FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Antioxidant activity, chemical and nutritional properties of raw and processed purple-fleshed sweet potato (*Ipomoea batatas* Lam.)

Queenie Ann L. Curayag, Erlinda Ignacio Dizon and Wilma A. Hurtada

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Abstract: Purple-fleshed sweet potato (Ipomoea batatas Lam.) has been reported to contain vital nutrients and bioactive compounds. This study evaluates the antioxidant activity, chemical composition, and nutritional value of raw and processed purple-fleshed sweet potato products. The antioxidant activity of the raw purple-fleshed sweet potato (PSP) significantly increased after drying and decreased when the resulting flour was substituted in the products. However, substituted products had higher antioxidant activity than the non-substituted ones. The chemical properties of raw PSP mostly decreased when processed into flour and when it was used in the products. Raw PSP and the flour are good sources of energy, iron, and zinc and the candy is a good source of energy while muffin and bread are promising sources of energy, protein, and iron. Hence, purple-fleshed sweet potato could be a promising raw material for calorie-rich specialty food for children and adults which could also be sources of antioxidants.

Subjects: Food Science & Technology; Substitutes - Food Chemistry; Food Analysis; Nutrition

ABOUT THE AUTHOR
Dr. Queenie Ann L. Curayag’s researches are geared towards the development of functional and innovative food products from underutilized commodities to help farmers add value to their agricultural produce and increase their income. Since the Philippines is continuously exerting its efforts to attain the Millennium Development Goal target of reducing the prevalence of underweight by 50%, Dr. Curayag and her mentors and co-authors pursued the research on purple-fleshed sweet potato and developed food products which could be used in feeding programs for children to help alleviate malnutrition problems in the region and the country. She is spearheading the Food Research and Development Center in her home institution where research, development, and commercialization of innovative food products from locally available raw materials are carried out and where technical and consultancy services are provided to clientele. The dream of having a food and nutrition secure nation motivates her to continuously conduct quality food researches.

PUBLIC INTEREST STATEMENT
Purple-fleshed sweet potato has been reported to contain vital nutrients and bioactive compounds but despite its potentials, sweet potato is still viewed as a poor man’s food and farmers gain little income from it. Hence, this study focused on evaluating the chemical and nutritional properties of raw and processed purple-fleshed sweet potato (PSP). Value-adding was done by converting the tubers into flour and used the flour in the making of various food products. Results of this study showed that the flour has higher antioxidant activity and the product models could be sources of antioxidants which could help scavenge free radicals in the body and help prevent the incidence of cancer and other diseases. Also, the product models are sources of energy, protein, and iron which makes the flour a promising raw material for calorie-rich food for children and adults that could be used to help solve malnutrition and food security problems in underdeveloped countries.
Keywords: antioxidant activity; flour; chemical composition; malnutrition; purple-fleshed sweet potato

1. Introduction

Food security has been defined by the World Food Program (WFP, 2009) as a condition when all people, at all times, have physical and economic access to sufficient, nutritious, and safe food to meet their dietary needs and food preferences for an active and a healthy life. Thus, when any of these conditions are not met, people become food insecure and as a consequence, protein-energy malnutrition (PEM) and micronutrient deficiencies occur particularly in children ages 0 to 5 years old. PEM is one of the most widespread and devastating forms of malnutrition affecting over 500 million children worldwide (Whitney & Rolfes, 1999) and results when there are inadequate intakes of energy and protein with co-existing multiple micronutrient deficiencies (Neumann, Gewa, & Bwibo, 2004).

In the Philippines, malnutrition is a perennial problem (Salvacion, 2017) and is still a continuing challenge. PEM, Vitamin A deficiency (VAD), Iron Deficiency Anaemia (IDA) and Iodine Deficiency Disorder (IDD) are the four major deficiency disorders among Filipino children with PEM causing high fatality rates among infants and children (Krejbl, 2009).

National survey results revealed that stunting, which is used as a measure of chronic malnutrition, was prevalent among 0-5-year-old children at 33.4% while underweight was prevalent among 5–10 year old at 31.2% with high prevalence being noted in rural areas (35.6%) (Department of Science and Technology—Food and Nutrition Research Institute [DOST-FNRI], 2016). Considering such, it is unlikely that the Philippines will achieve the Millennium Development Goal of a 50% reduction in underweight prevalence based on the 1989 baseline of 27.3% which is 13.7%. Whitney, Cataldo, and Rolfes (1994) stated that prevention of PEM emphasizes frequent, nutrient-dense and energy-dense meals.

Root crops and tubers have been considered as a contributing, if not, the principal source of food, nutrition and cash income in many of the world’s poorest farmers and food insecure people due to their ability to produce large quantities of dietary energy and their stability of production under conditions where other crops may fail (Alexandrators, 1995). Among the root crops, sweet potato is one of the most common in the tropics and has considerable untapped potential as a nutritious food crop particularly for the poor and more vulnerable groups of society in developing countries (Woolfe, 1992) as it yields two or three times as much calories as cereals and other valuable nutrients (Vaidhehi, 1988). In the Philippines, sweet potato is often consumed as a substitute for rice and corn and its availability for utilization is estimated at 14.93 g/day/capita (Fernandez-San Valentin & Berja, 2012). An estimate of 541, 265 metric tons of sweet potato was produced in 2010 (Bureau of Statistics [BAS], 2011) but significantly decreased to 112, 300 metric tons in 2019 (Philippine Statistics Authority [PSA], 2019).

Studies on sweet potatoes have been focused on purple-fleshed varieties since it was found to contain large quantities of anthocyanins which have excellent biological properties and potential value as natural colorants (Suda et al., 2003). Moreover, anthocyanins exert a strong anti-cancer effect through their antioxidant and anti-inflammatory activities, and through their ability to induce cell proliferation inhibition, cell cycle arrest and apoptosis in specific cancer cells (Kong, Chia, Goh, Chia, & Brouillard, 2003; Wang & Stoner, 2008). Dietary antioxidants are helpful in assisting the body to neutralize free radicals that cause cancer. Thus, consumption of foods rich in antioxidants is important to help reduce the harmful effects of oxidative stress (Teow et al., 2007).

The potential of sweet potato in food security and global well-being have been the subject of some studies. However, research focusing on the use of purple-fleshed sweet potato in food products and monitoring changes in the chemical and nutritional properties after processing is scarce and studies on its possible contribution to the energy, protein, iron and zinc requirements for various age groups in the Philippines have not been conducted. Purple-fleshed sweet potato can be made into flour and can also be useful in the development of specialty foods and food...
formulations for children to help address malnutrition and food security problems. Utilization of sweet potato for its nutritive value and as a source of natural food antioxidant and natural food color presents an opportunity to increase its production and consumption and could result in increased farm income. Thus, this study was undertaken.

2. Materials and methods

2.1. Processing of purple-fleshed sweet potato into flour
The raw purple-fleshed sweet potato roots Haponita variety (PSP) were washed with tap water to remove adhering soil and extraneous materials and the surface were allowed to dry. About 1 kg of fresh roots were segregated for chemical analysis. Ten 10 kg of the clean roots were cut into 3 cm thick, steamed for 15 min, allowed to cool and then were sliced into 2–3 mm thick. For flour processing, the chips were dried at 70°C for 9 hrs and were then ground to pass through a 100 mesh sieve. The purple sweet potato flour (PSPF) was used in the processing of candy, muffin, and bread at 40%, 40%, and 20% substitution levels, respectively. The raw PSP, PSPF, and PSPF-substituted products were then subjected to different chemical analyses.

2.2. Determination of antioxidant activity
The analysis of antioxidant activity was done according to the procedure by Shimada, Fujikawa, Yahara, and Nakamura (1992). The same method was used in the analysis of all samples.

2.2.1. Preparation of extract
Fresh samples were chopped and mixed properly. Two grams of each sample was added with 20 mL 50% methanol solution. The mixture was macerated using a mortar and pestle until it was completely homogenized. Approximately 5 mL of the extract was then filtered into a clean vial, was covered tightly and was kept in the refrigerator until use.

For powdered samples, 50 mg (0.050 grams) of each sample was placed in a test tube and was added with 5 mL 50% methanol solution. It was then mixed intermittently in a vortex mixer for 10 minutes and was filtered into a clean vial, was covered tightly and was kept in the refrigerator until use.

2.2.2. DPPH radical scavenging assay
One milliliter (1 mL) aliquot was taken from the extract and was added with 4.0 mL distilled water followed by 1 mL of freshly prepared 1 mM DPPH (1,1-diphenyl-2-picrylhydrazyl) methanolic solution. The resulting solution was left to stand for 30 minutes and absorbance of the solution was read at 517 nm. A reagent blank and a positive control using a different concentration of butylated hydroxytoluene (BHT) were also prepared as in the sample. The lower the absorbance at 517 nm represented higher DPPH scavenging activity. Percent DPPH scavenging activity was calculated as follows:

\[
\% \text{ DPPH scavenging activity} = \frac{1 - \text{(test sample absorbance /blank sample absorbance)}}{1} \times 100
\]

2.3. Proximate composition
The proximate composition of the raw PSP, PSPF, and PSPF-substituted products were determined following the methods by Association of Official Agricultural Chemists (AOAC, 1980).

2.4. Zinc content
The amount of zinc in raw PSP, PSPF and PSPF-substituted products was determined spectrophotometrically following the modified protocol of Areco, Dos Santos Afonso, and Valdman (2007). Twenty-five grams (25 g) of the sample was accurately weighed into a clean silica dish and was charred and ashed at temperatures not exceeding 500°C. The temperature of the muffle furnace was raised slowly to avoid ignition. When ash was carbon-free, the ash was dissolved in a watch glass in a minimum volume of HCl (1 + 1). Twenty ml of water was then added and the mixture was allowed to evaporate to near dryness on a steam bath. It was then added with 20 mL of 0.1 N HCl and heating was continued for 5 minutes. The mixture was then filtered through pre-washed fast filter paper into
100 mL volumetric flask and the dish and filter was washed with several 5 to 10 mL portions of 0.1 N HCl and was then cooled before diluting to volume with 0.1 N HCl.

For color development, 1 mL aliquot of the sample containing 8.0 ppm of Zn2+ was pipetted to a 5 mL volumetric flask. It was then added with 0.5 mL buffer solution and was mixed well. Zincon solution was then added drop by drop until the red color was one drop in excess and the solution was mixed well and was diluted to 5 mL using distilled or deionized water. The absorbance of the solution was then measured at 620 nm using a Cecil L920 UV/Vis spectrophotometer. The standard curve used for the computation of the amount of zinc in the sample was prepared.

2.5. Iron content
Iron determination was done following the procedures by AOAC (1980). One hundred milligrams (100 mg) of the sample was ignited in the furnace at 550°C overnight or until the ash was white in color. After ashing, 1 mL concentrated HCl was added and was mixed gently using a stirring rod. The mixture was then added with 4 mL distilled water and was heated on a hot plate at 100°C and was allowed to evaporate until the solution was about 2 mL. This was then added with 2 mL distilled water and was heated to about 90°C. The solution was then filtered through ashless filter paper of medium porosity using a volumetric flask as a receiver and the crucible, filter paper and funnel was rinsed several times with distilled water. The solution was then diluted to 20 mL volume with distilled water and was mixed well.

An aliquot of the ash solution estimated to contain no more than 0.10 mg of iron was taken and was added with approximately 0.01 g of ascorbic acid crystals. This was then added with 5 ml sodium acetate trihydrate, pH 5.5 buffer solution and the solution was mixed. One mL of 2’ 2’ bipyridine solution was added and the solution was diluted to 25 mL, was mixed and was allowed to stand for 1 hr. The absorbance at 520 nm was taken using a spectrophotometer. A blank was also run using the same procedure and reagents and a standard was also run together with the sample analysis.

2.6. Computation of nutritional value
The nutritional value of raw PSP, PSPF and PSPF-substituted products were computed based on its contribution to the recommended energy and nutrient intake (% RENI) for Filipinos for energy, protein, iron, and zinc (DOST-FNRI 2002). This was done to determine if raw purple-fleshed sweet potato and its products were high or good sources of the aforementioned nutrients for a particular age group. % RENI was computed using the formula:

\[
\text{% RENI} = \frac{\text{nutrient content of food per 100 g} \times 100}{\text{RENI for age}}
\]

The food was labeled as a good “source” of energy and minerals if it has ≥ 15% of the Nutrient Reference Values (NRV) per 100 grams and to be considered as a “high source” if it has ≥ 30% of NRV per 100 grams. In the case of protein, a food was labeled as a good “source” and as a “high source” if it has ≥ 10% and ≥ 20% of NRV, respectively (Codex Alimentarius Commission, 2007). The RENI represents the NRV used in this study since this is the dietary standards used in the Philippines.

2.7. Statistical analysis
All gathered data were analyzed using Analysis of Variance (ANOVA) using Microsoft Excel, version 2007 and were further analyzed using Duncan’s New Multiple Range Test (DNMRT) to compare treatment means. Significant difference for all tests was established at p < 0.05.
3. Results

3.1. Antioxidant activity
The antioxidant activity (AOA) of raw PSP, PSPF, and PSPF-substituted products were evaluated. Results in Table 1 show that the antioxidant activity of the samples ranged from 85.37 to 8.77 %. PSPF had the highest antioxidant activity value while the candy had the lowest. Results also show that the AOA of raw PSP increased after the drying process and the AOA of all PSPF-substituted products were much lower than the AOA values of raw PSP and PSPF. However, the AOA of all PSPF-substituted products were significantly higher than their non-substituted counterparts (Figure 1).

3.2. Chemical composition
The chemical composition of raw PSP, PSPF, and PSPF-substituted are shown in Table 2. In terms of moisture content, the raw PSP had higher moisture content compared to its flour counterpart. On the other hand, the moisture contents of the product models (18.54 to 29.44%) were higher compared with the flour.

The fat content of both raw PSP and PSPF (1.29% and 1.46% db; 0.47% and 1.38% fwb) were found to be low in amount. In terms of protein content, raw PSP, PSPF and PSPF-substituted candy were found to have lower protein contents at 1.82, 1.70 and 1.53%, respectively, and were found to decrease from the fresh root to the product like in the case of the candy. On the other hand, the protein contents of muffin and bread were generally higher at 10.07% and 11.60%, respectively. The ash content was found to be higher in raw PSP and PSPF (3.47% and 3.86% db; 1.27% and 3.62% fwb) than in the PSPF-substituted products (0.15–1.86% db). The same trend was observed for iron, zinc, and crude fiber content wherein lower contents were present in the product models than in the raw root and flour. Results also show relatively high amounts of carbohydrate in all the samples. The levels of iron and zinc were also found to generally decrease after drying and when PSPF was used in the different product models.

| Sample                  | Antioxidant Activity (% Scavenging Activity) |
|-------------------------|---------------------------------------------|
| Raw PSP                 | 74.22 ± 0.28                                |
| PSPF                    | 85.37 ± 0.30                                |
| Candy (40% PSPF)        | 8.77 ± 0.49                                 |
| Muffin (40% PSPF)       | 10.60 ± 0.38                                |
| Bread (20% PSPF)        | 10.14 ± 0.39                                |

Figure 1. Antioxidant activity of PSPF-substituted and non-substituted products.
3.3. Nutritional value

The nutritional values of raw PSP, PSPF, PSPF-substituted candy, muffins, and bread were assessed based on the computed % Recommended Energy and Nutrient Intake (RENI) contribution for energy, protein, zinc, and iron at different age groups (Tables 3 and 4).

As shown in Table 3, raw PSP is a good source of energy for 6 months to 12 months old infants while PSPF and candy were high sources of energy for children 6 months to 3 years old and a good source of energy for 4 years old and above. Muffin and bread were found to be high sources of energy for 6 to 12 months and good sources for 1 year old and above. It is also worthwhile to note that all foods were found to be a high source of energy for both pregnant and lactating women. In terms of protein, results show that despite substituting wheat flour with steamed PSPF, the bread can still be a high source of protein for children from 6 months to 6 years old and as a good source for older children and adults. Muffin can also be a high source of protein up to 3 years old and as a good source for older children and adults. The PSPF was also found to be a good source of protein for 6 to 12 months old infants while the raw root and candy were found to be poor sources of protein.

Table 4 presents the % RENI contribution for iron and zinc of raw PSP, PSPF, candy, muffin, and bread. Results show that both raw PSP and PSPF were high sources of iron for all age groups. The bread was also found to be a high source of iron for 6 months to 9 years old children and as a good source for older males and females. Muffin was also found to be a high source of iron for 1 to 6 years old children and a good source for 6 to 11 months and older children and adults. However, the candy was found to be a poor source of iron. In terms of zinc, both raw PSP and PSPF were good sources of zinc for 6 to 11 months old and raw PSP for female menstruating adults older than 19 years old. All three products had undetectable zinc content implying that these are poor sources of zinc.

4. Discussion

4.1. Antioxidant activity

Antioxidants are substances that can protect any materials against autoxidation regardless of the mechanism of action. These substances inhibit oxidation by reaction with free radicals and the decomposition of lipid hydroperoxides, which would otherwise form free radicals (Pokorny, 2007). According to Waramboi, Dennien, Gidley, and Sopade (2011), colored flesh sweet potatoes contain phytochemicals, pro-vitamins, and antioxidants.

The higher AOA of PSPF might be due to easier extraction of antioxidant components from the tissues which were ruptured during steaming (Jing, Chen, Zhao, & Mao, 2010) since raw PSP was steamed prior to drying. Chlopicka, Pasko, Gorinstein, Jedryas, and Zagrodzki (2012) also observed lower antioxidant activity of pseudocereal bread compared to the pseudocereal flour and other...
### Table 3. RENI contribution (% RENI) for energy and protein of raw PSP, PSPF, and PSPF-substituted products per 100 grams

| Age       | Raw PSP | PSPF | Candy | Muffin | Bread |
|-----------|---------|------|-------|--------|-------|
|           | Energy  | Protein | Energy | Protein | Energy | Protein | Energy | Protein | Energy | Protein |
| 6--< 12 mos. | 19.33* | 4.76  | 49.54** | 11.38* | 45.40** | 8.88  | 4.164** | 50.79** | 42.86** | 59.98** |
| 1–3 yrs.   | 13.01  | 2.38  | 33.34** | 5.69   | 30.55** | 4.44  | 28.02*  | 25.39** | 28.84*  | 29.99** |
| 4–6 yrs.   | 9.87   | 1.75  | 25.30*  | 4.19   | 23.18*  | 3.27  | 21.26*  | 18.71*  | 21.88*  | 22.10** |
| 7–9 yrs.   | 8.70   | 1.55  | 22.29*  | 3.71   | 20.43*  | 2.89  | 18.74*  | 16.53*  | 19.29*  | 19.53*  |
| Male (yrs.) |        |       |        |        |        |       |        |        |        |        |
| 10–12     | 6.50   | 1.23  | 16.67*  | 2.95   | 15.27*  | 2.30  | 14.01   | 13.17*  | 14.42   | 15.55*  |
| 13–15     | 4.97   | 0.94  | 12.74   | 2.24   | 11.67   | 1.75  | 10.71   | 10.01*  | 11.02   | 11.83*  |
| 16–18     | 4.90   | 0.91  | 12.56   | 2.18   | 11.51   | 1.70  | 10.56   | 9.74    | 10.86   | 11.50*  |
| >19 yrs.  | 5.59   | 1.00  | 14.33   | 2.38   | 13.13   | 1.86  | 12.04   | 10.61*  | 12.39   | 12.53*  |
| Female (yrs.) |        |       |        |        |        |       |        |        |        |        |
| 10–12     | 7.25   | 1.36  | 18.58*  | 3.25   | 17.02*  | 2.54  | 15.61*  | 14.51*  | 16.07*  | 17.14*  |
| 13–15     | 6.19   | 1.06  | 15.85*  | 2.53   | 14.53   | 1.97  | 13.32   | 11.29*  | 13.71   | 13.33*  |
| 16–18     | 6.79   | 1.13  | 17.40*  | 2.70   | 15.94*  | 2.11  | 14.62   | 12.05*  | 15.05*  | 14.23*  |
| >19 yrs.  | 7.48   | 1.15  | 19.18*  | 2.75   | 17.57*  | 2.14  | 16.12*  | 12.26*  | 16.59*  | 14.68*  |
| Pregnant women | 46.39** | 1.01  | 118.90** | 2.41  | 108.95** | 1.88 | 99.94** | 10.77*  | 102.85** | 12.72*  |
| Lactating women | 27.83* | 0.82  | 71.34** | 1.97  | 65.37** | 1.53  | 59.96** | 8.78    | 61.71** | 10.37*  |

PSP—purple sweet potato * good source
PSPF—purple sweet potato flour ** high source
authors also made the same observations (Holtekjolen et al. 2008; Martinez-Villaluenga et al., 2009; Moore, Luther, Cheng, & Yu, 2009). The lower AOA in the products compared to those of the flour could be due to lower amounts of PSPF used and due possibly to changes that occurred during processing. According to Ioannou, Hafsa, Hamdi, Charbonnel, and Ghoul (2012), synergies between the food matrix and antioxidant compounds can occur. The food matrix can act as a barrier to heat effect or can induce the degradation of antioxidant compounds which can lead to either increase or decrease in antioxidant activity. In addition, antioxidant active compounds present in flours might be damaged or degraded as a consequence of the heat/thermal process during cooking and baking and could also be lost during mixing and kneading. The antioxidant activity of bread could also be modified by active oxidative enzymes present in other ingredients used or could be oxidized by ambient oxygen (Holtekjolen et al. 2008; Leenhardt et al., 2006).

Current researches into free radicals (Fan, Zhang, Yu, & Ma, 2006) have confirmed that foods rich in antioxidants play an essential role in the prevention of cardiovascular diseases and cancers and neurodegenerative diseases, as well as inflammation and problems caused by cell and cutaneous aging. Thus, natural antioxidants in food such as in PSPF and in PSPF substituted products may not only inhibit lipid peroxidation in food and improve food quality and safety but can also possibly contribute in scavenging free radicals and detoxify the cells. The higher AOA of all PSPF-substituted products compared to its non-substituted counterparts implied that substituting PSPF in the different product models can significantly improve its antioxidant activity.

Table 4. RENI contribution (% RENI) for iron and zinc of raw PSP, PSPF, and PSPF-substituted products per 100 grams

| Age            | Raw PSP | PSPF | Candy* | Muffins* | Bread* |
|----------------|---------|------|--------|----------|--------|
|                | Iron    | Zinc | Iron   | Zinc     | Iron   | Iron   |
| 6—< 12 mos.   | 179.01**| 17.86*| 141.33**| 15.00*   | 1.37   | 28.20*| 34.47**|
| 1–3 yrs.      | 223.77**| 16.67*| 176.67**| 14.00    | 1.71   | 35.25**| 43.08**|
| 4–6 yrs.      | 198.90**| 13.89 | 157.04**| 11.67    | 1.52   | 31.33**| 38.30**|
| 7–9 yrs.      | 162.74**| 13.89 | 128.48**| 11.67    | 1.24   | 25.64* | 31.33**|

| Males (yrs.) | Raw PSP | PSPF | Candy* | Muffins* | Bread* |
|--------------|---------|------|--------|----------|--------|
| 10–12        | 137.70**| 11.03| 108.72**| 9.26     | 1.05   | 21.69*| 26.51*|
| 13–15        | 89.51** | 8.33 | 70.67** | 7.00     | 0.68   | 14.10 | 17.23*|
| 16–18        | 127.87**| 8.43 | 100.95**| 7.08     | 0.98   | 20.14*| 24.62*|
| >19 yrs.     | 149.18**| 11.72| 117.78**| 9.84     | 1.14   | 23.50*| 28.72*|

| Females (yrs.) | Raw PSP | PSPF | Candy* | Muffins* | Bread* |
|----------------|---------|------|--------|----------|--------|
| 10–12          | 94.22** | 12.50| 74.39**| 10.50    | 0.72   | 14.84 | 18.14*|
| 13–15          | 85.24** | 9.49 | 67.30**| 7.97     | 0.65   | 13.43 | 16.41*|
| 16–18          | 66.30** | 10.71| 52.35**| 9.00     | 0.51   | 10.44 | 12.77 |
| >19 yrs.       | 66.30** | 16.67| 52.35**| 14.00    | 0.51   | 10.44 | 12.77 |

| Pregnant women | Raw PSP | PSPF | Candy* | Muffins* | Bread* |
|---------------|---------|------|--------|----------|--------|
| 1st trimester | 66.30** | 14.71| 52.35**| 12.35    | 0.51   | 10.44 | 12.77 |
| 2nd trimester | 52.65** | 11.36| 41.57**| 9.55     | 0.40   | 8.29  | 10.14 |
| 3rd trimester | 47.11** | 7.81 | 37.19**| 6.56     | 0.36   | 7.42  | 9.07  |

| Lactating women | Raw PSP | PSPF | Candy* | Muffins* | Bread* |
|-----------------|---------|------|--------|----------|--------|
|                 | 59.67   | 6.52 | 47.11  | 5.48     | 0.46   | 9.40  | 11.49 |

PSP—purple sweet potato PSPF—purple sweet potato flour
* good source ^ menstruating
** high source # undetectable zinc level.

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4.2. Chemical composition

The chemical composition of any food is an indication of the nutritional quality of the food (Haruna, Udobi, & Ndife, 2011). Results show that most of the chemical components of the raw root significantly decreased after processing it into flour. The lower moisture content of the flour than the fresh root is expected due to the drying process that it had undergone. In addition, lower moisture content will logically make for extended postharvest utilization of sweet potato roots as low moisture activity in food materials discourages the growth of plant pathogenic microorganisms (Okaka & Okaka, 2001) and brings about a substantial volume reduction (Doymaz & Pala, 2003). On the other hand, the higher moisture contents of the product models compared with the flour was mainly contributed by the liquid ingredients used and the ability of PSPF to absorb more water.

In terms of fat content, the lower amount in both raw PSP and PSPF confirms that sweet potato is not a rich source of fat. A much lower fat content of sweet potato flour was reported by Ijarotimi and Ashipa (2006) at 0.70 g 100g⁻¹. However, the low fat content of sweet potato either in its raw or flour form could be compensated for by the ingredients in the food products which contain more fat as evidenced by the higher fat contents of PSPF-substituted muffin and bread at 6.55% and 6.65%, respectively.

The decrease in protein content from the raw PSP to PSPF and in candy could be due to denaturation of proteins during heat treatment wherein the hydrogen bonds and non-polar hydrophobic interactions of the secondary and tertiary structures are disrupted (Olajide et al., 2011). The higher protein contents of muffin and bread could be due to contributions of the other protein-containing ingredients used in the products such as eggs, milk and the wheat flour itself.

The ash content of the products, which reflects the mineral content of the food, decreased in the PSPF-substituted products and might be possibly due to the dilution of minerals in the products because of the lower levels of PSPF substitutions used. The trend was also evident in the iron and zinc contents. The ash content of the raw root was within reported values as previously stated while the ash content of the PSPF was found to be lower than that as reported by Dansby and Bouvelle-Benjamin (2003) on sweet potato flour at 4.8g 100g⁻¹ but higher than hard red spring wheat flour at 1.6 g 100g⁻¹ (Srivastava, Meyer, Rao, & Seibel, 2002). Ash content of the bread was also observed to be lower than those reported by Hathorn, Biswas, Gichuhi, and Bovell-Benjamin (2008) at 2.23 ± 0.1 to 2.53 ± 0.1g 100g⁻¹. Lower crude fiber contents were observed in the product models than in the raw root and flour. Processes involving heat treatment may also affect the fiber content of foods in different ways. Increased temperature may lead to breakage of weak bonds between polysaccharide chains and glycosidic linkages in the dietary fiber polysaccharides (Lola, 2009).

Carbohydrates are the body’s chief source of energy and which comprise about 40-80% of the total energy of the diet (DOST-FNRI 2002). The relatively high amounts of carbohydrate in all the samples confirmed that the sweet potato tuber and the PSPF-substituted products are good sources of carbohydrate.

Substituting PSPF in all product models significantly decreased its iron content while zinc became undetectable in all product models. As mentioned, dilution of the minerals possibly occurred in the products due to lower levels of PSPF substitution. Moreover, some of these minerals might have been partly lost as volatile compounds especially that PSPF-substituted products had undergone heat treatments at a higher temperature than the drying process. A decrease in both iron and zinc contents after drying were also observed by Eluagu and Onimawo (2010) in unblanched and blanched orange-fleshed sweet potatoes. Ijarotimi and Ashipa (2006) reported zinc and iron contents of sweet potato flour at 7.22 and 12.47 mg 100g⁻¹, respectively. Results show that zinc was lower and iron was higher compared to those values reported by Ijarotimi and Ashipa (2006). Reduction in both iron and zinc contents in steamed PSPF and in the product models suggests that their potential ability to supply these minerals had been reduced as a consequence of heat treatment.
4.3. **Nutritional value**

Results imply that PSPF can be used in the formulation and preparation of complementary foods and candy, muffins and bread as alternative snacks for children and adults. Based on their overall nutrient contribution, raw PSP and PSPF were good sources of energy, protein, zinc and iron for 6 to 11 months old infants making them promising raw materials for the formulation of complementary foods as well as good substitutes for wheat flour in muffins, bread and possibly for other bakery products and pastries. Yadav, Guha, Tharanathan, and Ramteke (2006) promoted the usefulness of sweet potato flour in the development of calorie-rich specialty foods and food formulations for children in which a higher solid content per volume is required. Results imply that wheat flour-based products, when substituted with PSPF, can still be considered as high sources of energy, protein, and iron. Utilization of PSPF can help lessen the importation of wheat flour and subsequently lessen the cost of the products and still can provide enough energy, protein, and iron needed by the body. Both raw PSP and PSPF can help alleviate protein-energy malnutrition and zinc and iron deficiencies in the country especially in 6 to 11 months old infants as well as in school children (except for zinc). Aside from its contribution to protein, energy, and iron requirements in children and adults, PSPF-substituted products can also probably play a role, little may it is, in providing the body with antioxidants to combat free radicals since these products had higher antioxidant activity and phytochemical components than the control (based on the previous study, results are not shown). In addition to the nutrients that the products provide, PSPF substitution also contributed to the flavor and color.

5. **Conclusion**

The processing of purple-fleshed sweet potato into flour significantly increases its antioxidant activity and decreases its chemical components. However, other ingredients used in the PSPF-substituted products can compensate for the lower fat and protein contents of raw PSP and PSPF. In terms of nutrient value, raw PSP and PSPF are good sources of energy, iron, and zinc. PSPF-substituted candy is a good source of energy while muffins and bread are potential sources of energy, protein, and iron. Wheat flour-based products like muffins and bread can still be considered as high sources of energy, protein, and iron even when substituted with PSPF. Therefore, the purple-fleshed sweet potato could be a promising raw material for calorie-rich specialty food and food formulations for children and adults which could potentially help alleviate protein-energy malnutrition and zinc and iron deficiencies problems in the country.
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