Some physico-chemical characteristics of taro, sweet potato and potato flours, and their extrudates
(Beberapa ciri fizikal dan kimia tepung ubi keladi, keledek dan ubi kentang serta sempritannya)

S. Y. Lee* and A. Hamidah*

Key words: root tubers, extrudates, physico-chemical characteristics

Abstrak
Umbisi seperti ubi keladi, keledek dan kentang boleh digunakan secara berkesan dengan memprosesnya kepada tepung. Tepung ini boleh disimpan dan digunakan kemudian sama ada secara langsung ataupun dicampur dengan bahan lain untuk menghasilkan snek sempitan. Sempitan daripada tepung ini mempunyai beberapa ciri fizikal dan kimia bagi snek yang baik seperti nisbah pengembangan, ketumpatan, warna, kekuatan patah dan zat makanan. Sempitan daripada ubi keladi dan keledek didapati boleh diterima berasaskan ciri-ciri tersebut dan penerimaan keseluruhan.

Abstract
Tubers such as taro, sweet potato and potato can be effectively used by processing them into flour. This flour can be stored and later used either directly or combined with other materials to produce extruded snacks. Extrudates produced from flour of these tubers possessed some physico-chemical characteristics of a desirable snack such as expansion ratio, density, colour, breaking strength and nutrient composition. It was found that taro and sweet potato extrudates can be accepted based on these characteristics and the overall acceptability.

Introduction
Extrusion cooking has been applied to process a wide variety of food such as snacks, cereals, meat analogues, pet and animal food, sausage products, protein supplements, pasta foods and confectionery products (Harper 1981). Extrusion cooking involves the generation of high temperatures and pressures within the extruder by forcing the material against a restricting orifice or die by a rapidly rotating screw. The material issuing from this die was instantaneously exposed, from a region of very high pressure, to a region of atmospheric pressure. As a result, the water in the hot mass flashes off as steam, leaving an expanded sponge-like texture which ideally dries quickly and sufficiently to prevent the collapse of the puff. Unfortunately, these conditions also tend to result in a loss of volatile flavouring substances which may be present (Blanchfield and Ovenden 1974).

Extrusion of food materials usually is a complicated process because food materials are often heterogeneous and contain a variety of ingredients. The properties of these ingredients depend on their source, age, pre-treatment, process history, etc.

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which undergo complex physico-chemical changes when they are subjected to high temperature, pressure and shear in the extruder barrel (Bhattacharya and Hanna 1987; Senounci and Smith 1988). These extrusion cooking conditions will ultimately cause some transformation in textural properties and some nutritional loss of the extruded products. Therefore, it is important to understand how changes in extrusion operating conditions affect the extrusion process (Lee 1994). It is also important to monitor proper extrusion operating conditions to achieve consistent product properties which include texture, density, colour, degree of cook, mechanical property, degree of puff and flavour. Extruded products from wheat and corn have been widely used while very little work has been done on extrusion of starch from root tubers such as sweet potato and taro except for potato. These tubers are available as intact tubers either cured or freshly harvested. The major constraints in availability of these tubers are their bulkiness, perishable nature, transportation and storage losses. An effective way to solve these problems is to convert the fresh tubers into flour. In this way, these raw materials would be available throughout the year. Therefore, this study was undertaken to study the use of root tubers to produce extruded snack.

Materials and methods
Preparation of tuber flour
Taro, sweet potato and potato tubers were bought from local markets and stored in the cold room at 5 °C for 1 week before processing into flour (Figure 1). The tubers were washed to remove surface dirt. They were hand-peeled and sliced using an automatic slicer (HLLDE, Sweden) to 2 mm thickness. The slices were spread over nettrays and dried in a forced-air dehydrator (Proctor and Schwartz Inc., Philadelphia, USA) at 60 °C for 7–8 h. After drying, the slices were cooled and ground into flour using a stone grinder (Engineering Machinery Ent., Kuala Lumpur, Malaysia).

Figure 1. Processing of tuber into flour

Sample preparation for extrusion
Tuber flour was tempered to 16% (wb) by adding a calculated volume of water slowly to the flour in a heavy duty mixer (Kenwood, England). The flour was blended, sealed into high density polyethylene bags and allowed to equilibrate at 5 °C for 24 h. Prior to extrusion, the flour was allowed to attain ambient temperature.

Extrusion
Extrusion was performed using a 1.90 cm diameter laboratory extruder 20DN Brabender (Model 823500 OHG Duisburg, Germany) having a barrel length-to-diameter ratio of 20:1. The extruder was powered by a 2.2 kW motor with an electrically variable speed between 0 and 250 rpm. A screw compression ratio of 3:1 and a round die with a die insert of 6.0 mm in diameter were used. Screw speed was maintained at 200 rpm for all runs and the raw material was fed through a gravity-feed hopper. The barrel was equipped with electrically-heated,
compressed air-cooled collars controlled by thermostats to maintain desired temperatures. The temperature of the first barrel zone (feed end) was 120 °C while that of the second and third zones were set at 150 °C for all runs. The extruder was operated until steady state was achieved before samples of the smooth flowing products were taken. A cutter at the discharge end of the extruder barrel cut the extrudate into small cylindrical particles.

Preliminary investigations showed that it was necessary for the first two barrel sections to be cooled sufficiently to condense any steam which migrated toward the feed opening of the extruder barrel. If these sections were not cooled, the steam would be absorbed by the incoming material causing it to be partially gelatinized and to clog the feed inlet. Being a single screw extruder, it is not self-emptying and with the feed inlet clogged, the remaining raw material in the extruder barrel will harden and lock the screw.

Analysis of physical properties of tuber flour and extrudate

Physical properties of tuber flour include particle size and the colour of tuber flour. Physical properties of extrudate include the colour, diameter, expansion ratio, density, breaking strength of extrudate and organoleptic attributes of the extrudate.

Particle size analysis was carried out to determine the size distribution of the flour particles to ensure consistent particle size. The procedure was carried out on a Rotap device (Endocott test sieve shaker, London, England) with five screens ranging from mesh no. 14 (1.4 mm) to mesh no. 60 (0.250 mm). The unit was shaken for 5 min.

The colour lightness (L) of the tuber flour and extrudate was measured using a Kett whiteness tester (Model C-300, Tokyo, Japan). A white standard tile was used as reference with \( L = 86.8 \). Extrudate samples were milled to 0.185–0.250 mm with a IKA-analytical mill A10 (Type A10S2, Staufen, Germany) to standardize any particle size effect on the colour values (Fletcher et al. 1985).

Expansion ratio was determined by using the method of Mercier and Feillet (1975). Duplicate measurements were made by using a micrometer (Mimituuyo MFG Co. Ltd., Tokyo, Japan) on 20 pieces of extrudate taken at random. The expansion ratio is expressed as,

\[
\text{Expansion ratio} = \frac{\text{cross-sectional area of extrudate}}{\text{area of die insert}}
\]

The density of the extrudate was determined by using the method of Fletcher et al. (1985) by weighing about 30 cm³ of extrudate and measuring its volumetric displacement with acid-washed sand (Gainland Chemical Co., U.K.). This was repeated three times for each sample. The density of the extrudate is given by,

\[
D_e = \frac{W_e}{W_{sr}} \cdot D_s
\]

where \( D_e \) = density of extrudate,
\( W_e \) = weight of extrudate,
\( W_{sr} \) = weight of sand replaced,
\( W_s \) = weight of sand,
\( W_s + e \) = weight of sand and extrudate,
\( W_e \) = weight of extrudate,
\( W_{sr} \) = weight of sand replaced,
\( W_s \) = weight of sand,
\( W_s + e \) = weight of sand and extrudate.

Texture of the extruded product was studied using the universal INSTRON machine (Model 1140, Buck, England). Twenty pieces of extrudate were randomly selected from each sample. The sample piece was placed on the loading cell and compressed using the Warner Bratzler shear press under the conditions: full scale load of 20 kg, cross-head speed of 50 mm/min and chart speed of 50 mm/min (Chauhan and Bains 1985). During compression, changes in the force required to break the sample were recorded on the chart in the form of peaks. The maximum force (expressed in kilograms) required to break or snap the sample was expressed as the breaking strength which is an indication of product toughness (Maga and Fapojuwo 1988).
Organoleptic acceptability was evaluated by 20 experienced panelists who were asked to rate the colour, flavour, crispness and overall acceptability using a 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely.

**Chemical analysis**
The moisture content, ash, fat, protein, crude fibre and total sugar of tuber flour were determined according to Pearsons Chemical Analysis of Food (Egan et al. 1987). Total carbohydrate was determined by difference. For each analysis, at least three replicates were made from each sample.

**Results and discussion**

**Analysis of physical properties of tuber flour and extrudate**
Using the processing method described in Figure 1, flour recovery from taro was found to be higher than that of sweet potato and potato (Table 1). Taro also had a higher moisture content than both sweet potato and potato. The moisture content of the tuber flour was found to range from 2.86% to 3.32% (wb) which would give good storability. The results indicated that taro flour ($L = 67.33$) is lighter in colour than sweet potato flour ($L = 45.67$) while potato flour is darker ($L = 35.33$). Statistically, it was found that the colour of taro flour differed significantly from the colour of sweet potato and potato flour. The lightness in colour of the tuber flour is important because it determines the final colour of the extrudate after extrusion. The colour of the taro extrudate ($L = 52.95$) was found to be significantly different from the colour of sweet potato ($L = 39.92$) and potato ($L = 27.53$) extrudates. However, the colour of the flour was not significantly different from the colour of the extrudate for taro, sweet potato and potato.

Particle size distribution of the tuber flour for extrusion is important because it provides consistency in feed material specification as well as to suit the limitation of the single screw extruder. The particle size distribution of the tuber flour is shown in Table 2.

The diameter of the extrudate from taro flour was 12.46 mm which was significantly larger than the potato extrudate of 11.26 mm and sweet potato extrudate of 10.50 mm as shown in Table 3. The small value of sweet potato extrudate diameter could be due to the high sugar content of the flour which did not contribute to good expansion. Expansion ratio is the ratio of extrudate cross-sectional area to the die insert area, therefore it is proportional to the extrudate diameter. The

### Table 1. Moisture content and flour recovery from three tubers

<table>
<thead>
<tr>
<th>Tuber</th>
<th>Moisture content (%)</th>
<th>Flour recovery (%)</th>
<th>Moisture content of flour (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taro</td>
<td>83.92</td>
<td>20.20</td>
<td>3.32</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>75.16</td>
<td>19.21</td>
<td>2.94</td>
</tr>
<tr>
<td>Potato</td>
<td>70.01</td>
<td>14.09</td>
<td>2.86</td>
</tr>
</tbody>
</table>

### Table 2. Particle size distribution of the three types of tuber flour

<table>
<thead>
<tr>
<th>Mesh no.</th>
<th>Size (mm)</th>
<th>Particle size distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>1.40</td>
<td>0.58 1.88 0.74</td>
</tr>
<tr>
<td>20</td>
<td>0.85</td>
<td>1.60 14.71 5.96</td>
</tr>
<tr>
<td>30</td>
<td>0.60</td>
<td>3.69 15.19 8.71</td>
</tr>
<tr>
<td>40</td>
<td>0.42</td>
<td>9.21 12.74 14.64</td>
</tr>
<tr>
<td>60</td>
<td>0.25</td>
<td>26.60 12.06 25.53</td>
</tr>
<tr>
<td>Pan</td>
<td>–</td>
<td>58.32 43.42 44.42</td>
</tr>
</tbody>
</table>
expansion ratio of taro extrudate of 2.08 (Table 3) was found to be significantly larger than the ratios for sweet potato (1.75) and taro (1.88) extrudates. The taro extrudate produced an almost twofold expansion which is considered desirable in extrudate quality.

The density of the extrudate is the inverse proportion of the extrudate diameter. The taro extrudate (0.23 kg/L) had significantly lower density than sweet potato (0.53 kg/L) and potato (0.34 kg/L) extrudates (Table 3). The lower the density, the more desirable it is in the extrudate quality. This is because, for the same volume of extrudate, lower density extrudate weighs less.

The breaking strength of the taro extrudate of 7.35 kgf was significantly less than the values of sweet potato extrudate (10.61 kgf) and potato extrudate (14.86 kgf, Table 3). Breaking strength which is the maximum force required to break or snap the extrudate, is an indication of product toughness (Maga and Fapojuwo 1988). Therefore, by this definition, the taro extrudate makes the most desirable snack.

**Chemical analysis of tuber flour and extrudate**

Chemical analysis of moisture content, ash, fat, protein, crude fibre, total carbohydrate and total sugar showed that the tuber flour had small amounts of ash, protein, crude fibre and very little fat. The major component was carbohydrate with sweet potato having a high percentage of total sugar (Table 4).

The chemical analysis of the extrudates showed that some values of the components have changed due to the high temperature and pressure in the extruder barrel. This is considered quite normal in extrusion cooking. There was a significant increase in the moisture content of the extrudate compared with the moisture content of the flour of taro, sweet potato and potato. The high moisture content (~ 8%) of the extrudate is due to the water added to bring the flour to 16% moisture content prior to

### Table 3. Extrudate properties produced from three types of tuber flour

<table>
<thead>
<tr>
<th>Tuber</th>
<th>Diameter (mm)</th>
<th>Expansion ratio</th>
<th>Density (kg/L)</th>
<th>Breaking strength (kgf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taro</td>
<td>12.46a</td>
<td>2.08a</td>
<td>0.23a</td>
<td>7.35a</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>10.50b</td>
<td>1.75b</td>
<td>0.53b</td>
<td>10.61b</td>
</tr>
<tr>
<td>Potato</td>
<td>11.26c</td>
<td>1.88c</td>
<td>0.34c</td>
<td>14.86c</td>
</tr>
</tbody>
</table>

Mean values with different letters in each column are significantly different ($p < 0.05$) based on t-test

### Table 4. Chemical analysis of flour and extrudate from three tubers

<table>
<thead>
<tr>
<th>Tuber</th>
<th>Moisture content (g/100 g)</th>
<th>Ash (g/100 g)</th>
<th>Fat (g/100 g)</th>
<th>Protein (g/100 g)</th>
<th>Crude fibre (g/100 g)</th>
<th>Total carboh. (g/100 g)</th>
<th>Total sugar (g/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taro flour</td>
<td>3.32a</td>
<td>2.74a</td>
<td>0.68</td>
<td>3.79a</td>
<td>2.23a</td>
<td>87.24a</td>
<td>1.38a</td>
</tr>
<tr>
<td>Taro extrudate</td>
<td>7.74b</td>
<td>2.53a</td>
<td>nd</td>
<td>2.63a</td>
<td>1.25b</td>
<td>85.86a</td>
<td>1.59b</td>
</tr>
<tr>
<td>Sweet potato flour</td>
<td>2.92a</td>
<td>2.61a</td>
<td>1.56a</td>
<td>3.75a</td>
<td>3.33a</td>
<td>85.83a</td>
<td>18.59a</td>
</tr>
<tr>
<td>Sweet potato extrudate</td>
<td>7.45b</td>
<td>1.99a</td>
<td>0.62b</td>
<td>1.39b</td>
<td>2.98a</td>
<td>85.56a</td>
<td>9.01b</td>
</tr>
<tr>
<td>Potato flour</td>
<td>3.19a</td>
<td>4.33a</td>
<td>0.57</td>
<td>4.43a</td>
<td>2.38a</td>
<td>85.09a</td>
<td>1.28a</td>
</tr>
<tr>
<td>Potato extrudate</td>
<td>7.73b</td>
<td>5.03b</td>
<td>nd</td>
<td>5.29a</td>
<td>1.99b</td>
<td>79.97b</td>
<td>1.27a</td>
</tr>
</tbody>
</table>

Mean values with different letters in each column are significantly different ($p < 0.05$) based on t-test

nd = not detectable
Characteristics of flour and extrudates from three tubers

extrusion. In terms of ash content, the flour did not differ significantly from the extrudates of taro, sweet potato and potato. Fat was not detectable in the extrudates of taro and potato. However, there was a significant change in the fat content of sweet potato flour and the extrudate. There was no significant change in the protein content of taro and potato flour compared with the protein content of the taro and potato extrudates. However, the protein content of sweet potato extrudate was found to be significantly lower than that of the sweet potato flour. Extrusion cooking had resulted in a significant change in the crude fibre content of taro and potato flour compared with their extrudates. However, the difference between the crude fibre content of sweet potato flour and extrudate was insignificant. It was found that the total carbohydrate content of potato flour was significantly different from the extrudate. There was a significant difference between the total sugar content of the flour and extrudate for taro and sweet potato.

Organoleptic evaluation
Results of organoleptic evaluation by 20 panelists (Table 5) showed that the taro extrudate differed significantly in colour from the sweet potato and potato extrudates. The flavour and crispness of the taro extrudate were not significantly different from those of the sweet potato extrudate but were significantly different from those of potato extrudate. The taro extrudate had a higher overall acceptability score than sweet potato and potato extrudates. Based on these four attributes, the taro extrudate was significantly different from the potato extrudate but almost not significantly different from the sweet potato extrudate. However, taro extrudate had the highest scores in colour, flavour, crispness and overall acceptability compared with sweet potato extrudate.

Conclusion
From the physico-chemical results obtained, it can be concluded that the taro, sweet potato and potato flour had a high carbohydrate content which is a good source of energy. However, they were fairly low in protein and crude fibre contents. The fat content was considered very low. Based on the physical properties, extrudates from taro flour produced desirable values in relation to its expansion, density, colour and breaking strength compared with sweet potato and potato extrudates. From the organoleptic evaluation, taro extrudate scored the highest overall acceptability. Therefore, taro extrudate has potential for acceptance as a snack. To cater for specific consumers, it is possible to increase its protein level by incorporating other high-protein materials such as legume flour or adding prawn or fish powder in the formulation or as a dusting on the final product. It is also possible to increase the fibre content of a snack by adding dietary fibre from vegetable sources. Therefore, this may be one of the effective ways of using the root tubers to produce extruded snacks.

Acknowledgements
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Table 5. Organoleptic evaluation* of extrudates produced from tuber flour

<table>
<thead>
<tr>
<th>Tuber</th>
<th>Colour</th>
<th>Flavour</th>
<th>Crispness</th>
<th>Overall acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taro</td>
<td>6.00a</td>
<td>5.95a</td>
<td>6.85a</td>
<td>6.15a</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>4.70b</td>
<td>5.90a</td>
<td>6.65b</td>
<td>5.15b</td>
</tr>
<tr>
<td>Potato</td>
<td>3.65c</td>
<td>4.24b</td>
<td>5.30c</td>
<td>3.85c</td>
</tr>
</tbody>
</table>

Mean values with different letters in each column are significantly different ($p <0.05$) based on t-test

*Using a 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely
References

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