Food Supply Chain Optimization Modelling in the Rice Crop Post Harvesting in the Philippines: An Agroecological Approach in Food Sustainability

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Abstract

The agricultural sector contributes fourteen percent to the Philippines' gross domestic product; however, the country's staple food requirement is still insufficient as data show a 16.4% loss in the post-harvesting process of rice crops due to the conventional way of harvesting. The purpose of this study is to provide an optimized process flow model that will lessen the loss incurred in the agro-food supply chain process. Literature reviews were done to validate the gathered data among government agencies, and through the use of Analytical Hierarchy Process (AHP), key variables were identified in determining the relative weights and criteria fitted in the model. Results show that type of seeds, timely harvest, temperature management, moisture content, and ethylene production are relevant factors that cause food loss in the agro-food supply chain. The recommendation includes the establishment of an integrated internet of things (IoT) process incorporating the key variables beneficial for the stakeholders.

Keywords:
Food Supply Chain, Rice Production, Post-harvest, AHP, Optimization

1. Introduction

The Philippines has a population of 104 million people, and seventy percent (70%) of its people depend on its agricultural sector (FAO, 2018). According to FAO (2007), rice is considered to be the most important staple crop in the country with its wide diversity, as eighty-nine percent (89%) of the entire population depends on it. Among the Southeast Asian nations, the Philippines ranked fourth as a rice producer with an estimated yield of 4.08 tons per hectare (USDA, 2015); however the country is not self-sufficient in its staple food requirements (Andales and Gragasin 2000; Castro, 2006) as 16.4 percent loss recorded in the post-harvesting process of rice crops due to the traditional production practiced (PhilMech, 2010) and lack of proper handling and equipment (Mopera, 2016). The Filipinos recorded a total waste of 987,952 kilograms of rice daily (FNRI, 2015). About one-third of the total food produced goes to waste in both developing and developed countries, equivalent to 1.3 billion tons of food loss per year, which can feed about 2 billion people each year (FAO, 2013).

The food supply chain is a process in which food travels from the producers to reach the consumers (Wunderlich & Martinez, 2018) and the impact of losses affect the economic standing of the Philippines' rice production, provided the agricultural sector contributes 14 percent to the Philippines' gross domestic product. Seventeen percent (17%) of rice losses are associated with the absence of poor post-harvesting facilities and practices (Philippine Star, 2018) and attributed due to factors such as the type of seeds, timely harvest, temperature management, moisture content, and ethylene production (IRRI, 1999). Based on the interview, the farmers' lack of experience and knowledge in post-harvesting aside from poor harvesting techniques incurs losses such as manual drying that resulted in the susceptibility of grain. In addition, storage also incurs losses as rodents and other pests cause the rice not to be fit for consumption.

Validating the claim, IRRI (2015) reported that during the post-harvesting process, about 15% of physical rice losses occur particularly in the production process, at the same time waste in water, fertilizers, labors, seeds, fuel, and other agricultural inputs also take place. This results in decreasing the availability of food in the market, Parfitt et al. (2010) reported that an estimated range of 10-37% of post-harvest losses becomes a threat to the Philippine farmers in terms of agricultural sustainability and food security. Rezaei and Liu (2017) indicated that this may increase food prices and reduce the capacity of low-income consumers to access food. Conclusively, the World Bank reported that the share of agriculture in the country's economy decreased by half, from 24.6% in 1895 to 12.8% in 2011. Given these ratios, the most sustainable alternative for increasing food production is by reducing food loss (Gustavsson et al., 2011), in which Koga Y. (1982) argue that it is much cheaper to reduce losses than to increase production.

This paper seeks to identify significant variables affecting the losses experienced by the farmers during the post-harvesting process of rice production. It aims to design an optimal flow process that maximizes the production that will lead to profit generation and integration of smart farming in the conventional process. The study focuses on the aspect of the agroecological food supply chain with a definite emphasis on the post-harvesting stage of the rice production process during the dry season.

This paper's focus is on rice production in terms of the traditional post-harvesting process during the dry season. The flow process model will be applicable only to the common type of seed which is the farmer's seed, a low-grade type of seed, in the dry season of harvesting. The identified controllable and measurable factors only will be used for Analytical Hierarchy to consider for the design.

2. Literature Review

In developing countries such as the Philippines, the population is considered in a rapidly growing stage and a significant number of people are experiencing food insecure and malnourished (ACF, IRIS., 2016); thus, food waste reduction efforts have been an issue leading to tackling the food supply chain (FSC) process loss, particularly in the production and consumption stage. The IRRI (1999) has implied that post-harvest loss occurs during the traditional method resulting in spillage, inefficient retrieval, and processing of rice due to machine inadequacy, poor manpower, biological deterioration, and storage pest infestation causing 296,869 kg of losses. FAO (1999) has identified factors affecting losses in post-harvesting of rice paddies include weather conditions, seed types, and insect infestations, that severely affect the quantity and quality of crops in the country.

As the country has been situated near the equator, it experiences only wet and dry seasons, and it is a key factor affecting rice production. PhilRice-BAS (1994) stated that 82.4% of rice losses were caused by typhoons, floods, and drought as it is considered a critical factor in the crop quantity and quality, resulting in chalky immature and unfilled grains (Baloch 2010 and Lantin 1999). However, rice can only gain moisture in a high humidity environment (Thompson, 1998) as molds are prone to grow in storage with the temperature between 20-40˚C with 70% of relative humidity (Abedine M., Rahman M., Rahman K., 2012).

It was presented by Chen (1997) and Bonazzi et al. (1997) that aside from temperature and relative humidity, the variety was one of the main factors that lead to rice losses. FAO (1999) settled that the difference in varieties affects the growth of the crop. A study by Hanks (1972) elaborated that this is due to each environment that offers unique light, moisture, temperature, and soil that creates mutation and variations within each field. With this, timely harvest in a study by Hong et al. (2017) implied that the varieties of hybrid rice seed alone are critical to predict and rare in reports. It also claimed that biochemical parameters such as ethylene are related to seed vigor, a comprehensive factor in predicting optimum harvest time to minimize loss. Evidently, the level of ethylene that affects the shelf-life is also determined by timely harvest (Kader, 2004).

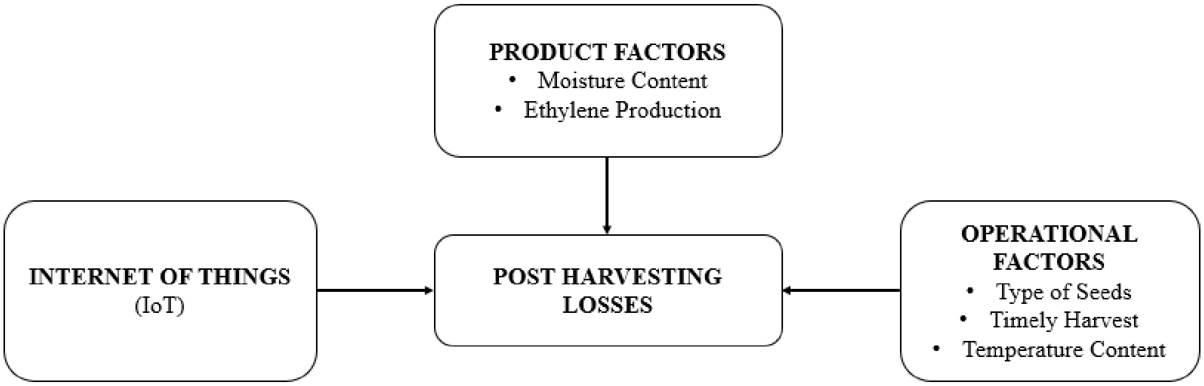

Figure 1. Conceptual framework

Just like all other studies concerning the supply chain, the goal is to provide an optimized flow process catering to the stakeholders that specially focus on providing sufficient livelihood to the small-scale farmers and food stability to the population. Factors that influence most of the loss must be identified to be addressed as it promotes maximized production. Succeeding, integrating the variables affecting the food supply chain to a model with the concept of Industry 4.0 that promotes sustainability. This would result in a greater contribution to the agricultural sector of the growth domestic product of the country.

The IoT technology integrated into rice farming was used to calculate the farms and to evaluate the temperature, humidity, and sunshine levels of farms. Its concept is to provide a solution to the increasing demand for food, shortages in the labor force, and to aid aging farmers, as well as the expansion of cutting-edge agricultural technology (Kim et al., 2018; Suanpang and Jamjuntr, 2019). Muangprathub et al. (2019) claimed that IoT can be used to assist farmers in any form of farming. Additionally, IoTs have been used in farming to increase crop yields, improve quality, and minimize costs.

3. Methodologies

Through literature reviews and data collection, the study recognized multiple variables to develop the supply chain process flow model among rice crop farmers in the Philippines. In this manner, various tools have been used to optimize the result and to provide viable recommendations for the improvement of the post-harvesting process. The figure below shows the sequence model followed in this paper.

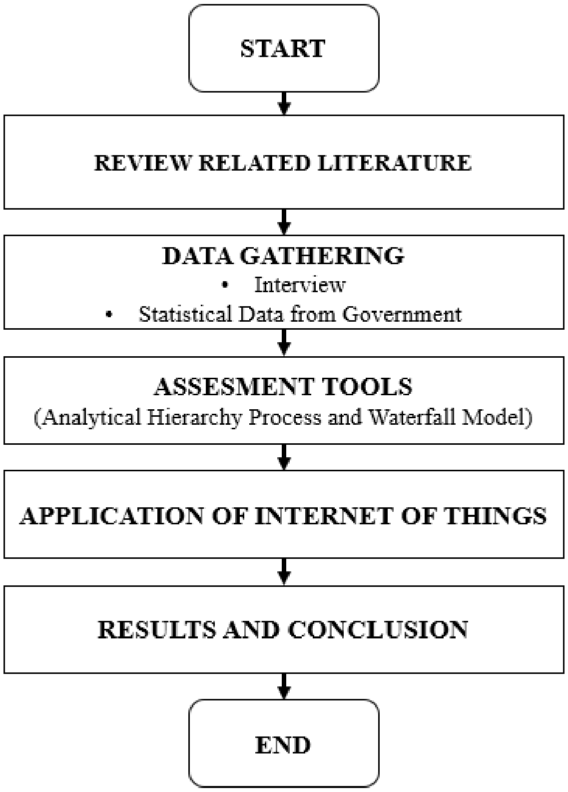

Figure 2. Research Design

The study focused its data gathering in Central Luzon, a specific region in the Philippines known to be as the rice-producing region in the country. The data collected in this paper is based on actual interviews and statistical data from government institutions in the country, proving the existence of the post-harvest loss in the harvesting process. In solving the problem, the Analytical Hierarchy Process was utilized to allocate numerical values among individual decisions on the parameter varieties to integrate the decisions into a single decision-making scale.

As technological advancements have been an emerging factor in sectors such as agriculture, the application of the Internet of Things (IoT) has been considered in the design of the supply chain process flow modelling to allow real-time information to be collected and processed. With its consideration, the government, rice crop farmers, and distribution centers (consumers) will benefit in the aspects of loss minimization and monitoring and satisfying consumer demand.

4. Results and Discussion

The variables such as type of seeds, timely harvest, temperature management, moisture content, and ethylene production were considered to be relevant factors causing a loss in the post-harvesting. In line with the study's scope, the study focused on one type of seed, particularly low-grade with grade factor for the purity of 85 (% by weight) and total maximum foreign matter of 15 as set by the Philippine National Standard (2019). Timely harvest was observed by the ideal physical maturity when 80-85% of the grains are straw-colored along with the ethylene level. The summarized target moisture content per post-harvesting process along with the primary loss incurred by IRRI (1999) is used for basis while temperature particularly during drying wherein temperature should not exceed 43.3°C. The actual data gathered with respect to each phase of the post-harvest process was assumed to be deterministic data that fall under the criterion of decision making under certainty as shown in Table 1.

Table 1. Summary of Data

Variable	Factor	Harvesting	Threshing	Milling	Drying	Storage
x_1	**Type of Seeds**	10%	1.25%	0	0	0
x_2	**Timely Harvest**	5.63%	0	0	0	0
x_3	**Temperature Management**	0	0	0	50%	3.2%
x_4	**Moisture Content**	20%	18.25%	12%	12.5%	10%
x_5	**Ethylene Production**	5%	0	0	0	0
Total Losses:		**2.03%**	**2.18%**	**5.52%**	**5.86%**	**0.8%**

Source: PhilRice.gov.ph

4.2 Data Analysis

4.2.1 Decision Hierarchy

The Analytical Hierarchy Process (AHP) is a widely known multiple criteria decision making (MCDM) tool that offers a systematic and controlled approach to take into account various considerations when making a single-scale decision (Burge, 2014). AHP utilizes a statistical methodology that allows the choices to involve a variety of matters, choosing the best from a range of alternatives and distribution of capital. This makes AHP the best approach particularly in the supply chain through the application of an automated flow of data, direct supply, and currency.

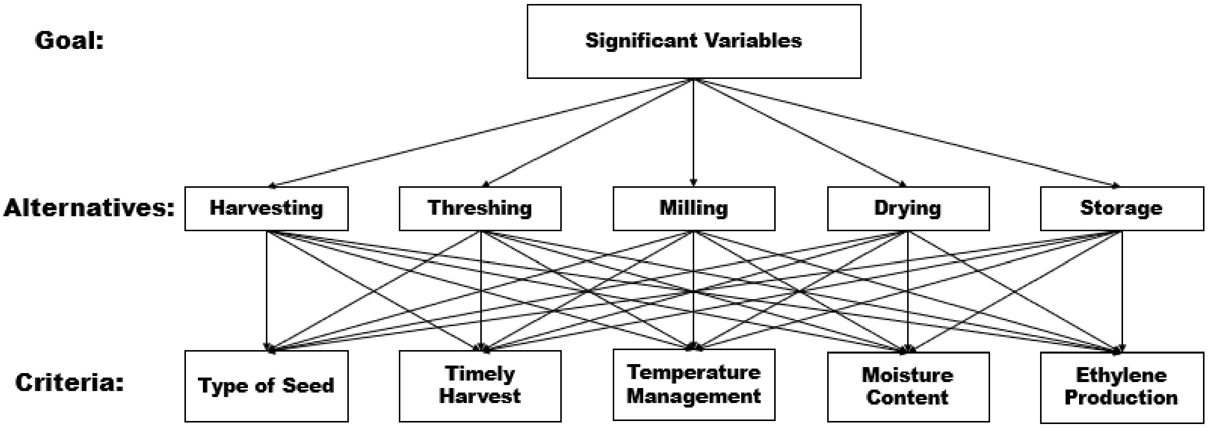

Figure 3. Decision Hierarchy for Post-Harvest

Figure 3 shows the Post-Harvest Decision Hierarchy by the representation of the goal, criteria, and alternatives in the general structure of AHP. At the root node, the framework has the main purpose, followed by the alternatives at the second level, and finally the criteria at the final level. The weights are assigned with respect to the percentage of losses per stage of the post-harvest process in order to put emphasis on the level of importance of the alternatives in identifying which criterion will fit the goal. The computation is done with a simple ratio of loss shown in the table below.

Table 2. Weighted Criteria

Variable	Criteria	Losses (%)	Weight (%)
w1	Harvesting	2.03	12.39
w2	Threshing	2.18	13.30
w3	Milling	5.52	33.68
w4	Drying	5.86	35.75
w5	Storage	0.80	4.88
Total:		**16.39**	**100**

The calculation in Table 3 implies that temperature management and moisture content holds the highest significance value with accumulated percentages of 51.98% and 40.18%, respectively; making them the key factors in the system process flow model.

Table 3. Summary of Result

Factor	Formula	Significance Value	Accumulated Percentage
Temperature Management	$x_1 = (w_1*10) + (w_2*1.25) + (w_3*0) + (w_4*0) +(w_5*0)$	18.03	51.98%
Moisture Content	$x_2 = (w_1*5.63) + (w_2*0) + (w_3*0) + (w_4*0) +(w_5*0)$	13.94	40.18%
Type of Seeds	$x_3 = (w_1*0) + (w_2*0) + (w_3*0) + (w_4*50) +(w_5*3.2)$	1.41	4.05%
Timely Harvest	$x_4 = (w_1*20) + (w_2*18.5) + (w_3*12) + (w_4*12.5) +(w_5*10)$	0.70	2.01%
Ethylene Production	$x_5 = (w_1*5) + (w_2*0) + (w_3*0) + (w_4*0) +(w_5*0)$	0.62	1.79%

4.2.2 Sensitivity Analysis

The study's findings were analyzed through sensitivity analysis by using different weights under certain conditions tabulated in Table 4.

Table 4. Weights under Certain Condition

Condition	Harvesting	Threshing	Milling	Drying	Storage
1	3.67%	4.42%	36.05%	53.83%	2.03%
2	4.25%	5.05%	36.56%	51.93%	2.21%
3	5.20%	11.08%	40.53%	40.45%	2.74%
4	6.01%	35.15%	15.17%	39.63%	4.04%
5	7.55%	10.00%	40.45%	39.53%	2.47%
6	8.11%	48.05%	9.13%	31.98%	2.73%
7	9.41%	10.53%	50.62%	27.57%	1.87%
8	12.64%	15.86%	24.77%	28.52%	18.21%
9	13.02%	16.55%	29.72%	36.88%	3.83%
10	13.64%	12.86%	21.77%	24.52%	27.21%

11	15.75%	12.08%	23.75%	29.52%	18.90%
12	19.05%	20.45%	14.79%	25.34%	20.37%
13	21.74%	13.38%	23.21%	25.38%	16.29%
14	32.32%	22.85%	7.37%	28.66%	8.80%
15	38.47%	10.18%	9.01%	34.36%	7.98%
16	43.65%	10.17%	9.21%	32.38%	4.59%
17	49.84%	5.14%	9.11%	33.32%	2.59%
18	51.14%	15.24%	9.04%	21.82%	2.76%
19	60.05%	14.69%	9.14%	12.96%	3.36%
20	63.86%	7.08%	9.75%	12.52%	6.79%

The analysis was done by using the same formulation in Table 3 to test the validity along with the applicability by determining the minimum and maximum percentage of losses per process that is possible. Visibly, the slight changes of weights under certain conditions shown in Table 5 proved that temperature management and moisture content still holds the highest significance values.

Table 5. Summary of Significance Values under Certain Condition

Condition	**Type of Seed**	**Timely Harvest**	**Temperature Management**	**Moisture Content**	**Ethylene Production**	**Total**
	x1	x2	x3	x4	x5	
1	0.42	.021	26.98	12.81	0.18	40.60
2	0.49	0.24	26.04	12.88	0.21	39.86
3	0.66	0.29	20.31	13.28	0.26	34.80
4	1.04	0.34	19.94	14.88	0.30	36.50
5	0.88	0.43	19.84	13.4	0.38	34.93
6	1.41	0.46	16.08	15.88	0.41	34.24
7	1.07	0.53	13.84	13.54	0.47	29.45
8	1.46	0.71	14.84	13.82	0.63	31.46
9	1.51	0.73	18.56	14.23	0.65	35.68
10	1.52	0.77	13.13	13.51	0.68	29.61
11	1.73	0.89	15.36	13.81	0.79	32.58
12	2.16	1.07	13.32	14.57	0.95	32.07
13	2.34	1.22	13.21	14.41	1.09	32.27
14	3.52	1.82	14.61	16.04	1.62	37.61
15	3.97	2.17	17.44	15.75	1.92	41.25

16	4.49	2.46	16.34	16.22	2.18	41.69
17	5.05	2.81	16.74	16.44	2.49	43.53
18	5.05	2.81	16.74	16.44	2.49	43.53
19	6.19	3.38	6.59	17.14	3.00	36.94
20	6.47	3.6	6.48	17.50	3.19	37.24

5. Conclusions and Recommendations

The researchers identified that the key factor to minimize the losses in the post-harvesting process in order for the farmers to maximize their profit is: Temperature Management and Moisture Content. It is identified that Temperature Management has a significant value of 18.03 which has an accumulated percentage of 51.98%, while a significant value of 13.94 belongs to Moisture Content having an accumulated percentage of 40.18%. Moreover, the sensitivity analysis validates the importance of Temperature Management and Moisture Content regardless of the weight's changes under certain conditions.

The study recommends a sensor that is programmed with the ideal values of the factors that will monitor the crops continuously before proceeding to the next process while alerting the farmers. Real-time monitoring through IOT will help the farmers lessen their losses. All the data collected after each process will be saved to the database as a reference in terms of maintenance. This will be used to reprogram the machine based on the data saved after analysis and research towards the effectiveness of the model. With the help of IoT, stakeholders can monitor each process of production of the FSC in order to apply a corrective action that will minimize the losses resulting in an increase in profit for farmers, enough food security, and sustainable FSC in rice crop production.

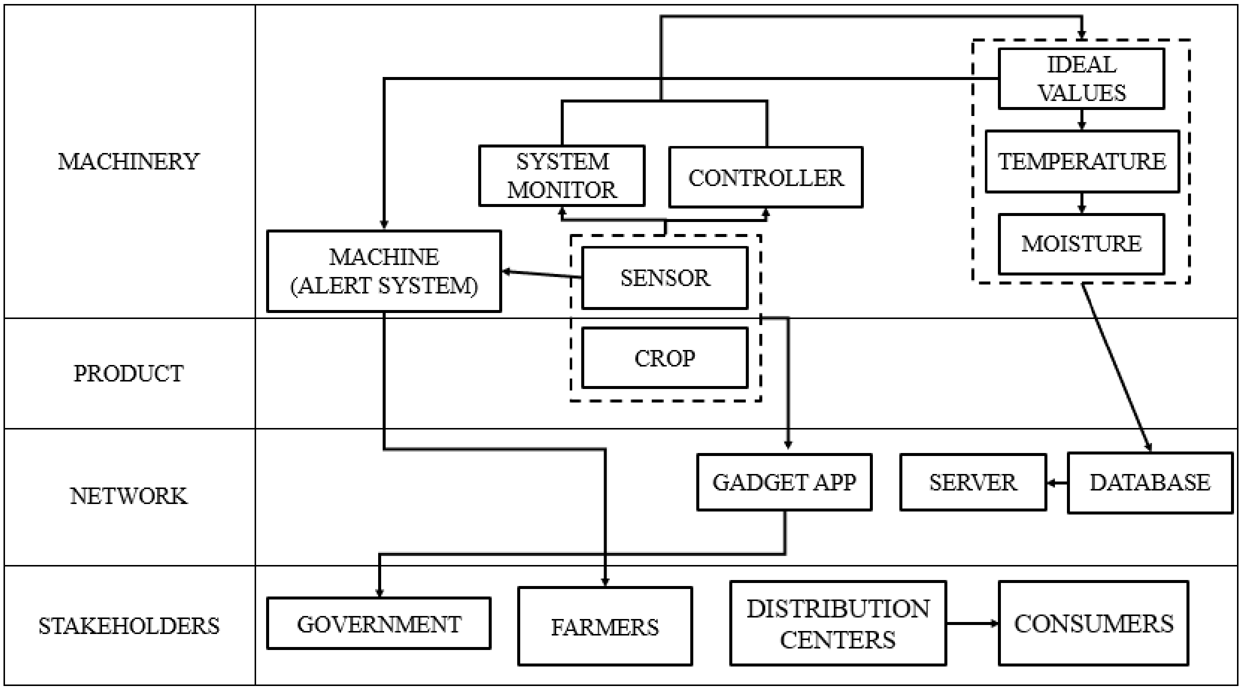

Figure 6. Process Flow Model

Each post harvesting process, the farmer will monitor the crops through the sensor which are programmed with the identified ideal values of key factors. The machine connected to the sensor will notify the farmer once it reaches the ideal values or in case of anomalies. The data will directly be stored in the database along with the server that will be integrated with the IoT to distribute it to the stakeholders to have their own monitoring and make corrective actions when necessary. The database will also be used to keep track of the production level of the farmers. After the harvesting process, the distribution centers can monitor the supply they can accumulate from the farm and the consumers will have food security.

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