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Dehydration of Pomelo (*Citrus grandis*) Albedo and Its Utilization As a Source of Dietary Fiber in Philippine Pork Sausage

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ABSTRACT

Albedo from pomelo fruits was dehydrated and utilized as a potential source of dietary fiber in Philippine pork sausage, a popular Filipino meat product. Both raw and debittered albedo were dehydrated (2 hr, 60 °C) and pulverized to prepare dehydrated raw albedo (DRA) and dehydrated debittered albedo (DDA). DRA and DDA were characterized in terms of drying kinetics, drying qualities (bulk density, water activity and coefficient of reconstitution) and proximate composition. The functional properties (water holding, swelling, gelation, solubility, fat binding and emulsifying capacities) of DRA and DDA were determined and compared to bulking and binding ingredients—namely, phosphate, textured vegetable protein, isolated soy protein and carrageenan. The water holding and fat binding capacities of DDA were significantly ($P < 0.05$) higher than the DRA and tested ingredients. DDA was utilized in pork sausage at 3% and 6% (weight per weight) incorporation. Pork sausage with 3% DDA was comparable ($P < 0.05$) to the control in terms of aroma, flavor and tenderness and was acceptable to consumers. The cooking characteristics of pork sausage with 3% DDA were significantly ($P < 0.05$) improved compared to the control. Philippine pork sausage with 3% DDA may serve as a potential source of dietary fiber with minimal changes in sensory qualities.

Keywords: *Pomelo Albedo*, fiber, pork sausag

INTRODUCTION

Dietary fiber refers to the plant substances that are not digested by human digestive enzymes and has been shown to play an important role in the prevention of various health problems such as carcinogenesis, atherosclerosis and in the control and proper management of diabetes mellitus (Raghavarao *et al.*, 2008). Its incorporation in meat systems is known to increase bulk, prevent cooking loss and improve textural parameters by enhancing water binding capacities (Grigelmo-Miguel *et al.,* 1999). Citrus fruits are underutilized sources of dietary fiber and are mainly used for juice, oil and pectin production (Aleson-Carbonell *et al.*, 2005). Citrus fruits have high concentrations of fiber, especially in the albedo layer of the peel, which is the white, spongy and cellulosic tissue and is the principal component of citrus peel and could be considered as a potential fiber source (Fernandez-Gines *et al.*, 2003). Pomelo (*Citrus grandis)* is the largest citrus fruit containing a thick albedo layer.

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Philippine pork sausage (locally known as *Longaniza*) is one of the most popular meat products in the country. It has the potential to become a functional food providing better health benefits, since fiber is completely absent in this meat product and is also deficient in the typical Filipino diet (Encarnacion, 2014). The objective of the present study was to dehydrate and to characterize albedo from pomelo (*Citrus grandis*) and to utilize it as a source of dietary fiber in Philippine pork sausage.

MATERIALS AND METHODS

Dehydration and characterization of pomelo albedo

Fully matured pomelo (*Citrus grandis*) peels of the Magallanes variety were locally obtained and albedo layers were cut off from the rest of the peel and stored in a freezer and then thawed overnight at refrigeration temperature prior to use.

Debittering process

Raw pomelo albedo was boiled repeatedly in water to remove bitterness from the material as adopted from the methods of LaBau (2012). Debittered albedo and raw albedo were dehydrated for 2 hr at 60 °C (FDL-115 dehydrator; Binder GmbH; Tuttlingen Germany), following the procedures of Crizel *et al.* (2013). The dried samples were pulverized and sieved to produce dehydrated debittered albedo (DDA) and dehydrated raw albedo (DRA). Samples were stored in airtight containers at room temperature until use.

Drying kinetics

Drying curves were constructed as plots of moisture content on a percentage dry basis and the drying rate measured in grams of water per square meter per hour of DRA and DDA against the drying time in hours at 60 °C. Periodic moisture content determinations in triplicate were done following the oven drying method described by Nielsen (2010).

Drying qualities

DDA and DRA were assessed using a precision hygrometer (model MS1; Novasina AG; Lachen, Switzerland) in terms of the water activity, bulk density (Akpapunam and Markakis, 1981), rehydration ratio (Jokic *et al.*, 2009), dehydration ratio and coefficient of reconstitution (Pervin *et al.*, 2008) and (Pervin *et al.*, 2008). All parameters were determined in three trials with the mean and SD reported.

Proximate composition and fiber analysis

The moisture content from the albedo samples determination adopted the oven-drying method described by Nielsen (2010). Ash was determined using incineration adopted from the method of James (1995). The fat content was assessed using solvent extraction (Velp Scientifica SER 148F). Protein was determined using the Kjeldahl method (No. 992.23, Association of Official Analytic Chemists, 2005). Total carbohydrate was determined by difference as described by Crizel *et al.* (2013). Total dietary fiber analysis adopted the enzymatic-gravimetry method (No. 985.29, Association of Official Analytic Chemists, 2005).

Functional properties

The functional properties of DDA and DRA were determined, as well as conventionally-used meat bulking and binding ingredients—namely, phosphate, textured vegetable protein (TVP), isolated soy protein (ISP) and carrageenan. The water holding capacity was expressed as the amount of water absorbed per gram of DDA, DRA or test ingredient (Chowdhury *et al.*, 2012). Swelling capacity was the ratio of volume occupied when a sample is immersed in excess water after equilibration to the actual weight (Robertson *et al.,* 2000). Gelling capacity was identified as the least gelation capacity or the lowest concentration of sample that can hold a gel matrix after heating and cooling (Aslam Shad *et al.*, 2011). Solubility in water of DRA, DDA and the other test ingredients was determined by the method described by Leach *et al.* (1959) with slight modifications. Fat-binding capacity was expressed as the volume of oil held by unit weight of sample (Petravic-Tominac *et al.*, 2011). The emulsifying capacity of samples was assessed using the procedures described by Daou and Zhang (2011).

Utilization of dehydrated pomelo albedo in Philippine pork sausage

A standard formulation for Philippine pork sausage was provided by the Animal Product Development Center of the Bureau of Animal Industry (2013), Department of Agriculture, the Philippines. DDA was added into the pork sausage at incorporation rates of 3% and 6% (weight per weight). The back fat ingredient was partially replaced with DDA in the formulations. All bulking and binding ingredients (phosphate, TVP, ISP and carrageenan) prescribed in the standard formulation were totally replaced with DDA. The control pork sausage followed the standard formulation with no addition of DDA.

Sensory evaluation

Pork sausages containing 0%, 3% and 6% (weight per weight) DDA were subjected to sensory evaluation to determine their degree of acceptability. Approximately 12–13 g of each sample were served to 50 untrained consumer panelists, primarily students from the College of Education, University of Santo Tomas, Manila, the Philippines. Sensory attributes such as appearance, aroma, flavor, tenderness, juiciness and overall impression toward the samples were assessed using a nine-point hedonic scale.

Cooking characteristics

The cooking characteristics of the pork sausages incorporated with 0%, 3% and 6% DDA were determined. The cooking yield was expressed as the ratio of the weight of the cooked sausage to the weight of the raw pork sausage (Aleson-Carbonell *et al.*, 2005). Cooking loss computed as a percentage was reported as the change in weight of sample after cooking (Wan Rosli *et al.*, 2011). Shrinkage of cooked sausage samples was based on the method of Wan Rosli *et al.* (2011) where the total decrease in dimensions of the product was determined. The method of moisture retention analysis adopted the procedure described by Aleson-Carbonell *et al.* (2005).

Dietary fiber content of pork sausage with pomelo albedo

The total dietary fiber of the most acceptable pork sausage formulation containing DDA was determined by the enzymatic-gravimetry method (No. 985.29, Association of Official Analytic Chemists, 2005).

Statistical analysis

All analyses were undertaken in triplicate trials with the mean ± SD values reported. Statistical differences ($P < 0.05$) among sensory acceptability scores and results in functional properties were tested using one-way analysis of variance and Duncan's Multiple Range Test with the IBM Statistical Package for the Social Sciences 20® software package (SPSS, Chicago, IL, USA).

RESULTS AND DISCUSSION

Drying kinetics and drying qualities of pomelo albedo

Drying kinetics refer to the changes in the average moisture content of a material and temperature with time. Figure 1 shows that in the initial phase of drying at 60 °C both DRA and DDA underwent the same pronounced trend of moisture reduction.

The drying rates of both samples were also highest during the initial drying phase, indicating rapid moisture loss. The weight of both the raw and debittered albedo was constant after drying for 5 hr since all the free moisture in the product had been evaporated. The drying kinetics are of great engineering and economic importance because they aid in the estimation of the time required for drying a batch weight of material in a dryer (Jyothi, 2008).

The results of the drying qualities of both DRA and DDA are presented in Table 1. The difference in the packed bulk density between DRA and DDA meant that DRA was more compact with a lower volume due to fewer spaces occupied by air (Pisecky, 1997). Among the drying qualities analyzed, the reconstitution coefficient of DDA was significantly higher than that of DRA ($P < 0.05$). Moreover, the high rehydration ratio of DDA indicated that the dried product was able to absorb water to regain its original properties including moisture content, volume, shape and quality (Al-Sulaiman, 2011). This further suggests that the debittering process of the pomelo albedo altered its rehydration properties significantly.

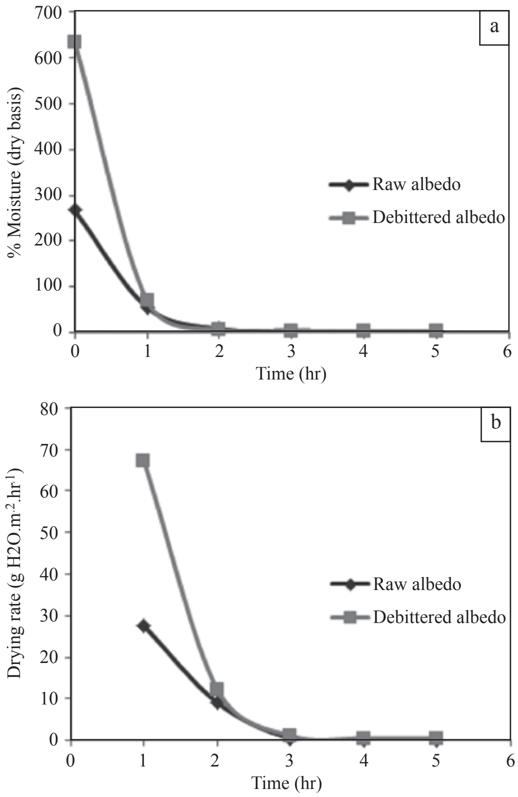

Figure 1 Drying kinetics of dehydrated debittered albedo and dehydrated raw albedo at 60 °C: (a) Drying curve (b) Drying rate.

Proximate composition

There were significant differences between DRA and DDA in all proximate components (Table 2). The notable increase in the total dietary fiber content in DDA compared with DRA was comparable to the study of Caprez *et al*. (1986) on wheat bran, where the total fiber content of wheat bran increased after it underwent thermal treatments. It was assumed that the increase in total fiber was not due to new synthesis, but rather to the formation of fiber-protein complexes that were resistant to heating and were quantified as dietary fiber. According to Spiller (1986), simple processes such as soaking and cooking tend to modify the composition and availability of nutrients; therefore these would have led to the higher fiber content in DDA.

Functional properties

The functional properties of DDA and DRA were determined and compared with conventional nonmeat ingredients (phosphate, TVP, ISP and carrageenan). The hydration properties of dietary fiber refer to its ability to

Table 1 Mean (±SD) qualities of dehydrated pomelo albedo

	Dehydrated raw albedo	Dehydrated debittered albedo
Loose bulk density ($g.mL^{-1}$)	1.42 ± 0.06^a	1.46 ± 0.02^a
Packed bulk density ($g.mL^{-1}$)	2.18 ± 0.07^a	1.95 ± 0.02^b
Water activity	0.59 ± 0.00^a	0.58 ± 0.009^a
Rehydration ratio	7.47 ± 0.06^a	17.22 ± 0.29^b
Dehydration ratio	3.28 ± 0.17^a	2.47 ± 0.21^b
Reconstitution coefficient	2.28	6.97

^{a,b} = Values with the same lower case superscript in a row are not significantly different at $P < 0.05$.

retain water within its matrix (Figuerola *et al.*, 2005). The water holding capacity and swelling capacity of DDA were significantly higher compared to all the ingredients tested (Table 3). The high water holding and swelling capacities may be attributed to the debittering process which may have opened the fiber structure and let the free hydroxyl group from cellulose become available to bind water (Daou and Zhang, 2011). Inclusion of dietary fiber with good hydration properties in meat emulsions is suitable because it retains water, decreases the cooking loss and increases the cooking yield (Dhingra *et al.*, 2012).

DDA also exhibited the highest values in terms of fat binding and emulsifying capacity compared with DRA, TVP and ISP. Ingredients with a high fat-binding capacity and emulsifying capacity allow the stabilization of high-fat food products and emulsions (Grigelmo-Miguel, 1999). Products having good hydration and oil properties mostly affect the consumer-desired characteristics like flavor and tenderness, as well as the product, and cooking yields (European Commission, 2013). Ingredients with high oil and water binding are desirable for use in meat products and emulsions (Jideani, 2011). Therefore, the results suggest that DDA can be a potential bulking and binding agent especially in muscle food systems.

Table 2 Proximate composition (±SD) and total dietary fiber of dehydrated pomelo albedo.

% Composition	Dehydrated raw albedo	Dehydrated debittered albedo
Moisture	12.55 ± 0.32^{a}	13.54 ± 0.21^{b}
Ash	3.21 ± 0.02^{a}	2.99 ± 0.01^{b}
Fat	0.09 ± 0.02^{a}	1.50 ± 0.35^{b}
Protein	3.80	2.60
Carbohydrates	80.35	79.37
Total dietary fiber	40.40	74.20

^{a,b} = Values with the same lower case superscript in a row are not significantly different at $P < 0.05$.

Table 3 Functional properties (±SD) of dehydrated pomelo albedo compared by bulking and binding ingredients.

	Functional property					
	Water holding capacity ($mL.g^{-1}$)	Swelling capacity ($mL.g^{-1}$)	Least Gelation Capacity (%)	Solubility (%)	Fat binding capacity ($mL.g^{-1}$)	Emulsifying capacity (%)
DRA	7.65 ± 0.05^{a}	10.93 ± 0.09^{a}	6.5	2.61 ± 0.01^{a}	1.45 ± 0.03^{a}	65.87 ± 1.54^{a}
DDA	21.92 ± 0.30^{b}	40.67 ± 0.75^{b}	1.5	NA	3.37 ± 0.08^{b}	98.87 ± 0.65^{b}
Phosphate	1.12 ± 0.17^{c}	NA	6.5	2.90 ± 0.73^{a}	NA	NA
TVP	4.29 ± 0.19^{d}	10.44 ± 0.36^{ac}	1.0	18.08 ± 0.59^{b}	1.99 ± 0.22^{c}	57.90 ± 1.57^{c}
ISP	1.17 ± 0.11^{e}	9.93 ± 0.13^{c}	9.0	NA	1.02 ± 0.04^{d}	45.53 ± 2.2^{d}
Carrageenan	9.02 ± 0.09^{f}	14.60 ± 0.06^{d}	0.5	NA	NA	NA

$^{a-f}$ = Mean scores in each column followed by different superscript letters are significantly different at $P < 0.05$. NA = Method was not applicable to the sample, DRA = Dehydrated raw albedo, DDA = Dehydrated debittered albedo, TVP = Textured vegetable protein, ISP = Isolated soy protein

Sensory evaluation

Table 4 shows that Philippine sausage with 3% DDA incorporation was acceptable in all sensory attributes as rated using a nine-point hedonic scale.

There was no significant difference between the control sausage (0% DDA) and sausage with 3% DDA in the sensory parameters of overall acceptability, aroma, flavor and tenderness. Furthermore, the 6% DDA incorporation was significantly lower in all sensory parameters compared with the control sample and 3% DDA incorporation except in aroma. It was noticed that the juiciness of the pork sausage decreased in both samples with DDA which may have been due to the partial replacement of fat with DDA in the pork sausage formulations.

Cooking characteristics

The pork sausage samples incorporated with DDA were analyzed and the results are presented in Table 5. The increased yield and reduced cooking loss observed in the samples with DDA may be correlated with the notable hydration and fat-binding properties of DDA (Table 3). High yield and low cooking loss percentages for sausages or any muscle food products are desirable from an economic standpoint.

The degree of shrinkage of sausages incorporated with 3% and 6% DDA was found to be just statistically comparable to the control. Biswas *et al.* (2011) explained that fiber addition causes less shrinkage when added in meat products since fiber swells and has good water retention properties. The moisture retention observed in both the pork sausages with DDA may have been related to its high water holding capacity.

Overall, the results in terms of cooking characteristics may be attributed to the ability of DDA to bind both moisture and fat and its ability to form a stable meat emulsion. Therefore, the albedo fiber has potential to improve the cooking characteristics relevant to sensory attributes like the juiciness and tenderness of the final product (Xiong *et al.,* 1999).

Table 4 Acceptability scores of pork sausage with varying levels of dehydrated debittered albedo (DDA) using a nine-point hedonic scale.

	Control	3% DDA	6% DDA
Overall acceptability	7.72^{a}	7.28^{a}	6.34^{b}
Appearance	7.80^{a}	7.28^{b}	5.22^{c}
Aroma	7.30^{a}	7.16^{ab}	6.68^{b}
Flavor	7.76^{a}	7.48^{a}	6.86^{b}
Tenderness	7.60^{a}	7.04^{a}	6.18^{b}
Juiciness	7.82^{a}	6.84^{b}	5.52^{c}

$^{a\text{-}c}$ = Mean scores across a row followed by different superscript letters are significantly different at $P < 0.05$.

Table 5 Cooking characteristics (±SD) of pork sausages incorporated with dehydrated debittered albedo (DDA).

Parameter (%)	Control	3% DDA	6% DDA
Cooking yield	56.61 ± 1.6^{a}	65.27 ± 0.8^{b}	63.48 ± 1.6^{b}
Cooking loss	43.39 ± 1.6^{a}	34.73 ± 0.8^{b}	36.52 ± 1.6^{b}
Shrinkage	14.88 ± 2.1^{a}	16.25 ± 1.5^{a}	18.69 ± 1.2^{a}
Moisture retention	37.31 ± 0.9^{a}	43.55 ± 0.6^{b}	45.54 ± 1.1^{b}

$^{a\text{-}b}$ = Mean values of 3 trials. Mean values followed by a different superscript letter in a row are significantly different at $P < 0.05$.

Dietary fiber content of Philippine pork sausages with pomelo albedo

The total dietary fiber of Philippine pork sausage with 3% DDA was 2.6 g per 100 g. Therefore, consumption of 100g, or approximately four pieces of the pork sausage would be a potential source of fiber in the Filipino diet as per the definition of the Codex Alimentarius (1997) which determines that a food product should contain at least 10% of the national daily fiber requirement for it to pass as a source of fiber in the diet.

Labeling claims for products containing dietary fiber vary globally and the Institute of Food Science and Technology (2007) mentioned that for a product to be a good source of fiber, at least 3 g of dietary fiber should be present per 100 g of food. However, other definitions such as Health Canada (2012) mention a lower requirement (2 g per 100 g).

CONCLUSION

Dehydrated debittered pomelo albedo can be a potential fiber ingredient in a muscle food system, such as the Philippine pork sausage. The innovative removal of conventional bulking and binding ingredients and the reduction of fat in the sausage by means of replacement with at least 3% DDA in the formulation resulted in a product that was a healthier option for a population suffering from lack of fiber intake. Pomelo waste products—specifically the albedo layer of the peel—may be a promising functional ingredient causing minimal changes in the sensory qualities and cooking characteristics of the final product. It is recommended that higher incorporation rates of dehydrated pomelo albedo be tested in foods to maximize the notable hydration properties of DDA in food systems and at the same time increase the fiber content.

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