

Process Design For Industrial Scale Production Of Naturally Fermented Carica Papaya (C.Papaya) Leaf And Garcinia Mangostana (G. Mangostana) Pericarp

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ABSTRACT

Naturally fermented Carica Papaya Leaf and Garcinia Mangostana Pericarp is a value product in the medicinal industry, namely alternative medicine and phytochemical industry. It comprises of both traditional and natural elements that constitutes to its value proposition. Traditionally, the way this two raw materials is being treated by just the act of boiling and blending it to make into some sort of juice out of it. The full essence of the Carica Papaya Leaf and Garcinia Mangostana Pericarp has not been fully extracted efficiently. Thus, the objective of this work is to design an economically viable production scheme for a locally developed Carica Papaya Leaf and Garcinia Mangostana Pericarp through naturally fermented production process that increases the efficiency of extraction rate of the essence of the two product. This work features the modelling and optimization process of Carica Papaya Leaf and Garcinia Mangostana Pericarp through Naturally fermented production through SuperPro Designer, a commercial batch process simulator. It is assume that 1000 kg of raw material from Carica Papaya Leaf and Garcinia Mangostana Pericarp was used in this simulation process. The final alternative that has been choosen collects its annual revenue amounted to 8 407 000 \$ (USD) and its gross margin rate is at 31.25%. Beside the Return on Investment (ROI) rate is at 112.69% and it Internal Rate of Return (IRR) after taxes deduction is at 46.33%. The Payback Period was estimated to complete within 0.89 years.

Keywords: process simulation, optimization, process debottlenecking, economic analysis.

I. INTRODUCTION

Garcinia mangostana, named after the French Laurent Garcin (1683-1751) or commonly known as Mangosteen is a tropical fruit commonly found in certain parts tropical Asia and is can be found native in Southeast Asia. As alternative medicine develops in notoriety, individuals are starting to look for natural, well-advancing nourishments, and supplements. It appears to be clear that organic medicine or supplements transcends ordinary in keeping up a healthy body. Mangosteen fruits weigh from 70-150g and they are for the most part thought to be one of the finest enhanced organic products with unique taste on the planet, outranking all other tropical fruits.

This fruit has commonly been used in traditional Asian medicine scene due to its natural health benefits through its strong antioxidants activity and medicinal properties of xanthones in its

pericarp (mangosteen by-product) which is assumed to be life-enhancing, thus deserves the title as “Queen of Fruits”. A recent research through a laboratory test known as ORAC proves that an ounce of Mangosteen juice provides 20 to 30 times more capacity or ability to absorb free radicals than an ounce of most fruits and vegetables. Aside of containing as much as 43 of the more than 200 Xanthones found in nature, it also contains a high concentration of vitamin C. It provides 12% out of the suggested daily value per 100 grams. As all know, vitamin C plays an important role in strengthening the immune system and fighting flu and other diseases. Therefore, eating food rich in vitamin C such as mangosteen is essential in order to keep staying healthy.

Nowadays, it can be seen that there are abundance production of product from fruits to be commercialized in various ways. However, by observing all of these production, it displays that there is an under-utilization of its raw materials which is, other parts of the fruit is not being utilized and it is discarded as waste. This is due to the fact that there is few research or existing process that has been done on the utilization of the fruit to its full potential including the outer parts of the fruit and also the leaf of the fruit that has always been considered to not bring any value to the production. Besides, there is also no existing economical analysis on the base process of the production that involves in utilizing the maximum potential of the fruit. Therefore, this work features the modelling and optimization of a Garcinia Mangostana Pericarp. It utilizes Naturally Fermented production process by using SuperPro Designer, a commercial batch process simulator and real process modelling.

Papaya has been widely used in alternative or folk medicine to treat many ailments. Papayas are excellent sources of dietary fiber, vitamin C, vitamin A, vitamin E, and folate, while at the same time being rich in antioxidants, flavonoids, and carotenes. The juice of papaya is usually being used to treat warts, corns, cancers, tumors and thickened skin. On the other hand, the extract of the roots is being used for uterus cancer, syphilis, tropical infection, haemorrhoids and removal of mineral concretions in the urine. The ripe fruit is utilized for rheumatism and alkalizing urine, to combat the seeds for intestinal worms and also to stimulate menstruation or abortion. Besides that, the unripe fruit act as a diuretic or mild laxatives other that stimulate lactation, labor or even abortion.

Furthermore, papaya leaves contains papain enzyme that is a rich source of anti-oxidants, specifically 20 times more powerful than Vitamin E. Although papaya leaf extract is often viewed as an excellent treatment for digestive disorders as well as disturbances of the gastrointestinal tract, the papain and chymopapain enzyme found rich in papaya has also been utilized around the world to eliminate parasites within the body. The potent antioxidant

activity of papaya leaf extract is due to the array of phenolic compounds such as caffeic acid, chlorogenic acid, quercetin and kaempferol which are the chief constituents.

Papaya leaf extract are one of the popular dietary supplements in Europe and fermented papaya products are commonly used in Japan for many decades. The papaya leaf extract is prepared by a natural fermentation process, after which the papaya is dried and ground into a powder. Fermented papaya extracts are obtained by natural fermentation process of mature green papaya over a period of several months

The main objectives of this research is to identify the optimum and possible process simulation for industrial scale production. Then design an economically viable production scheme for a locally developed *Garcinia Mangostana* Pericarp naturally fermented production process. Next to study the market economic analysis to find the best process for this industrial scale production that will give higher profit and benefit

In this work, SuperPro Designer v8.5 (Intelligen, 2005), a commercial process simulation tool, is used to develop an economically viable scheme for the production of *Garcinia Mangostana* Pericarp product. SuperPro Designer is a window-based simulation software for modelling biochemical, food, pharmaceutical, specialty chemical, as well as other continuous and batch manufacturing processes. In this research, there is three simulation process scheme that had been developed using Superpro Designer. The first scheme is the Base Scheme which is conducted using basic processing equipment for naturally fermented product. The First Scheme (Scheme 1) utilizes a parallel framework and it is part of the comparison analysis with the Base Scheme in terms of its efficiency and also its economic viability. The Second Scheme (Scheme 2) is an addition process to the Base Scheme that improves the add value and also the economic viability of the Base Scheme tremendously. The final alternative that has been chosen collects its annual revenue amounted to 9 887 000 \$ (USD) and its gross margin rate is at 84.04%. Beside the Return on Investment (ROI) rate is at 179.29% and it Internal Rate of Return (IRR) after taxes deduction is at 82.97%. The Payback Period was estimated to complete within 2.39 years.

II. METHODOLOGY

A. BASE CASE PROCESS SIMULATION

In the base case process there are six major processing steps involving 6 equipment that is divided to three different sections. The first section of the process is to grinding and blending the raw material with sugar and water. Second section is fermentation process that take place in 10000 litre fermenter that will ferment up to three months. The last section is to filter the solid waste and packaging the product.

In the first section, the grinder (P-2/GR-101) is assumed to have the capacity to grind 1000kg of raw material per batch with the process time of 60 minutes. The process of grinding involves the

work of breaking down large solid materials into smaller pieces. The product from the grinder will through stream (S-106) into a storage tank (P-4/V-102) where the process of blending takes place. During this process sugar and water is added to the tank with the ratio of 10% from the total process volume. Blending this three elements of material will take up a certain amount of time to ensure that the composition in the tank is well mixed.

Afterwards, the product of the blending process is transported through stream (S-101) into the fermenter (P-5/FR-101) to allow fermentation process to occur which is the second section of this process. The working volume allowable for this fermenter is 80% and the process time for the fermentation to complete is circa 3 months. After 3 months, the product of the fermentation process will then be moved into the centrifugation tank through stream (S-102). The centrifugation tank (P-1/BC-101) is an equipment that is designed for the removal of solid material. This is where the first part of the third section of this process takes place, which is the filtration process. The products undergo filtration process whereby the solid material is distinguished and removed from the product. The solid material consists of glucose, mangosteen pericarp and small amount of product which is in solid form. It is assumed that the component removal carries 98% tendency of solid glucose component and 98% tendency of mangosteen pericarp. While on the other hand, the product from the filtration is composed by the product itself and water which makes it exist in liquid form. The filtration process will take up about 3 hours to complete before it is transported for storage in storage tank (P-3/LD 101) through stream (S-103). In stream (S-104), the solid waste is being recycled and transported to storage tank (P-4/V-102) to undergo the whole cycle of the starting again, which revolves around the first and second section of this process. This exercise is carried out to ensure that the utilization of the raw material is at its maximum level. Storage tank (P-3/LD 101) is used to store the product of the filtration process before the work of packaging and bottling can be carried out and this tank has the capacity of 10 000 kg.

Lastly is the bottling and packaging process which involves the transportation of the product form the storage tank to the filling machine through stream (S-108). The bottling process involves the filling machine (P-6/FL101) with the capacity of 20 133 bottles per batch to fill 500 ml bottle in certain amount of time. The empty bottles will pass through stream (DS-101) while the filled bottles will be transported to the labelling machine (P-8/LB101) through stream (DS-102). The process of labelling preceded the filing process and the input for the labelling machine which is the label itself is being inserted by utilizing stream (DS-102). After the labelling process, the labelled bottle will then move to the conveyer belt (P-7/BC102) through stream (DS-104) which then being transported to packaging with the use of stream (DS-105). The filled bottles are then, packed manually by two operators into boxes of 12 bottle per box before they are sent out to the warehouse.

As the manufacturing process is carried out in continuous operation, efforts have been made to document the scheduling

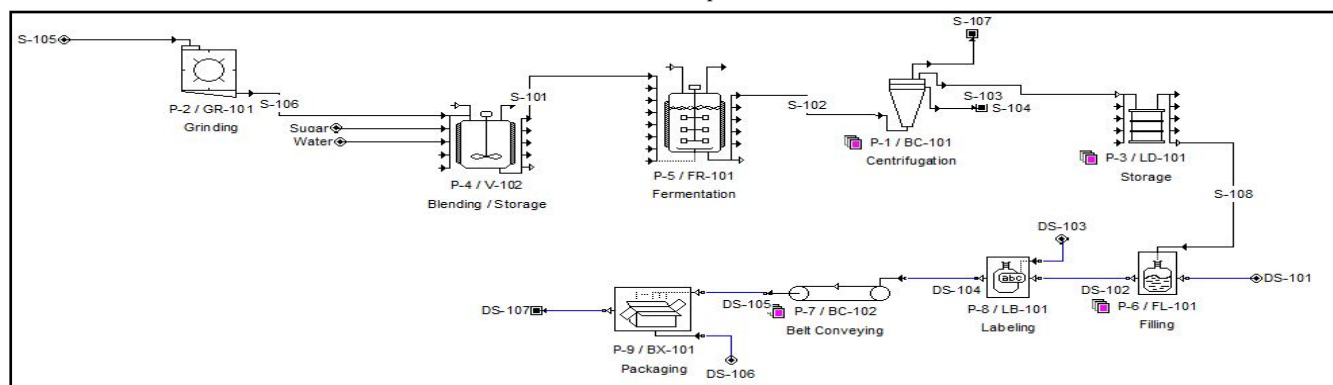


Figure 1: General Process (Base Case) simulation process

details of each processing steps. This includes the setup time, process time, and start time of each individual operation in each unit procedure. Setuptime (SUT) is the preparation time needed before an operation takes place. Often, this involves the loading of raw material (e.g., from loading area), equipment preparation or setup that often occur in Continuous processing. Process time (PT), on the other hand, represents the actual processing duration needed for each operation. Finally, start time (ST) documents the beginning of an operation. It also should be noted that the process time for certain operations are dependent upon other operations of other procedure. The process currently running at its maximum capacity and the demand for this product is expected rise in upcoming years. So the debottleneck the base case process will increase the production and also will develop solutions for future expansion. The details of this scheduling summary are shown the Operation Gantt Chart shown in Figure 2.

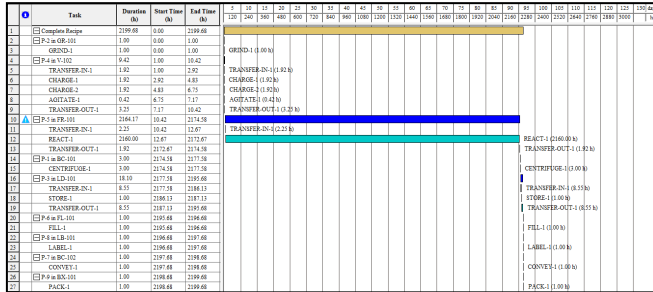


Figure 2: Operations Gantt Chart of base case simulation.

The total capital needed for the launch of this investment that undertakes general process (base case) is amounted to 1,095,000\$ (USD). In this project the operating cost can be broken down into three (3) main cost which are direct cost, fixed cost and general expenses. The operating cost for the production of the product through this process is amounted to 951,000\$ (USD) which took up to 87% of its capital investment. This is because the operating cost itself consist of fixed cost, direct cost and also general expenses that is needed for pre-production preparation and also to run the process fully once the preparation is set. Next, the revenue that is collected by utilizing the general process is amounted to be 2,013,000\$ (USD) per year. The amount of revenue collected proves to be almost 2 times of its cost. The unit production cost and unit production revenue is being calculated based on per box basis. Each of the boxes contains a dozen of bottles (12 bottles). For instance, the unit production cost is 188.85\$/MP Entity which means that the amount of that cost is per box. The amount of unit production cost in per bottle wise will then be amounted to 15.74\$ per bottle. This mechanism also applies to the unit production revenue which is 400\$ per box. Besides, the gross margin of this production is a high percentage of 52.79% which indicates the ability to retain enough money to service the sales and its debt obligations. Furthermore, the return of investment (ROI) for this process is 66.60%. The return rate if investment helps to determine the efficiency of the investment thus which such positive rate of ROI, it can be determined that process proves to be viable for investment. The payback time needed to recover the investment that's being put in is circa 1.50 years. The Internal Rate of Return which is after being taxed, is 36.64% and the net present value at 7.0% interest is 3,649,000\$ (USD). With both economic parameters indicates a positive figure it can be said that this base case process is viable enough to be undertake on.

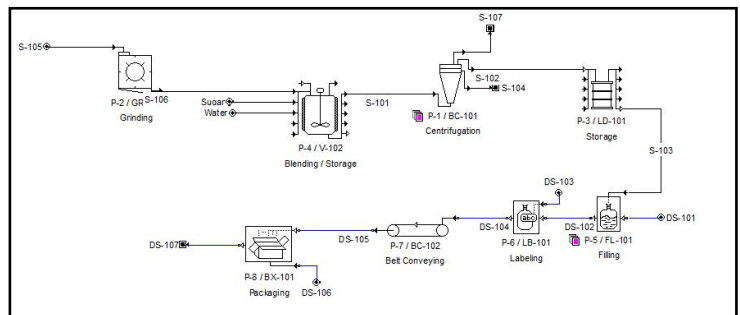
Cost item	Price (RM)	% contribution
Raw material	22,000	2.28
Labor-Dependent	747,000	77.46
Facility-Dependent	181,000	18.77
Transportation	14,400	1.49

Table 1: Annual operating cost break down of base case simulation

B. DEBOTTLENECK IDENTIFICATION STRATEGIES

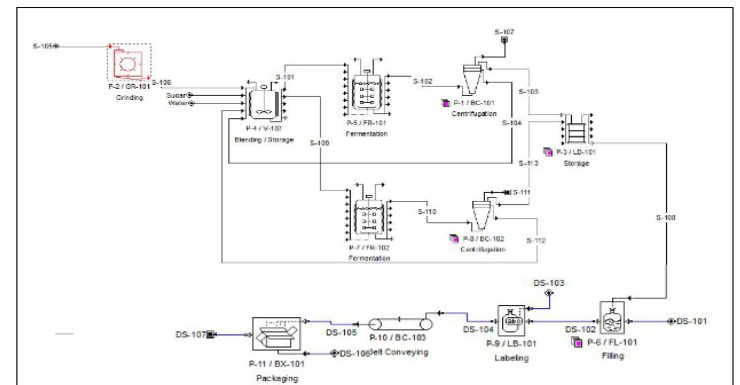
The previous section determined that the current production of Carica Papaya Leaf and Garcinia Mangostana Pericarp is economically infeasible due to the low revenue generated by the low annual production rate. However efforts to increase production were limited by the process scheduling bottleneck, i.e., fermentation process P-5/FR-101. Two debottlenecking schemes were developed based on the base case simulation. These schemes were analysed to evaluate their viability to increase the plant annual production. Economic evaluation was also performed to evaluate all debottlenecking schemes to identify the most economically attractive option. The debottlenecking schemes were developed based on the base case simulation. These schemes were analysed to evaluate their viability to increase the plant annual production. Economic evaluation was also performed to evaluate all debottlenecking schemes to identify the most economically attractive option.

This process is called scheme 1 (Parallel Process). Basically this process is identical with the base case process as it uses the same raw material and the same process flow. The only difference with Scheme 2 if to compare with base case process is that the number fermentation tank and the centrifugation tank is doubled and are put parallel to each other. In this process there are six major processing steps but involve 8 equipment that is divided to three different sections. The first section of the process is to grinding and blending the raw material with sugar and water. Second section is fermentation process that take place in 10000 litre fermenter that will ferment up to three months. The last section is to filter the solid waste and packaging the product



Parallel Process (Scheme 1)

By referring to the base case process, another alternative process framework which is called Scheme 2 (Add On Juice Process) has been developed in order to maximize the potential use of the raw materials (mangosteen pericarp and papaya leaf). From the previous process, the raw materials needed for that process is just the outer part of the fruit which is either mangosteen pericarp or papaya leaf. In this process, a way to utilize the fruit flesh is being developed. There are five major processing steps involving 5 equipment that is divided to three different sections.



Base Case + Juice Process (Scheme 2)

III. RESULTS AND DISCUSSION

The purpose of conducting a comparison analysis between General process (base case) and parallel process (scheme 1) is simply because both of these two process is being developed to process mangostana pericarp and papaya leaf. The end goal of this comparison analysis is to find the most efficient process that is also economically viable to be adopted as the prime process for the production of the product. This can be done by looking through the economic parameters. These economic parameters can be broken down into two scope which is the efficiency of the process and also the attractiveness of the economic return.

Through the efficiency of the process, the economic parameters that able to display a good comparison analysis example is by looking at both Unit Production Ref. Rate and also Batch Size. Both of these parameters have the same unit that is per box unit. By basing to this parameters, it is can be seen that Scheme 1 produces a better Unit Production Ref. Rate which is 7 550.40/MP Entities while the Base Case only produces 5 033.47/MP Entities. This also resonates to the batch size of both processes. For Scheme 1, the batch size that is produced is 2 516.80/MP Entities while for Base Case is around 1 677.82/MP Entities. Through this two parameters, it can be seen that Scheme 1 process has a higher efficiency by producing bigger amount of Batch Size and also higher rate of Unit Production Ref. Rate. The other parameters such as Annual Operating Time, Recipe Batch Time and also Recipe Cycle Time is not being highlighted is because there is only a small margin of difference between the two process but through the small margin also, Scheme 1 proves to have the higher rate than the other. The only parameters that is constant is the Number of Batches per year where both of them produces 3 batch annually. Other than that, although the Unit Production Revenue for both process remains stagnant at 400\$ (USD), the Unit Production Cost of Scheme 1 drops a little lower than Base Case which is 158.86\$ (USD) for Scheme 1 and 188.85\$ (USD) for Scheme 2. This indicates that Scheme 1 has a better efficiency of its process thus lowering the unit production cost.

Next is through economics viability. Monetary wise, the Annual Revenue collected by Scheme 1 is higher than Base Case that is for Scheme 1, it is amounted to 3 020 000\$ (USD) while for Base Case is 2 013 000\$ (USD). Although it can be argued that the Annual Operating Cost for Scheme 1 is a bit higher than Base Case, the

margin gap of revenue for both of this process is bigger. For instance, the Annual Operating Cost for Scheme 1 is 1 199 000\$ (USD) while for Base Case is 951 000\$ (USD). The margin gap between the cost of both process is only around 248 000\$ and this is dully to the fact of the addition of machineries and tank in Scheme 1 through its parallel framework and also to increase the efficiency of the process. While on the other hand, the margin gap for both of the process is amounted to 1 007 000\$ (USD) which is 4 times of the margin gap between the operating cost of both processes. On the other hand, the Return on Investment (ROI) of Scheme 1 is slightly lower that is by 53.94% as to be compared with Base Case that is by 66.60%. The payback period for Scheme 1 is also a bit longer for it to be able to pay its obligations that is 1.85 years while for Base Case its 1.5 years. Although the rate of Return on Investment (ROI) of Scheme 1 is a bit lower that Base Case, it is a positive and viable rate. In addition, the ROI between those processes also comprise of only a small gap between them. This is also reflected with the Payback Time. The difference between the time gap relatively small with a difference of only 0.35 years.

On the contrary, the Gross Margin of Scheme 1 is relatively higher than Base Case with 60.28% for Scheme 1 and 52.79% for Base Case which indicates that Scheme 1 more attractive for investment than Base Case. Furthermore, the Internal Rate of Return after taxes being deducted is 36.64% for Base Case and 34.92% for Scheme 1 which brings to a small difference of 1.72%. Lastly, there is quite a gap between the Net Present Value (NPV) at 7.0% interest whereby for Scheme 1, the NPV is at 6 463 000\$ (USD) while for Base Case is at 3 649 000\$ (USD). This indicates that the NPV of Scheme 1 is double the NPV of Base Case.

In Conclusion, by looking at the economic parameters that comprises of both scope of efficiency of the process and also the attractiveness of the economic return, it can be inferred that Scheme 1 proves to have a higher efficiency in terms of its production capacity and consist of a more viable economic return which makes the Scheme 1 process framework is an attractive investment.

From the comparison made before on general process (base case) and parallel process (Scheme 1), it is proven that the parallel process is better due to its efficiency and attractive economic return. This is duly because there is an addition element in the

Economic Parameters	Base Case	Scheme 1	Scheme 2
Annual Operating Time (hour/h)	6 528.01	6 550.14	7 919.92
Unit Production Ref. Rate (per box/MP Entities)	5 033.47	7 550.40	656 140.63
Batch Size (per box/MP Entities)	1 677.82	2 516.80	1 155.18
Recipe Batch Time (hour/h)	2 199.68	2 217.14	29.17
Recipe Cycle Time (hour/h)	2 164.17	2 166.50	13.92
Number of Batches per Year	3	3	568
Total Capital Investment	1 095 000	2 416 000	1 383 000
Annual Operating Cost (\$)	951 000	1 199 000	5 413 000
Annual Revenue (\$)	2 013 000	3 020 000	7 874 000
Unit Production Cost (\$/box)	188.85	158.86	8.25
Unit Production Revenue (\$/box)	400	400	12
Gross Margin (%)	52.79	60.28	31.25
Return on Investment (%)	66.6	53.94	112.69
Payback Time (years)	1.5	1.85	0.89
Internal Rate of Return (After Taxes)	36.64	34.92	46.33
Net Present Value - at 7.0% Interest (\$)	3 649 000	6 463 000	8 407 000

Table 2: Economic Evaluation

process itself which is the increase number of its machineries (fermenter and centrifuge tank) that create additional sub process which reflects the parallel process framework. Here, the addition element is also being introduced to the general process (base case) whereby another process is being added which is the juicing process. The idea of this process is being developed in order to address the excess waste from the raw materials which is the flesh of the fruit (ie: Mangosteen). It is understood that the raw material for general process is basically mangosteen pericarp and papaya leaf. Thus there is a waste of the fruit flesh itself. Through this abundance of extra resources, a juicing process is being developed to avoid wastage and also to fully utilize the potential of the fruit at its maximum level. The end product of this process is the mangosteen juice that contains health benefit that is going to be commercialized as common beverages.

Therefore, by referring to the above table, there is an increase in economic return of the new Base Case with the incorporation of Scheme 2 which is the juice process itself. The new Total Capital Investment is amounted to 2 478 000\$. The operating cost on the other hand, has risen to 6 364 000\$ and same goes to its revenue collected which is amounted to 9 887 000\$ that is almost 10 million (USD). Its Unit Production Cost per box has only a small increase from 188.85\$ (USD) per box to 197.1\$ (USD) per box with the introduction of Scheme 2 or the juicing process. The Gross Margin also corresponds with the increase of 31.25% making the new Gross Margin of Base Case with addition of Scheme 2 is circa 84.04%. The payback period of the new process is takes a bit longer with 2.39 years needed to settle its debt and obligations if to be compared with the original process (base case) that needs only 1.5 years to complete. Although with such minor of payback period, the base case process with the addition of scheme 2 with its process have a relatively high Return on Investment which is at 179.29% of investment while the original base case process gathers it Rate of Investment only at 66.6%. Furthermore, the difference between the payback period is only around 0.89 years but the increase of the ROI is at 112.69% that is almost double the original base case only ROI. The tremendous motivation was created by the new process that have an ROI of more than 100% although it takes a bit longer time to complete its obligations. Thus, this indicates that the new process of Base Case and Scheme 2 proves to be an attractive investment. Other than that, the Internal Rate of Return (IRR) after being taxed, also improves tremendously from the rate of 36.64% from the base case process alone, to 82.97% from when the juicing process that is Scheme 2 is being introduced to the base case process.

Lastly, the Net Present Value or NPV at 7% rate of interest also displays an incremental effect where the base case NPV that is at 36.64% rose to 82.97% when Scheme 2 is being added to the process. In conclusion, after looking at the economic parameters of the new process which introduces the Scheme 2 (Juice Process) to Base Case (General Process) has given a positive indication of its economic return thus signalling that this option of process is a viable and profitable process to be ventured into.

IV. CONCLUSION

The comparison analysis of the three (3) process is being done first of all is to find a process that gives the most added value that will eventually be adopted as a prime process to produce the product. It can be seen clearly that there are two process that proves to be better than the one process which is the parallel process and also the general process with the introduction of juice process. The parallel process had a better efficiency in terms of its added value. However, the general process with the addition of juice process does not only provides a more attractive economic return, it also maximizes the potential use of the raw materials by utilizing both inner and outer part of the fruit. Thus there will be no wastage and also omit the cost of dealing with it. Thus, it can be

inferred that the general process with the addition of juice process is the more favored process in terms of its attractiveness of investment viability also its own added value.

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