Assessing the Overall Feasibility of a Commercial Scale Food Irradiation Facility in Manila, Philippines

Chua, Justin
Student
International School Manila
Manila, Philippines
chuaju@ismanila.org

Abstract

Food irradiation is a novel, up and coming technology that preserves and extends the lifespan of food. The Philippines (more specifically, its capital city of Manila) is yet to capitalize on this effective technique, which has the potential to mitigate many of its pervasive issues such as hunger and food insecurity, unnecessary food wastage, and air pollution. Many of the Philippines' neighboring countries in the Asia-Pacific region (such as China, Japan and India) have had major success implementing food irradiation facilities. In fact, the Philippines already has a semi- commercial irradiation facility in Intramuros, Manila; however, it's relatively small and its impacts are negligible. Currently, there is a dearth of research on the feasibility of utilizing this technology on a larger scale in the Philippines, but the potential benefits a larger facility could bring to the country are too significant to ignore. Thus, this paper will conduct a cost-benefit analysis to assess the feasibility of the Philippines constructing a commercial scale gamma irradiation facility with a capacity of 1 millicurie (MCi)—comparable to those found in the aforementioned neighboring countries and 12 times larger than the current facility in Intramuros. A variation of Bateman et al.'s SEER framework ("Social, Economic and Environmental Assessment for Land Use Decision Making" model)—which evaluates a project from its environmental, economic, and social impacts—will be utilized to guide the cost- benefit analysis, in conjunction with the 5-point Likert assessment framework. Overall, the results deemed that a larger scale facility had a cost-benefit ratio of 1:5 and would be highly advantageous for the Philippines.

Keywords: cost-benefit analysis, economic, environmental, food irradiation, social

I. Introduction

Food irradiation is a versatile technique that helps solve various issues such as hunger and food waste through the preservation of food. The food irradiation process exposes products to a source of ionizing radiation for a predetermined time to sterilize the product. There are three types of radiation based processes approved for use on foods: Gamma rays, X-rays and Electron beams, however this paper will focus on the utilization of gamma rays. Gamma rays irradiate products by emitting sources of radiation from the elements Cobalt 60 or Cesium 137, these rays then kill disease-causing microorganisms in the food which increases the shelf life of perishable products. Other benefits of this process are, the reduction of the risk of food borne illnesses, prevention of invasive pests and delaying or even eliminating sprouting or ripening. In order to utilize this technique, a radiation facility must be built. Currently there are 180 large-scale gamma irradiation facilities in 42 countries which irradiate approximately 500,000 MT of food products worldwide each year, in particular, herbs and spices are among top irradiated foods [9]. However, in Manila and the Philippines, there are no commercial scale facilities. Other countries have had major success with this technology and even the semi-commercial facility in Manila has shown the potential of food irradiation. So this begs the question, would a commercial scale facility be beneficial to Manila? To start, the Philippines is filled with significant issues such as hunger, food waste and the production of methane emissions, which on the base level, food irradiation on a larger scale would tackle. It also creates the opportunity to make profit through more efficient exports and renting the facility. Thus, a cost benefit analysis will be conducted to determine a conclusion.

II. Method

In this paper, a cost-benefit analysis will be conducted to determine whether a commercial scale radiation facility would be beneficial in Manila and the Philippines. This will be done through the evaluation of a theoretical gamma ray facility which will have a capacity of 1 MCi—12 times larger than the existing facility in Intramuros. The cost-benefit analysis will be guided by Bateman et al.'s SEER framework [17]—which analyzes the social, economic and environmental impacts of the project—and various assessment schemes or indicators will be used within each individual category. For the environmental pillar, the benefits of reduced food waste, methane emissions, and the increase in the food's lifespan will be compared to the cost of energy consumption. For the economic pillar, the benefits in local and international revenue will be juxtaposed against the financial costs of conducting the radiation and costs to build the facility. Lastly, for the social pillar, the benefits of reduced hunger and increased job opportunities will be compared to the cost of exposing employees to radiation and the radiation hazards to the surrounding environment. From there, each individual indicator within the cost-benefit analysis will be evaluated using the Likert framework, which ranks the performances on a scale of 1 to 5, with 1 being the poorest score and 5 being the highest [10]. This will allow us to attain a cost-benefit ratio (benefits divided by cost). If the average ratio is greater than 1, the benefits outweigh the costs and the facility can be deemed overall beneficial.

IEECP'22, July 21-22, 2022, Oxford, United Kingdom

III. Results

A. Environmental Impacts

I. Benefits

The first environmental benefit is the reduction of food waste. Using food irradiation will prolong the lifespan of food, reducing food waste. According to World Wildlife Fund-Philippines, an estimated 439,350 tons of food scraps

in Metro Manila alone are thrown in the garbage annually [13]. Using data from the Intramuros facility (Cobalt-60 Multipurpose Irradiation Facility or MIF) on tons irradiated per year, an exponential trend of $y = 3.76 \times 10^{-34} e^{0.0413x}$. Using this equation, the tons of food this plant will irradiate in 2020 is estimated to be 641 tons. Since the capacity of the theoretical facility is 12 times larger than MIF, the tons irradiated annually at the 1 MCi facility would be 7,719 tons. Equation 1 will calculate the food waste reduction index (F.W.R.I.), where 0 represents an ineffective project and 1 denotes a perfectly effective project.

$$\text{Equation 1: } F.W.R.I = \frac{\text{food waste saved from project}}{\text{food waste of Metro Manila}} =$$

$$\frac{7{,}719}{439{,}350} = 0.01756913622 \approx 0.018$$

The value of this index may seem low and insufficient, but considering other food waste reduction methods into consideration, reducing 1.8% of the entire food waste of Metro Manila with just one factory is remarkable. Furthermore, the increased efficiency that comes with larger scale facilities that the Philippines is yet to experience suggests high potential in this new technology. Thus, it is determined that the environmental benefit of the reduction of food waste scores a **4**.

The reduction of food waste has a domino effect as it also reduces methane emissions from landfills, another major problem in the Philippines. Currently, Metro Manila has three major landfills that cumulatively produce 11.71 million tons of methane gas annually due to food decomposition [12]. According to Biocycle, 1 dry ton of food waste produces approximately 65 kg of methane [5]. Thus, the 1 MCi facility would decrease methane emissions from food waste by 1,501,735 tons. To put this into perspective, Equation 2 will calculate the methane emissions reduction index (M.E.R.I.), where 0 represents an ineffective project and 1 denotes a perfectly effective project.

$$\text{Equation 2: } M.E.R.I = \frac{\text{methane emissions saved from project}}{\text{methane emissions from Metro Manila}} =$$

$$\frac{1501735}{11710000} = 0.1283534188 \approx 0.13$$

13% of Metro Manila's methane emissions is an extremely significant reduction considering this positive impact is just from a single irradiation facility alone. Furthermore, this value is even more impressive due to the fact that the irradiation facility's primary purpose is to prolong the lifespan of food and not reduce methane emissions. This is a huge added environmental benefit, hence it is determined that the environmental benefit of reduction of methane emissions is a **5** on the Likert scale.

The third benefit is the increase in the food's lifespan without changing its nutrients through the irradiation. The United States' credible Food and Drug Administration has spent more than 30 years assessing the safety of irradiated food and has concluded the process to be safe and beneficial [4]. To illustrate, Table 1 displays the impact of irradiation for various foods.

Table 1: Impact of Irradiation on Various Food Products

Food Products	Impact	Results
Garlic, onion, potatoes, yams	Prevents sprouts	Reduces food spoilage
Pork	Kills trichinella spiralis worms	Reduces food borne diseases
Fruits and vegetables	Kills insects Delays ripening	Increases food safety Prolongs shelf life
Meat, poultry, fish, seafood	Inactives pathogens and microorganisms	Prolongs shelf life, and preserves food for export

Moreover, irradiating fruits benefits the exporting process as it allows the fruit to be exported without quarantine processing. The two top exported fruits of the Philippines are mangoes and bananas, and according to an experiment done by Bangladeshi scientists, when a banana was treated with <1 kGy, the banana's shelf life was extended by 20 days [19]. The International Atomic Energy Agency also released an article stating, "low dose gamma irradiation of mangoes in the dose range 10 to 200 krad alone or in combination with other physical and chemical treatments (i.e. hot water dipping and skin coating with 9 percent emulsion of acetylated monoglyceride) show that physiological, pathological and entomological factors can be controlled to extend the shelf-life of mangoes by one to two weeks." [18] Food irradiation may not be the cheapest option to extend a product's lifespan, however its ability to not interfere with the product's nutritional value is highly beneficial. Alternative methods to increase the lifespan of food, such as canning, bottling and pasteurization, either chemically alter the nutrients or don't fully eliminate all microorganisms. Thus, it is determined that the environmental benefit of increasing the food's lifespan without changing any nutrients is ranked a **3**.

To encapsulate, Equation 3 will calculate the average score of the environmental benefits for the cost-benefit ratio.

$$\text{Equation 3: } Average\ Score\ of\ Environmental\ Benefits = \frac{Benefit\ 1\ Rating + Benefit\ 2\ Rating...}{Number\ of\ Benefits}$$

$$= \frac{4 + 5 + 3}{3} = 4$$

This average rating of 4 is very high.

II. Costs

The first cost is energy consumption, the use of a gamma ray facility requires a lot of energy. A 60-kW Cobalt-60 facility operating for 6,000 hours in one year uses 2.7 × 1012 joules/year [7]. Using this as a reference point, the 1 MCi facility can be estimated to need 4.5 × 1013 joules/year, which is a good amount of energy. However, with every method comes energy usage in one way or another so this cost can be deemed insignificant. On top of this, the benefits brought at the cost of this energy for a facility makes this a good investment. Thus, it is determined that the environmental cost of energy consumption is a **2**.

$$Equation\ 4: Average\ Score\ of\ Environmental\ Costs = \frac{Cost\ 1\ Rating\ +\ Cost\ 2\ Rating...}{Number\ of\ Costs} = \frac{2}{1} = 2$$

This average rating is 2.

III. Cost-Benefit Ratio

Using our determined ratings, we can deduce a cost-benefit ratio for the environmental pillar using Equation 5.

$$Equation\ 5: Environmental\ Benefit\ Cost\ Ratio = \frac{Average\ Rating\ of\ Environmental\ Benefits}{Average\ Rating\ of\ Environmental\ Costs} = \frac{4}{2} = 2$$

To interpret this value, Table 2 can be consulted.

Table 2: Interpretation of Cost-Benefit Ratio

Benefit/Cost Ratio	Interpretation
> 1	Beneficial
= 1	Neutral
< 1	Costly

Thus, with a cost to benefit ratio significantly greater than 1, the environmental impacts of the 1 MCi irradiation facility have a net positive effect and would be overall beneficial to the country.

B. Economic Impacts

Recognizing the lack of an economic framework that fully encompasses the unique components of food security infrastructure and technology, we have developed a new system. We identified that the major economic factors that contribute to projects such as these are generally 1) profits from the local market, 2) profits from the international export market, 3) costs of technology, 4) cost incurred from the facility. As these are the four major economic factors regarding these projects, we can bring these together to determine the net economic impact.

I. Benefits

The first economic benefit is the local revenue generated from using the facility. In 2015, the Philippines Nuclear Research Institute (PNRI) produced revenues of ₱7 million from the 500 tons of food irradiated at MIF. Using this rate, the local revenue of the 1 MCi facility is estimated to be ₱108,006,000. To standardize this statistic, the 63.3 MW Calatagan Solar Farm (one of the Philippines government's most successful projects) will be used as a benchmark. Equation 6 will calculate the percentage yield of the annual local revenue for the irradiation facility in comparison to the Calatagan Solar Farm.

$$Equation\ 6: Percentage\ Yield = \frac{local\ revenue\ of\ the\ 1\ MCi\ irradiation\ facility}{local\ revenue\ of\ the\ Calatagan\ Solar\ Farm} = \frac{108066000}{101077440} = 1.06914065097 \approx 107\%$$

A 107% yield is phenomenal. With the value being greater than 100% , it indicates the estimated local revenue of the facility is greater than the income of a very successful government project. Additionally, the irradiation facility project is much cheaper to execute than the solar farm, costing ₱249.4 million and ₱5.7 billion respectively [3], a difference of ₱5,450,578,300. This data demonstrates the potential of an irradiation facility, it can cost 1/25 less than a solar farm and still generate more revenue. The MIF provided services for 80 clients, with a bigger facility there will be more room for clients or significantly larger orders. Therefore, it is determined that the economic benefit of local revenue generated receives a **5** on the Likert scale.

Not only will the irradiation facility generate local revenue, it can also produce International revenue through exports. The Philippines Department of Agriculture had plans to develop a commercial scale irradiation facility to serve the purpose to irradiate the country's top food product exports like mango, pineapple, and banana, however these plans haven't followed through yet. Food irradiation specifically of fruit can be beneficial for the exporting process as it speeds up the quarantining process of the products as it arrives in the US or other country. According to Oxford Business Group, in 2013, the Philippines exported 4.42 billion kg of fruits and vegetables worth a combined total of 1.97 billion USD or ₱98.7 billion [14]. Using this data, if 20% of the tons irradiated at the facility (1543.8 tons) are dedicated for exports, the estimated gross profit of the exported goods would be ₱34,314,582. In order to determine the net profit of the exported goods, the cost of the irradiation must be calculated, which can be quantified through Table 3.

Table 3: Dosage and Cost of Irradiation on Various Food Products

Food Products	Dosage (kGy)	Cost of Irradiation (PHP/kg)
Meat	3	25
Seafood	3	25
Rice	1	10
Fruits (Banana, Pineapple & Mango)	1	10
Vegetables (Onions, Garlic & Potatoes)	0.1	7

If the 20% of tons irradiated is separated into 15% fruit and 5% vegetables, the cost of irradiation would be ₱14,280,150. Therefore, the net profit of exported goods from the irradiation facility would be ₱20,212,987. Furthermore, the goods exported are often sold at a price higher than the expected value. For example, in 2018, the Philippines banana exports for all purchasing countries surged to 1.5 billion USD from 1.4 billion USD [16]. Thus, it is determined that the economic benefit of international revenue scores a **4** on the Likert scale.

To summarize, Equation 7 will calculate the average score of the economic benefits for the cost-benefit ratio.

$$Equation\ 7: Average\ Score\ of\ Economic\ Benefits = \frac{Benefit\ 1\ Rating + Benefit\ 2\ Rating\ ...}{Number\ of\ Benefits} = \frac{5\ +\ 4}{2} = 4.5$$

This average rating of 4.5 is extremely high.

II. Costs

The first economic cost is the cost of the technology. In order to irradiate food products, radiation must be utilized, which can be quite expensive. Using Table 3 and the estimate that fruits, vegetables, meat and seafood, and rice make up 70%, 20%, 5%, 5% of the food irradiated respectively, the total dosage needed to irradiate all the food for one year would be 7,101,400 kGy. The cost of this radiation would be ₱78,348,000, a hefty amount of money. Currently, there is no way to lower this price without changing the dosage of radiation, however modifying the measurements would affect the irradiation process and may take away the benefits of this technology. The only way to justify this expense is through the benefits brought by this process or that every alternative method would still cost money to implement. In the end, despite all the benefits, it cannot be denied that food irradiation is on the more expensive end of food preserving techniques costing millions. Thus, it is determined that the economic cost of the price of resources earns a **4** out of 5.

In order to even perform food irradiation, a gamma ray facility must be built. According to the University of Wisconsin, a typical commercial processing plant, specifically a gamma irradiation facility involves a capex of around 5 million USD as per estimates [11]. Converting that to PHP would make the cost to build a 1 MCi facility ₱249,421,700, a large capital investment. This may sound like a lot of money, however this is within the price range of plants for other technologies. For example, a moderately-sized, ultra-high temperature plant for sterilizing liquids costs about 2 million USD or ₱100.4 million [11]. Another example is a small vapor-heat treatment plant for disinfecting fruits, which costs about 1 million USD or ₱50.2 million [11]. Besides this, the ₱249,421,700 would be a onetime expense, once the facility is built, it just needs to be maintained which would not cost as much. Also as shown in the economic benefits section, the facility can earn back the invested money very quickly after a few years through its local and international revenue. Thus, it is determined that the economic cost of building a gamma irradiation facility is a 3 on the Likert scale.

Equation 8 will calculate the average score of the economic costs for the cost-benefit ratio.

$$Equation\ 8: Average\ Score\ of\ Economic\ Costs = \frac{Cost\ 1\ Rating\ +\ Cost\ 2\ Rating\ldots}{Number\ of\ Costs} = \frac{4\ +\ 3}{2} = 3.5$$

III. Cost-Benefit Ratio

Using our determined ratings, we can deduce a cost-benefit ratio for the economic pillar using Equation 9 and interpret the results using Table 2.

$$Equation\ 9: Economic\ Benefit\ Cost\ Ratio = \frac{Average\ Rating\ of\ Economic\ Benefits}{Average\ Rating\ of\ Economic\ Costs} = \frac{4.5}{3.5} = 1.285714\ldots \approx 1.3$$

With a cost to benefit ratio greater than 1, the economic impacts of the 1 MCi irradiation facility have a net positive effect on the country's economy.

C. Social Impacts

I. Benefits

The first social benefit is the reduction of hunger. With food irradiation, the lifespan of food increases, reducing waste since people won't need to buy as much food. This means that there is more food for the hungry to eat. In 2019 the Food and Agriculture Organization (FAO) revealed that 690 million people went hungry that year [2]. Using the average weight of an Filipino adult, it can be estimated that one Filipino eats about 1290 pounds of food or 0.585 metric tons [1]. This means that the 1 MCi facility has the potential to save food of an amount capable of feeding 13,191 people. This is not the largest decrease however this is a passive benefit, thus any difference is positive. Hence, it is determined that the social benefit of reducing hunger is a 3.

The second social benefit is creating job opportunities. We can take a conservative estimate that about 70 job opportunities are created from this facility. Not just inside the facility but also on the outside such as drivers and farmers. As society moves towards a more digital lifestyle, it is important to still have physical job opportunities that allow for people to make money and create a living which won't get replaced by AI. The only downside to this benefit is that 70 jobs isn't very many job opportunities for the amount of people. Thus, it is determined that the social benefit of creating job opportunities is a 2.

Equation 10 calculates the average score for the social benefits.

$$Equation\ 10: Average\ Score\ of\ Social\ Benefits = \frac{Benefit\ 1\ Rating\ +\ Benefit\ 2\ Rating\ldots}{Number\ of\ Benefits} = \frac{3\ +\ 2}{2} = 2.5$$

II. Costs

The first social cost is the negative impacts of prolonged exposure to radiation. A lot of risks may occur while working with radiation which may be a danger for workers in the facility. At very high radiation exposures, death will occur within several months or less. At moderate levels, radiation exposure increases the chance that an individual will develop cancer [15]. At low levels, the cancer risk decreases but still is a concern [15]. On top of this, gamma rays have extremely high penetrating power which can pass completely through the human body [8]. If it does pass through a human, it may damage tissue and DNA [8]. In the end, these costs all come with working with radiation, and if the facility is made correctly and run properly, this shouldn't be much of an issue. Thus, it is determined that the social cost of prolonged exposure to radiation is a 2.

Additionally, another social cost is the hazard of radiation to a gamma ray facility's surrounding environment. If a facility is poorly constructed, it could lead to devastating consequences to its surrounding areas. When working with a gamma ray facility, there is always the hazard of radiation, if the facility is made poorly, it could lead to devastating consequences on the area surrounding it. According to an employee from Symec Engineers (India), an irradiation plant manufacturer, "While constructing and maintaining an irradiation facility is expensive in itself, but what is harder is to ensure that the surrounding environment is free from any kind of contamination and this can get costly as well." [6] Ensuring the gamma ray facility is built well should be a priority. Manila is packed with 368 people per km2, a fair amount living in clumped slums. So one mistake handling the radiation would put millions of lives at risk. But as long as the facility is built properly and maintained, this shouldn't be the biggest concern. Many other projects pursued that use some form of radiation have been done before and there have been close to 0 freak accidents with these facilities. Theoretically, if there were to be a tragedy and an area in Manila does get contaminated by radiation then it can be expected that many people may get infected, this scenario a major factor in the scoring for this cost. But to combat this issue, the facility can either be built far away from civilization or living areas. Again, as long as the facility is built correctly and maintained properly, this cost can be disregarded. Thus, it is determined that the environmental cost of working with radiation is a 2.

Equation 11 calculates the average score for the social costs.

$$Equation\ 11: Average\ Score\ of\ Social\ Costs = \frac{Cost\ 1\ Rating\ +\ Cost\ 2\ Rating\ldots}{Number\ of\ Costs} = \frac{2\ +\ 2}{2} = 2$$

III. Cost-Benefit Ratio

Using our determined ratings, we can deduce a cost-benefit ratio for the social pillar using Equation 12 and interpret the results using Table 2.

$$Equation\ 12: Social\ Benefit\ Cost\ Ratio = \frac{Average\ Rating\ of\ Social\ Benefits}{Average\ Rating\ of\ Social\ Costs} = \frac{2.5}{2} = 1.25$$

With a cost to benefit ratio greater than 1, the social impacts of the 1 MCi irradiation facility have a net positive social effect.

IV. Conclusion

$$Equation\ 13: Benefit\ Cost\ Ratio = \frac{Environmental\ Benefit\ Cost\ Ratio\ +\ Economic\ Benefit\ Cost\ Ratio\ +\ Social\ Benefit\ Cost\ Ratio}{Number\ of\ Pillars}$$

$$= \frac{2\ +\ 1.3\ +\ 1.25}{3}$$

$$= 1.51666666667$$

$$\approx 1.5$$

Using Table 2 to intercept the results, the benefit cost ratio of 1.5 displays how a commercial scale irradiation facility will be beneficial to the Philippines. For this project, improvements can still be made on the economic and social pillars, something which can be changed with the size of the facility and time. The earlier a facility is built, the quicker it can earn the invested money back. Ultimately, this research has proven that food irradiation would be an overall success and a worthwhile endeavor to invest in. The lessons learned from this project should be considered when planning future food irradiation plants.

V. References

1. Aubrey, Allison. “The Average American Ate (Literally) a Ton This Year.” *NPR*, NPR, 31 Dec. 2011, https://www.npr.org/sections/thesalt/2011/12/31/144478009/the-average-american-ate-literally-a-ton-this-year.
2. BusinessMirror. “Millions of Filipinos Are Going Hungry.” *BusinessMirror*, 20 Apr. 2021, https://businessmirror.com.ph/2021/04/21/millions-of-filipinos-are-going-hungry/.
3. “Calatagan Solar Farm.” *Wikipedia*, Wikimedia Foundation, 14 May 2020, https://en.wikipedia.org/wiki/Calatagan_Solar_Farm.
4. Center for Food Safety and Applied Nutrition. “Food Irradiation: What You Need to Know.” *U.S. Food and Drug Administration*, FDA, https://www.fda.gov/food/buy-store-serve-safe-food/food-irradiation-what-you-need-know.
5. “Connection: Climate Calculations.” *BioCycle*, 19 June 2013, https://www.biocycle.net/connection-climate-calculations/#:~:text=For%20this%20approximation%2C%20we%20can,kg%20of%20methane%20(CH4).
6. dharm_anki. “Food Irradiation Advantages and Disadvantages.” *Symec Engineers*, 28 Sept. 2019, https://www.symecengineers.com/food-irradiation-advantages-and-disadvantages/.
7. ENERGY AND FOOD IRRADIATION. https://apps.dtic.mil/sti/pdfs/ADA058502.pdf
8. *EPA*, Environmental Protection Agency, https://www.epa.gov/radiation/radiation-basics.
9. *Global Status and Commercial Applications of Food Irradiation*. http://www.foodirradiation.org/Global%20Status%20of%20Food%20irradiation.pdf.
10. Mcleod], [Saul. “[Likert Scale Definition, Examples and Analysis].” *Simply Psychology*, 1 Jan. 1970, https://www.simplypsychology.org/likert-scale.html.
11. *A Mobile Food Irradiation Facility - Trace.tennessee.edu*. https://trace.tennessee.edu/cgi/viewcontent.cgi?article=2264&context=utk_chanhonoproj.
12. Neil. “A Solution to Metro Manila's Garbage Problem.” *BusinessWorld Online*, 30 June 2019, https://www.bworldonline.com/a-solution-to-metro-manilas-garbage-problem/.
13. Neil. “Collective Action to Combat Food Waste.” *BusinessWorld Online*, 25 Jan. 2021, https://www.bworldonline.com/collective-action-to-combat-food-waste/.
14. “Production Volumes and Exports of Philippine Fruit and Vegetables Continue to Rise.” *Oxford Business Group*, 8 Sept. 2015, https://oxfordbusinessgroup.com/analysis/fruitful-business-production-volumes-and-exports-fruit-and-vegetables-continue-rise.
15. *Radiation Damage and Its Study*, https://www2.lbl.gov/abc/wallchart/chapters/15/1.html.
16. Santiago, Danny. “Philippines Bananas Exports by Country.” *Philippines Around the World*, 13 Apr. 2021, https://www.philippinesaroundtheworld.com/philippines-bananas-exports-by-country/.
17. “Social, Economic and Environmental Research Project.” *Social, Economic and Environmental Research Project | Land, Environment, Economics and Policy Institute | University of Exeter*, https://www.exeter.ac.uk/research/leep/research/projects/socialeconomic/.
18. Thomas, Paul, and S.R. Padwal Desai. “Improvement of Shelf-Life and Quality of Mangoes by Gamma Irradiation.” *Indian Food Packer*, 1 Jan. 1976, https://inis.iaea.org/search/search.aspx?orig_q=RN%3A8347055.
19. Zaman, W, et al. “Shelf Life Extension of Banana (*Musa Sapientum*) by Gamma Radiation.” *Journal of Bio-Science*, https://www.banglajol.info/index.php/JBS/article/view/2202.