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DESIGN AND DEVELOPMENT OF A GRATING MACHINE FOR WET SAGO STARCH PRODUCTION

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By

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DESIGN AND DEVELOPMENT OF A GRATING MACHINE FOR WET SAGO STARCH PRODUCTION

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This thesis describes a study on the design, fabrication and testing of a prototype grating machine for wet sago starch production. In order to extract the starch, the mechanical method is required to break the trunk and producing fine grated sago. The more refined the grated sago produce, the more sago starch can be dissolved in water during the extraction process. In this case, it was reported that 65.7% of sago starch remained inside the residue. A new technology has been developed to overcome the issue. The determination of physical and mechanical properties of sago trunk was conducted as a prerequisite for designing process. A primarily study was conducted on Handheld Chainsaw, Roller Grater, Coconut Husk Decorticator and Coconut Grinder to determine the grating speed, grated sago size distribution and grating contact area. The result shown that the hand chainsaw produced the highest percentage of finer grated sago (56.80%: $X \leq 0.85$ mm) and the lowest teeth contact surface area of 4 mm2. However, it has the lowest capacity. A further study was conducted to determine the effect of grated sago sizes on starch recovery at different steeping periods and. As a result, a substantial amount of starch could be recovered from grated sago by reducing the grated size at $X<0.30$ mm which was up to 58% of the extraction efficiency. The increment of the steeping period from 5 min up to 24 hours increased the starch recovery. However, a longer steeping period showed an insignificant difference ($P>0.05$).

A new concept of sago grater was designed and developed. Initially, an assessment of sago grating machine design requirement was conducted using surveys. All the needs and goals were divided into several sub-objectives. The sub-objective was converted into functions modeling to generate sub-functions and then select the appropriate technology. A Morphological Chart was used to produce 6 complete system concepts. The selection of complete system concepts was based on matrix assessment and detail design of concept was generated for the fabrication process. The newness of sago grating machine has the advantages over the existing machines. It does not require conducting a debarking process (20 minutes per log). The machine has the capability to adjust the feeding height (0 cm to 5 cm) according to the sago trunk diameter size which is minimizing the losses during the grating process. The design novelty, the grater disc has ability of adjusting the disc diameter size (40 cm to 48 cm), which is no need to be made in various of sizes and each single part of grater teeth can be replaced to reduce the maintenance costs. The grating capacity was 45.9 kg/min with a total starch recovery percentage was 19.86±0.14% and at 47.97%.of extraction efficiency.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

REKA BENTUK DAN PEMBANGUNAN MESIN PEMARUT UNTUK PENGELUARAN KANJI SAGU BASAH

Oleh

WAN MOHD FARIZ WAN AZMAN

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Tesis ini menerangkan tetang kajian reka bentuk, fabrikasi dan pengujian prototaip mesin pemarut bagi pengeluaran kanji sagu basah. Untuk mengekstrakan kanji, kaedah mekanikal diperlukan untuk memecahkan batang pokok bagi menghasilkan parutan halus. Semakin halus saiz parutan, semakin banyak kanji sagu dapat dilarutkan di dalam air semasa proses pengekstrakan. Dalam hal ini, ianya dilaporkan sebanyak 65% kanji yang masih terdapat dalam hampas sagu. Satu teknologi baru telah dihasilkan bagi mengatasi isu ini. Penentuan sifat fizikal dan mekanikal batang sagu dilakukan sebagai prasyarat untuk proses mereka bentuk. Seterusnya, kajian pra-awalan dilakukan keatas Mesin gergaji tangan, Mesin pemarut penggelek, Mesin pelerai sabut kelapa dan Mesin pemarut kelapa untuk menentukan kelajuan memarut, taburan saiz parutan dan keluasan sentuhan parutan. Kajian menunjukkan Mesin gergaji tangan menghasilkan sagu parut halus tertinggi (56.80%: X≤0.85 mm) dan keluasan sentuhan parutan terendah (4 mm2). Walaubagaimanapun, kadar kapasitinya terendah (5 kg/min). Kajian lanjutan dijalankan untuk mengkaji kesan saiz parutan terhadap hasil kanji sagu yang diekstrak pada tempoh rendaman berbeza. Hasilnya, didapati sejumlah kanji sagu dapat diekstrak dari sagu parut bersaiz X<0.30 mm dengan kadar 58% kecekapan pengekstrakan. Peningkatan tempoh rendaman dari 5 minit ke 24 jam menunjukan peningkatkan hasil kanji sagu berlaku. Namun, jika lanjutkan tempoh menunjukkan perbezaan yang tidak signifikan (P>0.05).

Konsep mesin pemarut sagu telah direka bentuk dan dibangunkan. Awalnya, penilaian terhadap keperluan rekabentuk dilakukan menggunakan kaedah tinjauan. Kesemua maklumat keperluan dan sasaran dibahagikan kepada beberapa Sub-Objektif. Semua Sub-Objektif diubah kepada Pemodelan Fungsi untuk menghasilkan Sub-Fungsi dan kemudian pemadanan teknologi dilakukan. Carta Morfologi telah digunakan untuk menghasilkan 6 konsep

sistem lengkap. Pemilihan konsep dilakukan berdasarkan Penilaian Matriks dan konsep terpilih diperincikan untuk proses fabrikasi. Mesin pemarut sagu yang dihasilkan mempunyai kelebihan berbanding mesin yang ada. Antaranya ialah tidak memerlukan proses pengupasan kulit (20 minit per batang). Selain itu, ketinggian kedudukan masukan bahan boleh dilaras (0 cm hingga 5 cm) bergantung kesesuaian saiz diameter bahan bagi meminimumkan kadar kehilangan semasa proses pemarutan. Noveltinya, mesin ini mempunyai saiz diameter cakera pemarut yang boleh dilaras (40 cm hingga 48 cm), oleh itu cakera pemarut tidak perlu disediakan dalam pelbagai ukuran saiz. Manakala setiap bilah pemarut pula, ianya boleh ditanggalkan sekiranya rosak bagi mengurangkan kos penyelenggaraan. Kapasiti memarut adalah 45.9 kg/min dengan jumlah peratusan hasil kanji 19.86±0.14% dengan 47.97%. kecekapan pengekstrakan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

A	Cross section area [cm^2]
A_c	Cutting surface area [cm]
A_w	Material surface area [cm]
ANOVA	Analysis of variance
B	Bottom section
CAD	Computer aided design
D_b	Diameter of piston bore [cm]
D_m	Mode value of sago trunk diameter [cm]
d	Diameter [cm]
d_r	Diameter of piston rod [cm]
F	Force load [N]
F_k	Friction force [N]
F_t	Tangential force [N]
F_n	Normal force [N]
FS	Safety factor
FEA	Finite element analysis
FEM	Finite Element Method
G_u	Percentage of ungrated sago [%]
g	Gravity acceleration [9.81 m/s^2]
H_2O	Pure water
h	Height [cm]
h_1	Height of teeth cone [cm]
J_2	Second deviatoric stress invariant reaches a critical value
L	Length [cm]
L_d	Penetration depth [cm]
M	Middle section
M_c	Machines capacity [kg/hour]
MC%	Percentage of moisture content
m_t	Weight/ length [kg/cm]
$Na_2S_2O_5$	Sodium metabisulphite
n_s	Total pieces of sago trunk splits
P	Pressure [N/cm^2]
P_c	Sago trunk structure resistance to fracture acting at direction perpendicular to the fiber orientation [N]
P_w	Sago trunk structure resistance to fracture acting at direction parallel to the fiber orientation [N]
r	Radius [cm]
r_{max}	Maximum of radius [cm]
r_{min}	Minimum of radius [cm]
SD	Standard deviation
TSC	Total starch content
T	Top section
T_p	Penetration time [s]
T_t	Total time or grating process [hour]
t	Thickness [cm]
t_c	Average of sago trunk bark thickness [cm]
W	Rotation speed [rpm]

W_i	Initial weight [kg]
W_f	Final weight [kg]
W_g	Weight of grated sago [kg]
WPR%	Weight percentage ratio
w	Weight [kg]
w_f	Weighed of bark waste output [kg]
w_b	Final weigh of sago bark [kg]
w_t	Weighed of half splits sago trunk [kg]
v	Feeding speed [cm/s]
σ_y	Yield strength [Pa]
θ	Angle of repose [deg]
μ_k	Coefficient of kinetic friction
3D	Three dimensional

CHAPTER 1

INTRODUCTION

1.1 Background

Starch is a substance used in numerous staple food and a popular ingredient in several industrial products. Many staple food contains starch which is a common carbohydrate in the human diet. Various types of carbohydrates contain essential nutrients and as a source of energy. Recently, major sources of starch were produced from cereals and root (Anne-Charlotte and Eliasson, 2004). According to global reports in 2002, starches produced from cereals were approximately about 2050 million tonnes and, from roots and tubers was about 679 million tonnes (Tester and Karkalas, 2002). It is clear that starch is the predominant form of stored carbohydrates in plants and, the starch granules size and shape are species-specific (Stark and Lynn, 1992). The most common reserve carbohydrate in plants is starch and others such as hemicellulose and glucans, and it was utilised as a source of energy (Hoch, 2007). Starch is derived from cereals (corn, wheat, rice, sorghum), tubers (potato, sweet potato), roots (cassava), legumes (mung bean, green pea), and also from the palm stem (sago palm). In addition, the local starch source is different according to the respective areas.

In the starch production industry, it is required to extract the native starch between the fibre pith. Materials such as cereals, tubers, roots, legumes, and stem need to go through several processes which are preparation, size reduction, extraction, separation, and drying for a dry base product. Figure 1.1 shows the basic process flow of starch processing according to the different types of raw material. For the starch extraction process, firstly the preparation process is dehusking, decorer, peeling and debarking of the raw material is required to remove parts that are not involved in the extraction process which is do not contain a substantial amount of native starch such as an outer layer (bark). Furthermore, the material will complete the size reduction process such as grinding, milling, rasper, and grating which aims to break the fibre structure into a fine size so that the starch can be extracted as much as possible during the extraction process. A common practice is adding water during or after this process to dissolve the native starch that is mixed up with fibre produces starch which is in a slurry form (Flach, 1983). Then, the native starch is separated from the slurry material using a sieve to filter the fibre and other impurities. After that, the starch solution is temporarily collected inside a tank for the sedimentation process. The final step is the separation process which removes water at the top surface of the holding tank and those left in the tank is called wet sago. In several situations, the wet sago will be dried to produce a dried sago powder.

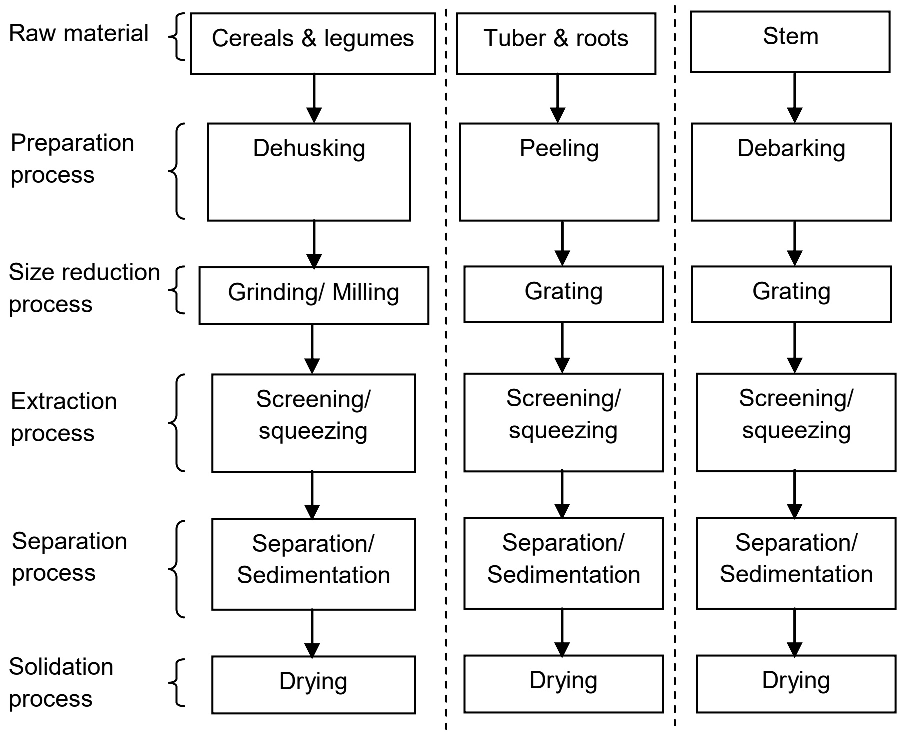

Figure 1.1: The general process flow of starch processing

1.2 Starch application

The use of starch has a wide range of application in the food and manufacturing sector. In the food industry, starch is usually used as an ingredient in traditional cakes and as an additional texture in drink products. For example, it has been estimated that about 70% of the starch is used to manufacture syrups for food (Tester and Karkalas, 2002). Starch is also widely used in processed food as a thickener and texturiser, as it gelatinized when heated in water to form pastes. Starch product is used in the agro-industry, biopesticides, bioethanols, cosmetics, and in the pharmaceutical sector of the food industry (Bintoro, 2011). In addition, starch pastes are incorporated in non-food fields such as in the production of paper and board (Ellis et al., 1998; Blennow et al., 2003), biodegradable plastics, and packaging materials (Zhang et al., 2014).

In Malaysia, the main source of carbohydrates (starch) is from rice which is a staple food. The total hectarage of paddy planted was reported to be about 525,043 hectares in Peninsular Malaysia which is approximately equal to 2,659,794 metric tonnes of production (DOA, 2018). However, it is different in Sarawak since most of the starch source is from sago palm (*metroxylon spp.*). Besides, it is used as a staple food or animal feed, and also as a raw material in the processing industry (Ishizaki, 2009). Sarawak has a large area of swampy land that is suitable for sago palm plantation. Furthermore, the sago industry in Sarawak is very well-established and became a significant industry which contributed to the export of state revenue (Kamal et al., 2007; Karim et al., 2008). However, sago palm cultivation is very encouraging in Peninsular Malaysia, but the crop area is only 13.3 hectares compared to Sarawak which is 61,561 hectares. In addition, the total output of sago starch production in Malaysia recorded about 184,163 metric tonnes in 2015 (DOA, 2015) and increased to 212,447 metric tonnes in 2017 (DOA, 2017). By considering its potential, the sago starch industry should be empowered to increase state revenue and improve the local social-economic status.

1.3 Problem Statement

Vikineswary et al. (1994) and Abd Aziz (2002) reported that after the extraction process, about 65.7% of sago starch remained inside the residue. Linggang et al. (2012) stated that there was 58% of starch inside the sago pith waste. The residues were disposed, and it is assumed that only 34.3% of sago starch was successfully extracted. In other words, considering the price and loss percentage, Malaysia recorded a production of 212,447 metric tonnes of sago starch in 2017 (DOA, 2017) which is considered to be equivalent to 34.3% of output and assuming that the remaining sago starch has not been extracted from the residue is about 65.7% which is equivalent to 406,932,770 metric tonnse. The exports value of sago starch was approximately worth RM 2000.00 per metric tonnes (DOAS, 2010). Therefore, the remaining sago starch inside residue is worth RM 813.87 billion. The increased efficiency of the extraction process by 1% will significantly increase the production output about 6193 metric tonnes that is approximately equivalent to RM 12.37 million per year.

The low sago starch yield is mainly due to the inefficient processing approaches. In general, the sago starch production involves several processes which are log debarking, size reduction, grating, extraction, sedimentation, and separation. Among these processes, the sago process has been identified as one of the main factors for the losses of the starch, which is related to grated sago size produce by grater machine. The grated sago size is an important factor since it affects the starch extraction process in terms of quantity. It is clear that to producing a fine grated sago is important to increase the effectiveness of the extraction process in producing higher starch recovery. Many existing sago grating machines design was focused on the basic function of size reduction and less assessing the material preparation, maintenance cost, percentage of fine grated sago produced, operator safety, and handling method (Darma et al., 2017; Kencana Jaya Teknik, 2017; Agrowindo, 2011). As a common practice, the sago trunk preparation is needed to remove the outer layer (debarking process) which is performed by using the special axe before being split into several small pieces. The literature shows that there are no available sago grating machines that can be operated without removing the trunk bark. The sago trunk has a hard bark and a soft core, since that the debarking process needs to be done with care. Lack of handling experience can cause the trunk core to still be attached on the bark which is not going through the grating process which is contributed to losses. The debarking process for a sago trunk with a length of 1 meter takes about 20 minutes on average per log based on an observation that was conducted at a processing factory in Mukah, Sarawak. The local factories can process up to 20 logs daily which contributed to the total time of debarking process to about 6 hours 40 minutes. In other words, it is possible to shorten the production period if the sago production can be performed without debarking process. Indirectly, it is able to increase the processing capacity per day. Currently, there are 2 types of sago graters normally used which are roller and disc grater type. Normally, the grater teeth will be nailed permanently to a rounded wood for disc type. Similarly, the roller grater teeth is welded permanently to the roller shaft surface that is made of steel. Therefore, both types of grater are high maintenance in cost since all sets of teeth of the grater need to be replace if they are worn out or damaged due to the high load during operating although only a few teeth were damaged.

1.4 Objectives of Study

The main objectives of this study are to design and develop a sago grating machine. The goal of developing the sago grating machine was to develop a grater machine that is able to produce a suitable grated sago size which can increase the sago starch recovery during extraction process. Also, the study aims to design a machine that is low in maintenance cost and possess easy-to-operate criteria. The specific objectives are as follows:

1. To determine the physical properties of the trunk at different sections of height, and the mechanical properties of the sago trunk (*metroxylon spp.).*
2. To design and develop a sago grating machine with a pusher mechanism, adjustable feeding platform mechanism, and grater blade teeth to produce high starch recovery.
3. To analyse the performance of grating machines in term of grated sago size, starch recovery, and machine efficiency at different grating and feeding speed.

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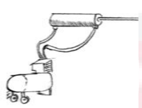
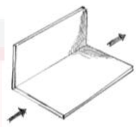
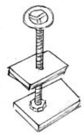
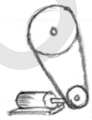
APPENDICES

A1 Assembles of conceptual ideas

Table A1: Accumulated of sub-function concept for complete system 1.

Sub-function	Pusher Mechanism	Feeding platform	Feeding adjustable	Grater disc	Power train
	Pneumatic	L Shape	Screw	Cylinder roller	Belting
Complete system 1					

(Source: Author, 2019)

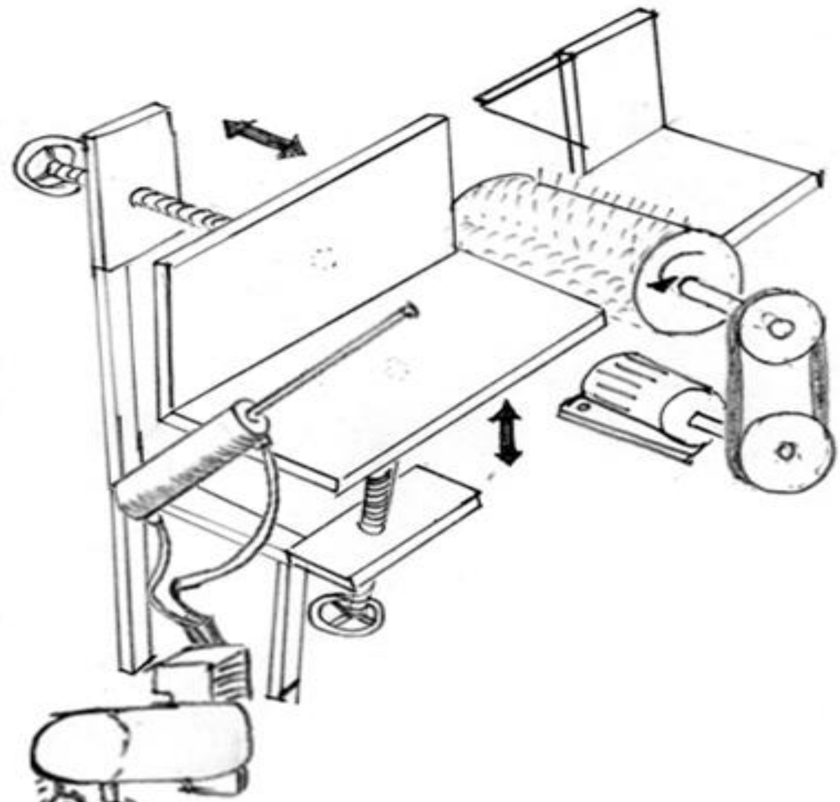
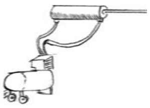
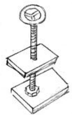
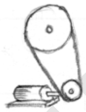


Figure A1: Complete system concept 1. (Source: Author, 2019)

Table A2: Accumulated of sub-function concept for complete system 2.

Sub-function	Pusher Mechanism	Feeding platform	Feeding adjustable	Grater disc	Power train
	Pneumatic	L Shape	Screw	Disc spinner	Belting
Complete system 2					

(Source: Author, 2019)

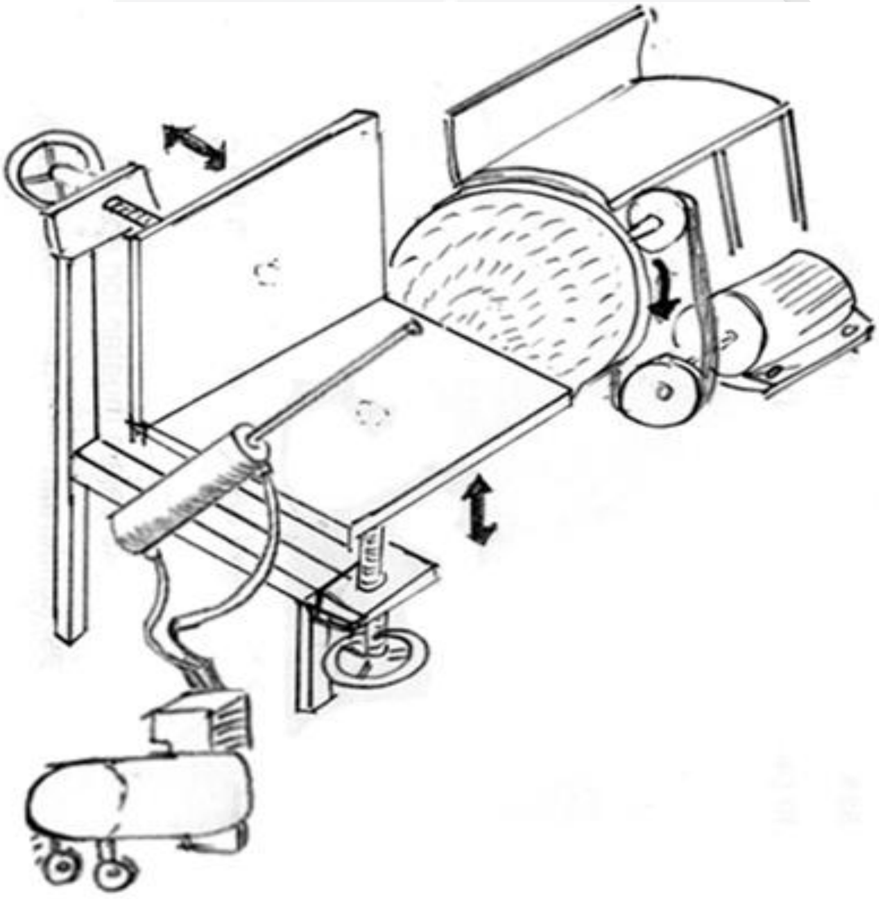
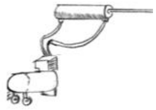
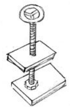
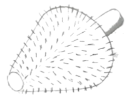
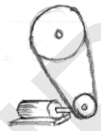


Figure A2: Complete system concept 2. (Source: Author, 2019)

Table A3: Accumulated of sub-function concept for complete system 3.

Sub-function	Pusher Mechanism	Feeding platform	Feeding adjustable	Grater disc	Power train
	Pneumatic	L Shape	Screw	Drum spinner	Belting
Complete system 3					

(Source: Author, 2019)

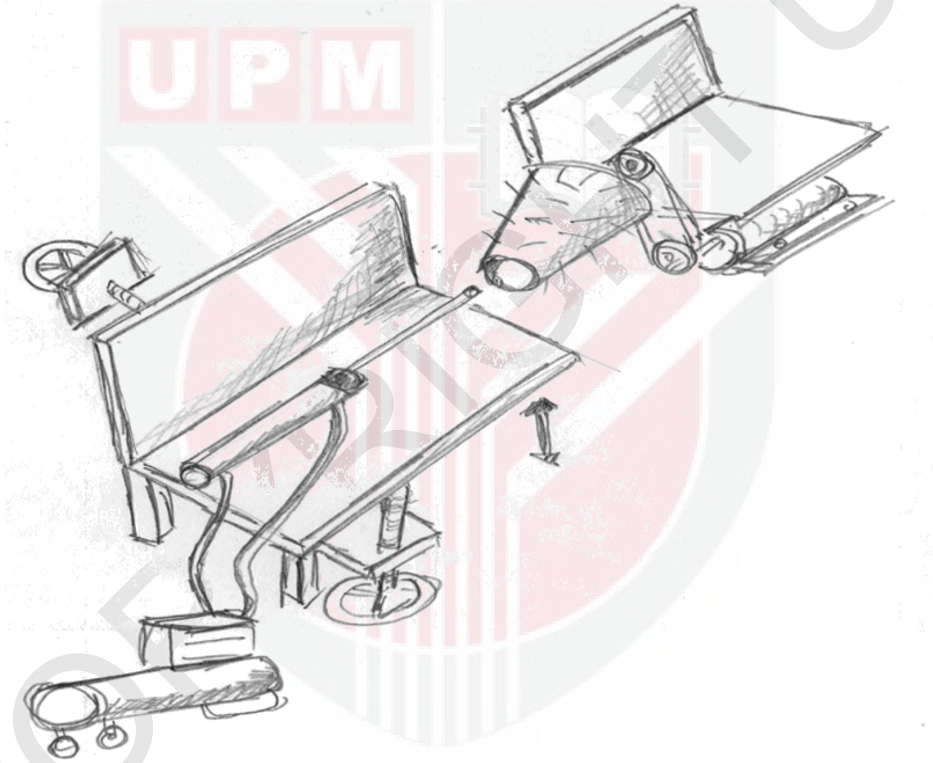
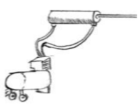
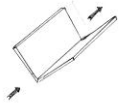
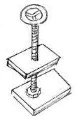
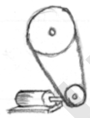


Figure A3: Complete system concept 3. (Source: Author, 2019)

Table A4: Accumulated of sub-function concept for complete system 4.

Sub-function	Pusher Mechanism	Feeding platform	Feeding adjustable	Grater disc	Power train
	Pneumatic	V Shape	Screw	Cylinder roller	Belting
Complete system 4					

(Source: Author, 2019)

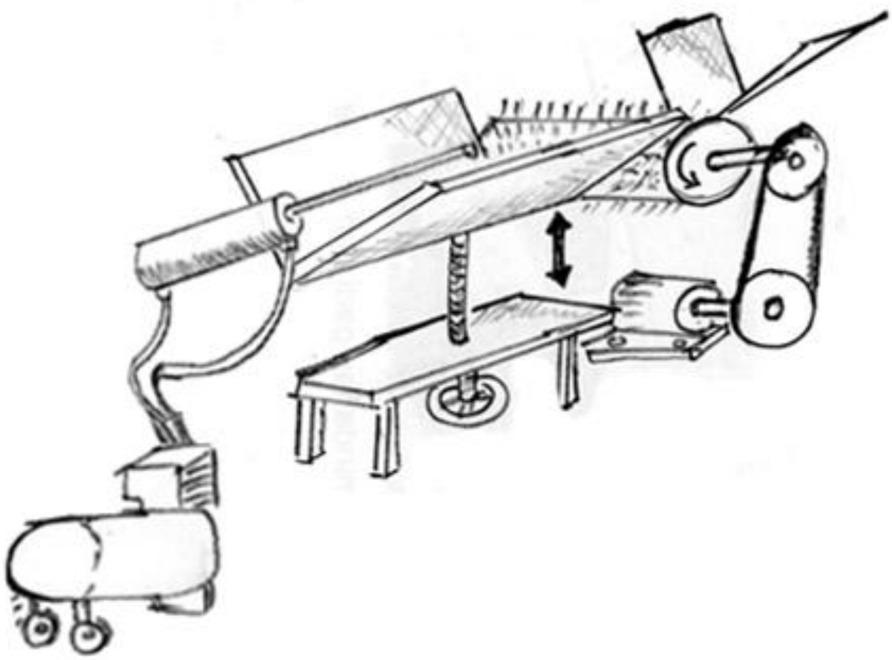
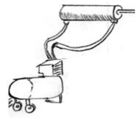
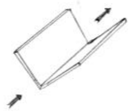
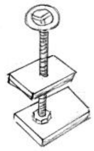
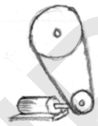


Figure A4: Complete system concept 4. (Source: Author, 2019)

Table A5: Accumulated of sub-function concept for complete system 5.

Sub-function	Pusher Mechanism	Feeding platform	Feeding adjustable	Grating disc	Power train
	Pneumatic	V Shape	Screw	Disc spinner	Belting
Complete system 5					

(Source: Author, 2019)

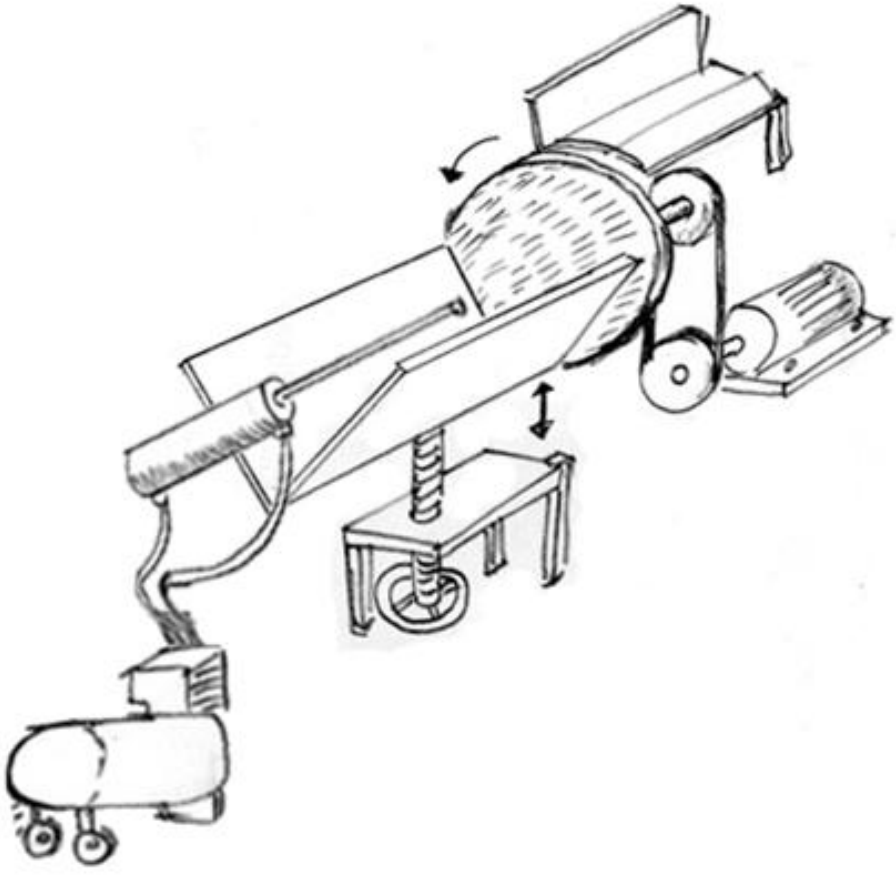
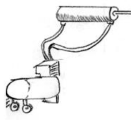
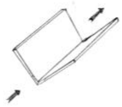
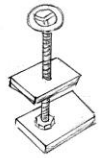
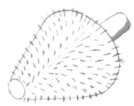
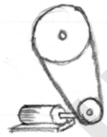


Figure A5: Complete system concept 5. (Source: Author, 2019)

Table A6: Accumulated of sub-function concept for complete system 6.

Sub-function	Pusher Mechanism	Feeding platform	Feeding adjustable	Grating disc	Power train
	Pneumatic	V Shape	Screw	Drum spinner	Belting
Complete system 6					

(Source: Author, 2019)

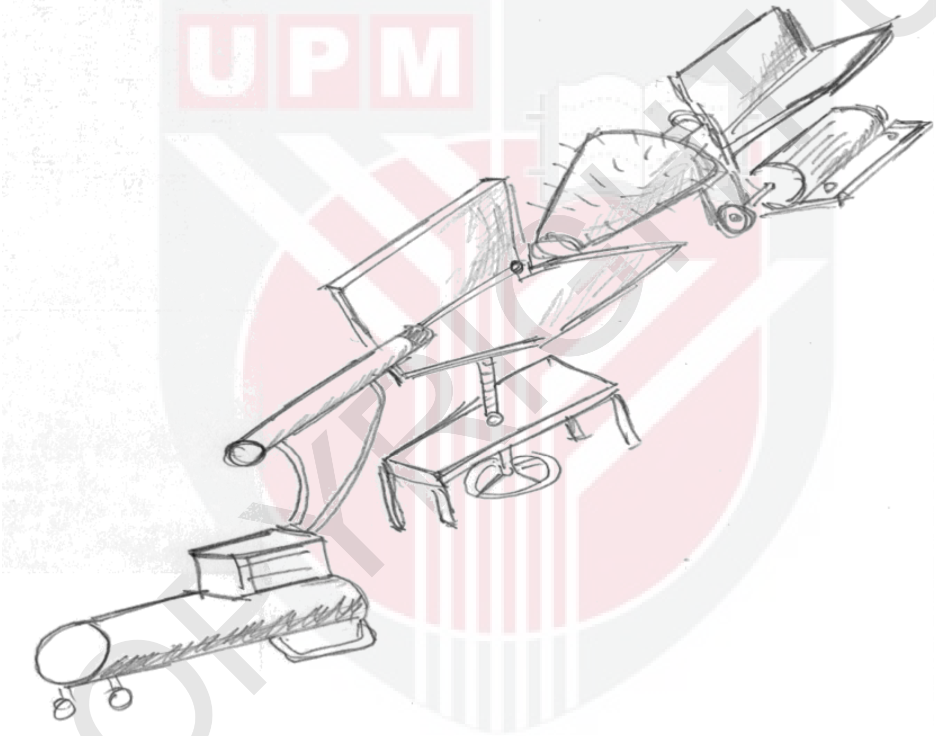
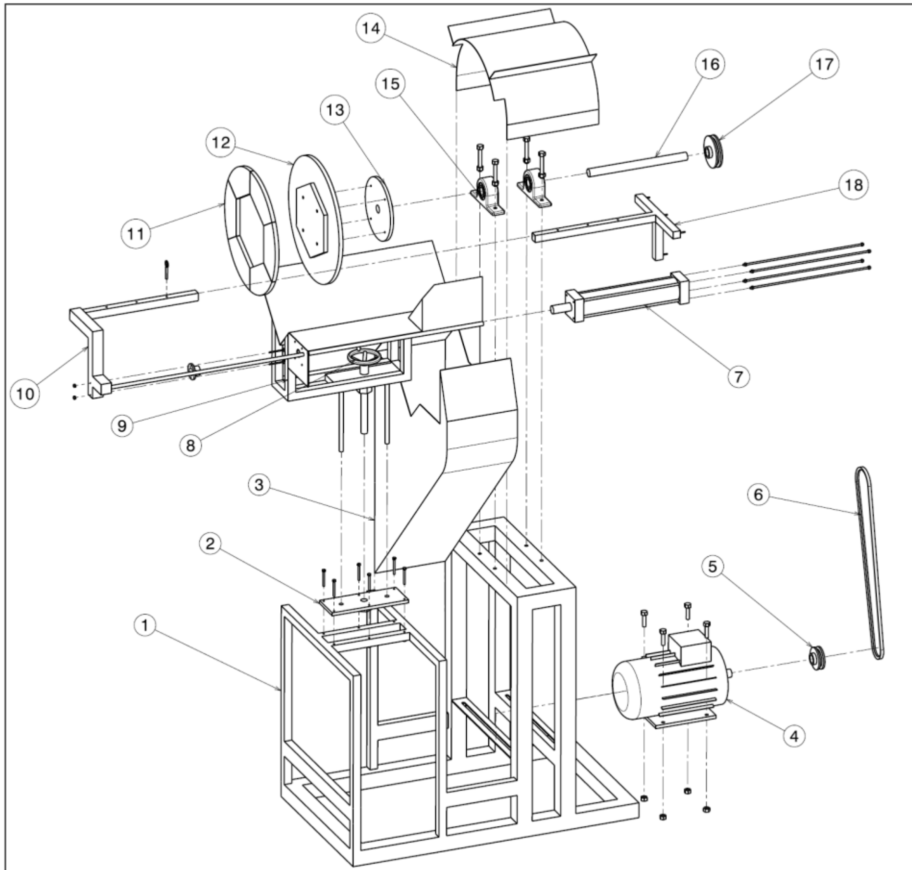


Figure A6: Complete system concept 6. (Source: Author, 2019)



No.	Part No.	Name
1	G001	Main frame
2	G002	Adjustable plate
3	G003	Sago grated fenders
4		Electric motor 3hp, 1500rpm, 3phase
5		Pulley D4'', V type
6		Pulley belt
7		Pnuematic, Bore D4cm, Rod D2.53cm, lenght 55cm
8		Lever, 2''
9	G004	Feeding Platform
10	G005	Pusher arm holder
11	G006	Grater disc slider
12	G007	Grater disc
13	G008	Grater disc holder
14	G009	Bark holder
15		Bearing, D2.53cm
16	G010	Shaft D2.53cm
17		Pulley D4'', V type
18	G011	Pussher arm

Disediakan Oleh:	Unit:	Skala:	Tarikh:	Tajuk:
Wan Mohd Fariz	mm	1:10	19/11/2020	Sago Grater Machine

Figure B1: Assembly drawing of sago grater (Drawn by Author, 2019)

C. The effect of the steeping period at difference grated size on starch extraction

Table C1. The extracted starch weight at different section of sago trunk palm according to grated sago sizes (mm) at different steeping periods (5 min, 24 h, 48 h & 27 h).

Trunk sections	Mesh size (mm)	Percentage of weight grated sago (%)			
		5 min	24 hour	48 hour	72 hour
Top	X<0.3	70.13±0.32	72.40±0.40	73.47±0.55	73.60±0.17
	0.3≤X<0.45	65.43±0.42	67.87±0.32	67.90±1.00	68.53±0.38
	0.45≤X<0.85	59.03±0.15	57.50±0.30	57.27±0.50	57.83±1.00
	0.85≤X<1	57.07±0.21	57.07±0.80	57.37±0.51	57.50±0.30
	1≤X<2	55.03±0.64	55.67±1.63	56.63±1.48	56.20±0.10
	2≤X<2.8	53.07±0.31	55.00±0.50	55.20±0.10	55.47±0.49
	X≥2.8	51.37±0.15	52.50±1.00	52.73±0.81	52.50±0.10
Middle	X<0.3	67.67±1.07	69.53±0.32	68.37±0.55	67.87±1.00
	0.3≤X<0.45	59.47±0.45	60.93±0.38	60.10±0.26	59.23±3.09
	0.45≤X<0.85	58.13±0.25	57.80±1.00	58.70±0.20	58.73±0.21
	0.85≤X<1	56.33±0.76	55.80±2.00	56.17±0.25	57.20±0.30
	1≤X<2	55.57±0.95	56.07±2.52	55.17±0.31	55.87±0.15
	2≤X<2.8	52.70±0.62	54.27±0.38	54.33±0.35	52.40±0.26
	X≥2.8	50.53±0.21	51.00±0.95	52.37±0.31	51.20±0.26
Bottom	X<0.3	67.40±0.36	68.60±0.26	68.53±0.06	68.17±1.03
	0.3≤X<0.45	59.14±0.32	61.03±0.21	60.63±0.32	60.73±0.71
	0.45≤X<0.85	58.10±0.10	58.60±0.61	59.20±0.36	59.27±0.55
	0.85≤X<1	55.67±0.12	56.74±0.55	56.20±0.26	57.03±0.25
	1≤X<2	55.60±0.10	56.10±0.20	55.63±0.40	55.83±0.47
	2≤X<2.8	53.03±0.15	53.17±0.35	53.63±0.31	52.60±0.26
	X≥2.8	50.67±0.15	51.27±1.62	51.33±0.59	51.80±0.44

* ± SD; n = 6

D. Optimization process of sago grating machine

Table D1: A percentage of grated sago weight distribution at difference mesh size for the difference combination parameter.

Mesh size (mm)	Percentage of weight grated sago (%)								
	A1B1	A1B2	A1B3	A2B1	A2B2	A2B3	A3B1	A3B2	A3B3
X<0.3	7.41±0.08	3.36±0.60	3.35±0.23	5.25±0.17	5.12±1.36	7.81±0.90	12.57±0.25	11.83±0.58	14.14±0.59
0.3≤X<0.45	5.80±1.16	3.87±0.30	4.83±0.40	4.69±0.02	6.79±0.78	4.85±0.40	7.49±1.24	7.83±0.29	9.19±0.46
0.45≤X<0.85	20.90±1.55	18.66±2.33	21.98±0.95	18.98±1.10	24.92±0.74	22.20±1.23	22.33±1.34	25.83±1.04	25.91±1.00
0.85≤X<1	5.52±0.18	5.04±0.50	6.30±0.22	6.03±0.30	6.12±0.50	6.86±0.09	5.21±0.01	6.33±0.29	5.78±0.23
1≤X<2	27.03±0.65	28.74±1.37	32.04±0.63	27.34±1.53	27.92±0.14	29.32±2.10	25.40±1.31	26.50±0.50	25.77±0.54
2≤X<2.8	13.49±1.53	12.77±1.57	13.54±0.25	14.29±0.83	11.68±0.86	14.68±1.63	10.69±0.59	10.67±0.29	9.36±0.55
X≥2.8	19.85±0.74	27.57±2.62	17.96±0.81	23.44±0.12	17.46±1.65	14.27±1.62	16.31±2.54	11.00±0.87	9.85±0.82

* ± SD; n = 6
Grating speed: A1= 1000 rpm, A2= 1500 rpm, A3= 2000 rpm
Feeding speed: B1= 0.1 m/min, B2= 0.3 m/min, B3= 0.5 m/min

Table D2: A percentage of grated sago weight distribution at mesh size X<1 and X≥1 for the difference combination parameter.

Mesh size (mm)	Percentage of weight grated sago (%)								
	A1B1	A1B2	A1B3	A2B1	A2B2	A2B3	A3B1	A3B2	A3B3
X<1	39.63 ±2.97	30.93 ±3.74	36.46 ±1.80	34.93 ±1.60	42.94 ±3.39	41.72 ±2.62	47.60 ±2.84	51.83 ±2.20	55.01 ±2.29
X≥1	60.37 ±2.92	69.07 ±5.57	63.54 ±1.69	65.07 ±2.48	57.06 ±2.65	58.28 ±5.36	52.40 ±4.44	48.17 ±1.65	44.99 ±1.92

* ± SD; n = 6
Grating speed: A1= 1000 rpm, A2= 1500 rpm, A3= 2000 rpm
Feeding speed: B1= 0.1 m/min, B2= 0.3 m/min, B3= 0.5 m/min

E. Effect of grater disc size on grated sago size distribution

Table E1: A percentage of weight grated sago distribution at different mesh size for difference disc diameter.

Mesh size (mm)	Percentage of weight grated sago (%)	
	40 cm	48 cm
X<0.3	7.81±0.90	7.71±0.81
0.3≤X<0.45	4.85±0.40	4.70±0.31
0.45≤X<0.85	22.20±1.23	22.70±1.32
0.85≤X<1	6.86±0.09	6.54±0.19
1≤X<2	29.32±2.10	30.12±1.90
2≤X<2.8	14.68±1.63	14.48±1.43
X≥2.8	14.27±1.62	13.37±1.32

* ± SD; n = 6
40cm and 48cm were expressed as grater dics size

BIOADATA OF STUDENT

Wan Mohd Fariz Wan Azman was born in Kota Bharu on 1st Sept 1987. He attended primary school at Sekolah Kebangsaan Sultan Ismail II, Kota Bharu and had his secondary education at SMK Ahmad Maher, Kota Bharu. In 2005, he enrolled in Pulau Pinang Matriculation College at Kepala Batas, Pinang. In 2006, he was offered to continue his study at Universiti Kebangsaan Malaysia (UKM), Bangi as a bachelor student of Mechanical Engineering (Eng.). After graduating in 2010, he has served in private companies as a Multipurpose CAD Engineer at DreamEdge, Cyberjaya for a year. In Year 2011, he continues his service at the Malaysian Agricultural Research and Development Institute (MARDI) as a research officer at the Engineering Research Center and still continues until this day.

In 2013, he had joined an Innovation at MARDI Science And Technology Exibition (MSTE) by presenting two technologies and had been awarded with Silver and Gold medal. During the exhibition, he also had been awarded as a Best Young Participant in Innovation Category (Special Award). In 2016, he joined the MSTE for the second time by presenting a technology in the Innovation Category and had been awarded with a Gold medal. Further, in 2018, he had joined an Innovation & Technology Exhibition (ITEX) and had been awarded with Gold medal and Best Invention in Design (Special Award) by Japan Intellectual Property Association. Finally, he had joined International Trade Fair (iENA) under innovation industry categories and had been awarded with a Silver medal.

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