Valorization of the green waste parts from sweet potato (*Impoea batatas* L.): Nutritional, phytochemical composition, and bioactivity evaluation

Jingyang Hong¹,²,³,⁴ | Taihua Mu¹,² | Hongnan Sun¹,² | Aurore Richel³ | Christophe Blecker⁴

¹Laboratory of Food Chemistry and Nutrition Science, Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences, Beijing, China
²Key Laboratory of Agro-Products Processing, Ministry of Agriculture and Rural Affairs, Beijing, China
³Biological and Industrial Chemistry Unit, Gembloux Agro-Bio Tech, University of Liège, Gembloux, Belgium
⁴Department of Food Science and Formulation, Gembloux Agro-Bio Tech, University of Liège, Gembloux, Belgium

Correspondence
Taihua Mu and Hongnan Sun, Laboratory of Food Chemistry and Nutrition Science, Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences and Key Laboratory of Agro-Products Processing, Ministry of Agriculture and Rural Affairs, No. 2 Yuan Ming Yuan West Road, Haidian District, P.O. Box 5109, Beijing 100193, China.
Email: mutaihua@126.com (T. M.); honey0329@163.com (H. S.)

Funding information
The authors gratefully acknowledge the Natural Science Funding of China (31701614), the National Key R&D Program of China (2016YFE0133600), and the earmarked fund for China Agriculture Research System (CARS-10-B21).

Abstract
In the present study, leaves from 13 sweet potato cultivars were collected as raw materials. The nutritional and functional composition, antioxidant activity, and sunscreen activity of different sweet potato leaf samples were determined, and the comprehensive nutritional quality was calculated by gray relational analysis. Results showed that the nutritional and functional components are significantly different between different cultivars. Tainong71 showed the highest comprehensive nutritional quality, followed by Fu22, Ningcai, Fu23, Ecai10, Zhecai726, Ecai1, Fu18, Pushu53, Guangcai5, Shulv1, Guangcai2, and Zhecai1. The antioxidant activity varied from 3.94 to 16.75 g Trolox equivalent/100 g dry weight. Pushu53 showed the highest sunscreen activity, with the sun protection factor 24.65. There was a positive correlation between antioxidant activity and sunscreen activity ($r = .737$, $p = .004$). In conclusion, sweet potato leaves possess high nutritional and functional properties, and have the huge potential to be used as green leafy vegetables and sunscreen agent.

KEYWORDS
antioxidant activity, chemical/nutritional characterization, correlation analysis, gray relational analysis, sunscreen activity, sweet potato leaves

1 | INTRODUCTION

Sweet potato (*Impoea batatas* L.) is one of the most important food crops and widely grown around the world (de Albuquerque, Sampaio, & de Souza, 2019). Sweet potato leaves are the above-ground part of sweet potato, which can be harvested 3–4 times in 1 year. The annual yield of sweet potato leaves is almost the same with root. Sweet potato leaves have become a new kind of vegetable in the United States, Japan, Taiwan, and Hong Kong. But in most areas of China, sweet potato leaves are still discarded as waste directly, resulting in huge waste of resources and the pollution of environment (Lu, Zhou, Ren, & Zhang, 2019). In recent years, there are increasing studies...
concentrated on the sweet potato leaves. Islam (2006) reported that sweet potato leaves have positive effects on human health and nutrition. Sun, Mu, Xi, Zhang, and Chen (2014) studied the nutritional compositions of leaves from 40 sweet potato cultivars and found that sweet potato leaves, which contain several nutrients and bioactive compounds, should be consumed as leafy vegetables in an attempt to reduce malnutrition. Although thousands of sweet potato leaf cultivars have been reported, information about nutrition and function of sweet potato leaves is still deficient.

Nutritional components are the main indicators for evaluating the nutritional value of sweet potato leaves. At present, judging the nutritional value of food from single component is inaccurate and incomprehensive. The gray relational analysis (GRA) is a technique of system theory that is used to evaluate the comprehensive nutritional value. Nowadays, GRA has been applied to evaluate the nutritional quality of different crops and the ideal varieties have been successfully selected (Liu et al., 2017). So it is sensible to choose GRA to evaluate the comprehensive nutritional value of different varieties of sweet potato leaves in this study.

In addition, ultraviolet radiation (UV) is the main cause of most skin diseases, especially skin cancer. The incidence of skin cancer induced by ultraviolet radiation has risen sharply all over the world. Chemical protection is one of the important ways to protect skin from UV, but long-term use of chemicals will change the active state of macrophages and break the immune balance of the body (Rubio, Valverde-Som, Sarabia, & Ortiz, 2019). In clinic, the main anti-radiation drugs are ammonia-mercapto, which can cause nausea, vomiting, hypertension, and other adverse reactions (Clémenson et al., 2019). So it is urgent to develop natural materials to protect skin from UV radiation. Studies have shown that both oral and topical application of polyphenols can significantly prevent skin from damage and skin cancer, such as green tea, pomegranate, and mulberry (Afaq & Katiyar, 2012; Hu, Zhang, Chen, & Wang, 2017). UV can form reactive oxygen species (ROS) which might react with oxygen molecules in human cells and prevent the body destruction by oxidative reactions (Ho et al., 2007). However, there is no relevant report on the prevention of UV by polyphenols from sweet potato leaves.

Therefore, in the present study, sweet potato leaves from 13 sweet potato cultivars were collected, and the nutritional and functional components, antioxidant activity, and sunscreen activity were determined. The comprehensive nutritional value was evaluated by GRA, so as to provide some theoretical support for the effective development and utilization of sweet potato leaves.

2 | MATERIAL AND METHODS

2.1 | Materials

Sweet potato leaves from 13 sweet potato cultivars (Guangcai2, Guangcai5, Ecai1, Ecai10, Zhecai1, Zhecai726, Fu18, Fu22, Fu23, Tainong71, Shulv1, Pushu53, Ningcai) were obtained from Agricultural Machinery Extension Station in Beijing, China. They were cleaned with tap water and lyophilized in freeze dryer machine (FD5-3, SIM USA Intl. Group) at −57°C for 96 hr and then ground into powder by an ultrafine grinder. Powdered samples were stored in well-labeled aluminum foil bag at −4°C until analyzed.

2.2 | Proximate compositions

Ash, crude fat, and crude protein contents were determined by AOAC methods (AOAC 923.03, 960.39, and 976.05, respectively). Crude fiber (g/100 g DW) was determined by ISO method 5498:1981. Carbohydrate content (g/100 g DW) was calculated by subtracting the sum of ash, crude fat, crude protein, and crude fiber contents from 100. Gross energy (kcal/100 g DW) was calculated according to the European Universal Energy Coefficient (Menezes et al., 2016), with the following Equation

\[ ME_{food} = 4 \times P + 9 \times F + 4 \times AC \] (1)

\[ ME_{food}: \text{metabolizable energy of food (kcal/100 g)}; \ P: \text{protein content (g/100 g)}; \ F: \text{crude fat content (g/100 g)}; \ AC: \text{carbohydrate content (g/100 g)}. \]

2.3 | Mineral content

Leaf samples were digested in concentrated HNO₃ (AOAC, 2000). The digest was transferred to a 25 ml volumetric flask, and the volume was adjusted to 25 ml with deionized water. A blank digest was prepared in a similar manner. Mineral content, expressed as mg mineral/100 g DW, was determined by inductively coupled plasma atomic emission spectrometry (ICAP6000, Thermo Fisher Scientific).

2.4 | Vitamin content

Vitamin C (VC), vitamin E (VE), vitamin B₁ (VB₁), vitamin B₂ (VB₂), vitamin B₃ (VB₃), and folic acid were extracted and determined by a slightly modified HPLC method previously reported by Gratacós-Cubarsí, Sárraga, Clariana, Regueiro, and Castellari (2011). Briefly, 1 g of sample was mixed with 9 ml of 0.1 M hydrochloric acid and maintained at 100°C for 30 min in a water bath. After cooling, 6 ml of 2.5 M sodium acetate and 1 ml of 10% (w/v) taka-diastase solution were added. Samples were incubated overnight at 37°C and centrifuged at 500 g for 5 min at 4°C. The resulting supernatant was adjusted to 20 ml with ultrapure water. An aliquot (5 ml) was purified using an Oasis MCX cartridge (6cc-150 mg, Waters Corp.) for the simultaneous determination of vitamins C, E, B₁, B₂, B₃, and folic acid.

β-carotene was determined via the slightly modified protocol of Kourouma, Mu, Zhang, and Sun (2019), and 2 g of sweet potato leaves powder was mixed with 20 ml petroleum ether: acetone (80:20, v/v) for 20 min at 40°C on ultrasonic water bath under dim light for carotenoids extraction. The extraction was repeated three
times. The extracts were collected after centrifuge 10 min at 7,000 g and concentrated under rotary vacuum evaporator at 30°C to get 4 ml of final extract. Every 1 ml of extract was dried under nitrogen gas, re-dissolved in 1 ml petroleum ether, filtered through 0.45 μm, and analyzed by HPLC.

Quantification of carotenoids was performed using reversed-phase high-performance liquid chromatography (RP-HPLC, Shimadzu LC-20A) on column C18 (150 mm × 4.6 mm; 5 μm particle size) with mobile phase of methanol-acetonitrile (90:10, v/v) at flow rate of 1 ml/min at 25°C. The injection volume was 20 μl, and the detection wavelength was 450 nm.

2.5 | Amino acid composition

The amino acid composition of leaf sample was obtained using the Biochrom 3.1 amino acid analyzer according to the method by Bártová, Bártá, Brabcová, Zdralí, and Horáčková (2015) with appropriate modifications. Briefly, 10 ml of 6 N hydrochloric acid was added to 100 mg sample in test tube. Blow the sample with nitrogen for 1 min, then covered and hydrolyzed in an oven at 110°C for 24 hr, and allowed to cool to room temperature. The hydrolysate was filtered to remove visible sediments and evaporated to dryness under vacuum at 60°C. The hydrolysate was dissolved in 1 ml of 0.02 N hydrochloric acid. An aliquot (20 μl) was injected into the amino acid analyzer (tryptophan could not be determined by this method). The amino acid score (AAS) was calculated with reference to FAO/WHO (Joint WHO/FAO/UNU Expert Consultation, 2007) reference amino acid pattern (Evan, Omoba, & Enujiugha, 2018).

\[
\text{AAS} = \frac{\text{limiting amino acid}}{\text{Reference amino acid}} × 100 \tag{2}
\]

The reference levels of each EAA (mg/g protein) were as follows: lysine, 45; histidine, 15; threonine, 23; valine, 39; isoleucine, 30; leucine, 59; methionine and cystine, 16; phenylalanine and tyrosine, 30.

2.6 | Total polyphenol content (TPC) and antioxidant activity

Total polyphenol content was measured by the Folin–Ciocalteu method with a slight modification (Figueiredo et al., 2014). Polyphenols were extracted according to the method of Sun et al. (2014). A calibration curve was generated with chlorogenic acid standards (Sigma-Aldrich, Inc.), ranging from 0.02 to 0.10 mg/ml. The linear regression equation was

\[
y = 0.8761x + 0.0068 \tag{3}
\]

and \( R^2 = 0.9994 \). TPC was expressed as milligram chlorogenic acid equivalents (CAE) per gram leaf powder on a DW basis. TPC was calculated according to the following equation:

\[
\text{TPC} = \frac{(A - 0.0068)}{8.7671} × V/M \tag{4}
\]

where \( A \) is the absorbance, \( V \) is the volume of the crude extract diluent (ml), and \( M \) is the mass of the tested sample on a DW basis (g).

Antioxidant activity of the leaf samples was determined with the Ferric ion reducing antioxidant power (FRAP) (Goel, Irshad, Mehdhi, Rizvi, & Ahmad, 2013). FRAP values were expressed as grams Trolox equivalents (TE) per 100 g leaf powder on a DW basis.

2.7 | SPF

One gram of each sample was diluted with 20 ml ethanol and extracted by ultrasonic method for 30 min and centrifuge at 7,500 g for 10 min, repeated for three times; collect centrifugal fluid, constant volume to 100 ml. After preparation, all the samples were scanned at wavelength between 290 and 320 nm, in the range of UVB, every 5 nm, and three replicates were made at each point. In the end of all measurements, the Mansur equation was applied to calculate SPF values (Prakash, Lokesh, & Manral, 2015).

\[
\text{SPF} = \frac{320}{290} \sum_{i=1}^{290} \text{EE}(i) × I(i) × \text{Abs}(i) \tag{5}
\]

Here, \( CF = \) correction factor (10), \( \text{EE}(i) = \) erythmogenic effect of radiation with wavelength \( i \), \( \text{Abs}(i) = \) spectro-photometric absorbance values at wavelength \( i \). The values of \( \text{EE}(i) \times I \) are constants. They were determined by Sayre, Agin, LeVee, & Marlowe, 1979. The values of \( \text{EE}(i) \times I \) from 290–320 nm were 0.0150, 0.0817, 0.2874, 0.3278, 0.1864, 0.0837, 0.0180, respectively.

2.8 | Comprehensive nutritional value

In this study, the leaf samples represent a gray system; each cultivar is a factor in the system. The nutritional value correlation between the samples and an ideal sample was determined. Based on the aim of this study, the ideal sample was selected by combining the upper or lower nutritional contents. Crude protein, dietary fiber, mineral content, vitamins, total polyphenol content, antioxidant activity, etc., which are positively correlated with nutritional content, utilized 5% of the maximum value of the tested leaves. However, crude fat, carbohydrate, gross energy, etc., which are negatively correlated with the nutritional content, utilized 5% of the minimum value of the tested leaves. A high correlation coefficient is indicative that the degree of similarity between the sample and the ideal sample is high. The correlation coefficient was calculated according to the method reported by Kadier (Kadier et al., 2015). Assuming that the ideal list was \( X_0 \), the compared list was \( X_i \), \( i = 1,2,3,..., \) and \( X_0 = (X_0(1), X_0(2), X_0(3) ... X_0(k)) \), \( X_i = (Xi(1), Xi(2), Xi(3) ... Xi(k)) \), \( k = 1,2,3 ... M \). The correlation coefficient between the samples and ideal sample at the \( k \) point was calculated using the following equation:
| Cultivar   | Moisture<sup>a</sup> | Crude protein | Crude fat | Crude fiber | Ash       | Dietary fiber | Carbohydrate | Gross energy<sup>b</sup> |
|-----------|----------------------|---------------|-----------|-------------|-----------|---------------|---------------|------------------------|
| Guang2    | 89.67 ± 0.87bc       | 33.64 ± 0.83c | 3.87 ± 0.64cd | 10.92 ± 0.07f | 15.62 ± 0.05f | 37.28 ± 0.1a | 36.31 ± 0.49d | 311.66 ± 2.35ab       |
| Guang5    | 88.67 ± 1.34abc      | 31.41 ± 0.69b | 2.75 ± 0.41a  | 9.26 ± 0.03a  | 14.86 ± 0.05d | 38.87 ± 0.33bcd | 41.98 ± 0.55fg | 316.23 ± 0.32bc       |
| Ecai1     | 87.92 ± 0.43ab       | 35.66 ± 0.2de | 4.28 ± 0.92d  | 9.82 ± 0.08bc | 13.43 ± 0.15a | 40.32 ± 0.1f | 36.79 ± 1.24d | 329.1 ± 7.34e         |
| Ecai10    | 89.95 ± 0.16bc       | 38.52 ± 0.33f | 4.25 ± 0.33d  | 10.63 ± 0.01e | 16.61 ± 0.12h | 38.71 ± 0.01bcd | 30.13 ± 0.74a | 312.26 ± 2.41ab       |
| Zhecai1   | 89.89 ± 0.36bc       | 35.45 ± 0.31d | 2.78 ± 0.23a  | 9.74 ± 0.12b  | 15.51 ± 0.03ef | 38.48 ± 0.42bc | 36.75 ± 0.88d | 311.93 ± 1.56ab       |
| Zhe726    | 90.01 ± 1.2bc        | 33.65 ± 0.34c | 2.74 ± 0.22c  | 9.91 ± 0.09c  | 14.61 ± 0.18c | 39.06 ± 0.3d | 38.15 ± 0.3e | 320.25 ± 1.67cd       |
| Fu18      | 88.41 ± 0.98abc      | 36.44 ± 0.25e | 2.78 ± 0.23ab | 10.19 ± 0.02d | 16.48 ± 0.03h | 38.91 ± 0.04e | 34.01 ± 0.19bc | 307.93 ± 0.72a        |
| Fu22      | 87.37 ± 0.82a        | 26.01 ± 0.19a | 2.74 ± 0.22a  | 10.11 ± 0.02d | 16.47 ± 0.01h | 41.45 ± 0.11cd | 42.64 ± 0.12g | 307.62 ± 1.45a        |
| Fu23      | 87.96 ± 2.03ab       | 36.16 ± 0.0e  | 2.75 ± 0.06a  | 11.4 ± 0.06g  | 15.45 ± 0.07e | 40.35 ± 0.14g | 34.22 ± 0.19bc | 306.25 ± 0.08a        |
| Taninong71| 88.24 ± 0.13abc      | 35.49 ± 0.07d | 3.3 ± 0.21abc | 10.2 ± 0.07d  | 15.93 ± 0.07g | 40.06 ± 0.13f | 35 ± 0.34c | 312.11 ± 1.35ab       |
| Shulv1    | 90.27 ± 0.17c        | 36.04 ± 0.14de| 3.03 ± 0.75ab | 9.77 ± 0.06bc | 16.99 ± 0.1i  | 39.58 ± 0.14bc | 33.64 ± 0.03b | 310.56 ± 0.92ab       |
| Pushu53   | 88.61 ± 0.02abc      | 31.36 ± 0.2b  | 3.25 ± 0.08abc| 9.39 ± 0a    | 13.74 ± 0.14b | 38.48 ± 0.13f | 42.19 ± 0.19fg | 323.42 ± 0.63d        |
| Ningcai   | 88.14 ± 0.4abc       | 31.14 ± 0.08b | 2.49 ± 0.56a  | 10.66 ± 0.05e | 14.88 ± 0.02d | 38.42 ± 0.14b | 41.11 ± 0.45f | 308.89 ± 2.23a        |

Note: Data are means ± SD (n ≥ 2). Values within columns with different letters are significantly different ($p < .05$).
Abbreviations: DW, dry weight; FW, fresh weight.

<sup>a</sup>Moisture content was expressed in g/100 g FW.
<sup>b</sup>Gross energy was expressed in kcal/100 g DW.
| Cultivar | K     | Ca   | Mg   | Na    | Cu    | Fe    | Mn    | Zn    | Cu    | Fe    | Mn    | Zn    | Cu    | Fe    | Mn    | Zn    | Cu    | Fe    | Mn    | Zn    | Cu    | Fe    | Mn    | Zn    |
|----------|-------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Guangcai2 | 53.71 ± 4.23 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |
| Guangcai5 | 54.65 ± 4.23 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |
| Ecai10 | 6.48 ± 0.12 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |
| Zhecai1 | 53.71 ± 4.23 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |
| Fu10 | 6.48 ± 0.12 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |
| Taimong | 5.940 ± 0.31 | 54.65 ± 4.23 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |
| Shulv1 | 6.72 ± 0.17 | 201.15 | 21.87 | 36.01 ± 1.91 | 294.23 | 5.94 ± 0.12 | 23.84 ± 0.31 | 528.11 ± 22.6 | 6.39 ± 0.19 | 2.47 ± 0.19 | 0.75 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 | 0.69 ± 0.09 |

Note: Data are means ± SD (n ≥ 2). Values within columns with different letters for minerals, vitamins, TPC or antioxidant activity are significantly different (p < .05).

Abbreviation: DW, dry weight.

aFolic acid was expressed in μg/100 g DW.
where $\Delta i(k) = |X_i(k) - Xi(k)|$, $\min|\Delta i(k)|$ is the minimum value of the first level, $\min|\Delta i(k)|$ is the minimum value of the second level, $\max|\Delta i(k)|$ is the maximum value of the first level, and $\max|\Delta i(k)|$ is the maximum value of the second level. In Equation 6, $\mu (0 \leq \mu \leq 1)$ is the distinguishing coefficient. The distinguishability was increased with the $\mu$ value decreased. In this study, $\mu$ was set to .5, because this value offers moderate distinguishing effects and good stability. The average gray relational degree at the $k$ point was determined using the following equation:

$$\gamma_k = \frac{1}{N} \sum_{j=1}^{n} \xi_{i(k)}$$ (7)

The weight at the $k$ point was calculated with the following equation:

$$W_k = \frac{\gamma_k}{\sum_{1}^{M} \gamma_k}$$ (8)

The gray relational degree was determined by the following equation:

$$G_i = \sum_{k=1}^{M} \xi_{i(k)} W_k$$ (9)

2.9 | Statistical analysis

All the experiments were carried out in triplicate. Statistical analyses were performed using the Statistical Product and Service Solutions software (IBM SPSS Statistical 21). Statistical significance was set to $p < .05$.

3 | RESULTS AND DISCUSSION

3.1 | Nutritional and functional composition

Table 1 shows the proximate compositions of leaves from 13 sweet potato cultivars. The moisture content ranged between 87.37 and 90.27 g/100 g FW. Shulv1 had the highest moisture content (90.27 ± 0.17 g/100 g FW), while Fu22 had the lowest moisture content (87.37 ± 0.82 g/100 g FW). The moisture contents obtained in this study were similar to those reported by Ishida et al. (2000). The moisture content of sweet potato leaves may be affected by the harvest time.

Protein is an essential nutrition in the human diet (Pereira & Vicente, 2013). The direct consumption of vegetable proteins in food products has been increasing over the years because of animal-related diseases, global shortage of animal protein, increasing demand for wholesome or religious food, and for economic reasons (Asgar, Fazilah, Huda, Bhat, & Karim, 2010). From the Table 1, we can see that protein content ranged from 28.01 to 38.52 g/100 g DW in sweet potato leaves. There was a significant difference in protein content among different cultivars. It was higher than the contents of Japan’s two cultivars Kogannesengen (KS) and Beniazuma (BA) which was reported by Ishida et al. (2000). The crude protein content of KS and BA was 29.5 g/100 g DW and 24.5 g/100 g DW, respectively.

Crude fiber content varied from 9.26 to 11.4 g/100 g DW while the dietary fiber content ranged from 37.28 to 41.45 g/100 g DW among different sweet potato cultivars. Sweet potato leaves can be used as a good plant source of dietary fiber. Fu23 has the highest crude fiber content (11.4 ± 0.06 g/100 g DW). It is higher than the crude fiber content of black tea from China (11.29 g/100 g) and India (11.26 g/100 g) (Śmiechowska & Dmowski, 2006). This may be related to the differences of sweet potato leaf varieties, maturity.

The ash content ranged from 13.43 ± 0.15 to 16.99 ± 0.1 g/100 g DW; it was higher than many other vegetables such as radish, garlic, and yam which is reported by Sipahioglu and Barringer (2003). Ash generally represents the total amount of inorganic elements which has important physiological and pathological significance in human life activities. Additionally, carbohydrate and gross energy of sweet potato leaf were 30.13 ± 0.74 to 42.19 ± 0.19 g/100 g DW and 306.25 ± 0.08 to 323.42 ± 0.63 g/100 g DW. The average contents of carbohydrate and gross energy was 37.15 g/100 g DW and 313.71 kcal/100 g.

3.2 | Mineral content

Table 2 shows the mineral content of leaves from 13 sweet potato cultivars. Minerals are classified into two groups: macroelements (Ca, K, P, Mg, and Na) and microelements (Fe, Mn, Zn, and Cu). In this study, Ca ranged from 1,002.90 (Ningcai) to 1,582.36 (Fu18) mg/100 g DW; K ranged from 5,321.62 (Ecai1) to 7,720.68 (Shulv1) mg/100 g DW; P ranged from 663.79 (Ecai10) to 1,016.02 (Shulv1) mg/100 g DW; Cu ranged from 11.93 (Fu22) to 41.02 (Guangcai2) mg/100 g DW. In this study, Ca ranged from 1,002.90 (Ningcai) to 1,582.36 (Fu18) mg/100 g DW; K ranged from 5,321.62 (Ecai1) to 7,720.68 (Shulv1) mg/100 g DW; P ranged from 663.79 (Ecai10) to 1,016.02 (Shulv1) mg/100 g DW; Mg ranged from 438.70 (Ningcai) to 761.25 (Zhecai1) mg/100 g DW; and Na ranged from 34.92 (Shulv1) to 197.52 (Fu23) mg/100 g DW.

The most abundant macroelement was K (average content of 6,065.63 mg/100 g DW), followed by Ca (average content of 1,289.57 mg/100 g DW), P (average content of 769.18 mg/100 g DW), Mg (average content of 628.03 mg/100 g DW), and Na (average content of 108.93 mg/100 g DW). K is important for the maintenance of fluid and electrolyte balance in body cells. Insufficient intake of K from the diet leads to hypokalemia, which contributes to life-threatening conditions such as cardiac arrhythmias and acute respiratory failure. Mg is essential in nucleic acid synthesis. Low Mg levels have been associated with several diseases including asthma, diabetes, and osteoporosis.

Fe ranged from 11.93 (Fu22) to 41.02 (Guangcai2) mg/100 g DW. Mn ranged from 4.98 (Fu22) to 10.66 (Fu18) mg/100 g DW,
Zn ranged from 2.53 (Guangcai5) to 11.33 (Fu22) mg/100 g DW, and Cu ranged from 0.54 (Guangcai5) to 0.91 (Ecai1) mg/100 g DW. The most abundant microelement was Fe (average content of 20.57 mg/100 g DW), followed by Mn (average content of 3.39 mg/100 g DW), and Cu (average content of 0.72 mg/100 g DW). Even though heme iron from meat is more bioavailable than nonheme iron from sweet potato leaves, the intake of heme Fe/hemoglobin from red meat may increase the risk of colorectal cancer (Wang & Farid, 2015). Mn is related to the oxidative stress system and participates in glucose homeostasis and calcium transport. Zn is a component of several metallo-enzymes. It is related to the metabolism of RNA and DNA, involved in gene expression, signal transduction, and so on. Cu is involved in the synthesis of collagen and various enzymatic reactions.

### 3.3 | Vitamin content

The vitamin content of sweet potato leaves from different cultivars is presented in Table 2. VB₁ can maintain the normal functions of circulation, digestion, nerve, and muscle, and adjust the function of gastrointestinal tract. VB₃ content ranged from 0.12 (Zhecai726) to 2.26 (Ecai10) mg/100 g DW. VB₂ is a component of many important coenzymes in the body. These enzymes can transfer hydrogen in the process of substance metabolism, promote growth and development, and protect the health of eyes and skin. VB₂ content ranged from 3.7 (Ningcai) to 4.69 (Guangcai5) mg/100 g DW. VB₂ can be converted into nicotinamide and participate in lipid metabolism, oxidation of tissue respiration, and anaerobic decomposition of carbohydrates. VB₃ content has no significant difference among different cultivars. VC is important in wound healing and in the prevention of scurvy, and it is an antioxidant that minimizes oxidative stress (Lee et al., 2013). VC content ranged from 10.78 (Shulv1) to 152.95 (Zhecai726) mg/100 g DW. VE content ranged from 4.33 to 8.75 mg/100 g DW. The function of vitamin E is related to the immune system. The folic acid content ranged from 5.29 to 56.84 μg/100 g DW and β-carotene content ranged from 47.92 to 119.23 mg/100 g DW. Additionally, β-carotene is a...
The AAS results were calculated according to the WHO/FAO/UNO (2007) adult essential amino acid requirement pattern.

Abbreviations: EAA, essential and semi-essential amino acid; NEAA, nonessential amino acid; TAA, total amino acid content.

Note: (SD) n ≥ 2.

### TABLE 3

Amino acid composition of leaves from 13 sweet potato cultivars (g/100 g DW)

| Cultivar   | Guangcai2 | Guangcai5 | Ecai1 | Ecai10 | Zhecai1 | Zhecai726 | Fu18 | Fu22 | Fu23 | Tainong71 | Shulv1 | Pushu53 | Ningcai |
|------------|-----------|-----------|-------|--------|---------|------------|------|------|------|-----------|--------|---------|---------|
| AASa       | 0.37      | 0.39      | 0.38  | 0.38   | 0.38    | 0.38       | 0.37 | 0.37 | 0.37 | 0.38      | 0.38   | 0.37    | 0.39    |
| EAA        | 6.73 ± 0.01 | 6.65 ± 0.22 | 6.89 ± 0.37 | 6.58 ± 0.15 | 6.60 ± 0.35 | 6.72 ± 0.23 | 6.67 ± 0.16 | 6.6 ± 0.30 | 6.29 ± 0.15 | 6.87 ± 0.18 | 7.26 ± 0.02 | 6.15 ± 0.15 | 6.45 ± 0.30 |
| NEAA       | 26.09     | 28.57     | 25.28 | 25.85   | 28.62   | 27.20       | 32.58 | 2.33 ± 0.04 | 2.2 ± 0.13 | 2.47 ± 0.04 | 2.29 ± 0.03 | 2.69 ± 0.01 | 1.99 ± 0.05 | 2.10 ± 0.09 |

### FIGURE 1

The weighted gray relational grades (WGRG) heat map of leaves from 13 sweet potato cultivars.
3.4 | Amino acid composition and evaluation

The AAS information of 13 sweet potato leaves is shown in Table 3. The first limiting amino acid of all samples was methionine + cysteine, which is the same results with the study of seaweeds from the Magellan Straits (Astorga-españa, Rodríguez-galdón, Rodríguez-rodríguez, & Díaz-romero, 2016). The total amino acids (TAA) include essential and semi-essential amino acid (EAA) and nonessential amino acid (NEAA). Shulv1 exhibited the highest TAA content of 19.23 g/100 g DW. The nutrition value of sweet potato leave protein was further evaluated by the AAS. Ningcai had the highest AAS of 7.26 g/100 g DW. The nutrition value of sweet potato leaf protein was further evaluated by the AAS. Ningcai may possess a good protein quantity.

3.5 | Comprehensive nutritional value

The content of one specific nutrient is not indicative of overall quality. Therefore, it is important to perform a comprehensive nutritional analysis. In this study, gray relational analysis was performed to assess the comprehensive nutritional value of 13 different cultivars (Table S1). The results revealed that varieties significantly affected nutritional values. The heat map (Figure 1) reflected the influence of every factor on the final results and explained the differences among the results. Tainong71 possessed the largest number of green parts, which represented the closeness to the ideal cultivar. Meanwhile, the heat maps for Zhecai1 showed more red and yellow parts, indicating that they had the lowest rankings. The rankings of all of the cultivars are shown in Table S2. In decreasing order of gray relational grade values was Tainong71 (0.8492) > Fu22 (0.8217) > Ningcai (0.8047) > Fu23 (0.8044) > Ecai10 (0.7903) > Zhecai726 (0.7880) > Ecai1 (0.7854) > Fu18 (0.7800) > Pushu53 (0.7787) > Guangcai5 (0.7786) > Shulv1 (0.7658) > Guangcai2 (0.7625) > Zhecai1 (0.7606). The results indicate that Tainong71 is the most approach to the ideal variety, followed by Fu22 and Ningcai. GRA has been recognized as comprehensive and less limited by factors, reasonable and natural, and can be processed by computer technology. It avoids the disadvantage that the previous evaluation only considers crude protein, crude fat, and crude fiber while ignoring other factors, so the evaluation results are more objective and accurate.

3.6 | Sunscreen activity

The Sun Protection Factor (SPF) value with different concentration of sweet potato ethanol extract was shown in Table 4. Different concentrations of ascorbic acid were taken as positive control. The SPF value was increased gradually with the increase of concentration. The variety with highest SPF is Pushu53, followed by Guangcai5 whereas the lowest was Shulv1. There were significant differences (p < .05) in SPF among different sweet potato cultivars, which was probably attributed to differences in genotype and other composition in sweet potato leaves. The maximum SPF of the sweet potato leaf ethanol extract we measured was 24.65 (Pushu53), while it was observed that the SPF values of topical applications were validated up to 30 SPF (Prakash et al., 2015).

SPF is a standard for quantitatively measuring the effectiveness of sunscreen which is faster and simpler than human body method. At present, chemical sunscreen agents such as methoxy cinnamate

### Table 4 SPF of sweet potato leaf extract with different concentrations (μg/ml)

| Cultivars | 100 | 200 | 300 | 400 | 500 | 600 | 700 |
|----------|-----|-----|-----|-----|-----|-----|-----|
| Guangcai | 0.43 ± 0.001d | 2.2 ± 0.001g | 2.52 ± 0h | 3.63 ± 0.003h | 4.83 ± 0.018i | 6.14 ± 0.001g | 6.72 ± 0.003h | 8.87 ± 0.002h |
| Guangcai5 | 0.5 ± 0.003h | 3.06 ± 0.006l | 4.26 ± 0.038l | 6.06 ± 0.001m | 8.37 ± 0.001m | 10.71 ± 0.122l | 13.26 ± 0.001l | 22.47 ± 0.004m |
| Ecai1 | 0.44 ± 0.001d | 2.55 ± 0.002b | 3.28 ± 0.01c | 4.65 ± 0.001d | 6.21 ± 0.004d | 9.29 ± 0.006d | 10 ± 0.006d | 13.06 ± 0.003d |
| Ecai10 | 0.35 ± 0.007b | 1.78 ± 0.002d | 1.39 ± 0.007d | 1.95 ± 0.006e | 2.51 ± 0.002e | 3.38 ± 0.007d | 3.43 ± 0.002e | 4.38 ± 0.007e |
| Zhecai1 | 0.41 ± 0.004c | 1.95 ± 0.006g | 1.94 ± 0.008k | 3.85 ± 0.002k | 3.61 ± 0.002k | 4.82 ± 0.003k | 5.21 ± 0.003j | 6.6 ± 0.004l |
| Zhecai726 | 0.36 ± 0.003b | 1.76 ± 0.004f | 1.43 ± 0.002f | 2.06 ± 0.002i | 2.61 ± 0.006h | 3.39 ± 0.002h | 3.61 ± 0.005h | 4.59 ± 0.001i |
| Fu18 | 0.45 ± 0.003e | 1.85 ± 0.004j | 1.88 ± 0.003j | 2.67 ± 0.018k | 3.3 ± 0.006k | 4.43 ± 0.005j | 4.83 ± 0.002k | 6.3 ± 0.109k |
| Fu22 | 0.49 ± 0.003g | 2.55 ± 0.002c | 3.54 ± 0.002b | 5.89 ± 0.000c | 6.39 ± 0.002c | 10.33 ± 0.007c | 9.83 ± 0.125c | 13.86 ± 0.007c |
| Fu23 | 0.44 ± 0.007d | 2.05 ± 0.004e | 2.31 ± 0.003e | 3.87 ± 0.006f | 4.71 ± 0.002f | 6.52 ± 0.007e | 6.76 ± 0.003f | 8.99 ± 0.002f |
| Tainong71 | 0.46 ± 0.002f | 2.27 ± 0.001h | 2.42 ± 0.003g | 3.54 ± 0.002g | 4.38 ± 0.001g | 5.86 ± 0.005f | 6.33 ± 0.02g | 8.31 ± 0g |
| Shulv1 | 0.34 ± 0.007d | 1.58 ± 0.003d | 1.37 ± 0.007b | 1.92 ± 0.006d | 2.46 ± 0.002b | 3.15 ± 0.003b | 3.24 ± 0.007b | 4.26 ± 0.006b |
| Pushu53 | 0.5 ± 0.002f | 2.96 ± 0.003k | 4.44 ± 0.006m | 6.55 ± 0.007n | 8.61 ± 0.002n | 11.54 ± 0.191m | 14.06 ± 0.002m | 24.65 ± 0.006n |
| Ningcai | 0.45 ± 0.001f | 2.33 ± 0.007i | 2.57 ± 0.003i | 3.91 ± 0.002j | 5.29 ± 0.002j | 7.08 ± 0.002i | 7.39 ± 0.003i | 9.95 ± 0.005j |
| Ascorbic acid | 0.44 ± 0.002e | 1.53 ± 0.004a | 0.73 ± 0.039a | 0.7 ± 0.005a | 0.73 ± 0.002a | 0.98 ± 0.007a | 0.86 ± 0.007a | 0.93 ± 0.002a |

Note: Data are means ± SD (n ≥ 2). Values within columns with different letters are significantly different (p < .05).
ethyl hexyl ester, butyl methoxy dibenzoyl methane are commonly used in cosmetics. However, these sunscreen agents may induce photosensitization (Collaris & Frank, 2008). Therefore, sweet potato leaves have potential to become urgently needed natural plant sunscreen agents.

### 3.7 Antioxidant activity

Antioxidant activity was determined by the FRAP method, and the results are shown in Table 2. Pushu53 had the highest antioxidant activity (16.44 ± 0.73 g TE/g DW), whereas Zhecai726 had the lowest antioxidant activity (3.94 ± 1.05 g TE/g DW). The antioxidant usually considered to be attributed to different TPC, polyphenol types, and nutrient composition, which maybe has synergistic or antagonistic effects on the antioxidant activity.

The correlations between SPF at 300 μg/ml and antioxidant activity, TPC, crude protein content, and crude fiber content are shown in Figure 2. The correlation coefficient between antioxidant activity and SPF of sweet potato leaves ($r = .737; p = .004$) was highest. Followed by is the correlation coefficient between TPC and SPF ($r = .348; p = .243$). There were negative correlation coefficients between SPF and crude protein ($r = -.687, p = .010$); then, the correlation coefficient between ash content and SPF is ($r = -.572; p = .041$). UV radiation can stimulate the activity of oxidase, damage the role of antioxidants, and lead to oxidative stress (Gęgotek, Ambrożewicz, Jastrząb, Jarocka-Karpowicz, & Skrzydlewska, 2019), so the varieties with strong sunscreen activity will also be accompanied by high antioxidant capacity. It has also been reported that there is a negative correlation between antioxidant capacity and protein content (Liu et al., 2017), which may contribute to the negative correlation between SPF and protein content. Therefore, antioxidant activity is considered to be the most important in resisting ultraviolet in sweet potato leaves. Because of their diversity and wide distribution, so may be many natural antioxidants exist in sweet potato leaves, which play significant roles in the organoleptic and nutritional qualities of fruits and vegetables.

### 4 CONCLUSION

There were significant differences in proximate composition among the sweet potato cultivars. GRA reveals that the best variety of comprehensive nutritional quality is Tainong71, followed by Fu22. Sweet potato leaves have good sunscreen activity. Antioxidant activity is the most important factor associated with SPF. In conclusion, sweet potato leaves which contain abundant nutrients and bioactive compounds should be consumed as leafy vegetables in an attempt to supplement nutrition and have big potential to become a new natural plant sunscreen agent.

**CONFLICT OF INTEREST**

The authors have no conflicts of interest to declare.

**ORCID**

Taihua Mu [https://orcid.org/0000-0002-1308-0121](https://orcid.org/0000-0002-1308-0121)

**REFERENCES**

Afaq, F., & Katiyar, S. K. (2012). Polyphenols: Skin photoprotection and inhibition of photocarcinogenesis. *Mini Reviews in Medicinal
Sun, H., Mu, T., Xi, L., Zhang, M., & Chen, J. (2014). Sweet potato (Ipomoea batatas L.) leaves as nutritional and functional foods. Food Chemistry, 156, 380–389. https://doi.org/10.1016/j.foodchem.2014.01.079

Wang, R., & Farid, M. M. (2015). Corrosion and health aspects in ohmic cooking of beef meat patties. Journal of Food Engineering, 146, 17–22. https://doi.org/10.1016/j.jfoodeng.2014.08.011

How to cite this article: Hong J, Mu T, Sun H, Richel A, Blecker C. Valorization of the green waste parts from sweet potato (Ipomoea batatas L.): Nutritional, phytochemical composition, and bioactivity evaluation. Food Sci Nutr. 2020;8:4086–4097. https://doi.org/10.1002/fsn3.1675