scientific reports

Check for updates

OPEN

Comprehensive evaluation on nutritional characteristics and anti-hyperglycemic active ingredients of different varieties of Yam

Yuzheng Lin[1,2], Li Qiu[1], Mengting Zhang[1], Chenjun Zhang[1], Yiyin Qin[1], Honghong Yu[1], Qiaoli Lin[1] & Li Ge[1]✉

Yam is a versatile economic crop that serves both medicinal and dietary purposes. Dehua County, located in Fujian Province, China, is renowned as one of the major yam production areas, with a cultivation history spanning over 600 years. It has successfully cultivated Qingfeng yam and Ziyu yam, both of which have been recognized with China's "Geographical Indications for Agricultural Products." However, no comprehensive studies have been conducted to evaluate their quality. This study meticulously utilized the authentic medicinal material "Iron yam" as a benchmark, employing advanced techniques such as high-performance liquid chromatography (HPLC), ultraviolet spectrophotometry, and flame atomic absorption spectrometry to systematically analyze the nutritional and hypoglycemic active components of three distinct yam varieties. In order to interpret the data, descriptive statistics, correlation analysis, principal component analysis (PCA), partial least squares discriminant analysis (PLS-DA), cluster analysis and multiple linear regression analysis were systematically applied. The results revealed significant variations in the concentrations of various indicators across the three yam types. Correlation analysis identified 65 pairs of indicators with exceptionally strong correlations and 39 pairs with statistically significant associations. Additionally, the principal component analysis demonstrated that Iron yam exhibited the most favorable overall quality. Notably, Ziyu yam, characterized by its high concentration of hypoglycemic active compounds, emerged as a promising raw material for the production of hypoglycemic products, showcasing significant potential in this field.

Keywords Chinese Yam, Nutrient content, Hypoglycemic active compounds, Quality evaluation

Yam, a member of the Dioscorea family, is an economic crop with significant edible and medicinal value. Its cultivation in China dates back over 3,000 years, with major production areas including Henan, Fujian, Hebei, and other regions[1]. The earliest record of yam appears in the "Shen Nong's Herbal Classic"[2]. In this book, yam is classified as a top-grade herb with properties described as being able to "nourish deficiencies, eliminate cold and heat pathogens, fortify qi, nourish the spleen and stomach, promote muscle growth, and enhance hearing and vision with long-term use". Modern research has identified a variety of nutrients and bioactive components in yam, including steroidal saponins, polysaccharides, amino acids, trace elements, and polyphenols. These components have been shown to exhibit diverse biological activities, such as antioxidant, anti-inflammatory, analgesic, hypoglycemic, and immunomodulatory effects[3]. Due to its exceptional nutritional value and health benefits, yam has garnered increasing attention in recent years[4].

Recent research has revealed significant disparities in the nutritional and hypoglycemic active components among various yam varieties[5,6]. Zhang Wujun analyzed the levels of anthocyanins, polysaccharides, allantoin, and other components in 17 purple yam samples collected from Fujian Province and neighboring regions[5]. The study found that Ziyu yam from Dehua County, Fujian Province, exhibited particularly high concentrations of starch, polysaccharides, and anthocyanins. Liu Ying et al. conducted a comparative analysis of the active components in Anshun yam and Iron yam, demonstrating that Iron yam contained higher levels of bioactive components, including diosgenin, allantoin, and polysaccharides[6].

[1]School of Nursing, Fujian University of Traditional Chinese Medicine, Fuzhou, Fujian Province, China. [2]Fujian Province Maternity and Child Health Hospital, Fuzhou, Fujian Province, China. ✉email: 2000005@fjtcm.edu.cn

In addition to hypoglycemic active components, minerals, amino acids, and proteins are also critical in assessing the hypoglycemic properties of yam.Mg are integral components of enzymes involved in the glucose oxidation pathway and contribute to glucose transport mechanisms[7].Proteins influence starch gelatinization and viscosity, thereby indirectly modulating blood glucose levels[4].Amino acids, including arginine and proline, can directly regulate insulin secretion and glucose metabolism[8].Therefore, a comprehensive analysis of yam's nutritional components can offer a more holistic understanding of the hypoglycemic potential across different yam varieties.

Dehua County, located in Fujian Province, benefits from an abundance of light and heat, adequate water resources, cool summers, and significant diurnal temperature variations. Its sandy loam exhibits excellent permeability, making the region highly suitable for the cultivation of root and tuber crops, including Chinese yam. With over 600 years of Chinese yam planting history, Dehua has established itself as a prominent cultivation area. The Dehua Yingshan Precious Chinese Yam Farmer's Cooperative, in collaboration with the Fujian Academy of Agricultural Sciences, has developed two distinct Chinese yam varieties, Qinfeng yam[9] and Ziyu yam[10], through systematic selection methods based on high-quality local germplasm. These varieties are characterized by high yields, large underground tubers, broad adaptability, strong stress resistance, and excellent taste and flavor. They are also well-suited for quick-freezing processing. Despite these advancements, no studies have been conducted to evaluate their nutritional profiles and hypoglycemic active components.

Iron yam, a specialty of Jiaozuo, Henan Province, holds a geographical indication for Chinese agricultural products and is recognized as a genuine medicinal material in the *Chinese Pharmacopoeia*. Therefore, using the locally produced Iron yam from Henan as a control, we comprehensively applied methods such as high-performance liquid chromatography (HPLC), ultraviolet spectrophotometry, and flame atomic absorption spectrometry to determine the contents of nutritional components and hypoglycemic active compounds in Qinfeng yam, Ziyu yam, and Iron yam. And thus, a comprehensive analysis and evaluation of the yam quality were conducted in the study. This comprehensive evaluation offered a scientific foundation for the further breeding, deep processing, and utilization of Chinese yam.

Results

Nutrient content

As shown in Table 1, there were highly significant differences ($P<0.01$) in the content of total carbohydrates, crude polysaccharides, proteins, ash, energy, moisture, lipid, total amino acids, and individual amino acids, including phenylalanine, alanine, proline, glycine, glutamic acid, arginine, lysine, tyrosine, leucine, serine, threonine, aspartic acid, isoleucine, histidine, and valine, among the three types of Chinese yam. The nutrient composition ratio across the three varieties ranges from 0.04 to 84.18%, with total carbohydrates being the most abundant, followed by crude polysaccharides, proteins, and other components. The energy content varied

Nutritional	Qinfeng Yam	Iron Yam	Ziyu Yam	F	*P*
Total carbohydrate	83.72 ± 0.19	73.32 ± 0.34[a]	84.18 ± 0.41[ab]	2116.47	0.001
Crude polysaccharides	18.38 ± 0.02	17.34 ± 0.01[a]	62.97 ± 0.07[ab]	2333510.39	0.001
Protein	7.52 ± 0.02	10.43 ± 0.18[a]	3.44 ± 0.03[ab]	6972.54	0.001
Ash	3.18 ± 0.08	3.78 ± 0.08[a]	2.27 ± 0.12[ab]	403.91	0.001
Energy(KJ/100 g)	1556.83 ± 11.74	1430.17 ± 3.37[a]	1489.17 ± 7.60[ab]	349.51	0.001
Moisture	5.33 ± 0.04	12.23 ± 0.08[a]	10.28 ± 0.31[ab]	2225.81	0.001
Lipid	0.10 ± 0.00	0.20 ± 0.00[a]	0.10 ± 0.00[b]	6.19 × 1023	0.001
Total amino acids	5.94 ± 0.04	7.17 ± 0.04[a]	1.92 ± 0.01[ab]	41175.98	0.001
Phenylalanine	0.35 ± 0.02	0.35 ± 0.02	0.14 ± 0.00[ab]	269.70	0.001
Alanine	0.27 ± 0.02	0.51 ± 0.02[a]	0.12 ± 0.00[ab]	994.68	0.001
Proline	0.29 ± 0.03	0.28 ± 0.02	0.05 ± 0.00[ab]	303.36	0.001
Glycine	0.18 ± 0.01	0.26 ± 0.01[a]	0.07 ± 0.00[ab]	480.40	0.001
Glutamic acid	1.11 ± 0.03	1.25 ± 0.02[a]	0.35 ± 0.01[ab]	3594.06	0.001
Arginine	0.74 ± 0.04	0.92 ± 0.02[a]	0.17 ± 0.00[ab]	1580.88	0.001
Lysine	0.29 ± 0.03	0.32 ± 0.03	0.10 ± 0.00[ab]	145.52	0.001
Tyrosine	0.26 ± 0.03	0.27 ± 0.02	0.08 ± 0.00[ab]	181.04	0.001
Leucine	0.42 ± 0.01	0.40 ± 0.02	0.04 ± 0.[00ab]	1279.55	0.001
Serine	0.42 ± 0.03	0.82 ± 0.03[a]	0.19 ± 0.00[ab]	1113.55	0.001
Threonine	0.24 ± 0.02	0.30 ± 0.02[a]	0.11 ± 0.00[ab]	249.22	0.001
Aspartic acid	0.77 ± 0.03	0.82 ± 0.03[a]	0.28 ± 0.00[ab]	932.39	0.001
Isoleucine	0.20 ± 0.01	0.22 ± 0.02	0.06 ± 0.00[ab]	303.71	0.001
Histidine	0.12 ± 0.02	0.15 ± 0.02[a]	0.04 ± 0.00a[b]	70.41	0.001
Valine	0.25 ± 0.02	0.31 ± 0.03[a]	0.10 ± 0.00[ab]	169.79	0.001

Table 1. Routine nutritional composition in the Yams (g/100 g). [a]Compared with Qinfeng yam $p<0.05$. [b]Compare with Iron yam $p<0.05$.

Mineral	Qinfeng Yam	Iron Yam	Ziyu Yam	F	*P*
Ca	207.67 ± 0.82	744.67 ± 3.98[a]	498.33 ± 5.430[ab]	28274.10	0.001
Mg	247.00 ± 2.61	221.67 ± 3.33[a]	151.67 ± 4.08[ab]	1270.97	0.001
K	157.800 ± 41.10	173.98 ± 0.29	19.47 ± 0.48[ab]	76.82	0.001
Fe	12.23 ± 0.19	14.43 ± 0.16[a]	26.33 ± 0.23[ab]	8929.14	0.001
P	10.60 ± 0.09	15.38 ± 0.08[a]	7.87 ± 0.03[ab]	17702.86	0.001
Mn	8.27 ± 0.03	6.75 ± 0.03[a]	4.08 ± 0.03[ab]	32711.38	0.001
Zn	14.28 ± 0.44	13.22 ± 0.15[a]	0.00 ± 0.00[ab]	5195.27	0.001
Cu	2.34 ± 0.03	6.29 ± 0.03[a]	0.90 ± 0.00[ab]	75472.64	0.001
Na	0.89 ± 0.00	4.52 ± 0.06[a]	0.56 ± 0.00[ab]	21065.79	0.001
Se	0.08 ± 0.12	0.03 ± 0.00	0.00 ± 0.00[b]	2.32	0.133

Table 2. The mineral content of the Yams (mg/kg). [a]Compared with Qinfeng yam $p<0.05$. [b]Compare with Iron yam $p<0.05$.

Vitamin	Qinfeng Yam	Iron Yam	Ziyu Yam	F	*P*
Vitamin B_1	0.18 ± 0.00	0.14 ± 0.01[a]	0.00 ± 0.00[ab]	2406.68	0.001
Vitamin C	0.00 ± 0.00	0.00 ± 0.00	2.05 ± 0.02[ab]	85132.64	0.001

Table 3. Vitamin content of the Yams (mg/100 g). [a]Compared with Qinfeng yam $p<0.05$. [b]Compare with Iron yam $p<0.05$.

Hypoglycemic active compounds	Qinfeng Yam	Iron Yam	Ziyu Yam	F	*P*
Yam polysaccharides	130.23 ± 27.38	66.10 ± 13.23[a]	137.09 ± 83.58	3.49	0.057
Allantoin	4.22 ± 0.54	5.97 ± 1.83[a]	3.39 ± 0.26[b]	8.39	0.004
Flavonoids	0.23 ± 0.04	0.55 ± 0.13[a]	0.61 ± 0.06[a]	33.12	0.001
Diosgenin	0.21 ± 0.07	0.43 ± 0.18[a]	0.21 ± 0.07[b]	7.13	0.007
Anthocyanin (mg/kg)	3.308 ± 0.50	12.45 ± 0.14[a]	211.50 ± 3.51[ab]	17156.75	0.001

Table 4. The content of the hypoglycemic active compounds of the Yams (mg/g). [a]Compared with Qinfeng yam $p<0.05$. [b]Compare with Iron yam $p<0.05$.

between 1430.17 kJ/100 g and 1556.83 kJ/100 g. Among the three varieties of Chinese yam, Iron yam exhibited the highest moisture, total amino acid, and protein content, while Qinfeng yam demonstrated the highest energy content. Ziyu yam standed out for having the highest levels of total carbohydrates and crude polysaccharides.

As shown in Table 2, there were highly significant differences ($P<0.01$) in the content of calcium(Ca), sodium(Na), potassium(K), magnesium(Mg), Manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and phosphorus(P) among the three types of Chinese yam. The mineral content across the three types of Chinese yam ranges from 0.00 to 744.67 mg/kg, with Ca being the most abundant, followed by Mg, K, and other minerals. Among the three varieties of Chinese yam, Iron yam contained the highest levels of Ca, K, and P, Qinfeng yam contained the highest levels of Mg and Zn, and Ziyu yam contained the highest Fe content.

As shown in Table 3, in this study, four indicators of vitamins were measured: Vitamin B1, Vitamin C, Vitamin A, and Vitamin D. Among them, Vitamin A and Vitamin D were not detected. There were extremely significant differences ($P<0.01$) in the content of Vitamin B1 and Vitamin C among the three types of Chinese yam. Specifically, Qinfeng yam and Iron yam contained Vitamin B1, while Ziyu yam contained Vitamin C.

Content of hypoglycemic active components

As shown in Table 4, there were highly significant differences ($P<0.01$) in the content of allantoin, flavonoids, diosgenin, and anthocyanins among the three types of Chinese yam. The content of hypoglycemic active components in the three types of Chinese yam ranges from 12.45 mg/kg to 137.09 mg/g. Among the hypoglycemic active components of the three types of Chinese yam, Ziyu yam contained higher levels of yam polysaccharides, flavonoids, and anthocyanins compared to Iron yam, but lower levels of allantoin and diosgenin. Qinfeng yam contained higher levels of yam polysaccharides and anthocyanins compared to Iron yam, but lower levels of flavonoids, allantoin, and diosgenin. These differences were statistically significant ($P<0.01$).

Correlation of hypoglycaemic active components and nutrient components

To further investigate the relationship between the hypoglycemic active components and nutritional components in the Chinese yams, a correlation analysis was performed. The results revealed the following key findings: polysaccharides showed a positive correlation with total carbohydrate content and a negative correlation with

alanine, glycine, serine, protein, P,Na, Cu, ash, and lipid. Flavonoid content was positively correlated with Ca, Fe, Vitamin C, moisture, and crude polysaccharide content, while it was negatively correlated with phenylalanine, proline, leucine, K, Mg, and others. Allantoin content exhibited a significant positive correlation with amino acids, protein, K, P, Na, Cu, ash, and lipid, but it was negatively correlated with Vitamin C, total carbohydrates, crude polysaccharides, and energy. Diosgenin content was significantly positively correlated with alanine, serine, P, Ca, Na, Cu, and lipid, while it was negatively correlated with total carbohydrates and energy. Anthocyanins were significantly positively correlated with Fe, Vitamin C, total carbohydrates, and crude polysaccharides, but were negatively correlated with total amino acids, phenylalanine, protein, K, and P, etc. (*As shown in* Table 5)

Correlation analysis (see Supplementary Figure: S1) revealed that nutritional indicators such as Ca, Na, Cu, and moisture exhibited positive correlations with each other, as well as with flavonoids, allantoin, diosgenin, ash, and lipid content. Conversely, these elements showed negative correlations with polysaccharides, total carbohydrates, and energy levels. Ash content demonstrated a negative correlation with polysaccharides, flavonoids, total carbohydrates, and energy. Lipid content was negatively correlated with polysaccharides, total carbohydrates, and energy. Total carbohydrates and energy levels were positively correlated with each other, as well as with polysaccharides.

Nutritional quality evaluation by principal component analysis

Principal component analysis was used to analyze 41 indicators. Following KMO and Bartlett's tests, it was determined that 12 indices, including diosgenin, allantoin, polysaccharides, flavonoids, Ca, Na, Cu, moisture, ash, total carbohydrates, lipid, and energy, satisfied the criteria for factor analysis (KMO = 0.740, $p < 0.01$).

Compounds	Yam polysaccharide	Flavonoid	Allantoin	Diosgenin	Anthocyanin
Total amino acids	−0.419	−0.400	0.641**	0.468*	−0.991**
Phenylalanine	−0.272	−0.570*	0.465	0.283	−0.978**
Alanine	−0.539*	−0.024	0.722**	0.631**	−0.843**
Proline	−0.296	−0.632**	0.554*	0.308	−0.976**
Glycine	−0.490*	−0.246	0.676**	0.570*	−0.940**
Glutamic acid	−0.379	−0.459	0.610**	0.42	−0.998**
Arginine	−0.426	−0.402	0.652**	0.470*	−0.989**
Lysine	−0.374	−0.536*	0.635**	0.415	−0.974**
Tyrosine	−0.348	−0.539*	0.517*	0.332	−0.978**
Leucine	−0.305	−0.617**	0.549*	0.326	−0.987**
Serine	−0.537*	−0.008	0.711**	0.668**	−0.838**
Threonine	−0.456	−0.321	0.650**	0.487*	−0.961**
Aspartic acid	−0.355	−0.497*	0.576*	0.376	−0.996**
Isoleucine	−0.36	−0.501*	0.563*	0.399	−0.988**
Histidine	−0.436	−0.298	0.619**	0.447	−0.930**
Valine	−0.421	−0.309	0.650**	0.488*	−0.959**
Protein	−0.486*	−0.217	0.683**	0.563*	−0.944**
Ca	−0.436	0.732**	0.454	0.592**	−0.047
K	−0.341	−0.490*	0.551*	0.419	−0.954**
P	−0.545*	−0.003	0.732**	0.651**	−0.833**
Mg	−0.229	−0.740**	0.388	0.175	−0.935**
Mn	−0.131	−0.784**	0.335	0.095	−0.895**
Na	−0.565*	0.257	0.702**	0.694**	−0.637**
Fe	0.264	0.669**	−0.468	−0.252	0.971**
Cu	−0.556*	0.092	0.724**	0.673**	−0.770**
Se	0.048	−0.474*	0.036	0.054	−0.335
Zn	−0.297	−0.613**	0.518*	0.3	−0.986**
Vitamin B	−0.214	−0.721**	0.42	0.197	−0.946**
Vitamin C	0.323	0.569*	−0.543*	−0.34	0.995**
Moisture	−0.396	0.813**	0.337	0.510*	0.151
Ash	−0.495*	−0.234	0.670**	0.547*	−0.943**
Lipid	−0.561*	0.322	0.690**	0.698**	−0.579*
Total carbohydrate	0.545*	−0.286	−0.699**	−0.697**	0.608**
Crude polysaccharides	0.333	0.555*	−0.552*	−0.351	0.997**
Energy	0.428	−0.715**	−0.491*	−0.587*	0.054

Table 5. The nutritional indicators of the Yams by correlation analysis. *Significant correlation at 0.05 level. **Highly significant correlation at 0.01 level.

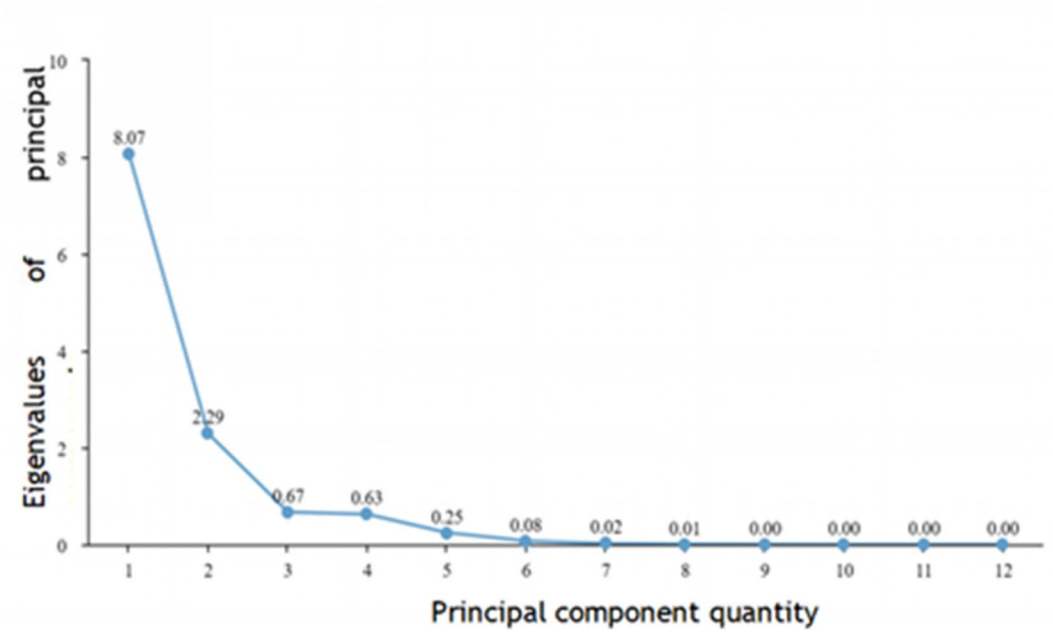

Fig. 1. Scree plot of eigenvalues for principal component analysis in the yams.

	PC1	PC2
Yam polysaccharides	−0.600	0.208
Flavonoids	0.414	0.869
Allantoin	0.722	−0.392
Diosgenin	0.767	−0.113
Ca	0.886	0.452
Na	0.973	−0.157
Cu	0.923	−0.332
Moisture	0.784	0.603
Ash	0.719	−0.639
Lipid	0.985	−0.086
Energy	−0.885	−0.434
Total carbohydrate	−0.977	0.122
Eigenvalue	8.066	2.288
Contribution ratio(%)	67.200	19.100
Cumulative contribution ratio(%)	67.200	86.300

Table 6. Factor loading, eigenvalue, and contribution ratio of the two principal components in the Yams.

Based on eigenvalue analysis and the scree plot (Fig. 1), two principal components were extracted in this study, accounting for a cumulative variance contribution rate of 86.300%, which encapsulated the majority of the information regarding yam composition. The eigenvalues of the first principal component (PC1) and the second principal component (PC2) were 8.066 and 2.288 respectively, and the variance contribution rates were 67.200% and 19.100%, respectively. The cumulative variance contribution rate of the two components was 86.300%. The first principal component primarily encompassed nutrients such as Na, Cu, lipid, and carbohydrates, with loading coefficients of 0.973, 0.923, 0.985, and −0.977, respectively. Therefore, the first component is referred to as the nutritional component factor, reflecting contribution ratio 67.200% of the original information.The second component was primarily flavonoid, with a load coefficient of 0.869. Hence, the second component is referred to as the hypoglycemic active component factor, reflecting contribution ratio 19.100% of the original indicator information (as shown in Table 6).

From Fig. 2, the correlation between each yam variety and PC1 and PC2 can be seen intuitively. Iron yam falls in the positive interval of PC1 (the first quadrant and the fourth quadrant), Qinfeng yam falls in the negative interval of PC1 (the third quadrant), and Ziyu yam falls in the negative interval of PC1 (the second quadrant), indicating that the information contained in these two principal components can effectively distinguish these three varieties. The Fig. 2 showed that the contents of Ca, Na, Cu, Moisture and Ash Lipid in Iron yam were

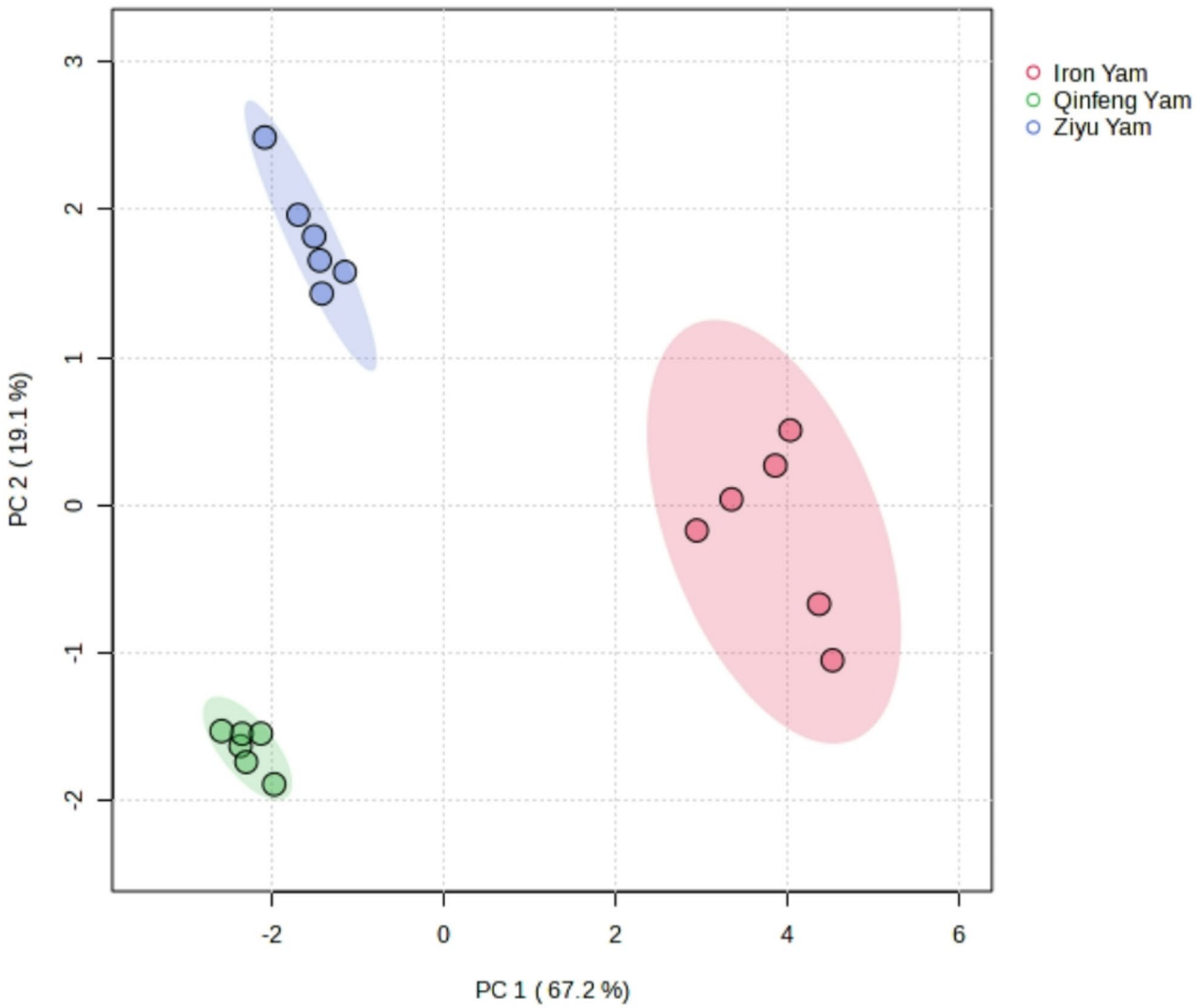

Fig. 2. Principal component analysis of PC1 and PC2 in the yams.

	Scores		Totals	Rankings
	F1	F2		
Qinfeng Yam	−2.289	−1.645	−2.134	3
Iron Yam	3.844	−0.178	2.955	1
Ziyu Yam	−1.555	1.823	−0.808	2

Table 7. Comprehensive rating and quality ranking of the Yams.

relatively high, which indicated that its nutrient content was relatively high and its quality was relatively good. The samples of Ziyu yam all fall in the positive interval of the second principal component, which indicates that it contains high Flavonoids.

Due to the varying contribution rates of different components, the impact of each factor on the quality of Chinese yam should be considered comprehensively. Using the relative variance contribution rates of the two principal components as weights, a comprehensive evaluation function for the quality of Chinese yam was constructed: $F = 0.779F1 + 0.221F2$. The comprehensive evaluation scores for the three types of yams were calculated separately (as shown in Table 7). According to the results of principal component analysis, a higher comprehensive score indicates better overall yam quality, and vice versa. The results indicated that Iron yam achieved the highest comprehensive score, followed by Ziyu yam, with Qinfeng yam receiving the lowest score. In the first principal component, Iron yam scored the highest with a positive value, while both Ziyu yam and

Qinfeng yam had negative scores. In the second principal component, Ziyu yam scored the highest with a positive value, while both Iron yam and Qinfeng yam had negative scores.

Characteristic in the three the three Yam varieties by partial least squares discriminant analysis

To visualize the data and facilitate further analysis, Partial Least Squares Discriminant Analysis (PLS-DA) was employed to assess the components of diosgenin, allantoin, polysaccharides, flavonoids, Ca, Na, Cu, moisture, ash, total carbohydrates, and lipids in the three varieties of yam. Component analysis score plots were generated to highlight the differences among the yam varieties. As shown in Fig. 3, the Iron yam samples are primarily located on the left side of Component1, Qinfeng yam samples are found on the right side of Component1 and below Component2, while Ziyu yam samples are positioned on the right side of Component1 and above Component2. The three sample groups are clearly separated along the principal component coordinate axis.

As illustrated in Fig. 4, allantoin, lipids, total carbohydrates, Na, Cu, and ash all exhibited VIP values > 1, indicating that these components significantly contributed to the differentiation among the three yam varieties. This is consistent with the results from the principal component analysis. Using five-fold cross-validation, the yam analysis scoring model achieved R2 and Q2 values of 0.8015 and 0.7030, respectively, demonstrating robust model stability and reliability, with statistically significant differences observed among the three yam varieties.

Characteristic indexes in the Yams by cluster analysis

R cluster analysis was performed on 12 indexes—polysaccharides, flavonoids, allantoin, diosgenin, Ca, Na, Cu, moisture, ash, lipids, energy, and total carbohydrates—across three yam species. The clustering results revealed strong correlations among diosgenin, lipids, flavonoids, Cu, Na, ash, allantoin, moisture, polysaccharides, and total carbohydrates, while Ca and energy exhibited distinct clustering. When the distance was set to 5, the 12 indexes of yam could be divided into two groups. The first group included polysaccharides, flavonoids, allantoin, diosgenin, Ca, Na, Cu, moisture, ash, lipids, and total carbohydrates, while the second group consisted of energy(as shown in Fig. 5). To further explore the relationships among the components, multiple linear regression analysis was conducted. The results showed that Ca, Na, Cu, moisture, ash, lipids, and total carbohydrates had multiple correlation coefficients close to 1.00, indicating strong interrelationships. The multiple correlation coefficient for flavonoids was 0.896.

Discussion

By measuring multiple indicators, such as the basic nutritional components and hypoglycemic active components of Qinfeng yam, Ziyu yam, and Iron yam, the results showed that they met the standards outlined in T/TFHT C029-2020 "Product Standard for Yam" and the "Pharmacopoeia of the People's Republic of China (2020 Edition)"[11]. In terms of nutritional content, Iron yam exhibited the highest levels of water, amino acids, and protein, with glutamic acid, arginine, and aspartic acid being the most abundant. This aligned with the findings of Ye et al.[4]. Proteins and amino acids played a crucial role in metabolism, particularly in regulating blood sugar levels[4,12,13].Beyond their effect on starch absorption, studies have shown that yam proteins also influenced starch gelatinization and viscosity, thereby affecting the formation of resistant starch and contributing

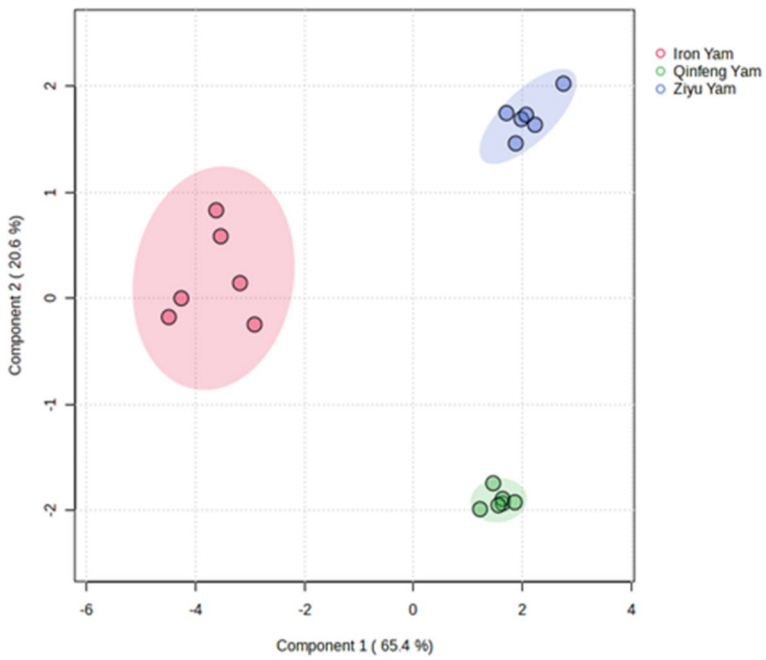

Fig. 3. Grave soil of partial least squares discriminant analysis in yams.

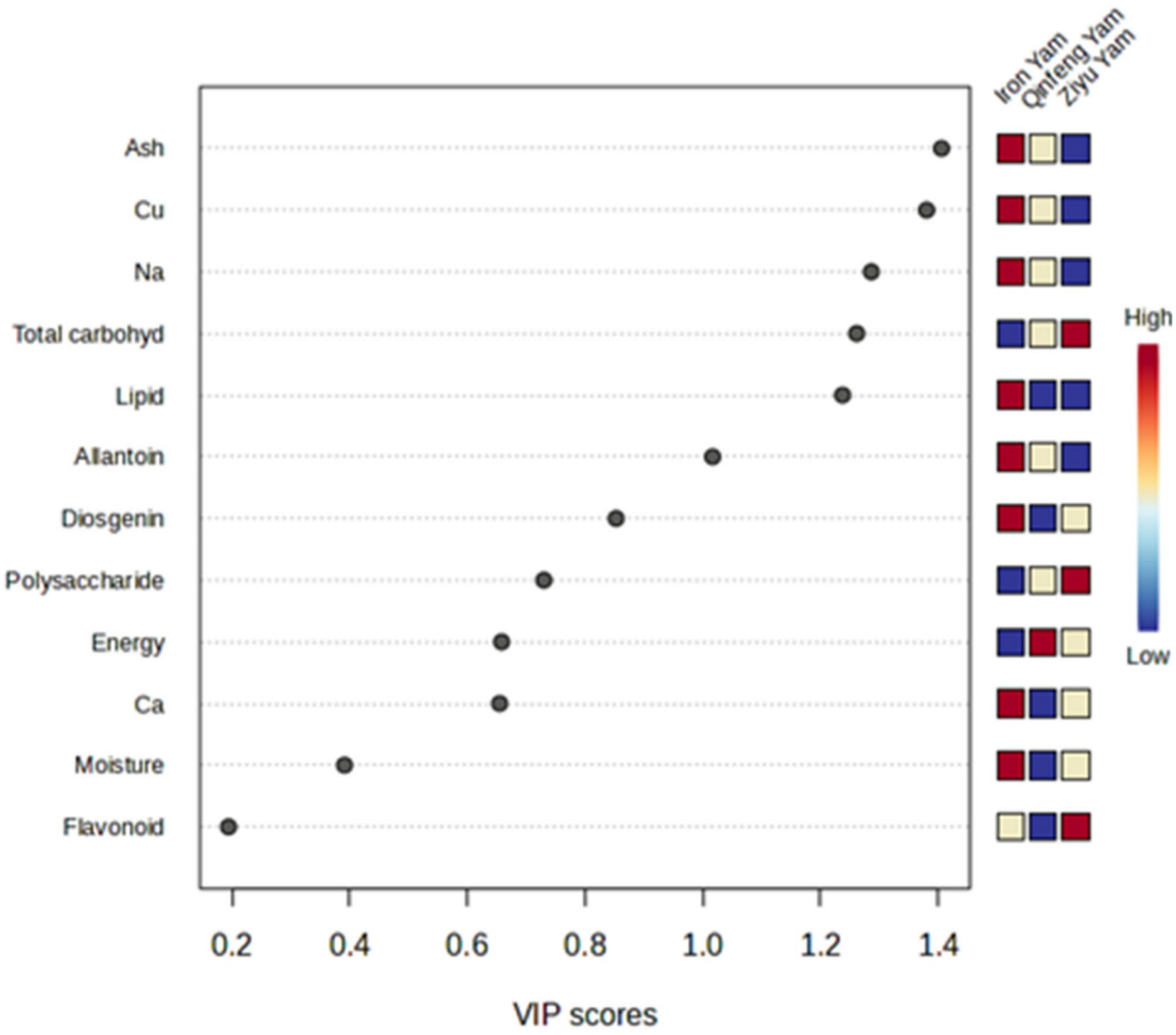

Fig. 4. Partial least squares discriminant analysis of VIP Scores in Chinese yams. (From red to blue, the three yam ingredients are from high to low).

to blood sugar regulation[4].Glutamic acid and arginine enhance insulin sensitivity and utilization, which can improve insulin resistance and regulate glucose metabolism[12,13]. The amino acid and protein content in Iron yam underscored its potential efficacy in supporting blood sugar regulation; analyzing these components can provide a comprehensive understanding of the hypoglycemic properties of various yam varieties. Additionally, Qinfeng yam had the highest energy content, while Ziyu yam boasted the highest carbohydrate and crude polysaccharide levels.

This study also observed that all three types of yam contained essential mineral elements such as P, K, Ca, Mg, Fe, and Zn, with K being the most abundant, consistent with the mineral content of yam recorded in the "China Food Composition Table"[14].The mineral substance also show that Iron yam had the highest K, Ca, and P content, Qinfeng yam had the highest Mg and Zn content, and Ziyu yam had the highest Fe content. This finding was consistent with previous studies that suggested plants exhibiting sugar-resistant properties contain essential elements such as Mg, Zn, Ca, K, and P[7,15,16].This phenomenon may be attributed to the role of these elements in sugar metabolism. Specifically, the presence of P enhances resistant starch content while reducing rapidly digestible starch, thus contributing to glycemic stability[15].The circulating micronutrient profile, including Mg, Zn, Ca, and K, plays a regulatory role in blood glucose levels and helps mitigate insulin resistance[7].Additionally, Fe influences insulin signaling pathways, which in turn modulates cellular insulin responsiveness[16].Additionally, both Qinfeng yam and Iron yam contained vitamin B1, while Ziyu yam contained vitamin C. However, the vitamin content was not high, which was also consistent with the records in the "China Food Composition Table"[14].

The hypoglycemic active components in the three varieties of yam, ranked from highest to lowest content, were yam polysaccharides > allantoin > flavonoids > diosgenin > anthocyanins, with yam polysaccharides being

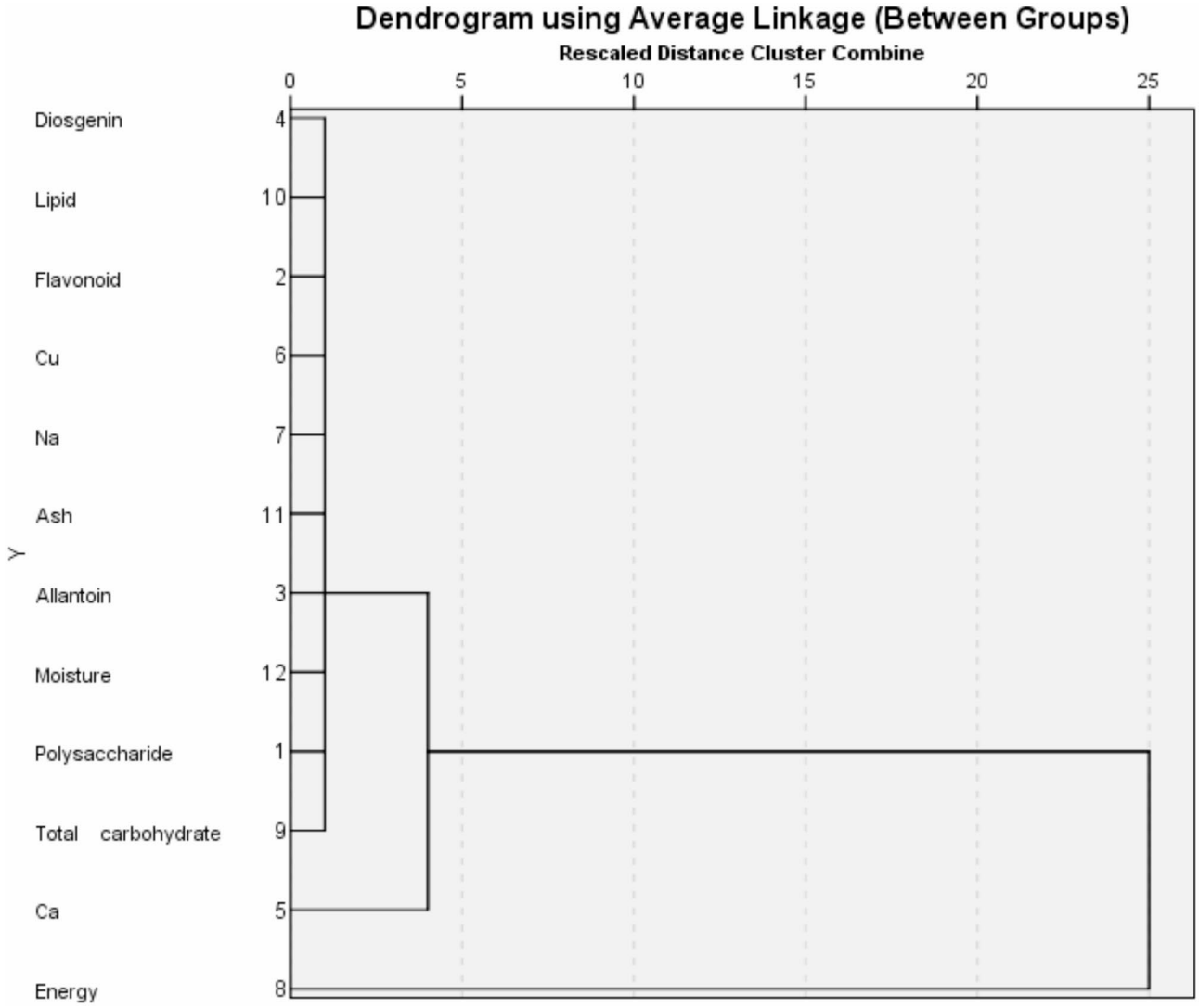

Fig. 5. Dendrogram of R-type cluster analysis of the yams.

the most abundant. This finding was similar to the findings of Zhang L et al.[3]. Studies have shown that the active components in yam exhibited significant hypoglycemic potential through multi-pathway and multi-target mechanisms[4] Firstly, yam polysaccharides can enhance the function of pancreatic β-cells and promote insulin secretion[17]. Their mechanism of action may involve the activation of the PI3K/AKT signaling pathway, a key pathway in insulin-mediated glucose metabolism, potentially by modulating the phosphorylation level of insulin receptor substrate (IRS) to improve insulin signal transduction efficiency[18]. Additionally, yam polysaccharides inhibit the activity of α-glucosidase and α-amylase, thereby delaying the breakdown and absorption of carbohydrates in the gastrointestinal tract and reducing postprandial blood glucose levels[19]. They also enhance glucose uptake and utilization in tissues, improving peripheral insulin sensitivity, especially by promoting the expression of glucose transporter protein (GLUT4) in skeletal muscle and liver[20]. Allantoin, another critical component of yam, exerts its hypoglycemic effects primarily through antioxidant and anti-inflammatory mechanisms. It significantly reduces oxidative stress in diabetic conditions by decreasing the production of reactive oxygen species (ROS) and protecting pancreatic β-cells from oxidative damage[21]. Additionally, allantoin inhibits the release of inflammatory factors such as TNF-α and IL-6, thereby improving insulin resistance[22]. Furthermore, allantoin has a protective effect on kidney function, which is crucial for preventing and managing diabetes-related nephropathy.The flavonoids in yam lower blood glucose levels by activating AMP-activated protein kinase (AMPK), a key regulatory molecule in cellular energy metabolism[23]. AMPK activation suppresses hepatic gluconeogenesis, reducing glucose production, and enhances glucose uptake in skeletal muscle cells. Flavonoids also alleviate inflammation in adipose tissue and improve lipid metabolism, thereby indirectly increasing insulin sensitivity[24].Moreover, flavonoids provide additional protection for glycemic management in diabetic patients by scavenging free radicals and reducing oxidative stress[25].Anthocyanins, important antioxidant components in yam, achieve their hypoglycemic effects primarily by reducing oxidative stress and improving the inflammatory microenvironment. Anthocyanins enhance the activity of insulin signaling

pathways, particularly in IRS and AKT pathways[26]. Furthermore, they regulate gut microbiota composition, promoting the production of short-chain fatty acids, which improve glucose metabolism[27].Anthocyanins also improve overall blood glucose homeostasis by increasing glucose uptake in the liver and muscle[28].The active components in yam has the function to improve insulin sensitivity, regulate glucose metabolism, and reduce oxidative stress and inflammation.

There was a significant correlation between the nutrient and active component contents across different yam varieties. The flavonoid content was positively correlated with Ca and moisture. This may be due to the fact that flavonoids are generally soluble in water; thus, higher water content may increase the flavonoid concentration. Additionally, the antioxidant effect of flavonoids helps maintain the stability of calciumions, and Ca can promote the accumulation of flavonoids[29]. The allantoin content was positively correlated with P, Na, and Cu, which may be related to the involvement of these elements in allantoin metabolism[30]. The anthocyanin content was positively correlated with Fe, vitamin C, and crude polysaccharides. It is likely that Fe plays an essential role in electron transport and the formation of chlorophyll and anthocyanins. Iron deficiency can disrupt photosynthesis and reduce chlorophyll and anthocyanin synthesis. Furthermore, vitamin C and anthocyanins work together in antioxidant processes, leading to a synergistic effect. Crude polysaccharides may also participate in this process[31,32].These findings were consistent with the results of Shi Xingyun[31] and Sun Zhigang[32]. The results suggested that higher levels of flavonoids were likely to be accompanied by higher Ca or moisture content, higher levels of allantoin were likely to be accompanied by higher P, Na, or Cu content, and higher levels of anthocyanins were likely to be accompanied by higher Fe, vitamin C, or crude polysaccharide content. These observations provided a theoretical basis for subsequent yam breeding and the development of functional products.

Moreover, the results of this study indicated that, compared to Iron yam, Ziyu yam contained higher levels of yam polysaccharides, flavonoids, and anthocyanins, but lower levels of allantoin and diosgenin. In comparison to Iron yam, Qinfeng yam contained higher levels of yam polysaccharides and anthocyanins, but lower levels of flavonoids, allantoin, and diosgenin. Therefore, both Qinfeng yam and Ziyu yam showed significant potential for processing into hypoglycemic products. Furthermore, through principal component analysis, it was concluded that yam polysaccharides, flavonoids, allantoin, diosgenin, Ca, Na, Cu, moisture, ash, lipids, total carbohydrates, and energy should be used to evaluate the nutritional quality of yam. In the first principal component, Iron yam exhibited a larger positive contribution and the highest score, while in the second principal component, Ziyu yam had the highest score, indicating that the content of hypoglycemic active ingredients in Ziyu yam was higher than that in Iron yam.

Partial least squares analysis further revealed that allantoin, lipids, total carbohydrates, Na, Cu, and ash content were key characteristic indexes distinguishing the differences among the three yam varieties. Among these, Na and Cu play roles in allantoin metabolism[29,30], and allantoin has been shown to regulate inflammation levels, improve lipid metabolism, and indirectly enhance insulin sensitivity[24]. The pharmacological effects of these indicators could be further explored in future studies.

Additionally, R-cluster analysis combined with multiple linear regression analysis further confirmed that mineral content and flavonoids are critical indicators for assessing the nutritional quality of Chinese yam. This finding aligns with the two principal components extracted from the principal component analysis. It is consistent with the study by Obidiegwu et al.[33], which proposed that carbohydrates are a key indicator of yam as an energy food, while mineral and active ingredient content are important indicators for evaluating the medicinal potential of yam. These results suggest that higher values for these metrics correlate with better model evaluation scores. Based on the analysis, it was concluded that Iron yam exhibited the best overall quality in terms of tuber characteristics, while Ziyu yam, with its higher levels of hypoglycemic active ingredients, was deemed more suitable for further development and utilization.

According to data from the International Diabetes Federation (IDF), the number of diabetic patients worldwide has surpassed 500 million and continues to rise[34]. There is significant demand among diabetic patients for safe and effective natural hypoglycemic products[35]. Ziyu yam, which contains higher levels of hypoglycemic active compounds and is rich in nutrients, aligns well with consumer preferences for "natural," "plant-based," and "functional" food products. In particular, the functional food and dietary supplement markets have experienced significant growth in recent years[36], providing a promising application space for Ziyu yam. The hypoglycemic potential of Ziyu yam makes it valuable for diabetic patients. Furthermore, Ziyu yam demonstrates significant agricultural potential and economic viability. It has a relatively short growth cycle, strong adaptability, and can thrive in a variety of climatic conditions[37]. Currently, China, India, and Southeast Asia are the primary cultivation regions for Ziyu yam, benefiting from low labor and land costs, which provide economic advantages for large-scale cultivation.

Despite the significant economic, market and medicinal value of Ziyu yam, challenges related to its bioavailability, potential side effects, and contraindications in certain populations must be carefully considered. Anthocyanins, as the primary active compounds, degrade rapidly under gastrointestinal conditions and undergo extensive metabolism by gut microbiota, leaving only a small fraction available for systemic absorption[38]. Similarly, polysaccharides must resist enzymatic breakdown in the digestive tract to exert their hypoglycemic effects[39]. Besides, the variability in the active compound content of Ziyu yam, influenced by cultivation conditions and processing methods, poses a core challenge in achieving standardization of compound extraction and formulation production. Additionally, stringent regulatory requirements regarding functional claims and market access for natural products in different countries further complicate its commercialization[40].To promote the successful commercialization of Ziyu yam in the natural hypoglycemic product market, future efforts should focus on the following aspects: enhancing research on the mechanisms of its active components to strengthen the scientific basis for efficacy validation; developing efficient extraction and formulation technologies to reduce production costs; and improving marketing strategies to increase consumer awareness and acceptance.

Furthermore, while yam is generally considered safe, it might pose risks to certain populations. For diabetic patients, excessive intake yam might lead to unexpected blood glucose fluctuations[4]. The slow digestion of polysaccharides might result in delayed glycemic responses, potentially complicating blood glucose management when used in conjunction with antidiabetic medications[41]. Future research should focus on developing strategies to enhance the bioavailability of active components, exploring the safety profiles of yam in various populations, and investigating its therapeutic potential in clinical settings. These efforts will maximize the health benefits of yam while minimizing associated risks, ensuring its broad applicability as a functional food and the development of innovative strategies for diabetes treatment.

However, the present study had some limitations of the analytical techniques. High-performance liquid chromatography (HPLC) used in the present study is a highly sensitive and versatile technique that allows for the precise quantification of specific compounds such as allantoin, diosgenin, and anthocyanin. Nevertheless, HPLC is time-consuming and requires extensive sample preparation, including solvent extraction and filtration, to avoid damage to the chromatographic column or interference with the detection system. The high cost of HPLC equipment, such as maintenance and consumables, might also pose challenges[42]. All above would affect the reproducibility or scale of the study. In addition, ultraviolet spectrophotometry is suitable for determining the presence and concentration of certain compounds, such as flavone and polysaccharide. However, it was prone to interference from other components in complex matrices, which might lead to over- or under-estimation of the target analytes[43]. Skilled personnel conducted the measures for the good quality control in the study.

The analysis was conducted using a limited number of yam samples, which may not fully capture the natural variability present within each variety. Influencing factors such as environmental conditions, cultivation practices, and genetic diversity could affect the content of nutrients and bioactive compounds. To ensure consistency and minimize variability caused by these factors, we carefully selected yam powder samples that adhered to consistent production standards, with uniform planting and harvesting seasons, as well as consistent storage conditions[44]. Furthermore, to reduce errors in the detection process, we performed six replicate measurements for each type of yam powder[41]. Future studies should aim to increase the sample size and include yam from diverse geographical regions and cultivation practices, providing a more comprehensive scientific foundation for the functional development of yam.

In summary, descriptive statistics, correlation analysis, principal component analysis, and other methods were used to evaluate the basic nutritional components and hypoglycemic active components of three types of yam. The results of this study indicate that Ziyu yam has higher levels of multiple hypoglycemic active components compared to Iron yam. There is a correlation between the nutritional components and hypoglycemic active components of different yam varieties. Twelve indicators, including yam polysaccharide, flavonoids, allantoin, diosgenin, Ca, Na, Cu, moisture, ash, fat, total carbohydrates, and energy, can be used to comprehensively evaluate the quality of yam.Allantoin, lipid, total carbohydrates, Na, Cu, and ash were the main components of difference among the three species.The overall score indicates that Iron yam has the best quality, while Ziyu yam has the highest content of hypoglycemic active components, suggesting that Ziyu yam has great potential as a raw material for the development of hypoglycemic products.

Furthermore, Iron yam, as a traditional and authentic medicinal material, was the reference standard of this study because it is recognized as a genuine medicinal material in the Chinese Pharmacopoeia. Our study also showed that the Iron yam is of the highest quality among the three type of yam. The high quality of Iron yam is not only based on the selective factors of its growing environment, cultivation technology and harvesting season, but also closely related to its unique pharmacological action. In future research, it is of great significance to explore the optimized cultivation and pharmacological component analysis of other yam varieties in conjunction with the quality characteristics of Iron yam. This process will not only promote the diversified application of yam varieties but also provide scientific evidence for the establishment of medicinal material standards. As the demand for higher quality medicinal materials continues to rise, how to utilize modern technological methods to further enhance the quality of Iron yam, ensuring its stability and traceability, will become a key focus of future research.

Materials and methods

Materials and instruments

Material source

The pure powder samples of Qinfeng yam and Ziyu yam were obtained from the yam planting base of the Yingshan Precious Chinese Yam Farmers' Cooperative in Dehua County, Quanzhou, Fujian Province. The pure Iron yam powder samples were sourced from Weimu Huai Medicine Co., Ltd. in Wuzhi County, Jiaozuo, Henan Province. The geographical and climatic characteristics of the two yam cultivation sites are presented in Table 8. These yam samples were collected from yam planted in April 2023 and harvested in December 2023.

Sample name	Location	Latitude (*N*)	Longitude (E)	Altitude (m)	Slope (°)	Average temperature (°C)	Annual rainfall (mm)
Qinfeng Yam	Dehua County, Quanzhou, Fujian Province	25° 27′ 37.48″	118° 11′ 20.90″	696	17	18.0	1769
Ziyu Yam							
Iron Yam	Wuzhi County, Jiaozuo, Henan Province	34° 59′ 54.56″	113° 14′ 54.86″	102	0	14.4	575.1

Table 8. The geographical and Climatic characteristics of the Yam cultivation sites. The dataset was provided by the Geographic Remote Sensing Ecological Network Platform (www.gisrs.cn).

The preparation of the yam powder was carried out in accordance with the Q/JZH 0001 S-2019 standard. Each indicator was tested six times per sample.

Instruments
LC-20AT high-performance Liquid Chromatograph (Shimadzu, Japan); Swiss TECAN Multifunctional Enzyme Label Infinite 200 PRO; SinoChrom ODS-BP Column (5μL, 250 mm×4.60 mm); SU-S2-20 L Ultra-pure Water Machine (Sichuan Delishi Technology Co., LTD.); TDL-40B Centrifuge (Shanghai Anting Scientific Instrument Factory); Automatic Ultrasonic Cleaning Machine (Hubei Dingtai Hengsheng Technology Equipment Co., LTD.).

Reagents
Diosgenin standard, Rutin standard, allantoin standard, Glucose standard (source leaf), HPLC grade methanol acetonitrile (concord technology), sulfuric acid, phenol, ethanol, vanillin, perchloric acid, ice acetic acid, NaNO2, AlC13, NaOH, ethanol, chromatographic methanol (Sinopsin Group).

Determination of compounds

Determination of nutrient content
The carbohydrate and energy content were calculated using formulas in accordance with GB 28,050 – 2011 "General Principles for the Nutrition Labeling of Prepackaged Foods under Food Safety Standards." The content of crude polysaccharides was determined using the phenol-sulfuric acid method, as outlined in SN/T 4260 – 2015 "Determination of Crude Polysaccharides in Exported Plant-derived Foods." Protein content was measured by the Kjeldahl method, following GB 5009.5–2016 "Determination of Protein in Foods." Ash content was determined according to GB 5009.4–2016 "Determination of Ash in Foods." Moisture content was quantified using the direct drying method, as specified in GB 5009.3–2016 "Determination of Moisture in Foods." Lipid content was analyzed using the Soxhlet extraction method, in accordance with GB 5009.6–2016 "Determination of Lipid in Foods." Amino acid content was measured by ninhydrin post-column derivatization ion exchange chromatography, following GB 5009.124–2016 "Determination of Amino Acids in Foods."

Ca, Na, K, Mg, Mn, Fe, and Zn content were determined using flame atomic absorption spectrometry, in accordance with GB 5009.92–2016 "Determination of Ca in Foods," GB 5009.91–2017 "Determination of Na and K in Foods," GB 5009.241–2017 "Determination of Mg in Foods," GB 5009.242–2017 "Determination of Mn in Foods," GB 5009.90–2016 "Determination of Iron in Foods," and GB 5009.14–2017 "Determination of Zn in Foods."Cu content was determined using inductively coupled plasma mass spectrometry, as per GB 5009.13–2017 "Determination of Cu in Foods." Selenium content was measured using hydride generation atomic fluorescence spectrometry, following GB 5009.93–2017 "Determination of Selenium in Foods." P content was determined using molybdenum blue spectrophotometry, in accordance with GB 5009.87–2016 "Determination of P in Foods."

Vitamin B1 content was determined using high-performance liquid chromatography (HPLC), in accordance with GB 5009.84–2016 "Determination of Vitamin B1 in Foods." Vitamin C content was measured using HPLC, following GB 5009.86–2016 "Determination of Ascorbic Acid in Foods." Vitamin A content was determined using reverse-phase HPLC, as per GB 5009.82–2016 "Determination of Vitamin A, D, and E in Foods." Vitamin D content was analyzed using liquid chromatography-tandem mass spectrometry, according to GB 5009.296–2023 "Determination of Vitamin D in Foods."

Determination of hypoglycemic active compounds
Determination of Polysaccharide Content in yam: The polysaccharide content was determined using the method described by Zhou S[45], employing ultraviolet spectrophotometry.Approximately 1.0 g of yam powder was mixed with purified water at a 1:15 ratio and incubated in a water bath at 60 °C for 1 h, with the process repeated twice. After preparing the yam polysaccharide sample solution, it was poured into two-thirds of a dialysis bag, with the open end clamped securely. The dialysis bag was then placed in a container of distilled water, ensuring that the water level did not exceed the bag. The polysaccharide solution was dialyzed in distilled water for 72 h, with the water being changed midway to remove small molecular impurities such as monosaccharides, oligosaccharides, and salts .After extraction and dialysis, the solution was reduced pressure and concentrated, and ethanol was added to achieve a final concentration of 80% ethanol. Let the solution sit overnight for alcohol precipitation, then centrifuge, collect the precipitation, dry and weigh.The resulting yam polysaccharide was dissolved in purified water and diluted to 40 mL to prepare the sample solution. To prepare the standard curve, 10 mg of D-anhydrous glucose was dissolved in ultrapure water in a 10 mL volumetric flask to prepare the stock solution. The stock solution was then diluted to concentrations of 0.02, 0.04, 0.06, 0.08, and 0.1 mg/mL. For each concentration, 1 mL of solution was transferred into a test tube, with 1 mL of purified water serving as the blank control. To each test tube, 1 mL of 5% phenol solution and 5 mL of concentrated sulfuric acid were added, mixed rapidly, allowed to stand for 10 min, heated in a boiling water bath for 15 min, and then cooled to 26 ℃ using an ice-water bath. Finally, the absorbance was measured at a wavelength of 490 nm.

Determination of Flavone Content: The flavone content was determined using the method described by Ruas A C[46], employing ultraviolet spectrophotometry. Approximately 1.0 g of Chinese yam powder was mixed with 95% (V/V) ethanol at a 1:20 ratio. The mixture was soaked for 12 h, followed by ultrasonication for 1 h. It was then centrifuged at 12,000 rpm for 10 min, and the supernatant was collected for analysis. For the preparation of the rutin standard solution, 10 mg of rutin was dissolved in a 10 mL volumetric flask and diluted to the mark with 95% (V/V) ethanol to obtain a 1 mg/mL solution. The solution was mixed thoroughly and stored for use. Serial dilutions of the standard solution were prepared with 95% (V/V) ethanol to obtain concentrations of 10, 20, 40, 60, 80, and 100 μg/mL, and stored at 4 °C. For the assay, 0.5 mL of each rutin standard solution was transferred

Time (min)	Velocity of flow (mL/min)	Mobile phaseA (%)	Mobile phaseB (%)
0.0	0.8	92.0	8.0
2.0	0.8	88.0	12.0
5.0	0.8	82.0	18.0
10.0	0.8	80.0	20.0
12.0	0.8	75.0	25.0
15.0	0.8	70.0	30.0
18.0	0.8	55.0	45.0
20.0	0.8	20.0	80.0
22.0	0.8	92.0	8.0
30.0	0.8	92.0	8.0

Table 9. High performance liquid chromatography (HPLC) measurement gradient elution conditions.

into a 10 mL test tube. To this, 0.5 mL of 5% NaNO2 solution was added, and the mixture was allowed to stand at 26 ℃for 5 min. Then, 0.5 mL of 10% AlCl3 solution was added, followed by another 5-minute standing period. Next, 2 mL of 4% NaOH solution was added, and the mixture was thoroughly mixed and allowed to stand for 15 min. Finally, the absorbance was measured at a wavelength of 510 nm.

Determination of Allantoin Content: Allantoin content was determined using the method described by Lee M[47], employing HPLC. Approximately 1.0 g of yam powder was mixed with 20 mL of 80% methanol, shaken thoroughly, and extracted by ultrasonication for 40 min. The mixture was allowed to stand, then diluted to a 20 mL volumetric flask to prepare the sample solution. To prepare the standard solution, 10 mg of dried, constant-weight allantoin standard was placed in a 10 mL volumetric flask, dissolved in ultrapure water, and diluted to the mark. The solution was mixed thoroughly and further diluted with ultrapure water to create a series of standard solutions at concentrations of 10, 20, 40, 60, 80, 100, and 200 μg/mL, which were stored at 4 °C for use. The chromatographic conditions were as follows: chromatographic column: Dalian Elite SinoChrom ODS-BP (5 μm, 250 mm × 4.60 mm); mobile phase: acetonitrile-water (10:90); flow rate: 0.4 mL/min; injection volume: 10 μL; column temperature: 30 °C; detection time: 15 min.

Determination of Diosgenin Content: Diosgenin content was determined using the method described by Wang Y[48], employing HPLC. Approximately 1.0 g of Chinese yam powder was mixed with 20 mL of 80% ethanol, sealed, weighed, and subjected to ultrasonication for 40 min. The extract was then filtered and evaporated to dryness. The residue was dissolved in the mobile phase, diluted to a 20 mL volumetric flask, mixed thoroughly, and filtered through a microporous membrane filter to prepare the sample solution. To prepare the standard solution, 5 mg of diosgenin standard was placed in a 10 mL volumetric flask, dissolved in chromatographic methanol, and diluted to the mark. The solution was further diluted with methanol to obtain concentrations of 2, 4, 8, 10, and 20 μg/mL. The chromatographic conditions were as follows: chromatographic column: Dalian Elite SinoChrom ODS-BP (5 μm, 250 mm × 4.60 mm); mobile phase: methanol-water (84:16); flow rate: 1 mL/min; detection wavelength: 206 nm; column temperature: 30 °C.

Determination of Anthocyanin Content: Anthocyanin content was determined using the method outlined in NY/T 2640 – 2014 "Determination of Anthocyanins in Plant-derived Foods," employing HPLC. Approximately 1.00 g of yam powder was placed in a 50 mL volumetric flask with a stopper, and the extraction solution (composed of anhydrous ethanol, water, and hydrochloric acid in a 2:1:1 ratio) was added to the mark. The mixture was shaken for 1 min, followed by ultrasonic extraction for 30 min. After extraction, the mixture was hydrolyzed in a boiling water bath for 1 h, then cooled and diluted again with the extraction solution to the mark. After standing, the supernatant was collected, filtered through a 0.45 μm aqueous phase filter membrane, and prepared for testing. The chromatographic conditions were as follows: chromatographic column: C18 column (250 mm × 4.6 mm × 5 μm); mobile phase: mobile phase A—1% formic acid aqueous solution, mobile phase B—1% formic acid acetonitrile solution; detection wavelength: 530 nm; column temperature: 35 °C; injection volume: 20 μL; The gradient elution conditions are shown in Table 9.

Data analysis

Statistical analysis of the data was performed using IBM SPSS Statistics 25.0 software. Measurement data were expressed as mean ($\overline{x} \pm s$). Independent sample t-tests were used for comparisons between two groups, and one-way analysis of variance (ANOVA) was used for comparisons between multiple groups. The Z-score normalization method was used to standardize the data, followed by correlation analysis, principal component analysis, partial least squares discriminant analysis, cluster analysis and multiple linear regression analysis,. Hypothesis testing was conducted using two-sided tests, and $P < 0.05$ was considered statistically significant.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files .

Received: 22 September 2024; Accepted: 20 March 2025
Published online: 12 April 2025

References

1. Huang Luqi (ed) A map of historical production areas of commonly used Chinese herbal medicines;Shanghai Science and Technology Press: Shanghai, China, ; p. 78. (2020).
2. (Wei)Wu Pu and others; (Qing) Sun Xingyan, Sun Fengyi; Dai Ming, Huang Zijian, Yu Zhiying, Cao Yun. Shennong ben cao jing;Guangxi Science and TechnologyPress:China. ; p. 21. (2016).
3. Zhang, L. et al. Prospects of Yam (Dioscorea) polysaccharides: structural features, bioactivities and applications[J]. *Food Chem.*, : 138897. (2024).
4. Li, Y. et al. Chinese Yam (Dioscorea): nutritional value, beneficial effects, and food and pharmaceutical applications[J]. *Trends Food Sci. Technol.* **134**, 29–40 (2023).
5. Zhang, W. et al. Comparison and comprehensive evaluation of the quality of Yam germplasm resources in Fujian Province[J]. *Food Res. Dev. 2024*, **45**(09):75–85 .
6. Ying, L. I. U. et al. Comparison of chemical composition and Pharmacological activity of two kinds of yam[J]. *J. Guiyang Coll. (Natural Sci. Edition) 2022*, **17**(04):44–48
7. Santos, R. K. F. et al. Association between Circulating micronutrient pattern, glycemic control, and insulin resistance in type 2 diabetes mellitus[J]. *BioMetals* **37** (2), 527–537 (2024).
8. Lin, B. et al. Betulinic acid from inonotus obliquus ameliorates T2DM by modulating short-chain fatty acids producing bacteria and amino acids metabolism in Db/db mice[J]. *J. Ethnopharmacol.*, : 119417. (2025).
9. Chen, Y. et al. Adaptability evaluation of 35 local Yam germplasm resources in Fujian Province[J]. *Fujian Agricultural Sci. Technol.* **54** (01), 24–31 (2023).
10. Chen, Y., Lin, Y. & Li, J. Identification and evaluation of 22 germplasm resources of purple yam[J]. *Subtropical Agricultural Res. 2024*, **20**(01):23–29 .
11. National Pharmacopoeia Commission. ed. Pharmacopoeia of the People's Republic of China, Part I, 2020 Edition;China Pharmaceutical Science and Technology Press:Beijing, China;2020; p.30.
12. Li, Y. et al. Antidiabetic effects and mechanism of γ-polyglutamic acid on type II diabetes mice[J]. *Int. J. Biol. Macromol.* **261**, 129809 (2024).
13. Hu, X. et al. Effects of chicken serum metabolite treatment on the blood glucose control and inflammatory response in Streptozotocin-induced type 2 diabetes mellitus rats[J]. *Int. J. Mol. Sci.* **24** (1), 523 (2022).
14. Yang Yuexin. Chinese Food Composition Table Standard Edition 6th Edition Volume 1 + Volume 2;Peking University Medical Press:Beijing, China;2020;p.41.
15. Moenga, M. N. et al. Determination of essential minerals in the Indigenous vegetables solanum nigrum (Stout Shade) and gynandropsis Gynandra (Spider Plant) from two agroecological zones in Kisii County, Kenya[J]. *Biol. Trace Elem. Res.*, : 1–17. (2024).
16. Sobieska, K. et al. Iron homeostasis and insulin sensitivity: unraveling the complex interactions[J]. *Reviews Endocr. Metabolic Disorders*. **25** (5), 925–939 (2024).
17. Alharazi, W. Z. et al. Could consumption of Yam (Dioscorea) or its extract be beneficial in controlling glycaemia: a systematic review[J]. *Br. J. Nutr.* **128** (4), 613–624 (2022).
18. Shamsan, E. et al. The role of PI3k/AKT signaling pathway in attenuating liver fibrosis: a comprehensive review[J]. *Front. Med.* **11**, 1389329 (2024).
19. Gong, L. et al. *Inhibitors of α-amylase and α-glucosidase: Potential Linkage for Whole Cereal Foods on Prevention of hyperglycemia[J]*86320–6337 (Food science & nutrition, 2020). 12.
20. Chadt, A. & Al-Hasani, H. Glucose transporters in adipose tissue, liver, and skeletal muscle in metabolic health and disease[J]. *Pflügers Archiv-European J. Physiol.* **472** (9), 1273–1298 (2020).
21. Dludla, P. V. et al. Pancreatic β-cell dysfunction in type 2 diabetes: implications of inflammation and oxidative stress[J]. *World J. Diabetes.* **14** (3), 130 (2023).
22. Kim, M., Song, K. & Kim, Y. S. Alantolactone improves prolonged exposure of interleukin-6-induced skeletal muscle inflammation associated glucose intolerance and insulin resistance[J]. *Front. Pharmacol.* **8**, 405 (2017).
23. Zhao, Y. et al. Allantoin reduces glucotoxicity and lipotoxicity in a type 2 diabetes rat model by modulating the PI3K and MAPK signaling pathways[J]. *Heliyon*, **10**(15). (2024).
24. Dai, Y. et al. Yam gruel alone and in combination with Metformin regulates hepatic lipid metabolism disorders in a diabetic rat model by activating the AMPK/ACC/CPT-1 pathway[J]. *Lipids Health Dis.* **23** (1), 28 (2024).
25. Ahmad, B. et al. Molecular mechanisms of adipogenesis: the anti-adipogenic role of AMP-activated protein kinase[J]. *Front. Mol. Biosci.* **7**, 76 (2020).
26. Sitorus, J. et al. Artocarpus altilis extract capsules reduce fasting blood glucose in Prediabetes[J]. *Open. Access. Macedonian J. Med. Sci.* **10** (A), 315–320 (2022).
27. Franco-San Sebastián, D. et al. Anthocyanins: potential therapeutic approaches towards obesity and diabetes mellitus type 2[J]. *Molecules* **28** (3), 1237 (2023).
28. Marques, C. et al. Gut microbiota modulation accounts for the neuroprotective properties of anthocyanins[J]. *Sci. Rep.* **8** (1), 11341 (2018).
29. Haynes, A. P. et al. The antioxidative effects of flavones in hypertensive disease[J]. *Biomedicines* **11** (11), 2877 (2023).
30. Omer, R. A. et al. Potential corrosion Inhibition properties of flavone derivatives on the Cu (111) surface: A combined DFT and Monte Carlo simulation Study[J]. *J. Fluoresc.*, : 1–14. (2025).
31. Shi, X. et al. Establishment of a quality evaluation model for mulberry based on principal component analysis[J]. *China Fruit Tree*, **2024**(03):54–59 .
32. Sun, Z. et al. Analysis of nutritional and health care functional components of 24 purple mountain drug lines in Yunnan[J]. *Anhui Agricultural Sci.* **52** (06), 185–189 (2024).
33. Obidiegwu, J. E., Lyons, J. B. & Chilaka, C. A. The Dioscorea genus (Yam)—An appraisal of nutritional and therapeutic potentials[J]. *Foods* **9** (9), 1304 (2020).
34. Magliano, D. J. & Boyko, E. J. IDF diabetes atlas[J]. (2022).
35. Nainu, F. et al. Natural products targeting inflammation-related metabolic disorders: A comprehensive review[J]. *Heliyon*, **9**(6). (2023).
36. Khol, M. et al. *Frontier Rev. Nutraceutical Chin. Yam[J] Foods*, **13**(10): 1426. (2024).
37. Owusu Danquah, E. et al. Sustainable intensification and climate-smart Yam production for improved food security in West Africa: a review[J]. *Front. Agron.* **4**, 858114 (2022).
38. Moriya, C. et al. Absorption of acylated anthocyanins from purple yam extract in rats[J]. Bioscience, Biotechnology, and Biochemistry, : zbae206. (2024).
39. Zhang, Y. et al. Advances in dietary polysaccharides as hypoglycemic agents: mechanisms, structural characteristics, and innovative applications[J]. *Crit. Rev. Food Sci. Nutr.*, : 1–21. (2023).
40. Hussain, S. A. Investigating the health claims and regulatory considerations of Kangen water: A comprehensive analysis with python and spiritual Insights[J]. **6**(3). (2024).
41. Wang, Y. et al. Association of slowly digestible starch intake with reduction of postprandial glycemic response: an update meta-analysis[J]. *Foods* **12** (1), 89 (2022).

42. Bosten, E. et al. Automated method development in high-pressure liquid chromatography[J]. *J. Chromatogr. A*. **1714**, 464577 (2024).
43. Feichen Ye. Ultraviolet spectrum-based molecular precision detection[J]. *Highlights Sci. Eng. Technol.* **99**,101–110 .
44. Xiao, Y. et al. Cultivation pattern affects starch structure and physicochemical properties of Yam (Dioscorea persimilis)[J]. *Int. J. Biol. Macromol.* **242**, 125004 (2023).
45. Zhou, S., Huang, G. & Chen, G. Extraction, structural analysis, derivatization and antioxidant activity of polysaccharide from Chinese yam[J]. *Food Chem.* **361**, 130089 (2021).
46. Ruas, A. C. *Amorphophallus paeoniifolius (Dennst.) Nicholson: Fonte De Nutrientes E Compostos Bioativos: Efeito Do Processamento[D]* (Universidade do Porto (Portugal), 2014).
47. Lee, M. et al. Quantitative analysis of Allantoin in Dioscorea Japonica Peel using an amino bonded-phase HPLC column[J]. *J. Food Hygiene Saf.* **36** (4), 347–352 (2021).
48. Wang, Y. et al. Dynamic changes of active substances of rice, pueraria and Yam fermentation by monascus ruber[J]. *LWT* **183**, 114925 (2023).

Acknowledgements

Thanks to the yam planting base of Dehua County Yingshan Precious yam Farmers' Co-operative for providing samples of Qianfeng yam and Ziyu yam.

Author contributions

"Conceptualization, Y.L. and L.G.; methodology, Q.Land M.Z.; software, Y.L. and C.Z.; validation, Y.L., Y.Q. and H.Y.; data curation, Y.L.and Q.L.; writing—original draft preparation, Y.L.; writing—review and editing, L.G.; supervision, L.G.; project administration, L.G.All authors have read and agreed to the published version of the manuscript.

Funding

This study is funded by the Fujian Provincial Natural Science Foundation Project in 2021, grant number: 2021J01945 the Science and Technology Plan Project of the Fujian Provincial Health Commission in 2021, grant number: 2021zylc27; the Nursing Plateau Discipline Special Subject of the Fujian University of Traditional Chinese Medicine School-Managed Subjects in 2021, grant number X2021002-Discipline; and the National Student Innovation and Entrepreneurship Training Program in 2020, grant number: 202010393012.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-95401-3.

Correspondence and requests for materials should be addressed to L.G.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.