Study of Gamma Irradiation and Its Possibility to Extend The Banana ‘Mas’ (*Musa acuminata* Colla) Shelf Life

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**Abstract.** Banana ‘Mas’ (*Musa acuminata colla*) is one of high productivity Indonesian superior fruits. However, because of its thin skin tissue, banana could easily damage physiologically as a result of inappropriate maturity levels determinations and postharvest handling. The aim of this research was to determine the relationship between storage duration and banana ‘Mas’ characteristics at various levels of maturity, based on color index of 4, 5, 6 gamma ray irradiation dose of 0.3 kGy for 6 days of storage. The results showed that there was a closely relationship between the duration of banana ‘Mas’ storage (6 days) at various levels of maturity as a result of irradiation of 0.3 kGy, to the physical and chemical characteristics of banana ‘Mas’, indicated by the correlation coefficient value approaching +1 and the determination coefficient between 78% – 99%.

1. Introduction

Banana *Mas* is one of the Indonesian superior fruit, having a highly productivity, good ability to adapt in moderate plains and a higher rendement of 85% compared with other type of banana such as banana *Raja Bulu* (70%), bananas *Ambon, Angleng, Lampung* and *Uli* [1]. However, the banana *Mas* deteriorates easily because its skin tissue is thinner compared with other banana [2]. It is usually a physiological damage due to incorrect harvesting time and improper post harvest handling. The maturity level is important for determining the best time of harvesting in order to keep the commodity is in the best quality when reaching consumers [3]. Maturity level can be differentiated based on the colour of fruit skins, in which immature banana generally has a green color and becoming yellow in line with the increasing of maturity. Improper postharvest handling can shorten shelf life of *Mas* banana 5 – 6 days after optimally ripe at room temperature (Ministry of Agriculture Decree No.516/Kpts/Sr.120/12/2005). Physiological damage can also cause nutritional destruction and the respiration activity becomes faster [4].

This study was to apply technology of preservation by using gamma ray irradiation with the aim to find out its influence on the food aging caused by internal factors within the food itself, through the observation on physical and chemical characteristics of food such as respiration rate, weight loss, total soluble solid, texture, pH and color (L*, a* and b* values). Food materials can be kept fresh because irradiation process itself is a process that occurred at the ambient temperature [5].

Technology of irradiation is a modern technology that use energy efficiently, and using ionizing radiation type, because it can cause ionization on the material it passes [6]. Compared with hot pasteurization, radiation technology can save at least 99% of energy used in the hot method, easy to control, can be used in wrapped condition, saving the materials used, producing better quality as an
added value, and reducing contamination. Maximum absorption dose for fruits and vegetables to inhibit maturation process is 1kGy (Ministry of Health Regulation No.701/Menkes/Per/VIII/2009).

2. Materials and Method
Material used was *Mas* banana type, obtained from the city of Sukabumi, West Java with the maturity level of 4, 5 and 6 respectively on the basis of Colour Index. Gamma ray used was derived from irradiation source of Cobalt-60. Equipment used in this study was *Panorama Serbaguna* Irradiation (Irpasena). Research method used was Experimental Method continued with regression analysis. Research consisted of 6 treatments with 2 replications (duplo). The treatments were as follows:

- A = Maturity Level with Colour Index 4 without Irradiation
- B = Maturity Level with Colour Index 5 without Irradiation
- C = Maturity Level with Colour Index 6 without Irradiation
- D = Maturity Level with Colour Index 4 with Irradiation of 0.3 kGy
- E = Maturity Level with Colour Index 5 with Irradiation of 0.3 kGy
- F = Maturity Level with Colour Index 6 with Irradiation of 0.3 kGy

- Independent Variable (Variable X) was the length of product storage, day- 0, 1, 2, 3, 4, 5, and 6.
- Dependent Variable (Variable Y) was an observed variable. Observation was made every day for 6 days, data was presented in the form of regression curve graph. The regression curve shows a relationship between the length of storage with observed variable of skin colour (L*, a* dan b*), texture, weight loss, respiration rate, total soluble solid, pH and moisture content. The laboratory test was carried out at the Laboratory of Post Harvesting, Padjadjaran University and the Irradiator Building of *Panorama Serbaguna* (Irpasena), National Atomic Power Agency (BATAN), South Jakarta.

Procedure of banana *Mas* irradiation was illustrated in the form of flow diagram as displayed in Figure 1. The irradiated bananas were observed for their characteristics such as respiration rate, moisture content, weight loss, total dissolved solids, texture, pH value, and skin color (L*, a*, b*).

3. Results and Discussion

3.1. Respiration Rate
The range of regression coefficients (slope) of banana *Mas* at various levels of maturity without irradiation was -2.490 to -2.126, whereas those irradiated was -0.215 to -0.047. The smaller the slope value of banana *Mas*, the slower the respiration rate in a storage. Based on its slope value, there was a tendency that irradiation treatment at early maturity level can maintain longer shelf life as it minimizes the change of respiration pattern of banana *Mas*.

According to Murray, irradiation can control the reaction of inorganic phosphate release in cells that can increase the supply of substrate for the respiration process in mitochondria [7]. According to Mollins, irradiation can inhibit the activity of ethylene enzyme formation and reduce the sensitivity to the activity of ethylene enzymes so as to slow the maturation process by minimizing the peak of the respiration rate [8].
The irradiation treatment of 0.3 kGy in banana *Mas* at maturity level 4 that has a correlation coefficient value (r) of 0.980, indicates a very close relationship between the storage duration and the respiration rate of banana *Mas* at maturity level 4 that irradiated with a dose of 0.3 kGy.

The value of determination coefficient (R^2) of irradiation treatment with a dose of 0.3 kGy on banana *Mas* at maturity level 4 is equal to 0.960. This means, the storage duration of banana *Mas* at maturity level 4 with a dose of irradiation treatment of 0.3 kGy will affect respiration rate of 96%, while the remaining 4% was influenced by other factors. Other factors that affect the rate of banana respiration during storage include packaging type, size uniformity, oxygen availability, and chemical composition of tissue.

![Flow chart of preparing banana sample](image)

**Figure 1.** Flow chart of preparing banana sample

![No Irradiation](image)

**Figure 2.** Relationship between storage duration and respiration rate at various level of maturity of banana *mas* without irradiation
3.2. Moisture Content

Based on the result of regression analysis test, the relationship between the storage duration and the moisture content of banana *Mas* at various level of maturation with irradiation dose of 0.3 kGy, showed a closely match with positive linear regression model as presented in Figure 5.

Regression coefficients (slope) of *Mas* banana at various levels of maturity without irradiation ranged from 0.685 to 0.811, whereas those irradiated ranged from 0.293 to 0.569. The smaller the slope value, the lower the moisture content of banana *Mas* on an each day storage. Based on the value of it’s slope, there was a tendency that irradiation treatment at the early maturity level can maintain longer shelf life because it can minimize the changes in the moisture content of banana *Mas*. Sutjipto and Sardjono mentioned that irradiation can maintain the freshness of the material, so that the diffusion of water from outside to inside will take place more slowly [9]. According to Swallow (1977) cited Dwiloka, radiation energy is absorbed by water molecules to form various radiolysis results, which in subsequent events can react with the food component [10].

The irradiation treatment of 0.3 kGy dose on banana *Mas* at maturity level 4, that has a correlation coefficient value (r) of 0.991, indicated a very close relationship between the storage duration and the
moisture content of banana *Mas* at that treatment. According to Suharni *et al.*, the penetration power of gamma ray radiation depends on the density of the foodstuff [11]. The higher the density of the material, the lower the penetration, so that at the maturity level 5, the density is somewhat lower and at the maturity level 6, the density is very low because there are already many compounds that are unraveled into more simple compounds.

Determination coefficient (R^2) of 0.982 of banana *Mas* at maturity level 4 with 0.3 kGy dose of irradiation, indicated that the storage duration of banana *Mas* will affect the water content of 98.2% while the remaining 1.8% will be affected by other factors. Other factors that affect the moisture content of banana *Mas* during storage include the packaging type, mechanical damage and the surface to volume ratio of banana *Mas*.

3.3. Weight Loss

Based on the results of regression analysis test, the relationship between the storage duration and the weight loss of banana *Mas* at various level of maturity with irradiation dose 0.3 kGy, showed a close match to positive linear regression model as presented in Figure 7.

![Figure 6. Relationship between storage duration and weight loss at various level of maturity of banana *mas* without irradiation](image)

![Figure 7. Relationship between storage duration and weight loss at various level of maturity of banana *mas* with 0.3 kgy irradiation dose](image)

Regeneration coefficients (slope) of banana *Mas* at various levels of maturity without irradiation ranged from 3.674 to 5.726, while those irradiated ranged from 1.155 to 4.574. The smaller the slope value indicated that the changes occurred on the weight loss of banana *Mas* at each day storage becomes lower. Based on the value of its slope, there was a tendency that the irradiation treatment at early maturity level can maintain longer shelf life as it minimizes the changes on weight loss of banana *Mas*.

Irradiation controlled at appropriate doses may inhibit the physiological process of the fruit, thus slowing the increase in weight loss when it is compared with the unirradiated fruits. This is due to the radiation resulted in the physical characteristics and function of cell molecules changed. Ionization produces free radicals that can break chemical bonds and DNA so that the physiological process of the fruit goes slowly, one of the physiological processes that are inhibited is respiration. The inhibition of the respiratory process causes the mass component being evaporated or lost becoming less, giving the weight loss decreases [12]. According to Irawati irradiation can change the biological and chemical processes in vegetables and fruits so that the process of cell division or normal life process in cells will be disrupted and the biological effects will cause the growth and metabolism of cells inhibited so that the process of respiration and transpiration goes slowly [13]. The irradiation treatment of 0.3 kGy dose on banana *Mas* at maturity level 4 that has a correlation coefficient value (r) of 0.98, indicated a very close relationship between the storage duration and the weight loss of banana *Mas*. Bananas that are
nearly close to the maturity phase will experience a sudden increase in respiration and transpiration activities because bananas are a kind of climacteric fruit. In this condition the reshuffle of hemicellulose and cellulose into starch substances will be occurred, so that the weight of banana skin is also reduced. The chemical composition changes in the banana tissue causes the water from the fruit to evaporate without any new supply resulting in the reduction of banana weight [14].

The determination coefficient (R2) of banana Mas of 0.960 at maturity level 4 with 0.3 kGy irradiation dose, indicated that the storage duration of banana Mas will affect the weight loss of 96% and the remaining 4%, affected by other factors, such as size, mechanical damage, and packaging type.

3.4. Total Soluble Solid

Based on the result of regression analysis test, the relationship between storage duration and total dissolved solids of various banana maturity level with irradiation dose 0.3 kGy, showed a close match to positive linear regression model as shown in Figure 9.

The regeneration coefficients (slope) of banana Mas at various degrees of maturity without irradiation ranged from 1.080 to 1.512, whereas those irradiated ranged from 0.485 to 0.941. The smaller the slope value, the lower the total soluble solids of banana Mas at each day storage. Based on its value of slope, there was a tendency that irradiation treatment at early maturity level can maintain a longer shelf life as it minimizes the change on total soluble solids of banana Mas. Pimentel and Walder mentioned that fruits with high starch content such as bananas and mangoes, when irradiated, will experience significant changes in total soluble solids and showing clearly visible differences compared with those without irradiated [15].

The irradiation treatment with 0.3 kGy on banana Mas at maturity level 4 that has a correlation coefficient value (r) of 0.990, indicated a very close relationship between the storage duration and the total soluble solids of banana Mas. Novita, et al. stated that the maturity level affects the changing in total soluble solids [16]. The difference in the change may be related to the genetic properties and material composition of each level of maturity, since the total soluble solids are known as indicators of maturity level [17]. The effect of maturity on the value of total soluble solids of banana is, that the older bananas have higher total soluble solids than the younger bananas [18].

The determination coefficient (R2) value of 0.980 on banana Mas at maturity level 4 with 0.3 kGy dose irradiation stated that the storage duration of Mas banana will affect the total soluble solids by 98% and the remaining 2%, is influenced by factors such as fruit size and storage temperature.
3.5. Texture

Based on the result of regression analysis test, the relationship between the storage duration and the texture at various maturity level of banana *Mas*, irradiated with gamma ray with 0.3 kGy dose, showed a close match with the negative linear regression model as displayed in Figure 11.

The regression coefficients (slopes) at the various maturity level of banana *Mas* without irradiation ranged from -286.0 to -185.4, whereas those irradiated ranged from -182.1 to -116.9. The smaller the slope value signifies that the changes occurring in the banana *Mas* texture become lower in each day of storage. Based on the value of its slope, the irradiation treatment at early maturity level tends to maintain longer shelf life as it minimizes the changes in banana *Mas* texture. According to Niemira and Fan, irradiation causes partial depolymerization of cell wall component such as cellulose, hemicellulose, polysaccharides and pectin, altering the activity of pectin enzymes of methyl esterase and polygalacturonase located in the cell wall which is the substrate of pectin [19]. Afrianti mentioned that ionization energy during irradiation will result in chemical changes that affect the metabolic process of the network which then affect the physical changes during storage [20]. Pimentel and Walder mentioned that irradiation would lead to the decrease in the activity of pectinamethylesterase enzymes, polygalacillonase, and b-galactosidase, thus maintaining fruit texture [15]. The irradiation treatment with 0.3 kGy dose on banana *Mas* at maturity level 4 that has a correlation coefficient value (r) of 0.990, indicated a very close relationship between the storage duration and the texture of banana *Mas*. According to Irawati the changes in chemical and physical characteristics caused by the effects of radiation, will be depending on the amount and composition of the material [13]. The maturity level of 4 has a higher starch content (has not been degraded yet into a simpler carbohydrate compound) compared with the other maturity levels [21]. Fruit maturity level gives an influence on the hardness of bananas that the older bananas will have a smaller texture compared with those of younger bananas. An increasing water content due to the ripening process causes the banana texture to soften. In the process of banana ripening occurs softening of fruit flesh due to changes in starch and insoluble protopektin to become soluble [18].

The determination coefficient (R2) of 0.959 of banana *Mas* at maturity level 4 that irradiated with 0.3 kGy dose, indicated that the storage duration of banana *Mas* influences texture equal to 95.9% and the rest 4.1% influenced by other factors, such as packaging type, mechanical damage as well as storage temperature.
3.6. pH

Based on the results of regression analysis, the relationship between the storage duration and pH of banana *Mas* at various maturity levels with 0.3 kGy irradiation dose, showed a closely match to the positive linear of regression model as presented in Figure 13.

The range of regeneration coefficients (slope) of banana *Mas* at various degrees of maturity without irradiation was 0.047 to 0.060, whereas those irradiated was 0.32 to 0.44. The smaller the slope value indicates that the changes of the pH value in each day storage of banana *Mas* was getting lower. Based on the value of its slope, there was a tendency that irradiation treatment at early maturity level can maintain the longer shelf life as it can minimize the changes of pH value of banana *Mas*. Irradiation inhibits the release of substances used in the respiration process, one of which is organic acids, so that the amount of acid in bananas can be maintained. *The less organic acid used, the lower the pH value.* Arvanitoyannis, *et al.*, and Srijaya, *et al.*, also mentioned that the increase of pH value is largely due to the use of organic acids as respiration substrate and as a carbon framework for synthesis of new compounds during maturation that reduced due to irradiation process [22, 23].

The irradiation treatment of 0.3 kGy dose on banana *Mas* at maturity level 4 that has a correlation coefficient value (r) of 0.984, indicates a very close relationship between the storage duration and pH of banana *Mas* banana. Novita, *et al.* mentioned that the fruits at early maturity levels have higher organic acid content so that the acid content is high (low pH value) [16].

Determination coefficient value (R2) of irradiation treatment with 0.3 kGy dose on banana *Mas* at the maturity level 4 was equal to 0.968. This means, the storage duration of banana *Mas* will affect respiration rate of 96.8% and the remaining 3.2% was influenced by other factors, such as packaging type, vitamin solubility, and oxygen availability.

3.7. L* Value

Based on the results of regression analysis test, the relationship between the storage duration and L* value of banana *Mas* at maturity level of irradiation with 0.3 kGy dose, showed a closely match with a negative quadratic regression model for maturity level 4 and 5, and a negative linear for maturity level 6 as shown in Figure 15.
The range of regeneration coefficients (slope) of banana Mas at various degrees of maturity without irradiation was -7.083 to -0.813, whereas those irradiated was -6.392 to -0.564. The smaller the slope value signifies that the changes occurred in the L* value of banana Mas at each day storage was getting lower. Based on the value of its slope, the irradiation treatment at early maturity level could maintain a longer shelf life as it can minimize the changes of L* value of banana Mas. Irradiation maintains the brightness by inhibiting the degradation of chlorophyll pigments into carotenoids and inhibiting carotenoid degradation [24]. Arvanitoyannis, et al. stated that irradiation will maintain the brightness of the fruit by clearing enzymatic browning and reducing the microflora in the fruit [22].

The irradiation treatment with dose of 0.3 kGy on banana Mas at maturity level 4 that has a correlation coefficient value (r) of 0.968, indicating a very close relationship between storage duration and L* value. Soltani, et al mentioned that the L* banana value will increase at the maturity level of 1 to 6, and the maturity level 6 is the highest with 70 – 75 value, but it will decrease in accordance with the storage duration towards the decomposition process [25]. The decrease in brightness level was due to the occurrence of brown spots on the surface of the banana skin. This is due to, at the maturity level 6, bananas have passed the peak of maturity process, and the next level of maturity is the phase of over ripening [26].

The value of determination coefficient (R2) of irradiation 0.3 kGy on banana Mas at maturity level of 0.937, showed that the storage duration of banana Mas at maturity level 4 with irradiation treatment dose of 0.3 kGy, will affect the L* value of 93.7% while the rest 6.3% will be influenced by other factors, such as packaging type, water content, and light factor.

3.8. a* Value
Based on the results of regression analysis, the relationship between the storage duration and the a* value of banana Mas at various maturity level of irradiation, resulted from irradiation dose of 0.3 kGy, matches with the linear regression model as presented in Figure 17.
The range of regeneration coefficients (slope) of Mas banana at various degrees of maturity without irradiation was 0.914 to 0.1021, whereas those irradiated was 0.375 to 0.689. The smaller the slope value indicates that the changes occurring in the value of a* of Mas banana each day storage was getting lower. Based on the value of its slope, the irradiation treatment at early maturity level could maintain a longer shelf life as it minimizes the change of the value of a* of Mas banana. Rosalina et al. quoted Ramdani mentioned that irradiation will increase the carotene content [27]. Irradiation triggers the formation of acetyl CoA (a compound to synthesize carotene) so that could maintain the color (red and yellow) in the fruit. The green color of the banana is thought to be due to an inhibitory mechanism by irradiation that inhibits the action of chlorophylase enzymes, that play a role in chlorophyll degradation. Hydrolytic chlorophyllase that breaks chlorophyll on the fitol and intact portions of porifirin will result in the chlorophyll that does not cause discoloration [28].

The irradiation treatment of 0.3 kGy on Mas banana at maturity level 4 has a correlation coefficient value (r) of 0.968, indicating a very close relationship between storage duration and the value of a* of Mas banana. Soltani et al. mentioned that the increase in value of a* in banana is related to maturity level [25]. The value of a* will increase as the banana leads to a full maturation phase. There is a positive correlation between a* value with the maturity phase of banana. This indicates that there is a reduction of green colour substance to red or yellow, as a result of the breaking of chlorophyll on the skin of bananas.

The value of coefficient of determination (R²) of Mas banana at maturity level 5, irradiated with dose 0.3 kGy of 0.991 states that the storage duration of Mas banana will affect the value of a* of 99.1% and the remaining 0.9% is influenced by other factors, such as temperature, carbohydrates and light.

3.9. b* Value

Based on the results of regression analysis, the relationship between storage duration and the value of b* of Mas banana at maturity level of irradiation dose 0.3 kGy, showed a closely match to a negative quadratic regression model for maturity level 4 and 5, and a linear negative for maturity level 6 as shown in Figure 19.

The regression coefficients (slope) of banana mas of various levels of maturity without irradiation range from -4.441 to -1.253, while those irradiated from -3.635 to -0.091. The smaller the slope value, indicates that the changes occurred in the value of b* of Mas banana in everyday storage is lower. Based on the value of its slope, the irradiation treatment at the beginning of maturity level tends to maintain a longer shelf life as it minimizes the change of b* value of Mas banana. Irradiation will
inhibit changes in chlorophyll and carotene. Kortei and Akonor mentioned that all organic colours are susceptible to some disturbance after exposure to irradiation [29]. The success of irradiation for products containing color compounds is highly dependent on the dosage used. The lower the dose, the lesser the effect of the resulting discoloration. According to Rosalina et al. quoted Ramdani the irradiation process stimulates the formation of acetyl CoA so it is sufficient to synthesize carotene molecules, so as to maintain the color of the fruit [27].

Figure 18. Relationship between Storage Duration and b* Value at Various Level of Maturity of Mas Banana without Irradiation

The irradiation treatment of 0.3 kGy on Mas banana mas at maturity level 4 that has a correlation coefficient value (r) of 0.968, showed a very close relationship between storage duration and the value of b* of Mas banana. Soltani et al. mentioned that the value of b* of Mas bananas will increase at the maturity level of 1 to 6, at which, the level of maturity 6 was the highest, then it will decrease again in line with the storage duration, toward the process of decay [25]. The decrease in the value of b* was due to the occurrence of brown spots on the skin surface of banana, resulting from the reaction of enzymatic and non enzymatic browning from inner part of material. This reaction caused the brown compounds dissolves in water, showing a gray and black pigment. Enzymes involved in the browning reaction include polyphenol oxidase, which catalyzes the oxidation of polyphenol compounds, phenylalanine amonialiase, which catalyzes precursor synthesis for phenolic substrates [30].

Figure 19. Relationship between Storage Duration and b* Value at Various Level of Maturity of Mas Banana 0.3 kGy Irradiation

The determination coefficient (R2) of Mas banana at maturity level 5 with irradiated dose 0.3 kGy that equal to 0.887, stated that storage duration of Mas banana will affect the value of a* equal with 88.7%, and the rest 11.3%, influenced by other factors such as packaging type, water content, light factor, and carbohydrates content.

4. Conclusions

There was a very close relationship between storage duration (6 days) of banana Mas at various levels of maturity (indexed colors 4, 5, and 6) treated with gamma ray irradiation with 0.3 kGy dose and respiration rate, weight loss, moisture content, total soluble solids, texture, pH value, and colour of banana Mas, indicated by correlation coefficient value approaching +1 and coefficient of determination which ranged from 78% to 99%. The characteristics of banana Mas were respiration rate, the value of L*, and the value of b*, showing the relationship in the form of quadratic pattern that resembles the respiration pattern of chili pepper that is climacteric. While other characteristics such as moisture content, weight loss, total soluble solids, texture, pH value, and a* values, forming a linear relationship pattern.
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