriculture for granting this research (Code Number: 1822.101.U10).

References

Bakri, A., Heather, N., Hendrichs, J., and I. Ferris. 2005. Fifty years of radiation biology in entomology: lessons learned from IDIDAS. *Ann. Entomol. Soc. Am.* 98, 1-12. https://doi.org/10.1603/0013-8746(2005)098[0001:FYORBI]2.0.CO;2

Balock, J.W., Burditt, A.K., Christianson, L.D., 1963. Effects of gamma radiation on various stages of three fruit flies species. *J. Econ. Entomol.* 56, 42-46. https://doi.org/10.1093/jee/56.1.42

Barkai-Golan, R., Follett, P.A., 2017. *Irradiation for Quality Improvement, Microbial Safety and Phytosanitation of Fresh Produce*. Academic Press, San Diego. https://doi.org/10.1016/B978-0-12-811025-6.00001-X

Bellec, F.L., Vaillant, F., Imbert, E., 2006. Pitahaya (*Hylocereus* spp.): a new fruit crop, a market with a future. *Fruit.* 61, 237-250. https://doi.org/10.1051/fruits:2006021

Cai, J., Yang, H., Shi, S., Zhong, G., X. Yi., 2018. Behavioral, morphological and gene expression changes induced by 60Co-γ ray irradiation in *Bactrocera tau* (Walker). *Front. Physiol.* 9, 118. https://doi.org/10.3389/fphys.2018.00118

Carreno J., Martinez, A., Almela, L., Fernandez-Lopes, J.A., 1995. Proposal of an index for the objective evaluation of the color of red table grapes. *Food Res.Int.* 24, 373-377. https://doi.org/10.1016/0963-9969(95)00008-A

Costa, K.Z., Costa, M.L.Z., Botteon, V.W., Faggioni, K.M., Costa, N., Mastrangelo, T., 2020. Quality control and characterization of the testicles and ovaries of irradiated *Anastrepha obliqua* from Brazil. *Sci. Agric.* 77, 1-7. https://doi.org/10.1590/1678-992x-2017-0253

Dias, V.S., Hallman, G.J., Martinez-Barrera, O.Y., Hurtado, N.V., Cardoso, A.A.S., Parker, A.G., Caravantes, L.A., Rivera, C., Araujo, A.S., Maxwell, F., 2020. Modified atmosphere does not reduce the efficacy of phytosanitary irradiation doses recommended for Tephritid fruit flies. *Insects.* 11, 376. https://doi.org/10.3390/insects11060371

Drew, R.A.I, Trung, H.M., Khanh, L.D., 2001. Ket Qua Thuc Hien du an Quan Ly Ruoi Hai Qua O Viet Nam. TCP/VIE/8823(A) 1999-2000. Results of Fruit Fly Project in Viet Nam. Code TCP/VIE/8823(A); MARD and FAO Publication, Ha Noi, 44 pp.

[FAO] Food and Agriculture Organization. 2014. Product Quality Control for Sterile Mass-Reared and Released Tephritid Fruit Flies, Version 6.0. FAO/IAEA/USDA, Vienna, Austria.

Fletcher, B.S., 1987. The biology of dacine fruit flies. *Annu. Rev. Entomol.* 32, 115- 144. https://doi.org/10.1146/annurev. en.32.010187.000555.

Follett, P.A., Armstrong, J.W., 2004. Revised irradiation doses to control Melon fly, Mediterranean fruit fly, and Oriental fruit fly (Diptera: Tephritidae) and a generic dose for Tephritid fruit flies. *J. Econ. Entomol.* 97, 1254-1262. https://doi.org/10.1093/jee/97.4.1254

Follett, P.A., Phillips, T., Armstrong, J.W., Moy, J.H., 2011. Generic phytosanitary radiation treatment for tephritid fruit flies provides quarantine security for *Bactrocera latifrons* (Diptera: Tephritidae). *J. Econ. Entomol.* 104, 1509-1513. https://doi.org/10.1603/EC11141

Follett, P.A., Sanxter, S.S., 2000. Comparison of rambutan quality after hot forced-air and irradiation quarantine treatments. *Hort. Sci.* 35, 1315-1318. https://doi.org/10.21273/HORTSCI.35.7.1315

Follett, P.A., Sanxter, S.S., 2003. Lychee quality after hot-water immersion and X-ray irradiation quarantine treatments. *Hort. Sci.* 38, 1159-1162. https://doi.org/10.21273/HORTSCI.38.6.1159

Follett, P.A., Weinert, E., 2009. Comparative radiation dose mapping of single fruit type and mixed-fruit boxes for export from Hawaii. *J. Food Process. Preserv*. 33, 231-244. https://doi.org/10.1111/j.1745-4549.2008.00315.x

Hallman, G.J., 1999. Ionizing radiation quarantine treatments against tephritid fruit flies. *Postharvest Biol. Technol.* 16, 93-106. https://doi.org/10.1016/S0925-5214(99)00012-5

Hallman, G.J., 2011. Phytosanitary applications of irradiation. *Compr. Rev. Food. Sci. Food Saf.* 10, 143-151. https://doi.org/10.1111/j.1541-4337.2010.00144.x

Hallman, G.J., 2012. Generic phytosanitary irradiation treatments. *Radiat. Phys. Chem.* 81, 861-866. https://doi.org/10.1016/j.radphyschem.2012.03.010

Hallman, G.J., Nichole, M.L., Zettler, J.L., Winborne, I.C., 2010. Factors affecting ionizing radiation phytosanitary treatments and implications for research and generic treatments. *J. Econ. Entomol.* 103, 1950-1963. https://doi.org/10.1603/EC10228

Hansen, I.A., Attardo, G.M., Rodriguez, S.D., Drake, L.L., 2014. Four-way regulation of mosquito yolk protein precursor genes by juvenile hormone, ecdysone-, nutrient-, and insulin-like peptide signaling pathways. *Front. Physiol.* 5, 103. https://doi.org/10.3389/fphys.2014.00103

Hoa, T.T., Clark, C.J., Waddell, B.C., Woolf, A.B., 2006. Postharvest quality of Dragon fruit (*Hylocereus undatus*) following disinfesting hot air treatment. *Postharvest Biol. Technol.* 41, 62-69. https://doi.org/10.1016/j.postharvbio.2006.02.010

Hu, F., Zhang, G.N. , Jia, F.X., Dou, W., Wang, J.J., 2010. Morphological characterization and distribution of *Antennal sensilla* of six fruit flies (Diptera: Tephritidae). *Ann. Entomol. Soc .Am.* 103, 661-670. https://doi.org/10.1603/AN09170

[ICGFI] International Consultative Group on Food Irradiation. 1991. *Irradiation as a Quarantine Treatment of Fresh Fruits and Vegetables*. ICGFI Document No. 13. International Atomic Energy Agency, Vienna.

[IPPC] International Plant Protection Convention. 2010. *ISPM 28. Annex 1 PT 11: Irradiation Treatment for Grapholita Molesta*. FAO, Rome.

Kheirallah, D., El-Samad, L., Fahmi, N., Osman, W., 2017. Ultrastructure alterations induced by gamma irradiation in spermiogenesis of the ground beetle, *Blaps sulcata*: reference to environmental radiation protection. *Environ. Sci. Pollut. Res. Int.* 24, 22102-22110. https://doi.org/10.1007/s11356-017-9869-5

Koswanudin, D., Basukriadi, A., Samudra, I.M., Ubaidillah, R., 2018. Host preference fruit flies *Bactrocera carambolae* (Drew and Hancock) and *Bactrocera dorsalis* (Drew and Hancock) (Diptera: Tephritidae). *Indones. J. Entomol.* 15, 40-49. https://doi.org/10.5994/jei.15.1.40
Lacroix, M., Follett, P.A., 2015. Combination irradiation treatments for food safety and phytosanitary uses. *Stewart Postharvest Rev.* 3, 1-7. https://doi.org/10.2212/spr.2015.3.4
Lopez-Guillen, G., Cruz-Lopez, L., Malo, E.A., Gonzalez-Hernandez, H., Cazares, C.L., Lopez-Collado, J., Toledo, J., Rojas, J.C., 2008. Factors influencing the release of volatiles in *Anastrepha obliqua* males (Diptera: Tephritidae). *Environ. Entomol.* 37, 876-882. https://doi.org/10.1093/ee/37.4.876
Mahattanatawee, K., Manthey, J.A., Luzio, G., Talcott, S.T., Goodner, K., Baldwin, E.A., 2006. Total antioxidant activity and fiber content of select Florida grown tropical fruits. *J. Agric. Food Chem.* 54, 7355-7363. https://doi.org/10.1021/jf060566s
Mahmoud, M.F., Barta, M., 2011. Effect of gamma irradiation on the male sterility and other quality parameters of peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae). *Hort. Sci.* 38, 54-62. https://doi.org/10.17221/88/2010-HORTSCI
McDonald, H., Arpaia, M.L., Caporaso, F., Obenland, D., Were, L., Rakovski, C., Prakash, A., 2013. Effect of gamma irradiation treatment at phytosanitary dose levels on the quality of 'Lane Late" navel oranges. *Postharvest Biol. Technol.* 86, 91-99. https://doi.org/10.1016/j.postharvbio.2013.06.018
McDonald, H., McCulloch, M., Caporaso, F., Winborne, I., Oubichon, M., Rakovski, C., Prakash, A., 2012. Commercial scale irradiation scale irradiation for insect disinfestation preserves peach quality. *Radiat. Phys.Chem.* 81, 697-704. https://doi.org/10.1016/j.radphyschem.2012.01.018
McQuate, G.T., 2010. Tephritid fruit fly populations in a dragon orchard in Hawaii: border plant use and infestation rate. *Proc. Hawaii. Entomol. Soc.* 42, 41-48.
Miller, W.R., McDonald, R.E., Chaparro, J., 2000. Tolerance of selected orange and mandarin hybrid fruit to low-dose irradiation for quarantine purposes. *Hort. Science.* 35, 1288-1291. https://doi.org/10.21273/HORTSCI.35.7.1288
Mizrahi, Y., Nerd, A., Nobel, P.S., 1997. Cacti as a crop. *Hort.Rev.* 18, 291-320. https://doi.org/10.1002/9780470650608.ch6
Moy, J.H., Wong, L., 2002. The efficacy and progress in using radiation as a quarantine treatment of tropical fruits-a case study in Hawaii. *Radiat. Phys. Chem.* 63, 397-401. https://doi.org/10.1016/S0969-806X(01)00557-6
Nasution, I.A., Elvinasari, Hastuti, D., 2018. Effect of gamma irradiation on the quality and mating competitiveness of fruit flies *Bactrocera dorsalis* in the cage scale. *J. Trop. Plant. Pests. Dis.* 18, 170-178. https://doi.org/10.23960/j.hptt.218160-168
Nerd, A., Gutman, F., Mizrahi, Y., 1999. Ripening and postharvest behaviour of fruits of two Hylocereus species (*Cactaceae*). *Postharvest Biol. Technol.* 17, 39-45. https://doi.org/10.1016/S0925-5214(99)00035-6
Obenland, D., Collin, S., Mackey, B., Sievert, J., Arpaia, M.L., 2011. Storage temperature and time influences sensory quality of mandarins by altering soluble solids, acidity, and aroma volatile composition. *Postharvest Biol. Technol.* 59, 187-193. https://doi.org/10.1016/j.postharvbio.2010.09.011
Obenland, D., Collin, S., Sievert, J., Arpaia, M.L., 2012. Impact of high temperature forced air heating of navel oranges on quality attributes, sensory parameters, and flavor volatiles. *Hort. Sci.* 47, 1-5. https://doi.org/10.21273/HORTSCI.47.3.386
Ogaugwu, C., Wilson, D., Cobblah, M., Annoh, C., 2012. Gamma radiation sterilization of *Bactrocera invadens* (Diptera: Tephritidae) from southern Ghana. *Afr. J. Biotechnol.* 11, 11315-11320. https://doi.org/10.5897/AJB12.960
O'Mahony, M., Wong, S.Y., Odbert, N., 1985. Sensory evaluation of novel oranges treated with low doses of gamma radiation. *J. Food Sci.* 50, 639-646. https://doi.org/10.1111/j.1365-2621.1985.tb13762.x
Parker, A., Mehta, K., 2007. Sterile insect technique: a model for dose optimization for improved sterile insect quality. *Fla. Entomol.* 90, 88-95. https://doi.org/10.1653/0015-4040(2007)90[88:SITAMF]2.0.CO;2
Perween, T., Mandal, M.L., Hasan, M.A., 2018. Dragon fruit: an exotic super future fruit of India. *J. Pharmacogn. Phytochem.* 7, 1022-1026. https://doi.org/10.20546/ijcmas.2018.705.255
Prabhakar, C.S., Sood, P., Mehta, P.K., Choudhary, A., 2009. Distribution and developmental biology of fruit flies infesting cucurbits in north-western Himalaya. *J. Insect Sci.* 22, 300-308.
Prasetia, H.A., Panjaitan, L., Salbiah, Widodo, Setiabudi, D.A., 2018. The role of hot water treatment and chitosan coating in controlling a latent infection of *Colletotrichum musae* on banana var. Mas Kirana. *Asian J. Agric. Biol.* 6, 576-586.
Puanmanee, K., Wongpiyasatid, A., Sutantawong, M., Hormchan, P., 2010. Gamma irradiation effect on guava fruit fly, *Bactrocera correcta* (Bezzi) (Diptera: Tephritidae). *Kasetsart J. Nat. Sci.* 44, 830-836.
Pushpakumara, D.K.N.G., Gunasena, H.P.M., Kariayawasam, M., 2006. *Flowering and Fruiting Phenology, Pollination agents and Breeding System in Hylocereus spp. (Dragon Fruit).* Proc Peradeniya University Research Sessions, Sri Lanka.
Rosman, R., Dimon, M.N., Yeow, Y.K., 2018. Correlation between reflection coefficient, dielectric properties and brix level of Malaysian oranges at microwave frequencies. *Indones. J. Electr. Eng. Comput. Sci.* 10, 853-858. https://doi.org/10.11591/ijeecs.v10.i3.pp853-858
Salomon, D., Singtoe, B., Narit, T., Surakrai, P., Chutamas, S., Niranjan K., 2018. Life history strategy of the Carambola fruit fly, *Bactrocera carambolae* Drew and Hancock (Diptera: Tephritidae) on guava *Psidiumguajava. Delta Agric.* 10, 39-53.

Schutze, M.K., Aketarawong, N., Amornsak, W., Armstrong, K.F., Augustinos, A.A., Barr, N., Boo, W., Bourtzis, K., Boykin, L.M., Caceres, C., Cameron, S.L., Chapman, T., Chinvinijkul, S., Chomic, A., De Meyer, M., Drosopoulou, E., Englezou, A., Ekezi, S., Gariou-Papalexiou, A., Geib, S.M., Hailstones, D., Hasanuzzaman, M. , Haymer, D., Hee, A.K.W., Hendrichs, J., Jessup, A., Ji, Q., Khamis, F.M., Krosch, M.N., Leblanc, L., Mahmoud, K., Malacrida, A.R., Mavragani-Tsipidou, P., Mwatawala, M., Nishida, R., Ono, H., Reyes, J., Rubinoff, D., Sanjose, M., Shelly, T.E., Srikachar, S., Tan, K.H., Thanapum, S., Haq, I., Vijaysegaran, S., Wee, S.L., Yesmin, F., Zacharopoulou, A., Clarke, A.R. 2015. Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. *Syst. Entomol.* 40, 456-471. https://doi.org/10.1111/syen.12113

Seo, S.T., Kobayashi, R.M., Chambers, D.L., Dollar, D.M., Hanaoka, M., 1973. Hawaiian fruit flies in papaya, bell pepper,and eggplant: quarantine treatment with gamma irradiation. *J. Econ. Entomol.* 66, 937-939. https://doi.org/10.1093/jee/66.4.937

Srimartpirom, M., Burikam, I., Limohpasmanee, W., Kongratarporn, T., Thannarin, T., Bunsiri, A., Follett, P.A., 2018. Low-dose irradiation with modified atmosphere packaging for mango against the oriental fruit fly (Diptera: Tephritidae). *J. Econ.Entomol.* 111, 135-140. https://doi.org/10.1093/jee/tox335

Zhan, G., Lili, R., Ying, S., Qiaoling, W., Daojian, Y., Yuejin, W., Tianxiu, L., 2015. Gamma irradiation as a phytosanitary treatment of *Bactrocera tau* (Diptera: Tephritidae) in pumpkin fruits. *J. Econ. Entomol.* 108, 88-94. https://doi.org/10.1093/jee/tou013

Zhan, G., Zhao, J., Ma, F., Liu, B., Zhong, Y., Song, Z., Zhao, Q., Chen, N., Ma, C. 2020. Radioprotective effects on late third-instar *Bactrocera dorsalis* (Diptera: Tephritidae) larvae in low-oxygen atmospheres. *Insects.* 11, 526. https://doi.org/10.3390/insects11080526