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EVALUATION OF NUTRITION AND GLYCEMIC INDEX OF SWEET POTATOES AND ITS APPROPRIATE PROCESSING TO HYPOGLYCEMIC FOODS

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ABSTRACT

Indonesia placed the fourth biggest diabetics in the world after India, China, and the USA with prevalence amounting to 8.6% of the population. Diabetes is an abnormal carbohydrate metabolism. Therefore, nutrition plays a key role in the management of the disease. This study aimed to find hypoglycemic sweet potatoes and appropriate processing to create low glycemic foods. Eight Indonesian sweet potato varieties/clones were used in this experiment, i.e. Kidal, Sukuh, Sari, Ungu, Jago, BB00105.10, B0464, and BB00106.18. Samples were firstly analyzed for their physicochemical and nutritional properties, which then followed by evaluation of their hypoglycemic responses. The selected variety was processed into three different basic processing methods, i.e. boiling, baking, and frying, and then their glycemic indexes (GI) were evaluated. Result showed that among eight sweet potato varieties/clones studied, BB00105.10 clone indicated the best hypoglycemic response. The highest hypoglycemic activity was supported with the highest resistant starch content (3.8%), protein content (5.47%), and low starch digestibility (51.4%). The sweet potato tubers contained medium to high amylose (24.94%). Processing methods influenced the GI value of foods. Fried sweet potatoes had the lowest GI (47), followed by the boiled one (GI = 62) and the baked one (GI = 80).

[***Keywords***: Sweet potato, glycemic index, glycemic response, diabetes mellitus]

INTRODUCTION

Diabetes mellitus is an inherited and acquired disorders characterized by elevated circulating blood glucose levels. This condition results from an absolute or a relative deficiency of insulin and/or insulin action with a consequent deranged metabolism of carbohydrate, fat, and protein (Sardesai 2003). Diabetes is one of the major health problems in the world, both in the developed and developing countries. According to WHO survey, Indonesia placed the fourth biggest diabetics in the world after India, China, and the USA. The number of diabetics in Indonesia is predicted around 12.4 million (8.6% of the people) in 2025, three times higher than that recorded in 1995, i.e. 4.5 million people (Depkes 2005).

Chronic diabetes could lead to blindness, renal failure, heart attack, and stroke. However, diabetes can be controlled and then the diabetic patients can lead a productive life. Nutrition plays a key role in the management of this disease. Short-term treatment with 4 g of white skin sweet potato extract per day improved the metabolic management in type 2 diabetic patients by decreasing insulin resistance without affecting body weight, glucose effectiveness, or insulin dynamics (Ludvik *et al*. 2003).

Diet therapy is the basic treatment for diabetics. Generally, diabetics have the same nutritional requirement as non-diabetic individuals, however, the diabetic's nutritional intake must be carefully monitored to minimize the load placed on the blood sugar-regulating mechanism. Therefore, the treatment for diabetics involved some forms of dietary modification. Diet for diabetics basically follows three aspects, i.e. (1) certain amount of calories, depending on nutritional status of the patients; (2) selected diet, especially for those have hypoglycemic effect or those potentially prevent complication; and (3) well scheduled diet presentation to avoid uncontrolled postprandial glucose load (Lasimo *et al.* 2002).

There is much better way to think about the way of carbohydrates act on our body. It is using what is called the glycemic index (GI). The thinking behind the GI is pretty simple (Vernon *et al*. 2004). The GI is a measure of how quickly a carbohydrate food affects the blood glucose levels. Because pure glucose raises blood sugar very quickly, 50 g of glucose is the standard reference food on the GI, it is ranked on 100 value. The effect of other carbohydrate-containing foods on blood sugar level can then be compared with the effect of glucose to ascertain a particular food glycemic ranking (Willett *et al.* 2002; Vernon *et al.* 2004).

The GI concept has developed since 1980s with purpose to help diabetes patients to minimize their postprandial rise in blood glucose (Jenkins *et al.* 1981). Since then, several studies in diabetics have shown that medium-term consumption (2-12 weeks) of a diet with a low GI was associated with sustained modest improvements in glycemic control (Brand *et al.* 1985).

The GI is a ranking of carbohydrates based on their immediate effect on blood glucose levels. It compares foods gram to gram of carbohydrate. Carbohydrates that broken down quickly during digestion have the highest GI and the blood glucose response is fast and high, while carbohydrates that broken down slowly, releasing glucose gradually into the blood stream, have low GI. In other words, GI measures the available 50 g of carbohydrate from food raising blood sugar and subsequently insulin levels. Based on GI value, foods can be devided in three groups, i.e. low GI (GI < 55), medium GI (GI = 55-70), and high GI (GI > 70). Nowadays, hundreds of common carbohydrate-containing foods have been recognized based on the GI values. There are some foods that have GI value of above 100, meaning they elevate the blood sugar even faster than when we eat pure glucose (GI = 100) (Vernon *et al.* 2004).

Sweet potato is one of the Indonesian foodstuff rich in olygosaccharides and dietary fiber. The two components contribute to the GI value of the food products. Varieties and processing methods also affect the GI value of foods. The common sweet potato varieties cultivated in Indonesia are Kidal, Sukuh, Sari, Ungu, and Jago, and advanced clones such as BB00105.10, B0464, and BB00106.18.This study aimed to find hypoglycemic sweet potato and appropriate processing methods to create low glycemic foods.

MATERIALS AND METHODS

Materials

The experiment used eight Indonesian sweet potatoes, consisted of five varieties and three clones. Such varieties were Kidal, Sukuh, Sari, Ungu, and Jago, while the clones were BB00105.10, B0464, and BB00106.18.

Sweet Potato Preparation

Tubers of the selected sweet potatoes were processed into three different methods, i.e. boiling, baking, and frying. The boiling method was conducted by washing and boiling sweet potatoes tubers for 30 minutes and then the boiled tubers were peeled and cut into small pieces. To make baked tubers, sweet potatoes were peeled and washed, then sliced into small pieces (0.5 cm thickness) and baked in the oven for 30 minutes. Fried sweet potatoes were prepared by peeling and washing the tubers, then they were cut into stick shape (0.5 cm x 0.5 cm x 5 cm) and deep fried for 5-8 minutes.

Starch Preparation

A part of sweet potato sample was processed into starch for hypoglycemic-response analysis. The rest of the samples was processed into flour by pelling, washing, slicing (0.2-0.5 cm thickness), and soaking in 0.03% sodium-metabisulphyte solution for one hour. The soaking was purposed to avoid browning-enzymatic reaction, therefore, the color of the chips and flour remained bright as the raw materials. The chips were then drained and dried using cabinet drier at 50-60°C up to 10% moisture content (Widowati *et al.* 2002).

Glycemic Index Assay

The GI value of a food was measured by feeding 10 healthy people (volunteers with 20-23 year old). A portion of the food contained 50 g of available carbohydrate. The volunteers took a night fasting (10-12 hours) and then the blood glucose was measured in the next morning (fasting blood glucoce level). After consumed the food (fried, baked, and boiled sweet potato containing 50 g of available carbohydrate), the blood glucose was measured for the next 30, 60, 90, and 120 minutes. In another day, the same treatment was done by feeding the volunteers with pure glucose as standard food (GI = 100). The GI was calculated by comparing the area under the curve of standard and tested foods (Jenkins *et al.* 1981; Rimbawan and Siagian 2004).

Blood Sampling and Analyses

Blood glucose level was measured by glucose oxidase biosensor method using One Touch Ultra glucose meter. For glucose measurement, capillary blood samples were taken from the finger. The test strip was inserted to turn on the meter automatically. The sample was applied by touch and hold blood drop to narrow channel in top edge of test strip, then blood glucose concentration was measured immediately (during 5 seconds).

Physical and Chemical Analysis

Physical properties of sweet potatoes were analysed visually based on skin color, flesh color, size, and shape. The proximate compositions, starch, and total sugar were measured by AOAC method (AOAC 2006). Amylose content was determined by using IRRI method (Khush *et al.* 1986), while dietary fiber was measured followed Asp *et al.* (1983) and resistant starch by Englyst and Cumming (1988) *in* Marsono (1993).

RESULTS AND DISCUSSION

Physical Properties of Sweet Potato

Sweet potato tubers were obtained from Muara Plant Station, CIP, Bogor, West Java. Physical characteristics of eight varieties/clones used in this experiment are presented in Table 1.

Nutrition Analyses

Nutritional composition

Fresh sweet potato tubers used in this experiment contained 59-69% (wb) of moisture and less then 2% (db) of ash. The protein content ranged from 3.71% (Sukuh variety) to 6.74% (B0464 clone). Table 2 shows that Sukuh variety had the highest fat content (2.01%, db), followed by Sari variety (1.42%, db) and the lowest was B0464 clone (0.26%, db).

Table 1. Physical characteristics of some sweet potato varieties/clones (n=10).

Varieties/ clones	Skin color	Flesh color	Tubers weight (g)	Shape
Kidal	Dark red	White	207	Oval
Sukuh	Yellow	White	212	Oval
Sari	Red	White	207	Round
Ungu	Violet	Violet	259	Round
Jago	Yellowish white	White	176	Oval
BB00105.10	Red	Dark-orange	358	Oval
B0464	Orange	Orange	80	Round
BB00106.18	Red	Pale-orange	63	Oval

Table 2. Proximate composition of several sweet potato varieties/clones.

Variety/clone	Moisture (% wb)	Ash (% db)	Protein (% db)	Fat (% db)	Carbohydrate (% db)
Kidal	65.98de	1.69c	5.32d	0.77c	92.22
Sukuh	59.26a	1.65c	3.71a	2.01e	92.63
Sari	65.44d	1.23b	4.83c	1.42d	92.52
Ungu	61.64b	1.62c	4.40bc	0.75c	93.23
Jago	66.41de	1.51c	4.24bc	0.81c	93.45
BB00105.10	63.71c	1.53c	5.47d	0.76c	92.24
B0464	67.26e	1.57c	6.74e	0.26a	91.43
BB00106.18	69.45f	0.68a	4.37b	0.39a	94.57

Numbers in the same column followed by different letters are significantly different ($p<0.05$).

Carbohydrate is the main factor that affects the GI of food (Willett *et al.* 2002). However, protein and fat also contribute to the glycemic response (Eckel 2003). High protein and fat content in the diet will decrease the glycemic response. In other word, higher protein and fat contents in food tend to decrease the glycemic response (Foster-Powell *et al.* 2002). Protein and fat tend to delay the gastric emptying rate, hence the digestibility rate in the small intestine is also slow. Based on this reason, the similar food with higher fat content results in lower glycemic response.

Carbohydrate composition

Amylose

Based on IRRI classification, amylose content of starchy food is grouped into three, i.e. low (< 20%), medium (20-25%), and high (> 25%). Table 3 shows that amylose content of sweet potatoes studied ranged from 21.62% (Sari variety) to 30.60% (B0464 clone). It meant that sweet potatoes used in this experiment were classified into medium to high amylose content. Amylose content will affect texture and taste of the tubers; the higher the amylose content, the softer the texture of the tubers.

Two forms of starch are found in food crops, i.e. amylose and amylopectin. Amylose is a polymer of simple sugar with no branch. The straight structure may construct a solid bond thus amylose it is difficult to be gelatinized and digested. Amylopectin is a polymer of simple sugar with plenty branches and open structure. Amylopectin is easier to be gelatinized and digested. Based on these properties, glycemic responses of high amylose foods differ from those of high amylopectin foods. High amylopectin foods

Table 3. The amylose, starch, resistant starch, and total sugar of several sweet potato flour.

Variety/clone	Amylose (% db)	Starch (% db)	Resistant starch (% db)	Total sugar (% db)
Kidal	23.86c	79.20b	3.00b	0.36b
Sukuh	22.57ab	88.40f	3.00b	0.34b
Sari	21.62a	72.00a	3.40c	2.08e
Ungu	23.02bc	85.40d	2.00a	0.12a
Jago	27.91f	81.80c	3.40c	0.45b
BB00105.10	24.94d	93.00g	3.80d	1.10d
B0464	30.60g	86.60e	2.80b	0.15a
BB00106.18	26.08e	89.00f	2.90b	0.61c

Numbers in the same column followed by different letters are significantly different based on Duncan's multiple range test ($p<0.05$).

tend to increase their glycemic response (Foster-Powell *et al.* 2002).

Amylose is more difficult to be gelatinized than amylopectin because it has strong bond. Based on this property, high amylose foods inclined to reduce glycemic response (Willett *et al.* 2002). Tubers of BB00105.10 clone contain 24.94% amylose and can be classified as medium amylose level.

Resistant starch and sugar

Starch is the main source of energy in most food crops. Starch content of sweet potato flour studied ranged from 72% (Sari variety) to 93% (BB00105.10 clone). It meant that the tubers of BB00105.10 clone provided the highest energy than those of other varieties/clones (Table 3). However, the amount of energy intake and capability for increasing circulating blood glucose levels were not always in line with starch or carbohydrate content. It might be caused by an existing resistant starch and starch digestibility levels. The tuber of BB00105.10 clone had the highest starch content as well as the highest hypoglycemic activity. In other word, BB00105.10 tuber was slowly increasing blood glucose levels, although it contained the highest carbohydrate.

The former concept on nutritional science convinced that starch was able to be completely digested in the human intestine. This is because saliva and pancreas produce amylase enzyme which is able to breakdown the starch. Nowadays, the postulate has already been corrected since experiments both *in vitro* as well as *in vivo* found that starch intake was not completely digested. The starch fraction that cannot be digested is called resistant starch. From physiological point of view, resistant starch is defined as the amount of starch and the result from starch digestion that cannot be absorbed by healthy human intestine. Slowly digested and absorbed carbohydrate will reduce the postprandial metabolic response. Thus, carbohydrates that broken down slowly, such as resistant starch, tend to reduce glycemic response.

Table 3 shows the resistant starch content of several sweet potato, varieties clones. BB00105.10 clone had The highest resistant starch content (3.8%) and the lowest one was Ungu variety (2.0%). The physico-chemical property of sweet potatoes that consistently affected the glycemic response was resistant starch. Increase in resistant starch levels will consistently decrease glycemic response. The result showed that BB00105.10 had the highest resistant starch and the lowest glycemic response, followed by Sari and Jago, and then by Kidal, Sukuh, BB00106.18, and B0464. Resistant starch content of Ungu variety was the lowest, therefore its glycemic response was the highest. It seems that resistant starch has negative response toward starch digestibility. In other word, the lower the resistant starch content, the higher the digestibility rate. In contrary, BB00105.10 clone had the highest resistant starch, therefore its starch digestibility was relatively low (51%). It was expected that this property was in line with the glycemic response. Thus, resistant starch content of sweet potato flour found in this experiment confirmed the concept that undigestible starch decreases the glycemic response.

Total sugar

Total sugar of BB00105.10 clone was relatively high (second highest after Sari variety), however, it was not directly increasing the glycemic response. It is probably because the kind of simple sugar in sweet potato flour is mainly non-glucose. Table 3 shows that total sugar of sweet potatoes studied ranged from 0.12 (Ungu variety) to 2.08% (Sari variety).

Digestibility

Starch digestibility

Generally, foods that are able to be broken down easily during digestion will immediately increase the plasma glucose levels. Quick ascending of plasma glucose levels pushed the pancreas to produce and release more insulin. As a consequence, high blood glucose levels will increase the insulin response (Ostman *et al.* 2001). Result indicated that BB00106.18 had the lowest starch digestibility (44.57%) and the highest one was Ungu variety (99.99%). Statistical analysis showed that BB00105.10 clone had the second lowest starch digestibility (51.40%) after BB00106.18 and Sari (Table 4).

Dietary fiber

Dietary fiber plays a key role in maintaining human health. Dietary fiber influences glucose assimilation and reduces serum cholesterol. Research has shown that certain plant fibers delay the absorption of carbohydrate and result in less postprandial hyperglycemia. Increasing fiber in the diet is associated with reducing insulin resistance. An increase in fiber from whole grain, legumes, and vegetables may appear to be beneficial for the diabetics (Sardesai 2003). Dietary fiber contributes to prevent various diseases, mainly those associated with digestion gutter (Eckel 2003). Indonesian people still lack in consuming dietary fiber. The average consumption of dietary fiber is only 10 g capita^{-1} day^{-1} (Astawan and Wresdiyati 2004), lower than that the recommended rate of 20-30 g capita^{-1} day^{-1}. Tubers, including sweet potatoes are the starchy foods rich in dietary fiber.

Dietary fiber inclines toward lower glycemic response because it is slowly digested. Dietary fiber coinciding with resistant starch reaches the large intestine and is fermented by anaerobic bacteria. These polysaccharides are then broken down into a simple saccharide by several reactions and result final products such as lactic acid, CO_2, H, CH_4, H_2O and short chain fatty acids (acetic, propionate, and butyric acids). BB00105.10 clone had high insoluble dietary fiber and relatively low soluble dietary fiber.

Table 4. Starch digestibility and dietary fiber content of sweet potato flour.

Variety/clone	Starch digestibility (% db)	Soluble dietary fiber (% db)	Insoluble dietary fiber (% db)
Kidal	71.05d	14.27d	27.74c
Sukuh	98.30e	13.89cd	36.69d
Sari	45.13a	21.24f	36.98d
Ungu	99.99e	13.28cd	38.77e
Jago	62.00c	13.30cd	17.23a
BB00105.10	51.40b	12.81bc	38.56e
B0464	99.00e	11.79a	26.79b
BB00106.18	44.57a	17.34e	17.02a

Numbers in the same column followed by different letters are significantly different based on Duncan's multiple range test ($p < 0.05$)

Hypoglycemic Activity

Screening of hypoglycemic activity response of sweet potatoes was done *in vivo* by using rats as animal model. Table 5 shows blood glucose levels at fasting and after food ingestion every 30 minutes during 2 hours. The result was then calculated and plotted in the curve as shown in Figure 1.

Figure 1 shows hypoglycemic activity in line with their resistant starch. This finding confirmed the previous reports that existing resistant starch tends to increase hypoglycemic response. In this experiment, the hypoglycemic response was clearly shown on BB00105.10 tuber. The tuber had the highest resistant starch (3.8%) and hypoglycemic response, followed by Sari and Jago varieties (RS 3.4%), Sukuh and Kidal varieties (RS 3.0%), as well as BB00106.18 (RS 2.9%) and B0464 clones (RS 2.8%). Ungu variety had the lowest resistant starch (2.0%) and was proofed with the lowest hypoglycemic response.

Starch digestibility has high contribution to the hypoglycemic activity of foods. Foods with low starch digestibility tend to have high hypoglycemic activity. Based on the changes in hypoglycemic response curve (Fig. 1), BB00105.10 clone had the highest hypoglycemic response. Although not the lowest, the clone had low starch digestibility (51.40%).

Glycemic Index Evaluation

Profile of processed sweet potatoes used for glycemic index evaluation as seen in Figure 2, indicated that changes in blood glucose levels after consuming

Table 5. Profile of blood glucose levels at fasting time and after food ingestion.

Variety/clone	Blood glucose (mg dl^{-1})				
	Fasting	30 min	60 min	90 min	120 min
Kidal	67	115	93	93	83
Sukuh	80	122	97	88	82
Sari	81	122	98	89	82
Ungu	77	139	126	111	101
Jago	74	106	91	92	84
BB00105.10	78	102	97	86	74
B0464	66	101	84	92	85
BB00106.18	69	117	96	95	86

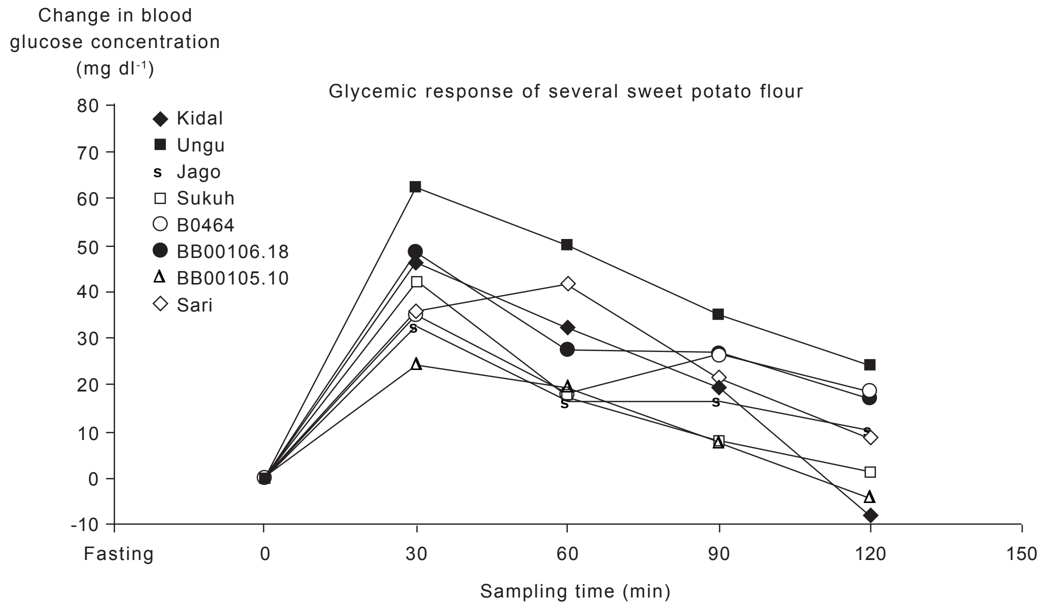

Fig. 1. Changes in blood glucose concentration after oral administration of several sweet potato starches in the rat.

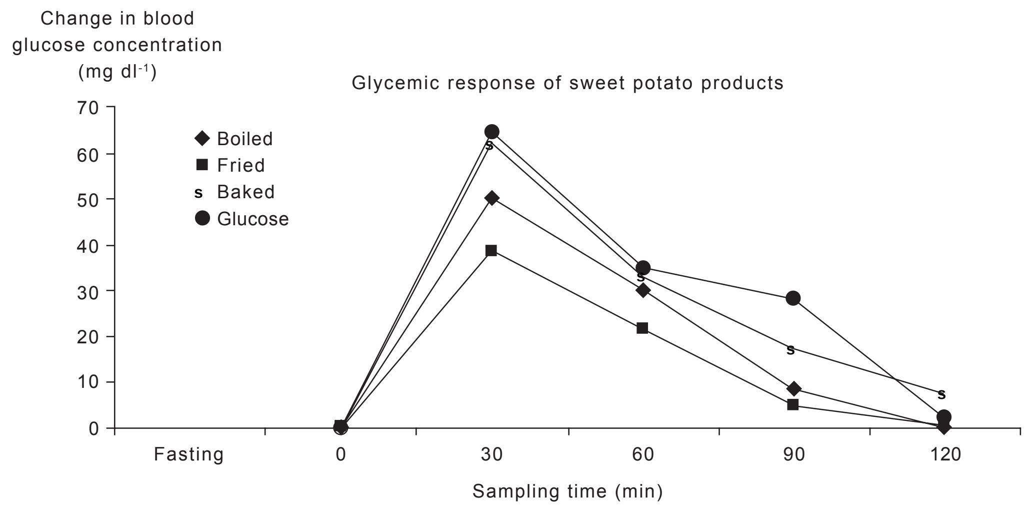

Fig. 2. Change in blood glucose levels at fasting and after consuming boiled, baked and fried sweet potatoes.

processed sweet potatoes were influenced by the processing methods. This finding confirmed the former results which concluded that processing is one of factors that affects the GI value of foods (Foster-Powell *et al.* 2002).

Result showed that BB00105.10 clone met the functional food characteristics for diabetics as it had the highest hypoglycemic activity. Tuber of the clone was then processed into three different products and analyzed for their GI. Result indicated that the GI value of boiled sweet potatoes was 62, while that of fried tubers was 47 and baked form was 80. It meant that frying reduced the GI value. Fat in fried sweet potatoes inclined toward lower glycemic response because it was slowly digested, thus emptying gastric rate will also be slowly. Therefore, higher fat content foods tend to have lower GI value. However, high fat content foods must be carefully consumed to maintain healthy life.

Selection of BB00105.10 clone as carbohydrate source for developing functional food, especially for diabetics, gives a special value for sweet potatoes breeding. BB00105.10 is an advanced clone. This finding may support its field characters, i.e. high productivity and resistant to common pests and diseases.

CONCLUSION

Among eight sweet potato varieties/clones tested, BB00105.10 clone indicated the best glycemic response followed by Sari, Jago, Sukuh, and Kidal varieties. The highest hypoglycemic activity of BB00105.10 was supported with the highest resistant starch content (3.80%) as well as protein (5.47 %) and a low starch digestibility (51.40%). BB00105.10 contained medium amylose (24.94%)

Processing methods influenced the GI value of foods. Frying was the best method as compared with baking and boiling. The GI values of fried, boiled, and baked sweet potatoes were 47, 62, and 80, respectively.

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