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The potential of mango, papaya, and melon seed dietary fibre extracts for functional food

[1]Guan, L.S., [2]Pasaribu, S.F., [3,*]Rabeta, M.S., [3]Akter, B. and [4]Ghazali A.

[1]*Food Technology Division, School of Industrial Technology Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia*
[2]*Department of Nutrition, Faculty of Health Sciences, Institut Kesehatan Helvetia, Medan, Indonesia*
[3]*Department of Community Health, Advanced Medical and Dental Institute, Universiti Sains Malaysia Bertam, 13200, Pulau Pinang, Malaysia*
[4]*Bioresource Technology Division, School of Industrial Technoology, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia*

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Abstract

Fruit seeds were previously discarded as waste, which could lead to an environmental burden. In this research, dietary fibre (DF) was extracted from mango, papaya, and honeydew seeds, and the optimum extraction conditions were determined. Analyses revealed that all DF extracts exhibit low moisture, fat, ash, and protein contents and present high amounts of total sugar, starch, and total DF. Mango seed DF extract produced the highest amounts of starch (28.68 g/100 g dry extract) and total sugar (41.77 g/100 g dry extract) whilst honeydew seed dietary fibre extract (HSDFE) revealed the highest total DF content (81.96 g/100 g dry extract). A great difference in the ratio of insoluble DF to soluble DF contents was found in papaya seed DF extract and HSDFE. Besides slightly acidic and low bulk density, all DF extracts were yellowish and showed high water-holding (WHC), water swelling (WSC), and oil-holding capacities (OHC). Results indicated all three DF extracts have good physicochemical and functional properties. However, honeydew seed had the best potential functional food due to its low-fat content and bulk density, high insoluble DF and total DF content, nearly neutral pH, and excellent WSC, OHC, emulsion ability (EA), and emulsion stability (ES).

1. Introduction

The linkage of dietary fibre (DF) to human health is strongly associated with the physicochemical and also functional properties of DFs and depends on other factors such as extraction methods (Wuttipalakorn *et al.*, 2009; Peerajit *et al*., 2012). The insoluble dietary fibre (IDF) has a high water retention capacity (WRC) and water swelling capacity (WSC) that may have a positive effect on human health (Ou *et al.*, 2001; Tungland and Meyer, 2002; Saura-Calixto, 2011; Liu *et al.*, 2016; Macagnan *et al.*, 2016).

In many instances, byproducts are relatively richer in bioactive compounds, BC, than pulp or end products (Silva *et al*., 2014), which makes them suitable for use as an inexpensive source of nutrients. By recovering the valuable BC from fruit wastes and utilizing it in other food applications, the waste burden would be tremendously reduced, and the intensive public demand for BC would also be met (Cheok *et al*., 2018). Furthermore, utilizing fruit waste also reduces the environmental burden and improves the overall economics of the processing units (Salim, 2017). Such practice contributes to the globally trending circularity initiatives by closing the materials flow loop where wastes become the commodity (Ghazali *et al*., 2024).

Malaysian adults consumed approximately 7.5 g of DF daily, indicating that consumption of DF among most Malaysian adults is less than the recommended amount of 20-30 g/day (Ng *et al.*, 2010). In recent years, food researchers have explored various types of agricultural fibre sources in search of new food ingredients for foodstuffs such as baked and fried products, as well as DF sources that can yield physiological benefits to consumers and also as an encouragement for Malaysians to increase their DF intake. For example, Choo and Abdul Aziz (2010) used banana peel flour to make noodles, while Kurhade *et al.* (2015) incorporated banana peel powder in Chapatti making, and they found

*Corresponding author.
Email: *rabeta@usm.my*

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that the food had improved quality in addition to the increased DF content. This research aimed to determine the physicochemical and functional properties of mango seed dietary fibre (MSDF), papaya seed dietary fibre (PSDF), and honeydew seed dietary fibre (HSDF) extracts.

2. Materials and methods

2.1 Sample collection and preparation

Harumanis mango (*Mangifera indica*), Eksotika papaya (*Carica papaya* Lin), and Inodorus honeydew (*Cucumis melo*) were purchased from local supermarkets in Gelugor, Penang, Malaysia in the second half of October and early November 2019. The seeds separated from the fruit flesh were oven-dried at 50°C for at least 48 hrs to a 14±1% moisture content (wet basis). The dried seeds were ground and placed in polyethene plastic bags for storage in a desiccator at room temperature (27°C) until further use.

2.2 Nutrient composition

The proximate composition of the samples such as moisture content, ash, crude protein, fat, and crude fibre was determined according to the methods of the Association of Official Analytical Collaboration (AOAC) International (2000). The percentage of total carbohydrate content was determined by:

$$\%\ \text{Carbohydrate} = 100 - (\%\ \text{ash} + \%\ \text{fat} + \%\ \text{protein} + \%\ \text{fiber content})$$

2.3 Determination of few types of dietary fibre content

The IDF, SDF, and TDF contents of the DF extracts were determined following the AOAC method 991.43 (AOAC, 2000). Duplicate test samples of 1 g of the DF extract were sequentially treated for starch gelatinization, enzymatic starch, and protein digestion in three incubation steps: heat stable α-amylase (or 1) (1500-3000 units/ mg protein; Sigma Chemical Co.) at 95 to 100°C for 15 mins; amyloglucosidase (5000-8000 units/ ml; Sigma Chemical Co.) at 60°C for 30 mins, pH 4.0-4.7; and protease (7-15 units/mg protein; Sigma Chemical Co.), pH 7.5. The IDF was washed with two portions of 15 mL 78% ethanol, 15 mL 95% ethanol, and 15 mL acetone and then dried in an oven (103°C) overnight. For SDF, the filtrate was precipitated with 95% ethanol at 60°C before filtering. The SDF was then washed with two portions of 15 mL 78% ethanol, 15 mL 95% ethanol and 15 mL acetone before being left to dry in an oven (103°C) overnight.

$$\%\text{IDF}/\%\ \text{SDF} = \frac{(\text{Residue weight} - \text{Protein content} - \text{Ash content} - \text{Blank})}{\text{Weight of sample}} \times 100\%$$

2.4 Determination of total starch

The total starch content of DF extracts was determined using the AOAC method 996.11 (AOAC, 2000). Approximately 100 mg of the DF extract was weighed in duplicate into Corning culture tubes. A 0.2 mL of 80% v/v aqueous ethanol was added, and the tube contents were stirred on a vortex mixer to completely wet and disperse the sample. Exactly 2 mL of cold 1.7 M sodium hydroxide solution was added, and the tube contents were stirred on a vortex mixer for 15 s. Then, 8 mL of 600 mM sodium acetate buffer was added, and the pH of the tube contents was ensured to be 5.0, followed by the addition of 0.1 mL of undiluted thermostable α-amylase and 0.1 mL of amyloglucosidase to one of the tubes (sample tube). Both tubes were capped and the contents were vortexed for 3 s, followed by incubation at 50°C for 30 mins. A 2.0 mL aliquot of each solution (sample and sample blank) was transferred to microfuge tubes, which were then centrifuged at 13,000 RPM for 5 mins. Absorbance was then determined against the reagent blank at 510 nm (Shimadzu UV-1650PC UV-Vis Spectrophotometer). Total starch content was expressed using the equation below:

Total Starch Content (%) = Absorbance × volume (mL) × dilution factor × 0.90

2.5 Determination of pH

Approximately 100 mL of deionized, boiled, and cold water were added to 10 g of DF extract. The sample was left to stand for 10 mins, and pH was measured using a pH meter (Mettler Toledo Delta 320 pH meter, Ohio, United States).

2.6 Determination of colour

The colour of DF extracts was measured using a colourimeter (Model Minolta Spectrophotometer CM-3500D, Osaka, Japan). The sample was agitated horizontally lightly to shuffle the content for a more accurate result.

2.7 Determination of bulk density

Bulk density determination employed the methods described by Kaur and Singh (2005). The result was derived using the equation below:

$$\text{Bulk density (g/mL)} = \frac{\text{The dry weight of the sample}}{\text{The volume of the sample after tapping}}$$

2.8 Determination of water holding capacity

The water-holding capacity (WHC) of DF extracts was measured using the method of Huang *et al*. (2018) with a slight modification. About 0.5 g of the extracted DF was centrifuged at 4800 rpm for 30 mins.

$$\text{WHC (g/g)} = \frac{\text{Hydrated sample weight} - \text{Dry sample weight}}{\text{Dry sample weight}}$$

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2.9 Determination of water swelling capacity

The water swelling capacity (WSC) was determined by the method of Huang *et al*. (2018) with slight modifications. Approximately 0.5 g of the DF extracts and 10 mL of distilled water were placed into a measuring cylinder for 18 hrs incubation at room temperature to examine the expansion of the free volume of the DF extract. The WSC was calculated using the equation below:

$$\text{WSC (mL/g)} = \frac{\text{The volume of swollen sample} - \text{Volume of dry sample}}{\text{The dry weight of the sample}}$$

2.10 Determination of oil holding capacity

The oil holding capacity (OHC) was determined by the method of Huang *et al.* (2018) with slight modifications. Approximately 0.5 g of the DF extracts were weighed into a dried pre-weighed centrifuge tube with 4 g of commercial cooking oil added. Afterwards, the solution was centrifuged for 20 mins at 4000 rpm.

$$\text{OHC (g/g)} = \frac{\text{Sample weight after oil absorption} - \text{Dry sample weight}}{\text{Dry sample weight}}$$

2.11 Determination of emulsion activity and emulsion stability

The emulsion activity (EA) and emulsion stability (ES) were determined by the method of Lan *et al.* (2012). The homogenized solution was centrifuged at 1200 rpm for 5 mins, and then the EA was calculated using the equation below:

$$\text{EA (mL/100mL)} = \frac{\text{The volume of the emulsifying layer}}{\text{Total volume}} \times 100$$

Finally, the prepared emulsion was heated at 80°C for 30 mins, cooled to room temperature, and centrifuged in a 50 mL graduated tube at 1200 rpm for 5 mins to determine the ES using the equation below:

$$\text{ES (mL/100mL)} = \frac{\text{The volume of the remaining emulsifying layer}}{\text{Original emulsion volume}} \times 100$$

2.12 Statistical analysis

A Post Hoc test (Bonferroni test) was conducted to determine which samples were significantly different from which samples. Both the ANOVA test and the Post Hoc test were calculated at a 5% significance level (p = 0.05), which means the statistical analysis conducted was 95% confident to be correct.

3. Results and discussion

3.1 Chemical composition of fruit seed dietary fibre extract

Table 1 shows the moisture content exhibited by all the DF extracts in this study was similar to those determined by Martínez *et al*. (2012) in mango, passion fruit, pineapple and guava fibre concentrates, which were 9.4, 9.3, 9.3, 9.3 g/100 g sample, respectively. Protein content in MSDFE (4.25 g/100 g dry sample), PSDFE (5.39 g/100 g dry sample) and HSDFE (5.99 g/100 g dry sample) was low as compared to mango and passion fruit fiber concentrates (8.0 and 6.2 g/100 g dry sample, respectively) (Martínez *et al*., 2012).

Table 1. Chemical composition of 3 different types of fruit seed dietary fibre extract on a dry basis (g/100 g sample).

Component	MSDFE	PSDFE	HSDFE
Moisture	9.77±0.18^{a}	9.36±0.23^{a}	9.20±0.16^{a}
Protein	4.45 ±0.46^{a}	5.39 ±0.26^{a}	5.99±0.24^{a}
Fat	4.31±1.80^{a}	3.72±0.25^{a}	2.36±0.20^{b}
Ash	3.50±0.69^{a}	4.08±0.16^{a}	3.35±0.30^{b}
Total Starch	28.68±0.72^{a}	19.61±0.89^{b}	11.46±0.90^{c}
Total Sugar	41.77±0.46^{a}	30.74±0.45^{c}	32.54±0.63^{b}

Values are presented as mean±SE, n = 3. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

Low-fat contents with $p<0.05$ in all the DF extracts ranging from 2.36 g/100 g dry sample in HSDFE to 4.31 g/100 g dry sample in MSDFE, lower than those reported in mango fibre concentrates (5.90 g/100 g dry sample) (Martínez *et al*., 2012) and *Citrus sinensis* peel fibre (22.2 g/100 g dry sample) (Chau and Huang, 2003). The only remarkable recorded difference in the fat content was between MSDFE with HSDFE and PSDFE with HSDFE at a 95% confidence level. A range of 3.35 to 4.08 g/100 g dry sample ash content was recorded, the lowest for HSDFE and the highest for PSDFE. These results were in agreement with the findings of Chau and Huang (2003), who reported 3.3 g ash in 100 g dry fiber from *Citrus sinensis* peel. A significant difference ($p<0.05$) in ash content between MSDFE with HSDFE and PSDFE with HSDFE.

There were significant differences $p<0.05$ in total starch content amongst all DF extracts. The total starch content in MSDFE was 28.68 g/100 g dry sample (Table 2). In terms of total sugar content, MSDFE showed ($p<0.05$) the highest amount of 41.77 g/100 g dry sample, followed by HSDFE (32.54 g/100 g dry sample) and PSDFE (30.74 g/100 g dry sample). Significant differences ($p<0.05$) in total sugar content were also found among all DF extracts.

According to the 'Database for the Added Sugars Content of Selected Foods' published by the United States Department of Agriculture (USDA) (2006), mango, papaya, and honeydew contain 14.80, 5.90, 8.12 g of sugar per 100 g of fruit, respectively which support the findings in this study which indicate that MSDFE contained the highest amount of total sugar whereas PSDFE had the lowest total sugar content. Out of the

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three types of fruit used in this study, papaya fruit was the least ripe. This may explain the low amount of sugar found in PSDFE.

TDF, IDF, and SDF content of all DF extracts on a dry basis as well as the ratio between IDF and SDF are presented in Table 2. Concerning TDF content, the DF extracts showed ($p<0.05$) TDF contents ranging from 60.47 to 81.96 g/100 g on a dry matter basis. TDF contents significantly differed ($p<0.05$) among all DF extracts. Among all samples, MSDFE had the lowest TDF content, and the value obtained was significantly lower than that of mango fiber concentrate (70 g/100 g dry sample) reported by Martínez *et al.* (2012). The low TDF content in MSDFE could be related to its high starch content. However, such a high starch level might be important for certain food products, given the additional functional properties imparted by starch.

Table 2. Total, soluble, and insoluble dietary fibre and the ratio of insoluble to the soluble dietary fibre content of 3 different types of fruit seed dietary fibre extract on a dry basis (g/100 g sample).

Component	MSDFE	PSDFE	HSDFE
TDF	60.47±1.55^{c}	68.74±1.99^{b}	81.96±2.60^{a}
IDF	41.00±0.64^{c}	53.67±2.87^{b}	66.85±3.31^{a}
SDF	19.46±2.00^{a}	15.07±2.88^{b}	15.12±3.39^{b}
The ratio of IDF/SDF	2.12±0.18^{b}	3.64±0.67^{a}	4.53±0.74^{a}

Values are presented as mean±SE, n = 3. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

In all samples, the IDF showed high content compared to SDF, and the trend same as guava fibre concentrate (57.7 g/100 g dry sample of IDF and 11.1 g/100 g dry sample of SDF) (Martínez *et al*., 2012). In this study, HSDFE showed the highest IDF content ($p<0.05$), followed by PSDFE and MSDFE. A high proportion of IDF in these DF extracts suggested their suitable use as food additives because they can help to modify the textural characteristics of the food (Elleuch *et al.*, 2011). Besides, a high IDF content could have beneficial health effects related to increases in satiety and the weight of the faecal mass, thus improving the function of the digestive system (Ku and Mun, 2008). In the case of all DF, extracts analysed here, only MSDFE showed similar levels ($p<0.05$) with IDF/SDF ratios of 2.12:1 as recommended by Spiller (1986), who indicated that the ratio should be in the range of 1.0-2.3 to obtain the physiological effects associated with both soluble and insoluble fractions. HSDFE showed the greatest difference between IDF and SDF content with an IDF/SDF ratio of 4.53:1.

3.2 pH and physical properties of fruit seed dietary fibre extract

Significant differences ($p<0.05$) in pH were found among the samples (Table 3). HSDFE showed the highest pH value (6.29) followed by PSDFE (5.87) whereas MSDFE had the lowest value of 5.36. The results indicated that all the samples were slightly acidic. Similar results were obtained for L* and a* values, while varietal differences were observed in b* values. The L* and a* values of DF extracts ranged from 83.77 to 87.75 and 3.70 to 5.18, respectively. The highest L* parameter for HSDFE indicated that it was lighter in colour than other DF extracts. All DF extracts showed positive a* values, which indicated a slight red tint in these samples. The b* value, an indicator of blue (-) and yellow (+), for all DF extracts ranged from 11.70 to 25.34, the lowest for PSDFE and the highest for HSDFE, indicating that HSDFE is more yellowish than PSDFE and MSDFE.

All the L*, a*, and b* values obtained in this study are almost similar to the values reported by Rosell *et al*. (2009) for 11 types of commercial DFs. This result suggested the high competitive potential of all these DF extracts as a new source of DF in terms of colour characteristics.

Table 3. pH values and physical properties of 3 different types of fruit seed dietary fibre extract.

Physical Properties	MSDFE	PSDFE	HSDFE
pH	5.36±0.04^{c}	5.87±0.0^{b}	6.29±0.02^{a}
L*	87.57±0.1^{a}	83.77±0.0^{b}	87.75±0.6^{a}
a*	3.70±0.08^{b}	4.55±0.4^{a}	5.18±0.18^{a}
b*	14.33±0.1^{b}	11.70±0.0^{b}	25.34±0.9^{a}
Bulk density (g/mL)	0.57±0.01^{a}	0.39±0.0^{b}	0.36±0.02^{c}

Values are presented as mean±SE, n = 3. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

Significant differences ($p<0.05$) were also observed for the bulk density of all DF extracts. The bulk densities of MSDFE, PSDFE, and HSDFE were 0.57, 0.39, and 0.36 g/mL, respectively. Prakongpan *et al.* (2002) also stated the shape and size of the particles largely affect the bulk density of the fibres. According to them, large particles showed a higher bulk density than small particles.

3.3 Functional properties of fruit seed dietary fibre extract

All of these important properties of DF sources are affected by the structural matrix of fibre, its IDF/SDF ratio, particle size, source, and extraction process (Zambrano *et al.*, 2003).

MSDFE, PSDFE, and HSDFE showed a WHC value

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of 6.40, 6.55, and 3.20 g/g, respectively (Table 4). It shows the ability of a moist material from DF to retain water when subjected to external factors (Ozyurt and Ötles, 2016). It can be explained by two action mechanisms: the physical interaction of water absorption capacity (WA_bC) and the chemical interaction of water adsorption capacity (WA_dC).

Table 4. Functional properties of 3 different types of fruit seed dietary fibre extract.

Properties	MSDFE	PSDFE	HSDFE
WHC (g/g)	6.40±0.66[a]	6.55±0.22[a]	3.20±0.20[b]
WSC (mL/g)	4.61±0.81[a]	4.76±0.85[a]	5.50±0.42[a]
OHC (g/g)	3.91±0.14[a]	4.26±0.31[a]	4.34±0.14[a]
EA (mL/100 mL)	21.21±0.53[c]	26.75±0.34[b]	28.51±0.29[a]
ES (mL/100 mL)	40.18±0.67[b]	34.29±1.20[c]	46.46±0.37[a]

Values are presented as mean±SE, n = 3. Values with different superscripts within the same row are statistically significantly different ($p<0.05$).

The DF extract's SDF fraction (Table 3) and its protein content (Table 1) are mainly responsible for WHC. The interaction between SDF compounds and proteins (Aminlari *et al.*, 2009), which have an affinity for soluble components, allows MSDFE and PSDFE to hold six times and HSDFE to hold three times their weight in water. MSDFE and PSDFE showed a higher WHC than those from sources other than fruits such as defatted rice bran (3.84 g water/g fiber) (Daou and Zhang, 2012) and cassava (4.02 g water/g fiber) (Huang *et al*., 2018) Although HSDFE demonstrated a comparatively lower WHC value than those mentioned above, it presented a great WHC in comparison with durum wheat (1.5-2.1 g water/g fibre) (Esposito *et al*., 2005).

At the gastrointestinal level, water-holding results increased bolus viscosity, high faecal mass, early postprandial satiety, and the trapping and removal of soluble components such as glucose (Mišurcová *et al.*, 2012). The high WHC of these DF extracts suggests that these materials could be used as functional ingredients in food systems requiring water capture and retention, such as jams, jellies, creams, ketchup, and baked products (Meneses *et al.*, 2011). This finding can be ascribed to the fact that SDF increases system viscosity and stability and disperses more readily in water than IDF (Dhingra *et al.*, 2012; Mudgil and Barak, 2013). High WHC would also make them potentially useful technological ingredients in meat products, in which they could impart juiciness and improve texture (Meneses *et al.*, 2011) in addition to reducing calories by the total or partial substitution of high-energy ingredients in a variety of formulated products.

HSDFE showed ($p<0.05$) the highest OHC value of 4.34 g/g, followed by PSDFE (4.26 g/g) and MSDFE (3.91 g/g). All DF extracts retained approximately four times their weight in oil because of the affinity of the IDF structure for oil components, expressed as the bond between the residues and lipids, such as cholesterol and fatty and bile acids (Mišurcová *et al*., 2012). Compared with other high-IDF content plant-origin by-products, all DF extracts had notably higher OHC values than those reported for pumpkin peel (3.75 g/g) (Nyam *et al.*, 2013), banana stem (2.68 g/g) (Jacometti *et al.,* 2015) and banana peel (2.64 g/g) (Alarcón García *et al.*, 2013).

HSDFE showed ($p<0.05$) the highest swelling capacity of all DF extracts (5.50 mL water/g sample), followed by PSDFE (4.76 mL water/g sample) and MSDFE (4.61 mL water/g sample). According to Navarro-González *et al*. (2011), WSC is generally related to the amount of SDF (especially of pectin). However, SWC could be related to the amount of IDF (Figuerola *et al.*, 2005). Based on the present results, the high IDF content of HSDFE is responsible for the high WSC.

The EA of HSDFE was slightly higher than PSDFE and MSDFE, but all DF extracts had high EA values (28.51, 26.75, and 21.21 mL/100 mL, respectively) (Table 4). The EA of the DF extracts also indicates their ability to adsorb biliary acids. DF extracts adsorb biliary acids, hence lowering the blood cholesterol level (Alfredo *et al.,* 2009).

The ES of the DF extracts ranged from 34.29 mL/100mL to 46.46 mL/100mL, the lowest for PSDFE and the highest for HSDFE. One-way ANOVA indicated that the ES was also significantly different ($p<0.05$) among all DF extracts. The high protein contents of DF extracts explain their high EA and ES values, considering that most of the proteins are strong emulsifying agents (Kohajdova *et al.*, 2011). According to McWatters and Cherry (1977), the difference in total protein composition and components other than proteins (possibly carbohydrates), may contribute substantially to the emulsification properties of the DF extracts.

4. Conclusion

Results indicated all three DF extracts have good physicochemical and functional properties. However, honeydew seed is the best potential functional food due to its low-fat content and bulk density, high insoluble DF and total DF content, nearly neutral pH, and excellent WSC, OHC, emulsion ability (EA), and emulsion stability (ES). Potential DF sources from honeydew seeds have also been discovered and can be used in food processing. For example, honeydew seed grounds were

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incorporated into cookie formulation, producing cookies with higher nutrient content and potential value in the prevention of diabetes and other chronic diseases. Commercialization of products from fruit seeds like coffee luwak and kuaci is not impossible.

Conflict of interest

The authors declare they have no conflict of interest.

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References

Alarcón García, M.Á., López Vargas, J.H. and Restrepo Molina, D.A. (2013). Characterization of the Technological Functionality of a Source Rich in Dietary Fibre Obtained from Banana Peel. *National School of Agronomy Magazine Medellín*, 66(1), 6959 -6968.

Alfredo, V., Gabriel, R., Luis, C. and David, B. (2009). Physicochemical properties of a fibrous fraction from chia (*Salvia hispanica* L.). *LWT-Food Science and Technology*, 42(1), 168-173. https://doi.org/10.1016/j.lwt.2008.05.012.

Aminlari, M., Shekarforoush, S.S., Gheisari, H.R. and Golestan, L. (2009). Effect of actinidin on the protein solubility, water holding capacity, texture, electrophoretic pattern of beef, and on the quality attributes of a sausage product. *Journal of Food Science*, 74(3), C221-C226. https://doi.org/10.1111/j.1750-3841.2009.01087.

Association of Official Analytical Collaboration (AOAC) International (2000). Official Methods of Analysis of AOAC International, 17th ed., Vol 1 and 2, AOAC International, Gaitherburg, Maryland, USA: AOAC.

Chau, C.F. and Huang, Y.L. (2003). Comparison of the Chemical Composition and Physicochemical Properties of Different Fibres Prepared from the Peel of Citrus sinensis L. *Journal of Agricultural and Food Chemistry*, 51(9), 2615-2618. https://doi.org/10.1021/jf025919b.

Cheok, C.Y., Mohd Adzahan, N., Abdul Rahman, R., Zainal Abedin, N.H., Hussain, N., Sulaiman, R. and Chong, G.H. (2018). Current trends of tropical fruit waste utilization. *Critical Reviews in Food Science and Nutrition*, 58(3), 335-361. https://doi.org/10.1080/10408398.2016.1176009.

Choo, C.L. and Abdul Aziz, N.A. (2010). Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. *Food Chemistry*, 119 (1), 34-40. https://doi.org/10.1016/j.foodchem.2009.05.004.

Daou, C. and Zhang, H. (2012). Study on Functional Properties of Physically Modified Dietary Fibres Derived from Defatted Rice Bran. *Journal of Agricultural Science*, 4(9), 85-97. https://doi.org/10.5539/jas.v4n9p85.

Dhingra, D., Michael, M., Rajput, H. and Patil, R.T. (2012). Dietary fibre in foods: a review. *Journal of food science and technology*, 49(3), 255–266. https://doi.org/10.1007/s13197-011-0365-5.

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C. and Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, 124(2), 411-421. https://doi.org/10.1016/j.foodchem.2010.06.077.

Esposito, F., Arlotti, G., Bonifati, A.M., Napolitano, A., Vitale, D. and Fogliano, V. (2005). Antioxidant activity and dietary fibre in durum wheat bran by-products. *Food Research International*, 38(10), 1167 -1173. https://doi.org/10.1016/j.foodres.2005.05.002.

Figuerola, F., Hurtado, M.L., Estévez, A.M., Chiffelle, I. and Asenjo, F. (2005). Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment. *Food Chemistry*, 91(3), 395-401. https://doi.org/10.1016/j.foodchem.2004.04.036.

Ghazali, A., Azhar, N.H., Rabeta, M.S., Khairuddean, M., Rafatullah, L. and Mahmud S.H. (2024). Nano cells from fruit bunch residue: nestling nanotechnology within the circular oil palm milling residue management, *Heliyon,* 10(10), e30824. https://doi.org/10.1016/j.heliyon.2024.e30824.

Huang, L., Zhang, X., Xu, M., An, S., Li, C., Huang, C. and Liu, Y. (2018). Dietary fibres from cassava residue: Physicochemical and enzymatic improvement, structure and physical properties. *AIP Advances*, 8(10), 105035. https://doi.org/10.1063/1.5054639.

Jacometti, G.A., Mello, L.R.F., Nascimento, P.H.A., Sueiro, A.C., Yamashita, F. and Mali, S. (2015). The physicochemical properties of fibrous residues from the agro industry. *LWT - Food Science and Technology*, 62(1), 138-143. https://doi.org/10.1016/j.lwt.2015.01.044 .

Kaur, M. and Singh, N. (2005). Studies on functional,

thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. *Food Chemistry*, 91(3), 403-411. https://doi.org/10.1016/j.foodchem.2004.06.015 .

Kohajdova, Z., Karovičacuteová, J., Lauková, M. and Kukurová, K. (2011). Application of citrus dietary fibre preparations in biscuit production. *Journal of Food and Nutrition Research*, 50(3), 182-190.

Ku, C.S. and Mun, S.P. (2008). Optimization of the extraction of anthocyanin from Bokbunja (*Rubus coreanus* Miq.) marc produced during traditional wine processing and characterization of the extracts. *Bioresource Technology*, 99(17), 8325-8330. https://doi.org/10.1016/j.biortech.2008.03.013.

Kurhade, A., Patil, S., Sonawane, S.K., Waghmare, J.S. and Arya, S.S. (2015). Effect of banana peel powder on bioactive constituents and microstructural quality of chapatti: Unleavened Indian flat bread. *Journal of Food Measurement and Characterization*, 10(1), 32-41.

Lan, G., Chen, H., Chen, S. and Tian, J. (2012). Chemical Composition and Physicochemical Properties of Dietary Fibres from Polygonatum Odoratum as Affected by Different Processing Methods. *Food Research International*, 49(1), 406-410. https://doi.org/10.1016/j.foodres.2012.07.047.

Liu, S., Luo, W. and Huang, H. (2016). Characterization and behavior of composite hydrogel prepared from bamboo shoot cellulose and β-cyclodextrin. *International Journal of Biological Macromolecules*, 89, 527-534. https://doi.org/10.1016/j.ijbiomac.2016.05.023.

Macagnan, F.T., Silva, L.P. and Hecktheuer, L.H. (2016). Dietary fibre: The scientific search for an ideal definition and methodology of analysis, and its physiological importance as a carrier of bioactive compounds. *Food Research International*, 85, 144-154. https://doi.org/10.1016/j.foodres.2016.04.032.

Martínez, R., Torres, P., Meneses, M.A., Figueroa, J.G., Pérez-Álvarez, J.A. and Viuda-Martos, M. (2012). Chemical, technological and in vitro antioxidant properties of mango, guava, pineapple and passion fruit dietary fibre concentrate. *Food Chemistry*, 135 (3), 1520-1526. https://doi.org/10.1016/j.foodchem.2012.05.057.

McWatters, K.H. and Cherry, J.P. (1977). Emulsification, foaming and protein solubility properties of defatted soybean, peanut, fieldpea and pecan flours. *Journal of Food Science*, 42(6), 1444-1450. https://doi.org/10.1111/j.1365-2621.1977.tb08395.x.

Meneses, S.M.O., Restrepo-Molina, D.A. and López-Vargas, J.H. (2011). Microbiological and bromatological characterization of burgers with addition of green banana fibre entirety. Revista Facultad Nacional de Agronomía, *Medellín*, 64(1), 5993-6005.

Mišurcová, L., Škrovánková, S., Samek, D., Ambrožová, J. and Machů, L. (2012). Health Benefits of Algal Polysaccharides in Human Nutrition. *Advances in Food and Nutrition Research Advances in Food and Nutrition Research,* 66, 75-145. https://doi.org/10.1016/B978-0-12-394597-6.00003-3.

Mudgil, D. and Barak, S. (2013). Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fibre: A review. *International Journal of Biological Macromolecules*, 61, 1-6. https://doi.org/10.1016/j.ijbiomac.2013.06.044.

Ng, T.K., Jr, Chow, S.S., Chan, L.P., Lee, C.Y. and Lim, S.Q. (2010). Recommended nutrient intake for dietary fibre: bar set too high for malaysians?. *Malaysian Journal of Nutrition*, 16(2), 271-280.

Nyam, K.L., Lau, M. and Tan, C.P. (2013). Fibre from pumpkin (*Cucurbita pepo* L.) seeds and rinds: physico-chemical properties, antioxidant capacity and application as bakery product ingredients. *Malaysian Journal of Nutrition*, 19(1), 99-109.

Ou, S., Kwok, K., Li, Y. and Fu, L. (2001). In Vitro Study of Possible Role of Dietary Fibre in Lowering Postprandial Serum Glucose. *Journal of Agricultural and Food Chemistry*, 49(2), 1026-1029. https://doi.org/10.1021/jf000574n.

Ozyurt, V.Y.H. and Ötles, S. (2016). Effect of food processing on the physicochemical properties of dietary fibre. *Acta Scientiarum Polonorum Technologia Alimentaria*, 15(3), 233-245. https://doi.org/10.17306/j.afs.2016.3.23.

Peerajit, P., Chiewchan, N. and Devahastin, S. (2012). Effects of pretreatment methods on health-related functional properties of high dietary fibre powder from lime residues. *Food Chemistry*, 132(4), 1891-1898. https://doi.org/10.1016/j.foodchem.2011.12.022.

Prakongpan, T., Nitithamyong, A. and Luangpituksa, P. (2002). Extraction and Application of Dietary Fibre and Cellulose from Pineapple Cores. *Food Chemistry and Toxicology*, 67(4), 1308-1313. https://doi.org/10.1111/j.1365-2621.2002.tb10279.x.

Silva, L.M.R.D., Figueiredo, E.A.T.D., Ricardo, N.M.P.S., Vieira, I.G.P., Figueiredo, R.W.D., Brasil, I.M. and Gomes, C.L. (2014). Quantification of bioactive compounds in pulps and by-products of tropical fruits from Brazil. *Food Chemistry*, 143, 398

-404. https://doi.org/10.1016/j.foodchem.2013.08.001.

Rosell, C.M., Santos, E. and Collar, C. (2009). Physico-chemical properties of commercial fibres from different sources: A comparative approach. *Food Research International*, 42(1), 176-184. https://doi.org/10.1016/j.foodres.2008.10.003.

Salim, N.S.M. (2017). Potential Utilization of Fruit and Vegetable Wastes for Food through Drying or Extraction Techniques. *Novel Techniques in Nutrition and Food Science*, 1(2), 15-27. https://doi.org/10.31031/NTNF.2017.01.000506.

Saura-Calixto, F. (2011). Dietary Fibre as a Carrier of Dietary Antioxidants: An Essential Physiological Function. *Journal of Agricultural and Food Chemistry*, 59(1), 43-49. https://doi.org/10.1021/jf1036596.

Spiller, G.A. (1986). Suggestions for a basis on which to determine a desirable intake of dietary fibre. In G.A.Spiller (Ed.), CRC Handbook of Dietary Fbre in Human Nutrition, p. 281-283. Florida, USA: CRC Press.

Tungland, B.C. and Meyer, D. (2002). Nondigestible Oligo- and Polysaccharides (Dietary Fibre): Their Physiology and Role in Human Health and Food. *Comprehensive Reviews in Food Science and Food Safety*, 1(3), 90-109. https://doi.org/10.1111/j.1541-4337.2002.tb00009.x.

United States Department of Agriculture (USDA). (2006). US Department of Health and Human Services. Dietary Guidelines for Americans. Retrieved from USDA website: https://health.gov/sites/default/files/2020-01/DGA2005.pdf

Wuttipalakorn, P., Srichumpuang, W. and Chiewchan, N. (2009). Effects of pretreatment and drying on composition and bitterness of high-dietary-fibre powder from lime residues. *Drying Technology*, 27 (1), 133-142. https://doi.org/10.1080/07373930802566036.

Zambrano, M., Gallardo, Y., Meléndez, P. and Arjona, J. (2003). Metodología de superficie de respuesta aplicada a la optimización de la capacidad de hidratación en un extruído de cascarilla de maíz con base en avena. *Informacion Technologica*, 14 (3), 37 -40. https://doi.org/10.22320/S07179103/2017. [In Spanish].

