LAPORAN PENUH DAPATAN DARIPADA PROJEK PENYELIDIKAN JANGKA PENDEK USM

PERKEMBANGAN HASILAN MAKANAN MELALUI TEKNOLOGI EKSTRUSI

Ketua Projek: **Prof. Madya Dr Abd Karim Alias**
Pusat Pengajian Teknologi Industri
Universiti Sains Malaysia

RINGKASAN DAPATAN PENYELIDIKAN

Kajian bagi kesan penggantian grit jagung dengan 20% beras hancur dan 20% sagu terhadap sifat-sifat fizikal (nisbah pengembangan, ketumpatan pukal, kekuatan pemecahan, indeks penyerapan air, indeks keterlarutan air, warna, aktiviti air, isoterma jerapan) dan mikrostruktur bagi snek jagung teresktrud telah dilakukan. Pemprosesan ekstrusi telah dijalankan dengan menggunakan mesin penyempritan kembang terus di bawah keadaan yang malar iaitu pada kelembapan 17%, kelajuan skru 60 Hz, kelajuan pemotong 50 rpm, dan pada suhu 170°C untuk menghasilkan 3 jenis snek teresktrud (100% grit jagung, 80% grit jagung + 20% sagu, 80% grit jagung + 20% beras hancur). Penggantian 20% beras ke dalam grit jagung menghasilkan perbezaan signifikan dalam nisbah pengembangan, ketumpatan pukal, kekuatan pemecahan, jumlah nilai penurun dan warna. Penggantian 20% sagu ke dalam grit jagung pula mempunyai kesan signifikan dalam indeks penyerapan air, indeks keterlarutan air, jumlah nilai penurun dan aktiviti air. Penggantian dengan sagu juga menghasilkan snek teresktrud yang lebih berkualiti daripada 100% grit jagung snek teresktrud terutamanya dari aspek nisbah pengembangan, ketumpatan pukal kekuatan pemecahan dan warna tetapi tidak sebaik snek teresktrud yang dibuat daripada 80% grit jagung + 20% beras hancur. Kajian mikroskopik menunjukkan bahawa penggantian 20% sagu dan 20% beras ke dalam grit jagung menghasilkan snek tereskrud yang lebih kembang dengan sel udara yang lebih banyak dan dinding sel yang lebih nipis. Graf isoterma jerapan menunjukkan penggantian 20% sagu dan 20% beras hancur akan memanjangkan jangka hayat bagi snek teresktrud dengan mengekalkan kerangupan.

SUMMARY OF RESEARCH FINDINGS

Studies were conducted to investigate the effect of substitution of corn grits with 20% rice and 20% sago starch on the physical and microstructure properties (expansion ratio, bulk density, cutting force, water absorption index (WAI), water solubility index (WSI), colour, water activity and sorption isotherm) of an extruded corn snack. Extrusion processing was carried out, using a direct expanded single screw extruder under constant conditions, i.e., feed moisture of 17%, screw speed 60 Hz, cutter speed 50 rpm, and temperature 170°C to produce 3 types of extruded snack (100% corn grits, 80% corn grits + 20% sago, 80% corn grits + 20% broken rice). A substitution of 20% rice into corn grits resulted in significant difference on the expansion ratio, bulk density, cutting force, total reducing value and colour. Substitution of 20% sago into corn had significant effects on the WAI, WSI, total reducing value and water activity. Substitution with sago also produced a better quality extruded snack in terms of expansion ratio, bulk density, cutting force and colour as compared to 100% corn extruded snack but not as good as extruded snack made by 80% corn + 20% rice. Microscopy studies showed that substitution of 20% sago starch and 20% broken rice resulted in more expanded extrudates with more number of air cells and thinner cell walls. Sorption isotherm graph indicated that substitution of 20% sago starch and 20% broken rice increased shelflife of the extruded snack with respect to maintenance of crispness.

1. BACKGROUND

Snack foods are enjoyable food products that are consumed throughout the world. Snack foods include a broad range of products that can take many forms, and definitions of snacks are being modified to include sandwiches, yogurt, and even ice cream. However, as defined by the Snack Food Association (Huang, 1995), snacks include only savory products, such as chips, extruded snacks, nuts, popcorn and so forth.

There is a continuous evolution in products appearing on the shelves. More and more snacks from extruded snack can be seen. According to statistic (Anon, 2005a), extruded snack increased in terms of retail value in the world and Asia pacific with total sales of US $16,096 million and US$ 6,971 million, respectively. In addition, extruded snack sales in Malaysia has grown the second fastest among sweet and savoury snacks, just behind chips/crisps with total sales of RM137 million in 2004 (Anon, 2005a).

Extruded snacks are generally prepared form cereals such as de-germinated maize meal, and rice and wheat flour. In Malaysia, maize meal, and to a certain extend, potato and rice, are major ingredients for extruded snack. All of these materials are imported. However, limited work has been done on the extruded snack from sago and rice, which are the major crops in Malaysia, resulting in the limited of sago and rice extrudates on the local market.

Extrusion cooking is used worldwide for the production of expanded snack foods, breakfast cereal, baby foods, flat breads, meat and cheese analogues, modified starch, ready to- eat cereal foods, pet foods and porridge. It has also been used as a thermal process to eliminate undesirable flavors, to inactivate growth inhibitors, and to modify starch, (i.e., cross-linking, substitution, etc.). Extrusion cooking technology is getting popular in the production of snack foods owing to their technological advantages over the traditional food processing techniques. Extruded snacks consist essentially of a cereal blend extruded with a certain amount of water. Despite increased use of extrusion processing, extrusion is still a complicated process that has yet to be mastered.

Rice (*Oryza sativa L.)* is one of the major cereals worldwide and the staple food for about 2.7 billion people in Asia alone. Rice flour (starch) is one of the primary and major ingredients of various food products. Rice pasting quality, cooking and eating quality vary considerably between different types of rice cultivar and rice cultivars with different amylose.

Broken rice (broken rice size ¼ of normal rice), sometimes referred as brewers rice, one of the raw materials of this study is good for cooking porridge and shima because of its natural small size, hence easier to cooked and easier to dissolve. Broken rice resulted in a more uniform expanded product than when whole rice was used. The most desirable particle size for expansion obtained when these rices were comminuted in corrugated cracking rolls (Mottern et al., 1969). With its other unique attributes such as bland taste, and ease of digestion, broken rice become an attractive ingredients in the manufacturing of new cereal foods.

Sago starch has increasingly become one of the important starch sources in the Asia Pacific regions. Sago starch was used for a long time especially in South East Asia in the food Industry for the production of vermicelli, bread, crackers, biscuits and many other traditional foods (Ahmad et al., 1999). With extrusion technology, one of the fastest growing, and most important, food-processing operations of recent years (Harper, 1981;

Paton and Spratt, 1984), sago starch may be processed into various products, such as extruded snack, which in turn will add to its economical value.

Corn is the most widespread cereal used for expanded snack products. Corn is the primary ingredient for corn collets (both baked and fried), onion rings and many pellet products. It is used because of its low cost and it expands well even from simplest of extruders. Degermed corn grits are used in most cases due to it has much greater expansion than extruded whole corn. They expand better because the oil content is much lower for degermed corn grits. Flint corn grits are considered better by millers because of more recovery of grits while the sweet corn grits are preferred by the snack industry because of their richer colour.

2. RESEARCH OBJECTIVES

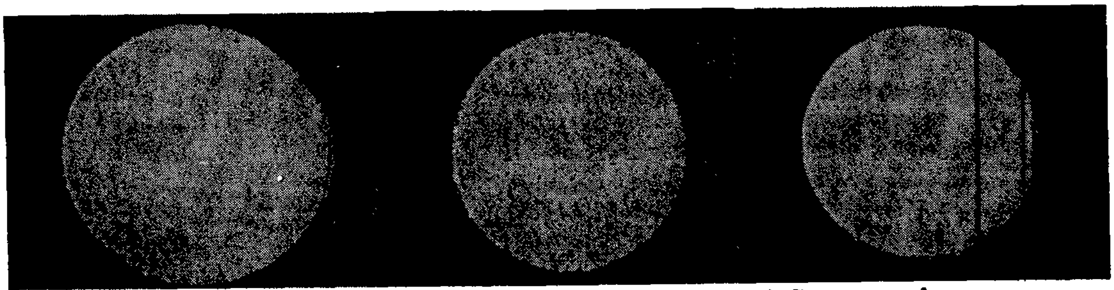
This research was conducted with the aim to investigate the effect of substitution of 20% rice and 20% sago on the physicochemical properties (expansion ratio, bulk density, cutting force, water absorption index (WAI), water solubility index (WSI), colour, water activity and sorption isotherm) of extruded snack product.

Successful completion of this project will lead to development of extruded snack made from sago starch and rice which consequently diversify the utilization sago and rice, which in turn will increase its economic value.

3. MATERIAL AND METHODS

3.1 Materials

The raw material mix for extrusion experiments included 100 % corn grits, 80% corn grits + 20% sago starch, as well as 80% corn grits + 20 % broken rice. Sago starch was supplied by SIM Company Sdn. Bhd. (Penang, Malaysia), while broken rice was from SerbaWangi Sdn. Bhd. (Kedah, Malaysia). Maize grits fine (Special grade) was packaged by Soon Soon Oilmills Sdn. Bhd. (Penang, Malaysia).



a) Corn grits b) Broken rice c) Sago starch

Figure 3.1: Raw materials used for production of expanded snack

3.2 Preparation of samples

The samples were packed in bags and kept in the chilling room and were brought to room temperature to equilibrate the moisture overnight before extrusion. Feed moisture of each sample was adjusted to 17% moisture content by spraying calculated amounts of water and mixing continuously in a Ribbon mixer (Figure 3.2).

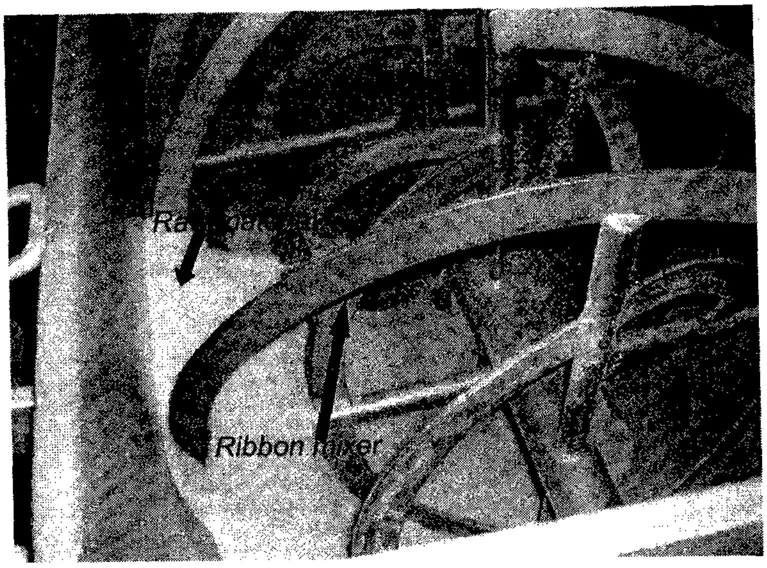


Figure 3.2: Raw material was mixing continuously in a Ribbon mixer

3.3 Extrusion

Extrusion cooking of different feed component samples was carried out in a direct expanded single screw extruder (Model: POP – 301 H, NO: 1396 M, HP: 24.75, kW Foundry Engineering Corporation Sdn. Bhd., Melaka. Com. No.: 43527 m) with 6 inches barrel. The extruder was fitted with a die nozzle having 5 mm diameter and the distance between die and cutter for expansion of plate is 0.8 mm. All extrusion variables were displayed on the control panel.

Before the extrusion was started, the die and plate were preheated to about 80 °C. During the extrusion process, screw speed was maintained at 60Hz, cutter speed at 50 rpm, and temperature at 170°C. Due to time constraint, each sample underwent single run. First sample underwent extrusion cooking was pure corn, followed by mixture of 80% corn grits + 20 sago, and the last run was mixture of 80% corn grits + 20 sago.

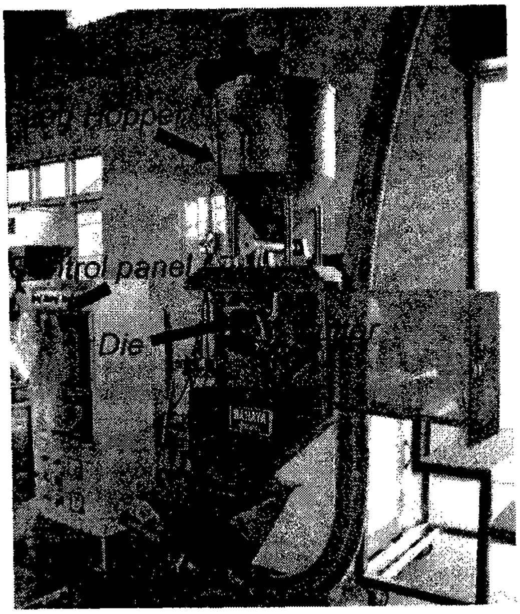


Figure 3.3: Photograph of direct expanded single screw extruder

Figure 3.4: Components of the extruder

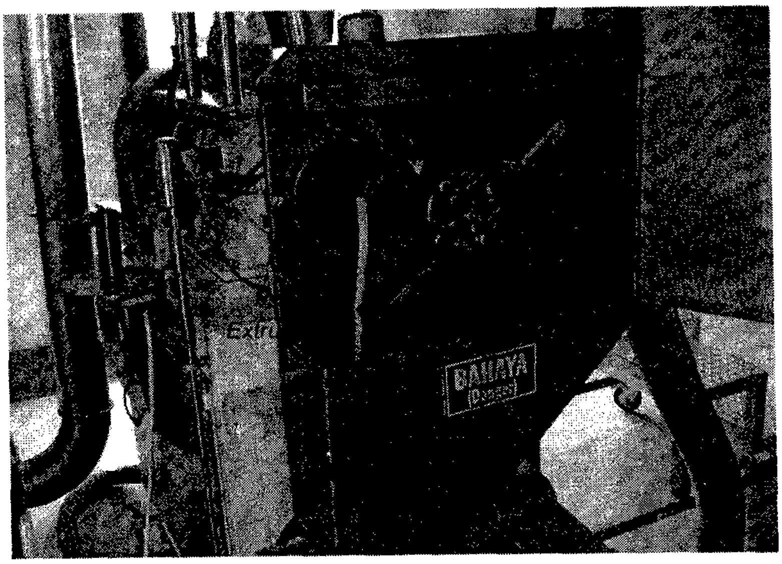


Figure 3.5: Photograph of extrudate exited from the die

Each samples were then collected, dried at 130 °C in a three tier tunnel oven (Model: OV – 101 EW NO: 1393 M HP: 5.625 kW, conveyer speed = 30 rpm) for 20 minutes (Figure 3.6). The samples were then collected and placed in plastic bags, sealed and stored until tested. Some samples were ground by Retch mill (Model: ZM 100, Germany) for certain analysis such as colour analysis, water activity and water absorption index and water solubility index.

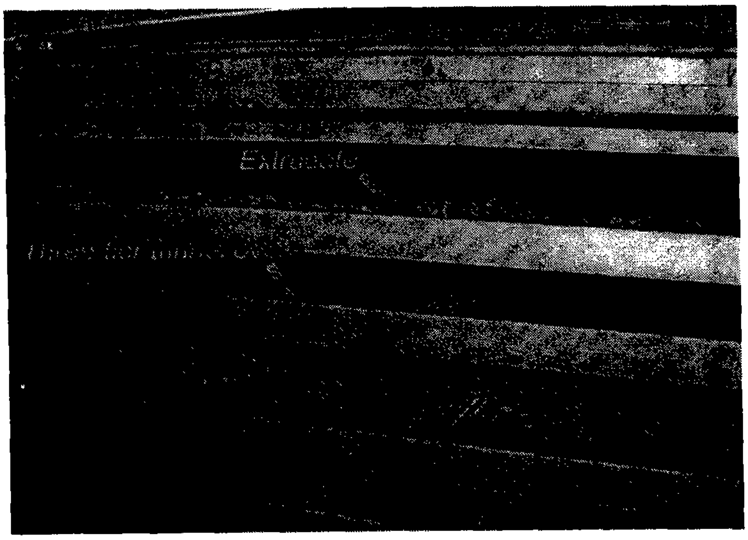


Figure 3.6: Extrudate dried in the three tier tunnel oven

3.4 Analysis method

3.4.1 Proximate analysis

Proximate analyses of the moisture, fat, fiber, ash and protein for corn grits and broken rice were performed according to the AOAC (1984) methods. Total carbohydrate was determined by difference.

3.4.2 Apparent amylose content

Apparent amylose content of corn grits, sago and broken rice was determined with rapid colorimetric method as mentioned by McGrance et al. (1998). Since corn grits and broken rice were insoluble in dimethyl sulfoxide (DMSO) solution, purification was carried out prior to amylose content determination.

3.4.3 Pasting properties

Pasting properties were determined using a Rapid-Visco Analyser (Newport Scientific model 3D, Warriewood, Australia) following the AACC Approved Method 76-21 (2000). RVA analyses were performed on 100% corn grits, blends of 80% corn grits + 20% sago starch and blends of 80% corn grits + 20% broken rice. Each RVA canister contained 2 g of sample and was made up to 27 g using distilled water. Peak viscosity, pasting temperature, pasting time, holding strength, breakdown, final viscosity and setback were recorded. Each analysis was performed in triplicate.

3.4.4 Expansion ratio

Expansion ratio of the extruded snack was calculated by dividing the diameter of the extrudates by the diameter of the die-nozzle orifice. Each value was an average of 15 readings.

3.4.5 Microscopic method

3.4.5.1 Scanning Elektron Microscopy (SEM)

Samples were cut along the cross-section using sharp razor blade. They were mounted on aluminium stubs and then sputter coated with gold by using sputter coater (Model: Palaron Sc515, Palaron Instruments Inc., Cambridge, MA, U.S.A.). After that, microstructure of the extruded snack was observed by scanning electron microscope (Model: Leo Supra SO VP Field Emisson, Carl-Zeiss SMT, Oberkochen, Germany) at 5kV. This scanning electron microscope was controlled by a computer software, the Oxford INCA 400 energy dispersive x-ray microanalysis system.

3.4.5.2 Stereo light microscopy

Olympus SZ40 fitted with a JVC K- F55B colour video camera and analySIS Docu version 3.1 image analysis system (Olympus optical Co. Ltd., Tokyo, Japan) was used to observe the extruded snack structure. The samples were prepared by cutting extruded snack along the cross-section with sharp razor blade. All samples were observed under same magnification.

3.4.6 Bulk density

The bulk densities of extruded snack were determined by using seed displacement. An amount of 500 mL rapeseeds was used. The seeds were poured into a graduated cylinder (1 L) and tapped soundly 5 times. The bulk density (g/mL) was calculated by dividing the weight of the extruded snack by the volume displaced. Three determinations were conducted for each extruded snack.

3.4.7 Cutting force

A TA-XT2 Texture Analyser (Stable Micro Systems, Surrey, UK) was used to analyze the texture of the extruded snacks. Blade knife test and three point bend test were carried out to determine the cutting force that is required to break the extruded snack. The settings in blade knife test for all samples is the same which are pre test: 2 mm/s, test speed: 7 mm/s, post speed: 10 mm/s, distance: 15 mm, trigger force: 0.10 N, while the setting in three point bend test is pre test: 2 mm/s, test speed: 7 mm/s, post speed: 10 mm/s, distance: 25 mm, trigger force: 0.10 N. The results were gathered by Texture Expert software and the peak force of extrudate was determined. Twenty five replicate measurements were performed for each type of sample.

3.4.8 Water absorption index and water solubility index

The water absorption index (WAI) is the weight of gel obtained per gram of dry ground sample. It was determined by AACC method 56-20 (AACC, 1983) with modification.

The ground extruded snacks pass trough 250 µm sieving. A 2.0 ± 0.005g of ground sample was placed into a centrifuge tube tared with the stopper. Twenty mL of water was added, the stopper was replaced and the tube was shaken vigorously to suspend the sample. The suspension was left standing for 10 minutes. During this time, the suspension was mixed by inverting the tube with a stopper three times at the of the 5 and 10 minutes periods. The stopper was removed and the tube was centrifuged for 15 minutes at 1000 *g* (Bench Top centrifuge KUBOTA 5100, Kubota Corporation, Japan). The supernatant was decanted into a container. The tube was inverted to drain the supernatant for 5 minutes, and then weighed. The supernatant collected was used for determining WSI. WAI was calculated as

$$\text{WAI} = \frac{(\text{weight of sediment + tube}) - (\text{weight of tube})}{\text{Sample dry weight}}$$

The water solubility index (WSI) is the percentage of dry matter recovered after the supernatant is evaporated form the water absorption determination. The supernatant was dried in conventional oven for 24 hours and weighted. WSI was calculated by

$$\text{WSI} = \frac{(\text{weight of container + dried supernatant}) - \text{weight of container})}{\text{Sample dry weight}}$$

For WAI and WSI, three determinations were conducted for each sample.

3.4.9 Colour

A Minolta Spectrophotometer equipped with Compaq computer system (Model: CM-3500d, Minolta Co. Ltd., Japan) was used to determine colour values of the ground extruded snack in terms of the L^* value with 0 for darkness and 100 for brightness; a^* represented the extent of green colour in the range from -100 to 0 and red in the range from 0 to 100; b^* quantify blue in the range from -100 to 0 and yellow in the range from 0 to 100. The data were gathered by spectramagic software. For each sample, three measurements were taken and averaged.

4 RESULTS AND DISCUSSION

4.1 Proximate analysis

Table 4.1: Proximate composition and amylose content for raw material (g/100 g)

	Sample (dried weight basis)		
	Corn Grits	Sago	Broken Rice
Moisture	9.42	12.30	11.50
Fiber	3.73	0.28	2.47
Fat	3.99	0.05	3.96
Ash	3.17	0.02	1.22
Protein	2.91	0.20	2.56
Carbohydrate	76.79	99.45	78.05
Amylose*	14.33[a]	35.60[b]	15.88[a]

4.2 Apparent amylose content

Apparent amylose content is the amount of amylose that include complex of amylose-lipid. Apparent amylose in the starches was determined as such without the endogeneous lipid. Structure and amount of amylose play an important role in pasting properties as well as physical properties in extruded snacks.

When corn grits was substituted with 20% broken rice or 20% sago starch, the order of apparent amylose content in each mixture was: 80% corn + 20% sago > 80% corn + 20% rice > 100% corn. It means that mixture of 80% corn + 20% sago has the highest amount of amylose whereas sample of 100% corn has the lowest amylose content.

Mixture of 80% corn + 20 % sago contain the highest amylose contents with intermediate peak viscosity, whereas mixture of 80% corn + 20 % rice have the highest peak viscosity at middle amylose content among the three samples. Since amylose content in mixture of 80% corn + 20 % sago was significantly higher than mixture of 80% corn + 20 % rice, it can be postulated that amylose content do not affect peak viscosity in this study.

In this study no relationship was found between amylose content and breakdown viscosity. Mixture of 80% corn + 20% sago have the highest amylose content and breakdown viscosity, whereas mixture of 80% corn + 20% rice which have a middle amylose contents have the lowest breakdown viscosity.

There is no relation between apparent amylose content and expansion found in this study. Temperature and moisture content are also important in expansion. Hence, it could be suggested that mixture of 80% corn grits + 20% rice with 15.55 % amylose content has better expansion capabilities under extrusion conditions that were carried out in this study. Amylose content has a similar trend with WAI values in this study.

4.3 Pasting properties

RVA pasting properties of each type of sample are presented in Table 4.2. Mixture of 80% corn + 20% rice exhibited the highest peak viscosity at 36.25 RVU, followed by mixture of 80% corn + 20% sago (36.04 RVU) and the lowest peak viscosity (28.83 RVU) is found in the sample of 100% corn. There is a significant difference between mixture of 100% corn compared to mixture of 80% corn + 20% rice and mixture of 80% corn + 20% sago. It indicates that when 20% sago or 20% rice are substituted in the corn, obvious changes in peak viscosity will be obtained. However, there is no statistical difference between mixture of 80% corn + 20% rice and mixture of 80% corn + 20% sago.

Pasting temperatures in this study ranged from 76.95 – 84.55°C. A blend of 80% corn + 20% sago achieved peak viscosity at the lowest temperature which is 76.95 °C and has a significant difference compared to the other two samples. This result shows that it requires less energy to cook and produce the paste. It can be postulated that starch granules of sago are low in integrity, thereby substitution of 20% sago starch into corn lowered the pasting temperature significantly.

Table 4.2: RVA pasting properties of raw material

Pasting properties	Sample (8% dried weight basis)		
	100% corn	80% corn + 20% sago	80% corn+20% rice
Peak viscosity (RVU)	28.83[a]	36.04[b]	36.25[b]
Peak time (min)	5.28[ab]	4.82[a]	5.47[b]
Pasting temperature (°C)	84.55[a]	76.95[b]	82.35[a]
Holding Strength (RVU)	26.17[a]	28.75[b]	32.92[c]
Breakdown (RVU)	2.67[a]	7.29[b]	3.34[a]
Final viscosity (RVU)	34.83[a]	40.25[b]	44.79[c]
Setback (RVU)	8.67[a]	11.50[b]	11.88[c]

- Values is mean values (n=2)
- Letters with the same alphabet under one row are not significantly different at 5% probability level ($P > 0.05$)

Breakdown viscosity peak in a mixture of 80% corn + 20% sago is 7.29 RVU, and the lowest breakdown viscosity is found in a sample of 100% corn at 2.67 RVU. A significant difference was found between samples containing 80% corn + 20% sago and

100% corn. Substitution 20% of sago in corn would bring a markedly different effect on breakdown viscosity. It is postulated that granules of sago in this study are easy to breakdown and contribute to higher breakdown values. However, there is no significant difference between mixture of 80% corn + 20% rice and 100% corn. This indicates that starch granules of rice can hold the strength well as starch granules in corn and do not bring any significant effect in breakdown values.

Breakdown viscosity was regarded as a measure of the degree of disintegration of starch granules. Thus, for sample of 80% corn + 20% sago, it could be assumed that it will most likely disintegrate under severe processing conditions whereas sample of 100% corn is most resistant to severe treatment such as extrusion conditions in a combination with high shear, high temperature and high pressure.

The setback values for the 3 samples were obviously different. The setback value of sample of 80% corn + 20% rice was the highest at 11.88 RVU, followed by sample of 80% corn + 20% sago and the lowest setback was 100% corn which read 8.67 RVU. Highest setback in mixture of 80% corn + 20% rice indicates that it is most prone to retrogradation whereas sample of 100% corn is more resistant.

In our study, mixture of 80% corn + 20% sago contains 18.6 % amylose content which has the highest amylose content among the three samples did not have the highest setback values when compared with the other two samples. However, sample of 100% corn which contains lowest amount of amylose has the lowest setback value. Thus, the setback values in this study show little or no relationship with the amylose content.

4.4 Expansion ratio

Expansion ratio of each extruded snack is presented in Table 4.3. Expansion of extruded snack with 80% corn + 20% rice was excellent, whereas extruded snack with 100% corn did not expand well (Figure 4.1). The expansion ratio of extruded snack with 80% corn + 20% rice has a significant difference (P < 0.05) with extruded snack of 100% corn and extruded snack of 80 % corn + 20% sago. However, extruded snack with 80% corn + 20% sago has no significant difference (P < 0.05) with extruded snack of 100% corn. It indicated that substitution of 20% rice can affect expansion ratio of corn significantly whereas substitution of 20% sago only slightly increased the expansion ratio of corn.

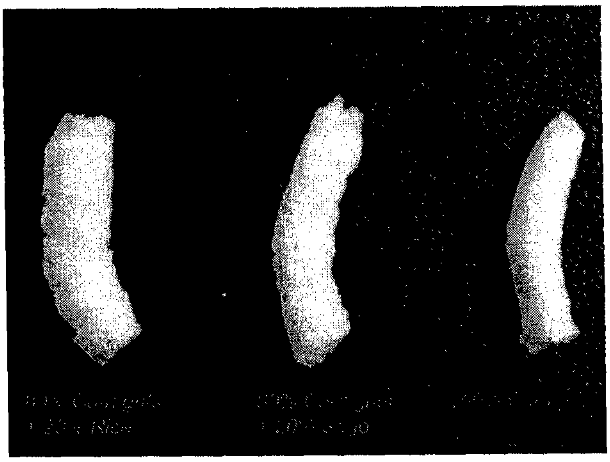


Figure 4.1: Photograph of three types of extruded snack

Table 4.3: Expansion ratio of extruded snack and proximate composition of raw material

	Sample		
	100% corn	80% corn + 20% sago	80% corn + 20% rice
Expansion ratio*	2.2 [a] ± 0.1	2.3 [a] ± 0.1	2.7 [b] ± 0.1
Amylose	14.33	18.58	14.64
Fat	3.99	3.20	3.91
Protein	2.91	2.37	2.84
Fiber	3.73	3.04	3.48

* Values is mean ± standard deviation (n=15)
* Letters with the same alphabet under one column are not significantly different at 5% probability level (P > 0.05)

Proximate composition of raw material in Table 4 is to manifest better understanding about its influence in expansion ratio. It is interesting to note that mixture of 80% corn + 20% rice have a very close values in terms of amylose content, protein content and fat content with sample of 100% corn, but have a significant difference in expansion ratio in the final extruded snack.

Furthermore, although amylose content, protein content as well as fat content in mixture of 80% corn + 20% sago have an obvious difference with mixture of 100% corn, no statistical difference (P > 0.05) was found in expansion ratio between extruded snack with 80% corn + 20% sago and extruded snack with 100% corn. A possible explanation can be made that since each sample involves different types of starch, thus it can be believed that there are differences in their structure and molecular weight of amylopectin which is also involved in determining the expansion volume of starch.

Although the amylose content and amylopectin content of mixture of 80% corn + 20% rice is similar with the sample of 100% corn, the structural and molecular weight of amylopectin which is responsible in expansion ratio might be different. It agrees with

For mixture of 80% + 20% sago which have a lower amount of amylopectin, it is suggested that it has a branching pattern and branch point which is easily degradable and contributes to decreased melt elasticity. This phenomenon will contribute to lower expansion ratio. Another suggestion could be made is that many linear structure found in the amylopectin molecules in sago starch also allows them to entangle and thus increase the viscosity.

Expansion of extruded snack affects the microstructure of finished products. Extruded snack of 80% corn + 20% rice with the highest expansion ratio showed very porous structures with large number of air cells and thinnest cell walls, while extruded snack of pure corn with the lowest expansion ratio showed with least porosity and thickest cell walls among the three samples (refer to section 4.4.1).

In this study, expansion ratio has an inverse trend with the cutting force, which is the higher the expansion ratio, the lower the cutting force which can be found in extruded snack with 80% corn + 20% rice. As mentioned earlier, extruded snack of 80% corn + 20% rice with the highest expansion ratio showed very porous structures with a large number of air cells and thinnest cell walls. Thus, less cutting force was required to break it.

4.5 Microscopy

Two types of microscopy were used to obtain information regarding the microstructure of extruded snack, namely Scanning Electron Microscopy (SEM) and stereo light microscopy.

4.5.1 Scanning Electron Microscopy (SEM)

By observing Figures 4.3 (a, b, and c), the variation in the morphology of the extruded snack can be observed. By comparison, the air cells of pure corn extrudate were intermediate, varied in air cells size and the cell walls were the thickest and well defined. On the other hand, extrudate of 80% corn + 20% rice has the smallest and homogeneous size of air cells couple with thinnest air cells. In addition, the biggest air cells and medium thickness of cell walls were found in extruded snack with 80% corn + 20% sago. During extrusion cooking, the melted starch material undergoes rapid puffing process as it exits the extruder die owing to sudden reduction in pressure, the resultant structure is cellular but generally not closed, and the openings, consisting of intercellular channels or fractures in the cell walls.

Extruded snack with 100% corn with the lowest expansion showed the least number of air cells, thickest cell walls and randomly distribution of air cells owing to its starch granule easier to breakdown which consequently reduced melt elasticity and melt extensibility. The reduced melt elasticity and melt extensibility contribute to melt material difficult to expand. The microstructure of extruded snacks follow the same trend as expansion increased. The structure varied gradually from smooth and dense to a highly expanded one characterized by very thin walls and flaky internal surfaces (Figure 4.3).
Figure 4.4 provides a clear illustration about the thickness of cell walls for three extruded snack under magnification of 100X. In the extruded snack produced with 80% corn grits + 20% rice, air cell walls were the thinnest among three extrudates. Meanwhile, extruded snack with 100% corn has the thickest air cell walls.

Extruded snack with 80% corn + 20% rice which has a greater number of small air cells couple with thinner cell walls had a lower density and higher expansion than the extruded snack with 80% corn + 20% sago and 100% corn which has a higher amount of large air cells and thicker cell walls. An interesting correlation between density and average cell size in this study is that the lowest density extrudates had the smallest average cell size.

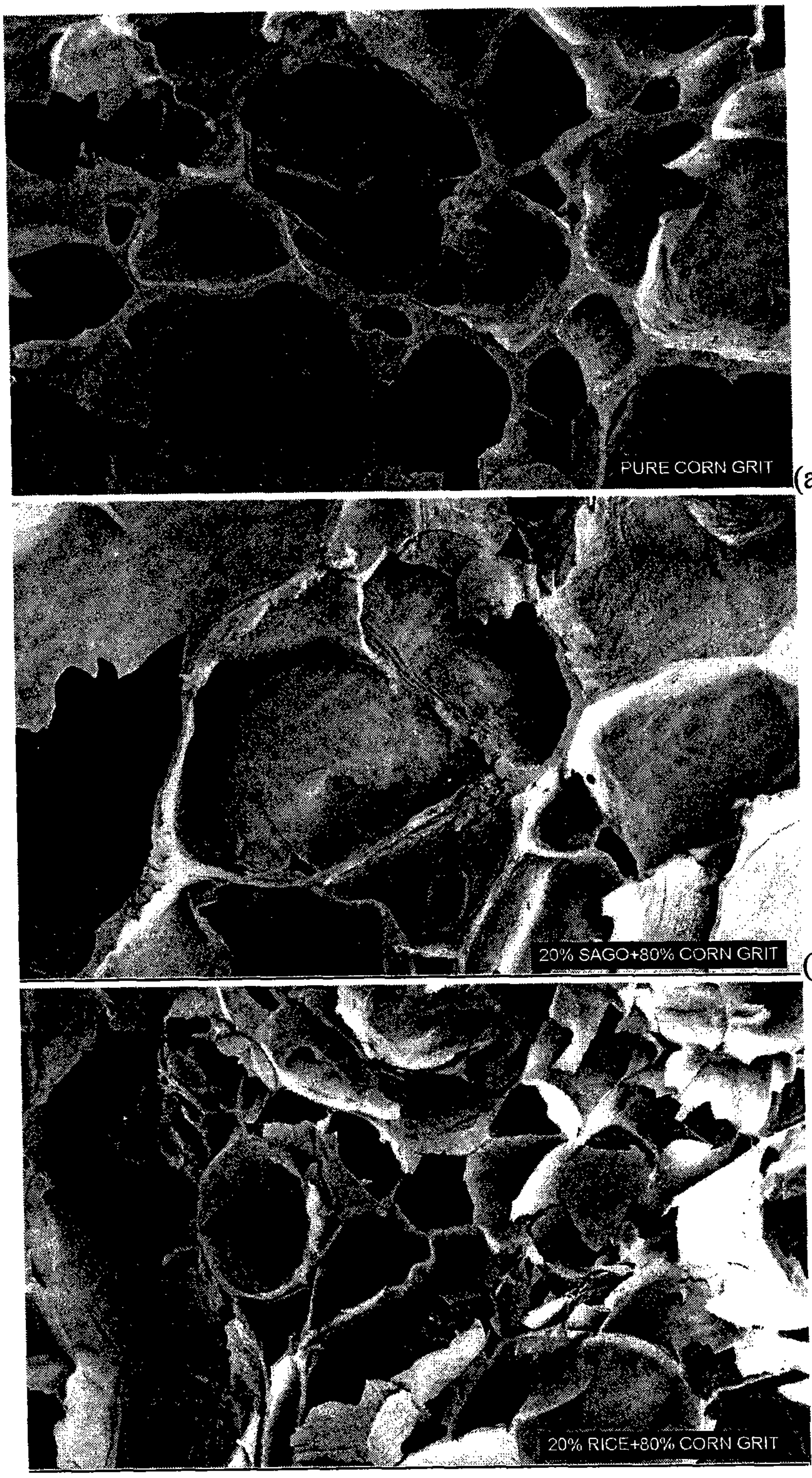


Figure 4.3: Scanning electron micrographs of the three types of extruded snack. (a) 100% corn grit, (b) 80% corn grits + 20% sago and (c) 80% corn grits + 20% rice. Photographs were magnified by 40X

Extruded snack with 100% corn has a thicker cell walls and are inherently less fragile and less likely to rupture than are thin cell walls that can be found in extruded snack with 80% corn + 20% rice. Therefore, it requires higher cutting force to break it. On the other hand, extruded snack with 80% corn + 20% rice with great number of air cells and thin cell walls has a lesser resistance to the cutting force. It is interesting to note that the increase in number of air cells results in higher global resistance in the extrudates, whereas the decrease in thickness cell walls weakens the mechanical resistance of cells. These contrasting effects contribute to the lesser cutting force to break it.

Numerous air cell and thinner cell walls in the extruded snack with 80% corn + 20% rice contribute to number of sharp multi-minipeaks before the maximum peak force in the force texture profile (Figure 26a, 26b). It is due to many air cells with thin cell walls in the extruded snack with 80% corn + 20% rice that have to be ruptured when the blade cut through the structure. Meanwhile, since the extruded snack with 100% corn has a lesser air cells and thicker cell walls, force texture profile shows a lesser number peak and the minipeaks are bigger than the minipeaks found in the force texture profile for extruded snack with 80% corn + 20% rice before reaching the maximum peak. Similar observations were found in previous studies (Stanley and de Man, 1978; Voisey and Stanley, 1979; Owusu-Ansah et al., 1984).

4.5.2 Stereo Light Microscopy

Stereo Light Microscopy provides detail about cell size distribution and cell organization of the extrudate. Characterization of cell size distribution and cell organization may provide information that helps control the extrusion process so as to produce a desired and uniform extrudate product.

As shown in Figure 4.5, the extruded snack with 100% corn was characterized by variable cell sizes, with pockets of large and small cells randomly intermingled. While the extruded snack with 80% corn + 20% sago shows a collection of smaller cells near the layer of the cross-section separate by much larger cells in the centre, the location of large and small cells was random. The air cells of the extruded snack with 80% corn + 20% rice were more homogeneous, with relatively uniform in size and distributed evenly throughout the cross-section.

As can be seen in Figure 4.5, stereo light microscopy captured well the colour of the extruded snack and it is consistent with the result obtained from colourimeter.

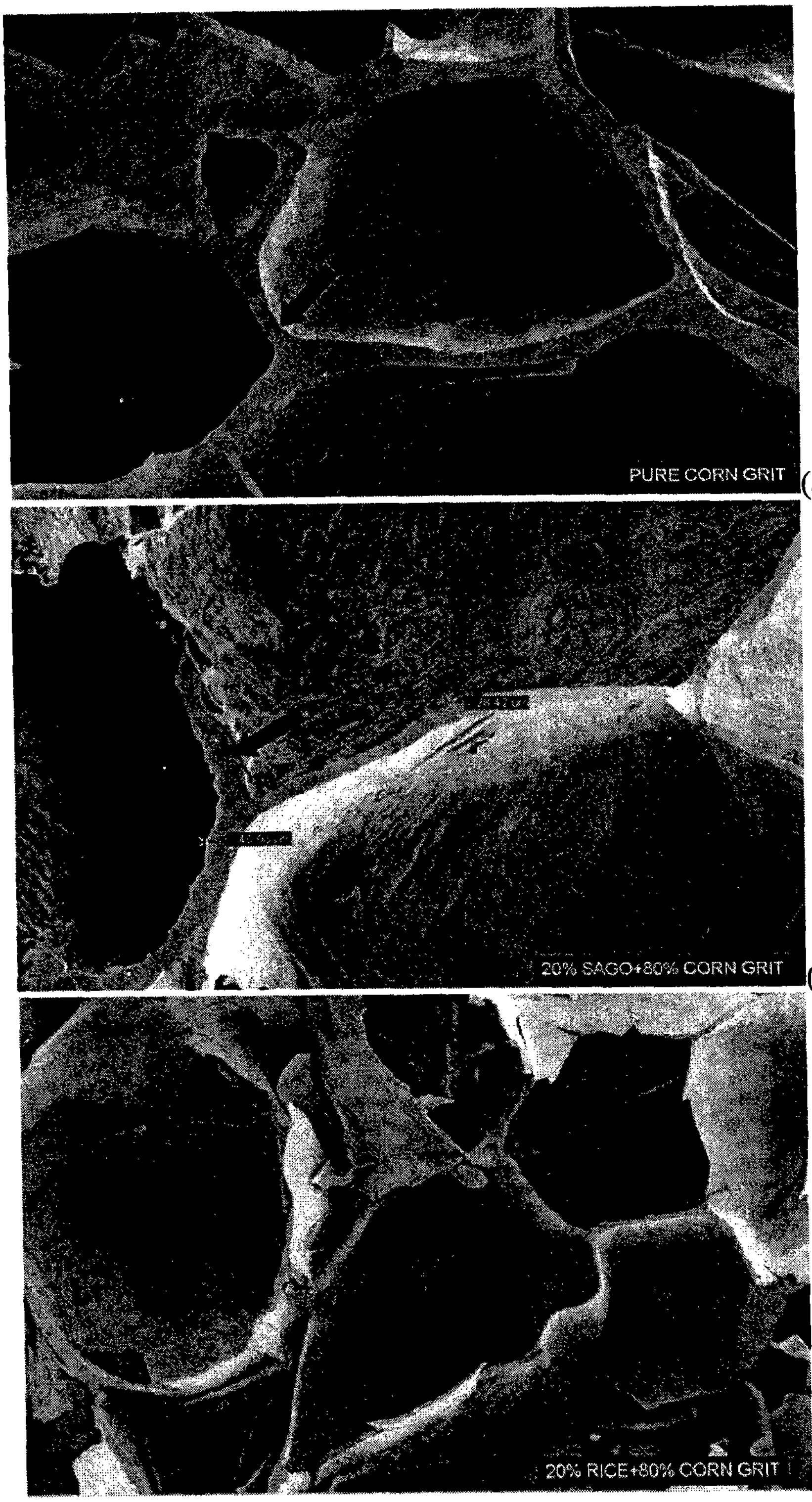
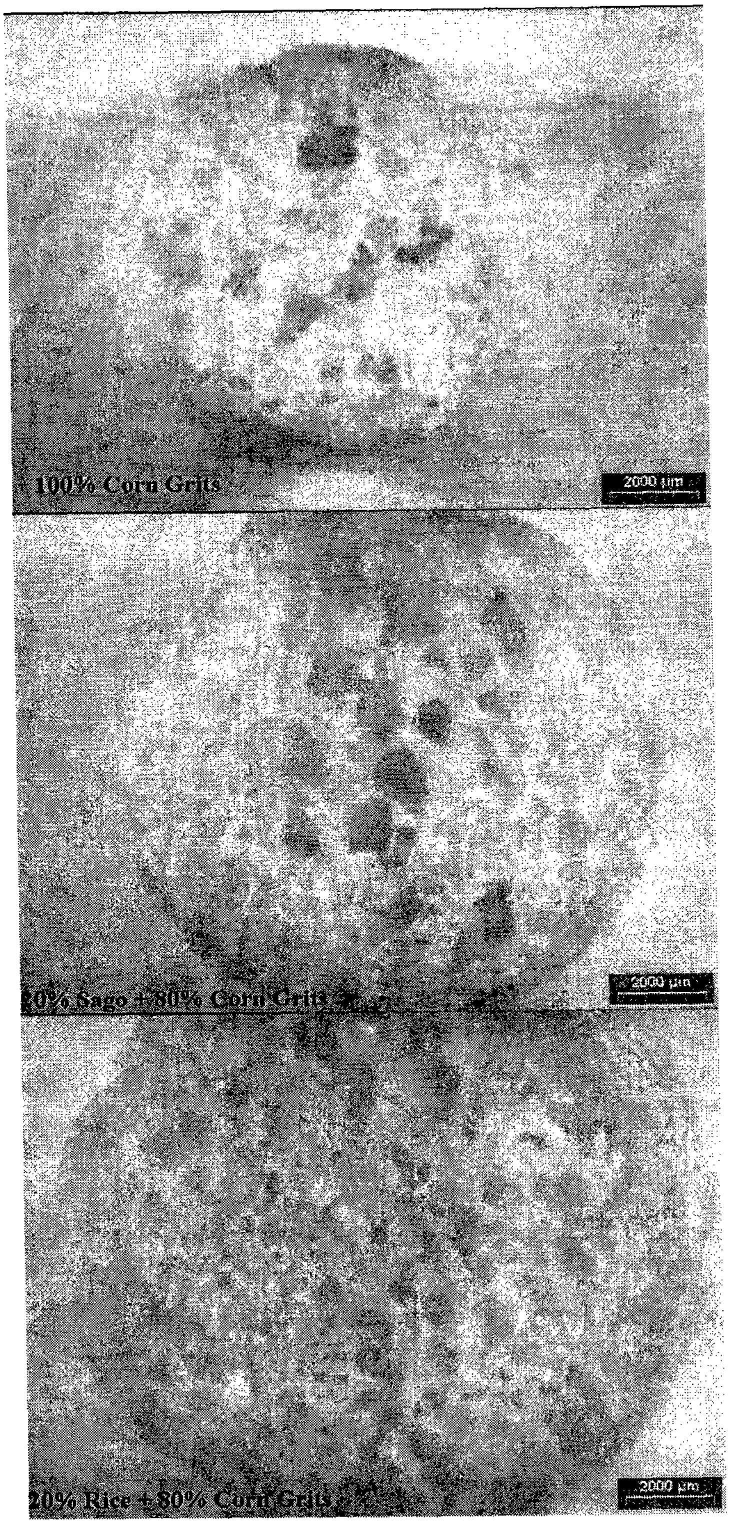


Figure 4.4: Scanning electron micrograph of the three types of extruded snack. (a) 100% corn grit, (b) 80% corn grits + 20% sago and (c) 80% corn grits + 20% rice. Photographs were magnified by 100X. indicates cell walls



(a)

(b)

(c)

Figure 4.5: Stereo Light Micrograph of the three types of extruded snack. (a) 100 % corn grit, (b) 80% corn grits + 20% sago and (c) 80% corn grits + 20% rice. Photograph were captured under same magnification

4.6 Bulk density

Bulk density is a volumetric measurement, referring to the weight of a specific volume of a product. The bulk density of the samples varied from 0.064 to 0.106 g/mL (Figure 4.6). Under the same extrusion conditions employed, raw materials significantly ($P < 0.05$) affect the bulk density of the products.

In this study, it was found that extrudate of 100% corn has the highest bulk density, followed by extrudates of 80% corn + 20% sago and the least dense obtained in extrudate of 80% corn + 20% rice. Extruded snacks of 80% corn + 20% rice which have the lowest bulk density feel lighter, and possess a more delicate crunch. Additionally, because most snacks are packaged and sold for a specific advertised weight, a bulkier product will look more appealing to the consumer than a pack that appears half-empty.

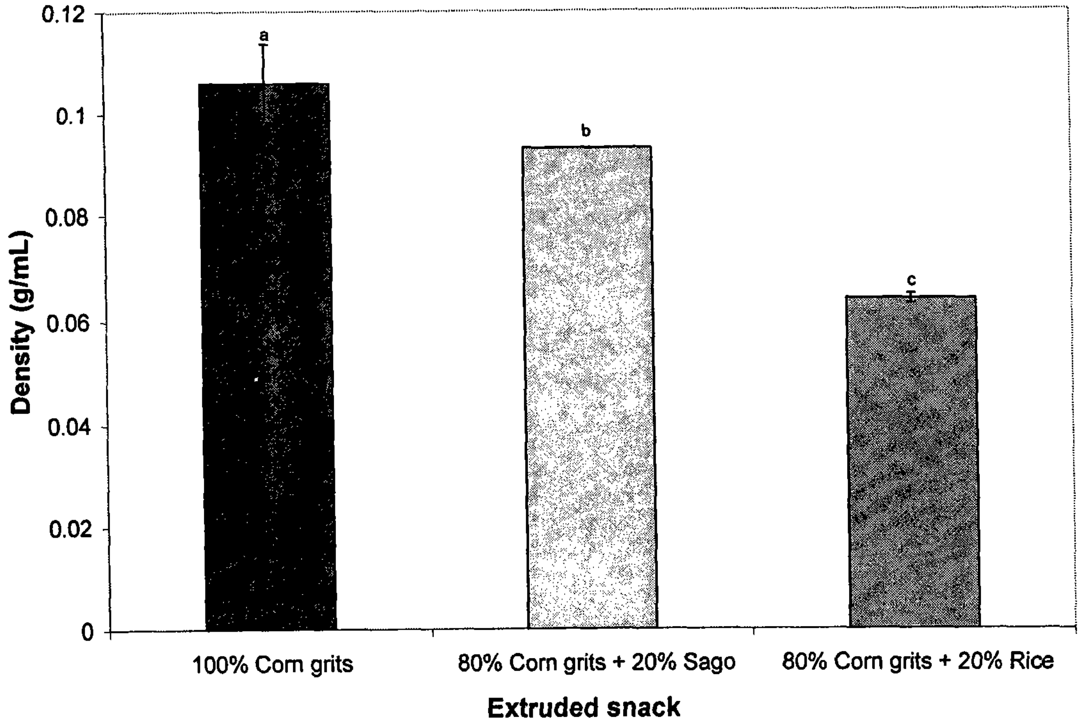


Figure 4.6: Density of the three types of extruded snack

* Letters with the same alphabet on top of bar are not significantly different at 5% probability level ($P > 0.05$)

Apparent amylose content, amount of fat and protein in raw material appear to have minimal effect to bulk density in this study. Since expansion and bulk density are interrelated, therefore, the same explanation as mentioned earlier can be applied.

In this study, extrudate with 100% corn has the highest density and showed least amount of air cells, intermediate cell size and the thickest cell walls among the three samples. On the other hand, extrudate with 80% corn + 20% rice has the lowest bulk density and showed the smallest cell size, more amount of cell and thinnest cell walls when compared with the other two extruded snacks. On the other hand, extruded snack of 80% corn + 20% sago which has the intermediate bulk density among the samples has the biggest size air cells and an intermediate structure in terms of number of air cell and thickness of cell walls.

4.7 Cutting force

Cutting force gives an indication of a sample's resistance to compression. The higher the cutting force, the higher the resistance towards compression. Assessment of the cutting force (Figure 4.7) indicated that cutting force from the Three Bend Point test and Blade Knife test have a similar trend, with the extruded snack with 100% corn required the highest cutting force, while the extruded snack with 80% corn+ 20% rice required lowest cutting force to break it. According to the statistical analysis, extruded snack of 100% corn has no obvious difference ($P > 0.05$) with extruded snack of 80% corn + 20% sago, but has a significant difference ($P < 0.05$) with extruded snack produced from 80% corn + 20% rice. It indicates that when corn is substituted with 20% of rice, the cutting force is significantly decreased. In addition, lowest cutting force found in the extruded snack of 80% corn + 20% rice reflects that it has a relatively weaker structure. Consequently, it is susceptible to product losses due to breaking during handling, transportation, and storage of the extrudate.

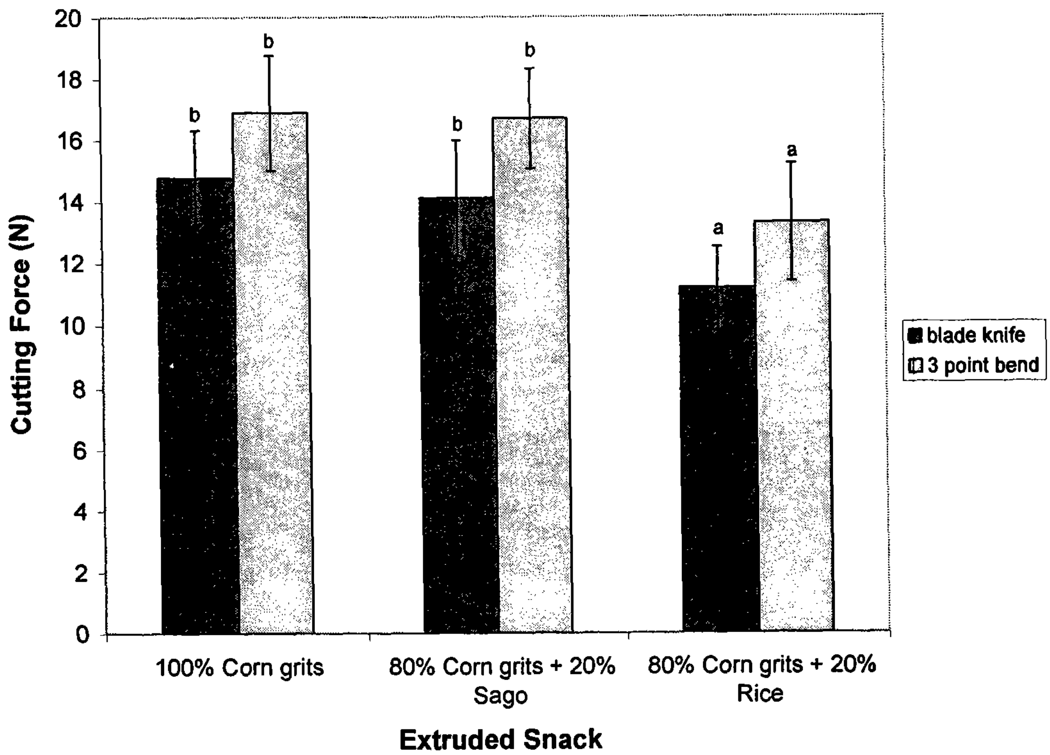


Figure 4.7: Cutting force of the three types of extruded snack

* Letters with the same alphabet on top of bar are not significantly different at 5% probability level ($P > 0.05$)

On the other hand, as shown in Figure 4.7, the extruded snack with 80% corn + 20% sago was slightly harder than the corn flour samples, although the differences were not statistically significant. Higher cutting force resistance mentioned previously for extrudates that contained 80% corn + 20% sago and 100% corn could be an advantage for the handling and transportation of the extruded snack because it reduces product losses.

The force texture profile (Figure 4.8a, 4.8b) was found to be related to the microstructure whereby extruded snack with 80% corn + 20% rice showed a number of sharp multi-minipeaks before breakage was completed and the number of peaks produced was related to its highest porosity (i.e., the number and distribution of the air cells) and thinner cell walls. Extruded snack with 100% corn showed least sharp multi-minipeaks before reaching the highest peak shows that it has the least number of air cells and thicker cell walls. It has been suggested that the number of peaks is related to microstructure, and can be useful as an index for sensory attributes such as crispiness or crunchiness.

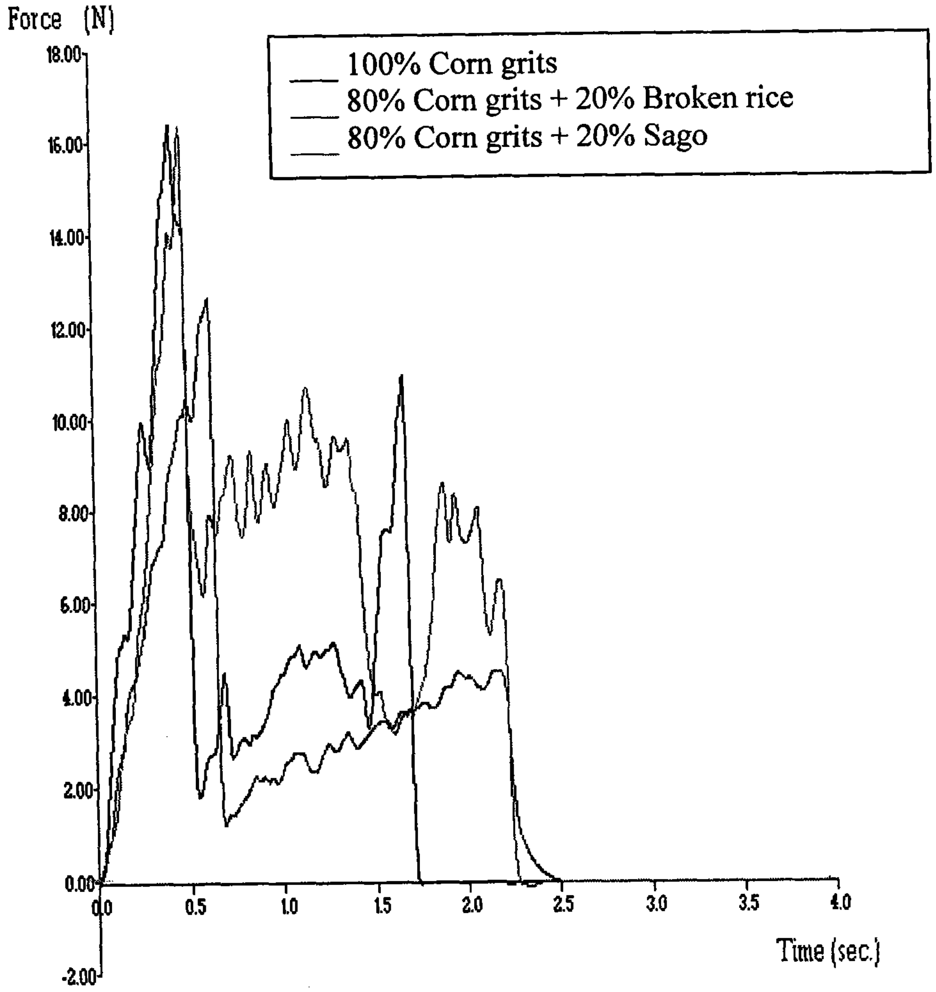


Figure 4.8a: Force texture profile for the three types of extruded snack obtained from Blade knife test

4.8 Water absorption index (WAI) and water solubility index (WSI)

WAI indicates the amount of water immobilised by the extrudate, while WSI indicates the amount of small molecules solubilised in water. Water solubility and absorption parameters characterize the extruded product and are often important in predicting how the extruded material may behave if further processed. The WAI measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion. WAI depends on the availability of hydrophilic groups which bind water molecules and on the gel-forming capacity of macromolecules. Water absorption capacity is an important functional characteristic in the development of a ready-to-eat food for cereal grains, since a high water absorption capacity may assure product cohesiveness.

The WAI of three samples ranged from 5.41 to 6.68 g/g, with the extrudate of 80% corn + 20% sago having the highest WAI and followed by extrudate of 80% corn + 20% rice and the lowest WAI was found in extrudate of 100% corn under similar extrusion condition.

From Table 4.4, the effect of corn substituted with 20% sago starch on WAI value was significant ($P < 0.05$). However, there is no significance difference ($P > 0.05$) in WAI value when corn grits was substituted with 20% broken rice. Extrudate with 80% corn + 20% rice has no significant difference with extrudate of 80% corn + 20% sago and 100% corn. However, it cannot be assumed that extrudate of 80% corn + 20% sago is the same as extrudate of 100% corn in terms of WAI value.

Table 4.4: Water absorption index (WAI) and water solubility index (WSI)

Extruded snack	WAI	WSI
100% corn grits	$5.41^{a} \pm 0.49$	$0.37^{b} \pm 0.05$
80% corn grits + 20% sago	$6.68^{b} \pm 0.30$	$0.25^{a} \pm 0.02$
80% corn grits + 20% broken rice	$5.98^{ab} \pm 0.24$	$0.33^{b} \pm 0.01$

* Values is mean ± standard deviation (n=3)
* Letters with the same alphabet under one column are not significantly different at 5% probability level ($P > 0.05$)

This phenomenon indicates that extrudate of 80% corn + 20% sago has more undamaged long polymer chains and a greater availability of hydrophilic group which could bind more water molecules. Besides, it also reflects that the highest amounts of intact starch granules are present in the extrudate of 80% corn + 20% sago than 100% corn. It may suggest that granules in sago have a high resistance in extreme conditions during the extrusion process, whereas granules of 100% corn underwent more severe degradation, which consequently have more damaged short polymer chains which cannot bind the water molecules and led to lowest WAI among three samples.

In this study, WAI shows a positive relationship with amylose content, which means the higher the amylose content, the higher WAI values. Extruded snack with 80% corn + 20% sago has the highest amylose content which read 35.88% and thereby has the highest WAI value. This is perhaps due to the fact that the amylose component has a helix structure which gives rigidity to starch granules, therefore starch granules do not break easily. Another explanation of this situation is the amylose has a high ability to form a gel after the starch granules have been cooked and the water that is trapped in the gel is difficult to be removed by centrifugation. Thus, the weight of gel is increased and higher WAI values will be obtained.

An inverse relationship is shown with protein content and WAI value in this study. Extruded snack with 100% corn contains highest protein content among three samples, and having lowest WAI. Protein, an insoluble component, depresses WAI values. This result agrees with suggestion made by Noguchi et al (1981).

Extrudate of 100% corn has the highest WSI value, which is 0.37 g/g, and the lowest is extrudate of 80% corn + 20% sago. It shows that extrudate of 100% corn has the highest amount of soluble molecules which means it underwent most severe degradation during extrusion if compared with the other two extrudates.

The WSI was negatively correlated with the reducing value. This might be explained by considering that even though extruded snack with 80% corn + 20% sago has the highest amount of reducing value, but has lesser number of hydroxyl group, hence, less tendency to interact with its surrounding water leading to a greater solubility. In contrast, the extruded snack with 100% corn has highest WSI values couple with lowest level of reducing value. In this case, the plausible explanation is that extruded snack with 100% corn contained a large number of hydroxyl group which consequently increased WSI values. However, our results were contrary to the experimental observation by Ansharullah (1997). It is suggested that the starch mixture as used in our study behaved in different way than starch extruded individually (i.e., sago starch used in Ansharullah's (1997) study).

4.9 Colour

Colour is an important quality characteristic of extruded snacks. For a better perception of colour in the extruded snacks, a Hunter L, *a* and *b* colour solid is shown in Figure 4.10. The scales L, a^* and b^* represent the direction of colour hue. In overall, all extruded snack are yellow in colour. As showed in Table 4.5, colour of all extruded snack was significantly different ($P< 0.05$) in terms of L, a^*, b^*, c. However, extruded snack produced from 80% corn + 20% and 100% corn has a statistical difference ($P<0.05$) with the extruded snack of 80% corn + 20% sago in hue.

By comparison, extruded snack with 80% corn + 20 % rice has the highest L values and lowest *a* value and *b* value. When superimposes these data on the Hunter colour solid (Figure 4.10), it is clear that overall colour hue tended toward light reddish yellow. This light reddish yellow colour may be due to it underwent lesser Maillard reaction, since it has an intermediate reducing value and protein content.

Table 4.5: Colour parameter for the three types of extruded snack

Colour parameter	Extruded snack		
	100% corn	80% corn+ 20% sago	80% corn+20% rice
L	82.85 ± 0.15[a]	82.59 ± 0.28[b]	81.41 ± 0.13[c]
*a**	3.93 ± 0.05[a]	3.77 ± 0.18[b]	3.53 ± 0.06[c]
*b**	33.89 ±0.41[a]	32.52 ± 0.34[b]	27.26 ± 0.17[c]
C	34.12 ±0.40[a]	32.74 ± 0.36[b]	27.49± 0.17[c]
h	83.39 ± 0.16[a]	83.39 ± 0.25[a]	82.61± 0.14[b]

- values is mean values ± standard deviation (n=3)
- letters with the same alphabet under one row are not significantly different at 5% probability level (P> 0.05)

Extruded snack with 80% corn + 20% sago has the intermediate L, a, b value. When these data were placed on the Hunter colour solid (Figure 4.10), it is characterized as darker and more reddish yellow than the extruded snack with 80% corn + 20 % rice. This result might be owing to it underwent lesser expansion and longer Maillard reaction when compared to extruded snack with 80% corn + 20 % rice.

On the other hand, extruded snack with 80% corn has the lowest L value with the highest a value and b value among three samples. From the Hunter colour solid (Figure 4.9), these values shows that it has the darker and most reddish yellow colour when compared with the other two samples. Its darkest reddish yellow colour might be due to it has the highest amount of protein which is the limiting factor in the Maillard reaction in this study and lowest reducing value. Consequently, it underwent longer Maillard reaction. Another explanation that could be made is that it has the lowest expansion ratio and thus less colour fading occurred.

These results are consistent with the observation in the stereo light microscopy, in which extruded snack with 80% corn has the darkest yellow, followed by extruded snack with 80% corn + 20% sago and the lightest yellow found in the extruded snack with 80% corn + 20% rice.

5 Conclusions

Corn grits has the highest amount in terms of fiber, fat, ash and protein. Amylose content appeared to have minimal effect on pasting properties, expansion ratio, bulk density, but affects WAI and WSI. Pasting parameters from RVA in this study could not be used to predict the extrusion processing. Substitution with 20% rice resulted in significant increased in expansion ratio. It was noted that expansion ratio showed an inverse trend with the density and cutting force. SEM and stereo light microscopy showed that substitution of 20% sago starch and 20% broken rice resulted in more expanded extrudates with more number of air cells and thinner cell walls. Highest bulk density was observed in extrudate with 100% corn grits and it could be related to expansion ratio, microstructure and cutting force. Higher cutting force resistance for extrudates that contained 80% corn + 20% sago and 100% corn could be an advantage for the handling and transportation of the extruded snack as it reduces product losses. Cutting strength could be related to extrudate's microstructure. WAI and WSI correlated well with amylose, protein content of the raw material. The highest WAI and WSI were found in extrudate of 80% corn grits + 20% sago and 100% corn grits, respectively. Highest total reducing value was found in extrudate of 80% corn grits + 20% sago. It was noted that reducing value have a negative relationship with WSI and not related with the colour. All extrudates showed reddish yellow colour. All extrudates exhibited a very low a_w value and hence can be considered as a stable food product.