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2 Year Wencheng Waxy Yam Pesticide Residue Investigation and Quality Evaluation

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ABSTRACT: Wencheng waxy yam is famous for its glutinous and resilient taste, similar to waxy rice, but there is currently a lack of systematic research on the quality of this featured product, and little is known about its pesticide residues. We carried out a 2 year investigation of Wencheng waxy yam at seven sites from 2021 to 2022 to determine the oxidase content and phytochemical characteristics, namely, amylose, amylopectin, protein, reducing sugar, and mineral contents, such as K, Fe, and Zn, including the status of pesticide residues. The results showed that the oxidase content was affected by rainfall, and adequate water reduced the production of oxidase, including polyphenol oxidase, peroxidase, and superoxide dismutase, during the late growth stage of waxy yam, which was beneficial for reducing browning in yam processing. Radar map analysis showed that, with comprehensive evaluation, standardized production sites 1 and 2 had a relatively higher quality than 3−7 with small farmers. The results of pesticide multiresidue testing showed that no pesticides were detected in 64.29% of the samples, and the detected residues in the samples were very low, making the consumption of yam safe for consumers. These findings could be beneficial for the exploitation of the health benefits of waxy yam tubers and the innovation of yam-based functional products.

1. INTRODUCTION

Yam, a candidate for "the homology of medicine and food" published by China in 2020,[1] was first recorded in "Shennong's Classic Material Medical" in China. With its main edible part being its underground tuber, yam is effective at improving blood circulation and enhancing spleen, lung, stomach, and kidney channel functions, and yam has a long history of cultivation and medicinal use in China.[2,3] Wencheng is located in Wenzhou City, Zhejiang province, China (27°34′−27°59′N, 119°46′−120°15′E). The mountainous area within Wencheng County accounts for 82.5% of the total area of the county, and most of the landforms are typical mountainous areas. The mean annual precipitation is 1772.6 mm, and the average humidity is 76.5%. Wencheng has plentiful rain and a mild climate, and more than 80% of rainfall is concentrated from March to October. The warm climate conditions provide a foundation for the growth of waxy yam. Waxy yam is a unique variety of yam in Wencheng, with a glutinous and resilient taste. In 2022, there were 650 households planting waxy yam in the county, with a cultivation area of 400 ha, and the total output value was 100 million RMB. Waxy yam makes important contributions to the development of the primary, secondary, and tertiary industries in Wencheng County and has become a "golden card" for Wencheng County.

Yam is also called "Shanyao" in China. More than 600 species have been reported worldwide, and about 60 species are edible and medicinal.[4] More than 55 *Dioscorea* species are distributed in northeastern, central, and southeastern China.[5] As waxy yam is a unique variety, Wencheng waxy yam is famous for its glutinous and resilient taste, similar to waxy rice. Its unique efficacy and flavor are highly attractive to

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Figure 1. Waxy yam appearance and the location of Wencheng.

consumers, indicating good market prospects and development potential for yam products.

For yam quality, previous reviews have primarily focused on nutritional and functional ingredients, including starch, fiber, protein, polysaccharides, sapogenins, dioscorin, allantoin, flavonoids, polyphenols, and other active compounds.[6−8] There is still a lack of comprehensive information about the physicochemical properties and applications of yam nutrients, and in addition, pesticide residues in yams are little known to consumers. The main purpose of this work was to investigate the relationship between phytochemical characteristics, as well as the oxidase content, and browning degree of Wencheng waxy yam at different production sites and positions in 2 years, and 68 pesticides commonly used in yam were examined to assess the safety of yam for consumption. This study provides useful data for further exploitation of the health benefits of waxy yam tubers and the development of yam-based functional products. The aims of this study were (1) to determine the contents of three oxidase contents (PPO, POD, and SOD) in Wencheng waxy yam and to investigate the relationship between oxidase contents and enzymatic browning; (2) to analyze the quality indexes of waxy yam, i.e., the contents of mineral materials, amylose, amylopectin, protein, and reducing sugar; and (3) to perform a pesticide multiresidue assay on Wencheng waxy yam.

2. MATERIALS AND METHODS

2.1. Sample Collection. Wencheng waxy yam was planted in April and collected from September to December. The samples were collected in December 2021 and December 2022. Waxy yam is primarily grown on family-owned farms; seven typical growers were chosen for the 2 year investigation. Sites 1 and 2 were standardized production demonstration sites with a relatively large production scale, and sites 3 to 7 were sites worked by small-scale farmers. Fresh yam tuber samples with uniform thickness, no pests or diseases, that were intact and undamaged, and had no fungus pests were collected. The appearance and planting location of the waxy yam are shown in Figure 1.

The sliced sample was ground in a domestic blender for chemical analysis. Chemical analysis techniques were conducted according to the methods of AOAC (1998) to determine the moisture content (Method 934.01) and protein content (Method 984.13).[23] The dry matter of the yam tuber was obtained by subtracting the moisture content from the total weight of the tested sample.

2.2. Reagents and Materials. The contents of three oxidases, namely, polyphenol oxidase (PPO), peroxidase (POD), and superoxide dismutase (SOD), were detected. Mineral materials, including K, Fe, and Zn, were detected. The contents of amylose, amylopectin, protein, and reducing sugar were detected.

For oxidase content analysis, fresh sliced yam tubers (500 g) were quickly homogenized in 500 mL of 0.1 mol L^{-1} phosphate buffer (pH 7.0, 4 °C) containing 30 mmol L^{-1} ascorbic acid using a domestic blender for 2 min. The resultant homogenate was quickly filtered through four layers of clean cheesecloth. The filtrate was then centrifuged at 8000 rpm for 10 min at 4 °C. The supernatant was used for the analysis of the oxidase activity. The PPO activity was determined by measuring the increase in the absorbance at 525 nm over time. Briefly, 1 g of yam tissue was added to 10 mL of extraction buffer [containing 1% polyvinylpolypyrrolidone (PVPP) and 1.33 mM ethylenediaminetetraacetic acid (EDTA)] for grinding. Then, one unit of PPO activity was defined as a change in absorbance of 0.01 min, and the enzyme activity was expressed in U kg^{-1} fresh weight (FW).[9]

The POD activity was determined by measuring the increase in the absorbance at 470 nm over time. Samples were extracted by grinding 10 g of a frozen sample with sterile sea sand in 0.8 mL of PBS buffer (pH 7.2) in an Ultra-Turax T25 at 4 °C and centrifuged at 10,000*g* for 15 min at 4 °C after adding the respective substrate (2 mL of guaiacol). POD activity was expressed as U kg^{-1} fresh yam protein content.[10]

The SOD activity was determined by measuring formanzan at an absorbance of 560 nm over time. The oxidase reaction with the reaction solution generated the superoxide anion (O^{2-}), which restored nitroblue tetrazolium and produced formanzan. SOD was able to clear the O^{2-} and suppress or reduce the formation of formanzan. Thus, the darker the reaction solution, the lower the SOD activity. SOD activity was expressed as U mL^{-1} protein content when the inhibition percentage reached 50%.[11] The activities were calculated as follows

$$\text{PPO (U/g fresh weight)} = 60 \times \Delta A \div W \tag{1}$$

$$\text{POD (U/g fresh weight)} = 2000 \times \Delta A \div W \tag{2}$$

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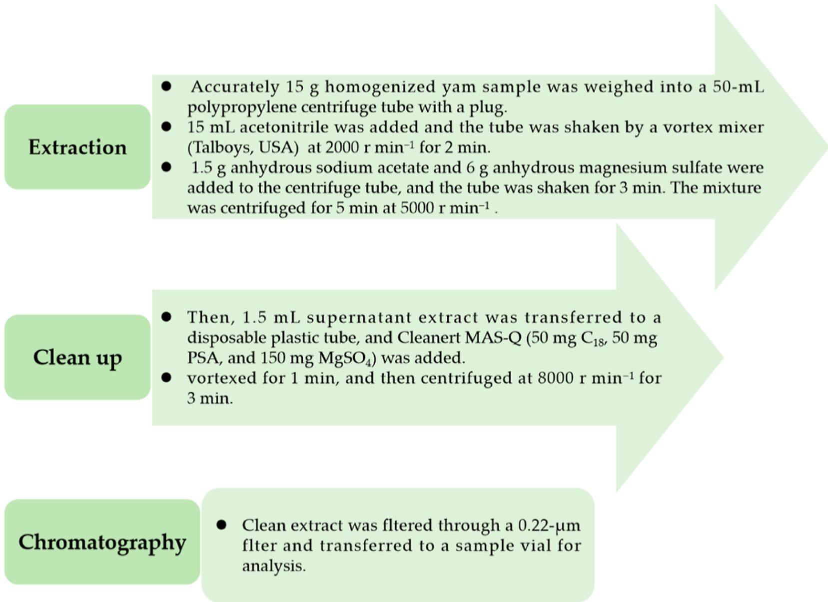

Figure 2. Analytical steps of the QuEChERS.

$$\text{SOD} = 11.11 \times \text{inhibition percentage} \div (1 - \text{inhibition percentage}) \div W \tag{3}$$

where ΔA means the change in absorbance value, and W means the sample weight (g).

Amylose and amylopectin contents were determined by a dual wavelength iodine binding technique.[12] Proteins were detected using the Chinese national standard GB 5009.5−2016, "National standard for food safety determination of protein in foods".[13] Reducing sugar was detected following national standard GB 5009.7−2016, "National standard for food safety determination of reducing sugar in food".[14] Minerals including potassium (K), iron (Fe), and zinc (Zn) were analyzed following the method of Heghedus-Mindru et al.[15] Specific descriptions can be found in Supporting Information A−D.

The radar chart analysis method was used based on evaluating indicators, including amylose, amylopectin, protein, reducing sugar contents, and K, Fe, and Zn mineral material contents after dimensionless processing. A dimensionless procedure was carried out to constrain the values between 0 and 1; the closer the value to 1, the better the trait.

$$r_{ij} = \frac{r_{ij}}{\max r_{ij}} \tag{4}$$

where r_{ij} is the evaluation index value.

The radar chart area S and perimeter L were calculated as follows

$$\text{const angle} = 2 \times \text{math.PI}/7 \tag{5}$$

$$L = \text{math. sqrt}(a \times a + b \times b - 2 \times a \times b \times \text{math. cos(angle)}) \tag{6}$$

$$S = 0.5 \times a \times b \times \text{math. sin(angle)} \tag{7}$$

For a comprehensive evaluation of samples from seven sites, radar chart areas S and perimeter L were used. The values of S and L and the ratio of $S\ L^{-1}$ were used for the comprehensive evaluation of waxy yam. We chose the average value between 2021 and 2022 for a 7-site evaluation.

For the detection of pesticides, sample extraction and purification were performed as described by Sun et al.[16] Fresh waxy yam samples were homogenized and stored at −20 °C after the removal of surface soil residues for analysis. The steps for the QuEChERS process are shown in Figure 2.

A total of 42 batches of glutinous yam samples were collected in 2021−2022 for 68 pesticide multiresidue tests. Ultrahigh-performance liquid chromatography coupled with tandem mass spectrometry (HPLC−MS/MS, LCMS 8050, Shimadzu, Japan) was used to measure the pesticide multiresidues. Based on a study by Xu et al.,[17] the conditions for chromatography and mass spectrometry were established. Specific information on the 68 pesticides tested is provided in the Supporting Information (Table S1).

2.3. Statistical Analysis. The mean ± SE values were calculated. Statistical calculations were performed by one-way analysis of variance (ANOVA) using SPSS software, version 22 (SPSS, Inc., Chicago, IL, United States). Multiple comparisons among treatments of significant differences were conducted by using LSD (least significant difference) ($p < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Oxidase Content of PPO, POD, and SOD. The contents of the three oxidases in the 2 years are shown in Figure 3. As Figure 3 shows, the contents of the three oxidases from the seven sites varied greatly between 2021 and 2022. The PPO contents were 127.34−142.78 U g^{-1} fresh weight in 2021 and 124.47−195.18 U g^{-1} fresh weight in 2022. The POD contents were 115.83−360.82 U g^{-1} fresh weight in 2021 and 112.34−357.25 U g^{-1} fresh weight in 2022. The SOD contents were 112.34−357.25 U g^{-1} fresh weight in 2021 and 68.25−126.67 U g^{-1} fresh weight in 2022. Sites 1 and 2 were large-scale sites with more than 1 ha of area. The two large sites had carried out standardized production for several years. Large-scale sites (sites 1 and 2) have an advantage over farmer household production (sites 3−7) because they are large in scale and have the brand awareness to build quality products,

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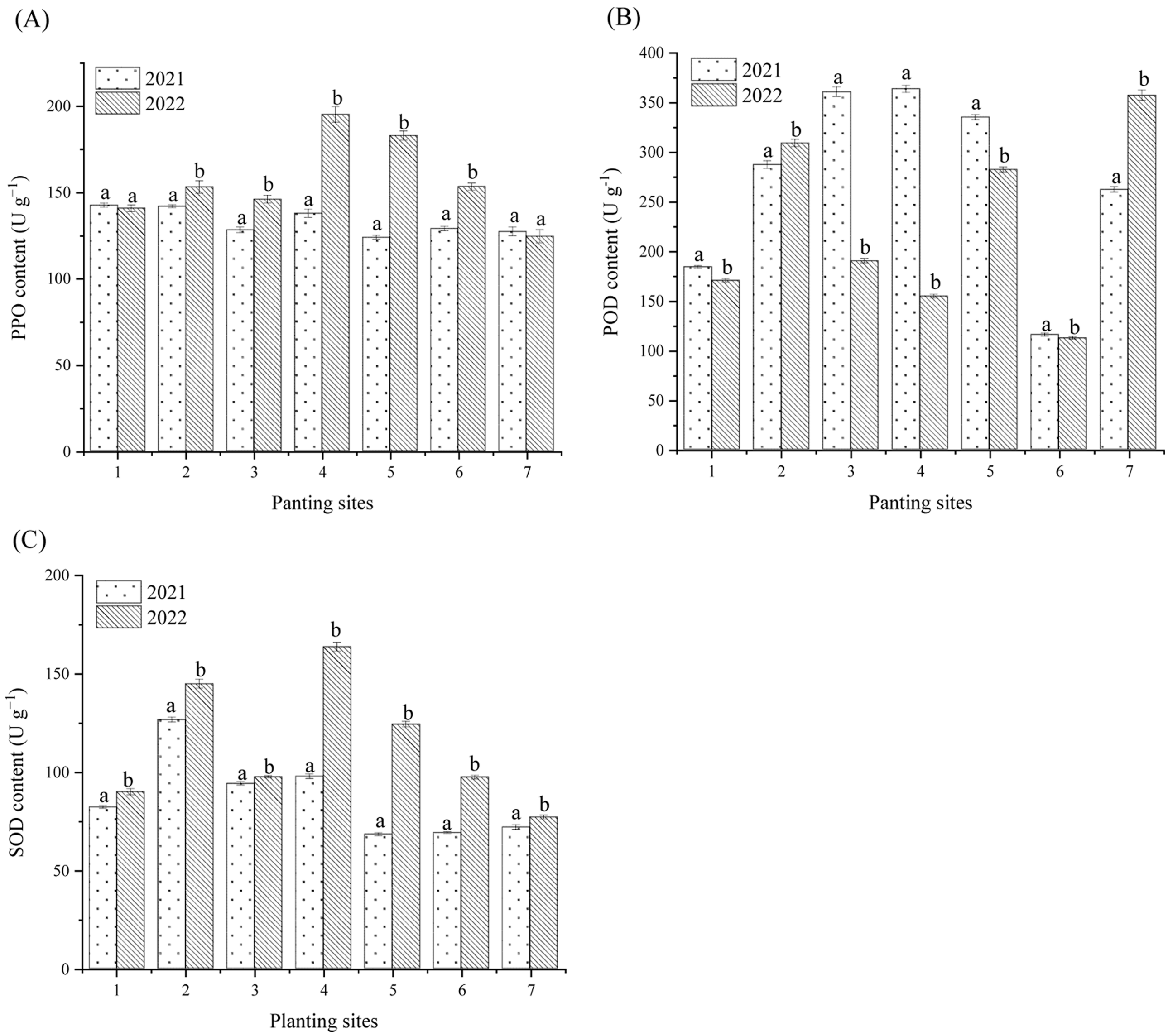

Figure 3. Contents of three oxidases at seven sites in 2 years [(A) polyphenol oxidase (PPO) content at seven sites; (B) peroxidase (POD) content at seven sites; (C) superoxide dismutase (SOD) content at seven sites]. Different lowercase letters represented a significant difference at $p < 0.05$ level.

and the use of production inputs such as fertilizers and pesticides is more standardized and reasonable; therefore, compared to farmer household production, the quality of waxy yam from large-scale sites is more stable.

Oxidase content is the key enzyme involved in enzymatic browning, including resistance-related enzymes such as PPO, POD, and SOD. PPO, a copper-containing nuclear-encoded enzyme of oxidoreductase, typically consists of three parts with a plastid peptide, a copper ion active center, and a C-terminus with a shielding function, and it is responsible for the oxidative conversion of phenolic compounds to polymers.[18] The PPO can be converted to oxy-PPO by reaction with O_2, and enzymatic browning occurs. The browning stage is classified into three states based on its interaction with copper and oxygen: met-PPO ($Cu^{2+}-OH-Cu^{2+}$), deoxy-PPO (no bridging to oxygen), and oxy-PPO ($Cu^{2+}-O_2-Cu^{2+}$).[19] The background content of PPO, POD, and SOD is affected by the yam genotype, and the extent of their activity varies during the yam maturation time, especially from August to October. The oxidase content is affected by planting technology and soil properties. The results showed that at different planting sites, the PPO, POD, and SOD varied greatly according to the rainfall, temperature, and humidity changes between 2021 and 2022 in Wencheng. According to the local meteorological data recording, the rainfall and temperature were relatively normal in 2021, but the weather was relative, with high temperatures and less rainfall in 2022. Rainfall is an important factor that affects the yam features in the late growth stage. The rainfall in October was 239.7 mm in 2021 and 16.3 mm in 2022. The minimum and maximum temperatures in October 2021 were 11 and 33 °C, respectively, while the minimum and maximum temperatures in October 2022 were 8 and 37 °C, respectively, with a greater temperature difference in October 2022. Wencheng climate data is shown in Table 1.

Figure 3 and Table 1 show that PPO and SOD contents in 2021 were relatively lower than the values in 2022 for the 7 typical planting sites. For POD content, the values of sites 1, 3, 4, 5, and 6 in 2021 were higher than those in 2022, and the values of sites 2 and 7 were lower in 2021 than in 2022. Adequate water reduced the production of oxidase during the

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Table 1. Wencheng Climate Data in 2021 and 2022

		lowest temperature (°C)	highest temperature (°C)	rainfall (mm)
2021	August	21	35	432.1
	September	16	36	39.8
	October	11	33	239.7
2022	August	20	40	559
	September	16	36	39.3
	October	8	37	16.3

late growing stage of waxy yam and was beneficial for the processing and preservation of yams to prevent enzymatic browning.

3.2. Mineral Materials, Amylose, Amylopectin, Protein, and Reducing Sugar Content Analysis. The detection of amylose, amylopectin, protein, reducing sugar, K, Fe, and Zn contents from 7 sites in 2021 and 2022 is shown in Table 2.

The radar map analysis is shown in Figure 4. As an important staple food in Wencheng, the taste quality of waxy yam is a decisive factor that affects quality and consumer preference. In the present study, research on the taste quality of waxy yam mainly focused on amylose and amylopectin contents. Table 2 shows that the amylose content varied from 26.74 to 33.79% and that the amylopectin content varied from 41.34 to 56.48%. The amylopectin content was generally higher than the amylose content, which is the main factor affecting its waxy features. Compared with waxy rice, the amylose content was relatively low (0.00−24.8%), and the amylopectin content contained most of the starch value, distributed between 75.2 and 100.0%.[20] Compared with the high proportion of amylopectin content in waxy rice, the amylopectin content in glutinous rice yam is relatively low. The amylose content varied greatly, which is the main factor affecting the glutinous stability of the waxy yam. The protein content of waxy yam varied from 1.40 to 3.04%. The reducing sugar content of waxy yam varied from 0.31 to 0.77%, as it plays a vital role in the edible quality and processing properties of waxy yam. Previous studies have shown that during processing, Maillard reactions occur between carbonyl compounds (reducing sugars) and amino compounds (amino acids and proteins), which give unique flavor and color to food products. As amino acids and proteins are limited, the reducing sugar content plays an important role in affecting the color of the waxy yam. Therefore, it is necessary and significant to accurately monitor the reducing sugar content in waxy yam to improve its acceptability and utilization.[21] Currently, waxy yam is consumed fresh, and a small amount is used for processing. It is necessary to further study the best contents of protein, amino acids, and reducing sugars to improve the quality of the waxy yam processing products.

Waxy yam contains rich K elements, ranging from 3102 to 5412 mg kg^{-1}. The Fe content varies from 4.12 to 6.59 mg kg^{-1}, and the Zn content varies from 3.90 to 7.30 mg kg^{-1}. These three types of elements are essential for human health, and the results suggest that waxy yams have good health functions. As a tonic, the market value of waxy yam is steadily rising, and yam has become increasingly popular. The cultivation area therefore has continuously expanded, and the value and profitability of this crop to farmers have increased in recent years.[22] An appropriate supply of N, P, and K fertilizer is beneficial for increasing yam yield and nutrient accumulation.[23]

For a comprehensive evaluation, the balance of nutrients is crucial for foods.[24] For waxy yam, amylose, amylopectin, protein, reducing sugar, and mineral contents, including K, Fe, and Zn, are important nutrient components in yam tubers. Although there is currently a lack of standards for evaluating the quality of waxy yams, a dimensionless procedure was carried out to constrain the values between 0 and 1; the closer the value to 1, the better the trait. The chart area S and perimeter L are calculated in Table 3. The sum of the L and S values and the total number were used to evaluate the order of the seven sites.

Table 3 shows that the quality evaluation order of the sites was as follows: 2 > 1 > 7 > 5 > 3 > 4 > 6. The comprehensive evaluation results showed that standardized production sites 1 and 2 had a relatively higher quality than sites 3−7 with small farmers.

Table 2. Detection Results of Quality Indicators from 7 Sites

quality index	year	site 1	site 2	site 3	site 4	site 5	site 6	site 7
amylose, %[a]	2021	33.79 ± 1.52	31.58 ± 2.38	27.06 ± 2.39	27.71 ± 1.96	26.74 ± 1.89	29.20 ± 2.96	30.36 ± 2.68
	2022	32.37 ± 2.36	29.00 ± 1.64	31.35 ± 2.58	32.88 ± 2.03	33.71 ± 2.37	31.60 ± 2.35	33.59 ± 2.56
amylopectin, %[a]	2021	49.30 ± 3.84	50.97 ± 4.26	49.35 ± 3.96	48.72 ± 3.84	53.60 ± 4.26	45.45 ± 5.27	41.34 ± 3.83
	2022	49.81 ± 3.26	49.88 ± 3.98	45.10 ± 4.08	44.41 ± 4.02	45.87 ± 3.84	48.73 ± 4.38	56.48 ± 4.98
protein, %[b]	2021	2.38 ± 0.16	2.82 ± 0.84	2.22 ± 0.98	1.40 ± 0.02	2.00 ± 0.26	1.62 ± 0.14	3.04 ± 0.69
	2022	2.29 ± 0.12	2.36 ± 0.24	1.98 ± 0.12	2.32 ± 0.04	1.72 ± 0.12	2.36 ± 0.16	2.25 ± 0.12
reducing sugar, %[c]	2021	0.54 ± 0.08	0.53 ± 0.03	0.31 ± 0.09	0.57 ± 0.03	0.65 ± 0.08	0.39 ± 0.02	0.31 ± 0.05
	2022	0.57 ± 0.05	0.53 ± 0.04	0.77 ± 0.06	0.37 ± 0.02	0.38 ± 0.04	0.31 ± 0.04	0.41 ± 0.03
K, mg kg^{-1}[d]	2021	4060 ± 125	4510 ± 236	3113 ± 126	3102 ± 156	5412 ± 214	3136 ± 236	5368 ± 356
	2022	3996 ± 108	5126 ± 208	3338 ± 253	4165 ± 189	4071 ± 198	4023 ± 248	4028 ± 298
Fe, mg kg^{-1}[d]	2021	5.25 ± 0.08	6.59 ± 0.26	5.19 ± 0.26	5.14 ± 0.08	4.76 ± 0.08	4.14 ± 0.24	4.12 ± 0.18
	2022	5.72 ± 0.06	6.4 ± 0.98	6.15 ± 0.08	6.3 ± 0.23	5.82 ± 0.12	5.36 ± 0.37	5.26 ± 0.24
Zn, mg kg^{-1}[d]	2021	4.44 ± 0.04	3.48 ± 0.56	4.12 ± 0.12	3.90 ± 0.24	4.12 ± 0.38	3.87 ± 0.15	4.03 ± 0.19
	2022	5.72 ± 0.08	7.30 ± 0.87	6.86 ± 0.36	6.57 ± 0.36	6.33 ± 0.26	6.55 ± 0.24	6.13 ± 0.38

[a]Amylose and amylopectin contents were determined by a dual-wavelength iodine binding technique. The detailed process is described in Supporting Information A. [b]Protein content was determined by the Kjeldahl method. The detailed process is described in Supporting Information B. [c]Reducing sugar content was determined by direct titration. The detailed process is described in Supporting Information C. [d]Minerals (K, Fe, and Zn) were determined by the atomic absorption spectroscopy technique. The detailed process is described in Supporting Information D.

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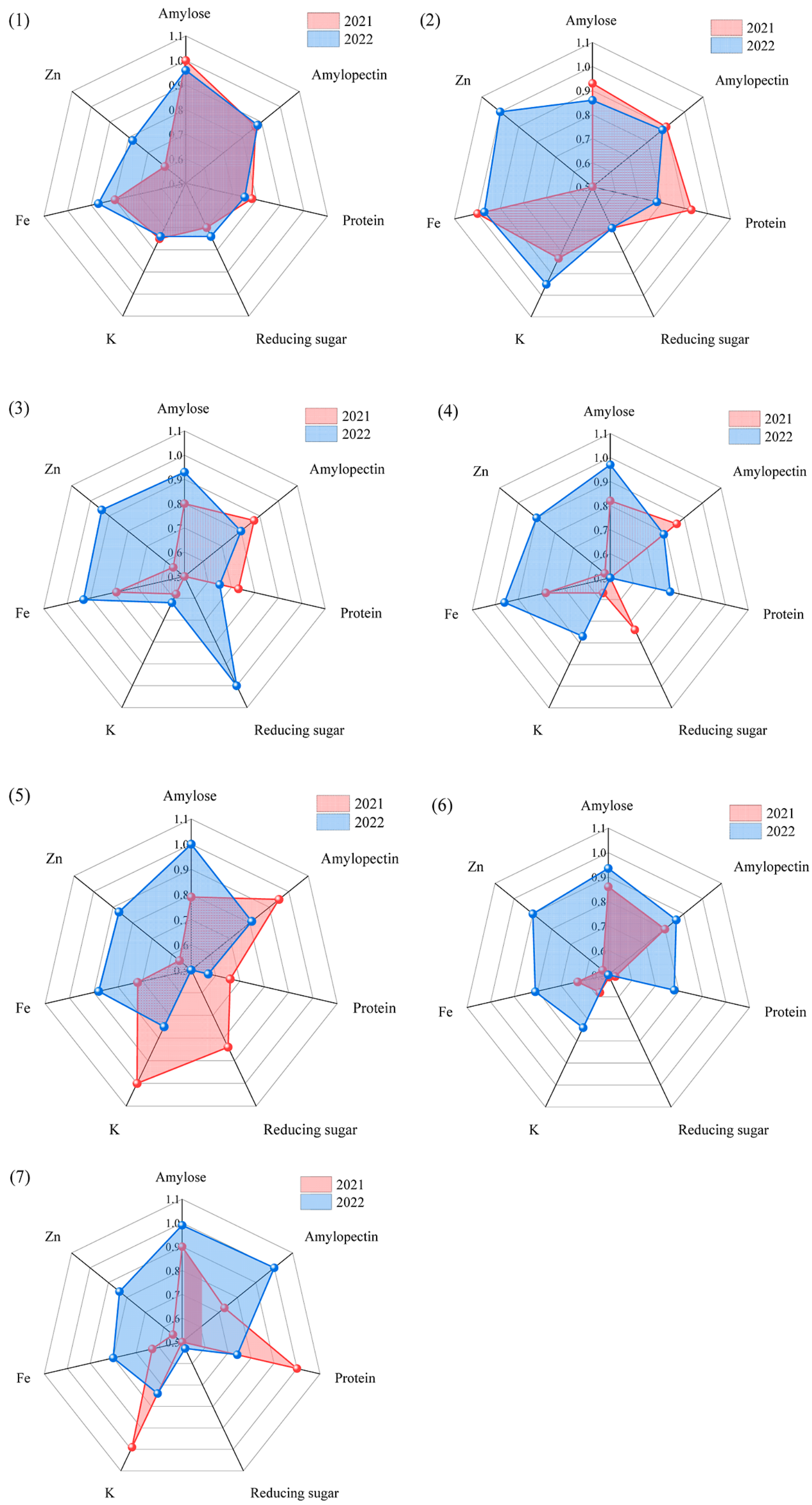

Figure 4. Radar map analysis of the 7 sites between 2021 and 2022 (planting sites 1 to 7).

3.3. Analysis of Pesticide Residues. A total of 42 samples were collected from 2021 to 2022, with 6 samples from each planting site, respectively. As shown in Figure 5, among all of the samples of waxy yam, no pesticides were detected in 27 samples. Among them, all samples from planting sites 1 and 2 were not detected with pesticides, and the number of uncontaminated samples from collection sites 3 to 7 was 3, 3, 2, 3, and 4, respectively. A total of three different pesticides were detected in the 42 samples. The detection rate of pesticides reached 35.71%, and contamination ranged from one to three detectable pesticides per sample. Pesticides were not detected in most of the samples, indicating that waxy yam is safe for consumption (Figures 5 and 6). Fewer pesticides were detected in waxy yam from large-scale production subjects (sites 1 and 2) compared to small-scale farmers (sites 3 to 7) because agricultural-scale subjects have more advantages than small-scale farmers in that they are large in scale, are standardized in production and marketing, and the

Table 3. Comprehensive Evaluation of Nutrient Components in Yam Tubers

quality indices	years	1	2	3	4	5	6	7
amylose[a]	2021	1.00	0.93	0.80	0.82	0.79	0.86	0.90
	2022	0.96	0.86	0.93	0.97	1.00	0.94	0.99
amylopectin[a]	2021	0.87	0.90	0.87	0.86	0.95	0.80	0.73
	2022	0.88	0.88	0.80	0.79	0.81	0.86	1.00
protein[a]	2021	0.78	0.93	0.73	0.46	0.66	0.53	1.00
	2022	0.75	0.78	0.65	0.76	0.57	0.78	0.74
reducing sugar[a]	2021	0.70	0.69	0.40	0.74	0.84	0.51	0.40
	2022	0.74	0.69	1.00	0.48	0.49	0.40	0.53
K[a]	2021	0.75	0.83	0.58	0.57	1.00	0.58	0.99
	2022	0.74	0.95	0.62	0.77	0.75	0.74	0.74
Fe[a]	2021	0.80	1.00	0.79	0.78	0.72	0.63	0.63
	2022	0.87	0.97	0.93	0.96	0.88	0.81	0.80
Zn[a]	2021	0.61	0.48	0.56	0.53	0.56	0.53	0.55
	2022	0.78	1.00	0.94	0.90	0.87	0.90	0.84
average S[b]		1.78	2.03	1.65	1.58	1.71	1.43	1.72
average L[b]		4.87	5.16	4.59	4.51	4.70	4.28	4.70
S/L		0.366	0.393	0.359	0.350	0.363	0.335	0.365
order		2	1	5	6	4	7	3

[a]Data processing of amylose, amylopectin, proteins, reducing sugars, and minerals (K, Fe, and Zn) in the table was based on eq 4. [b]Data processing of average S and average L in the table was based on eqs 5−7.

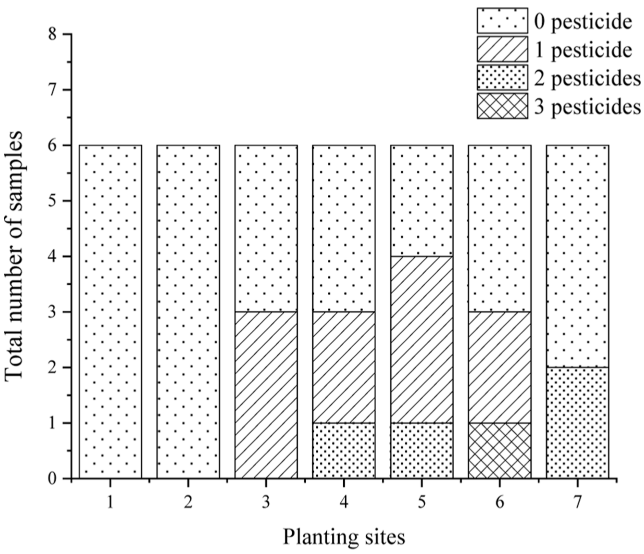

Figure 5. Detection of pesticide residues in samples from planting sites 1 to 7.

exact responsibility of the subjects can be accurately tracked by recording input use and production management practices. Large-scale production addresses the challenges faced by retail farmers by centralizing the purchase of inputs, providing technical training, and supervising the production of products.[25]

In this study, the detected pesticides were azoxystrobin (nine samples), with a residue range of 0.008−0.031 mg kg^{-1}; prochloraz (six samples), with a residue range of 0.007−0.027 mg kg^{-1}; and carbendazim (six samples), with a residue range of 0.009−0.049 mg kg^{-1}; specific data are presented in Supporting Information (Table S2). Among the 3 pesticides detected in all samples, only the maximum residue limits (MRLs) of prochloraz have been established in yam according to GB 2763−2021,[26] with values of 0.3 mg kg^{-1}. The test values are well below this limit (0.3 mg kg^{-1}). According to the EU pesticide database, the maximum residue limits of azoxystrobin, prochloraz, and carbendazim in yam are 1.0, 0.03, and 0.1 mg kg^{-1}[27], respectively. It is clear that the residues of the three pesticides detected in this study were very low; thus, this indicates that the risks associated with the consumption of waxy yam are considered safe for humans and do not pose a potential risk to human health as far as food safety. Since yams are eaten mainly from underground tubers, they are not directly exposed to pesticides, which may be one of the reasons why fewer pesticides were detected in yams than in other leafy vegetables. Yilmaz and Balkan tested potatoes for

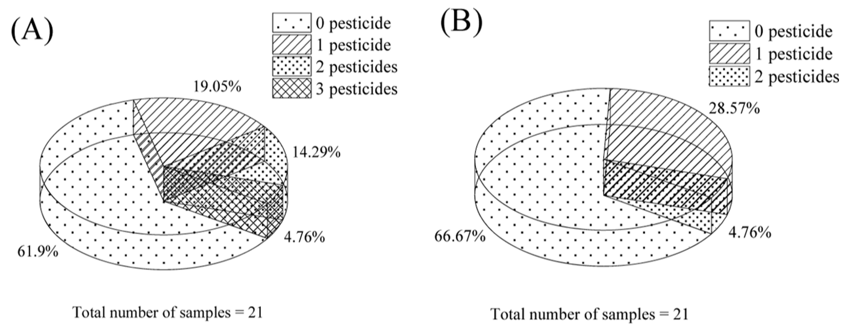

Figure 6. Proportion of pesticide residues in samples (A) representing 2021 and (B) representing 2022.

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135 pesticides in a multiresidue assay, and no pesticide residues were found in 93 out of 104 samples, and the other samples in which pesticides were detected had very low residue levels,[28] which is consistent with the results of our study. Sun et al. found that the median residue values of chlorfenapyr in radish and radish leaves were 0.12 and 3.92 mg kg^{-1} for the same duration of treatment (14 days), respectively, and the residue values in radishes were much lower than those in radish leaves.[29] In addition, it may be attributed to microbial degradation in the soil.[30] The types and mechanisms of microbial degradation of organophosphorus pesticides were systematically described by Ji et al.[31] Degradative strains isolated from pesticide-contaminated soils can utilize organophosphorus pesticides as a carbon and energy source for growth.

However, it is not optimistic that some organic products on the EU market are contaminated with pesticides, which is a cause for concern among consumers. Kazimierczak et al.[32] analyzed 96 samples of organic agricultural products sold in the Polish market for pesticide multiresidue analysis and found that 7.3% of the samples (2 potatoes and 5 carrots) were contaminated with pesticides, and chlorpyrifos was detected above the MRL (0.1 mg kg^{-1}) for one of the carrot samples. Apart from the use of unapproved pesticides, the probable cause was the transfer of pesticides that had previously accumulated in the soil to the plants. In fact, pesticides have been used in Europe for more than 70 years. Geissen et al.[33] conducted pesticide residue tests on 340 agricultural soils in the European Union and found that pesticide residues in soils of conventional farms could reach up to 16 pesticides, whereas residues in soils of organic farms could reach up to 5 pesticides, and the concentration of pesticide residues in organic soils was 70−90% lower than that in conventional soils.

Brevik et al.[34] showed that pesticide residues in soil can enter the food chain and thus affect food quality and human health. Since most soils are more or less exposed to pesticides, pesticide residues can be detected in organic crops. China has been developing green and organic agriculture in recent years, and even though pesticide residues in Wencheng waxy yam were detected at a very low level, we still need to pay attention to controlling the use of pesticides and preventing pesticides from accumulating in the soil and contaminating the product.

4. CONCLUSIONS

In this study, we investigated the oxidase content, including PPO, POD, and SOD, and quality properties, including amylose, amylopectin, protein, reducing sugar, and mineral contents, of Wencheng waxy yam through a 2 year investigation. The PPO content varied from 124.47 to 195.18 U g^{-1} of fresh weight, while the POD content varied from 112.34 to 360.82 U g^{-1} of fresh weight. The SOD content varied from 68.25 to 357.25 U g^{-1} of fresh weight. Rainfall was an important factor affecting the yam features and the formation of oxidase during the late growth stage. Adequate water reduced oxidase production and was beneficial for the processing and preservation of yams to prevent enzymatic browning. A comprehensive evaluation was carried out using radar map analysis; the results showed that with a quality content evaluation of amylose, amylopectin, protein, reducing sugar, and mineral contents, including K, Fe, and Zn, standardized production sites 1 and 2 had relatively higher quality than sites 3−7 with small farmers. In addition, the results for pesticide residues also show that yams contain very little pesticide residue and are safe for consumers. Individual farmers are the basic unit of the Chinese agricultural economy, and green and standardized production is the trend of modern agricultural development. It is recommended that individual farmers join family farms and farmers' cooperatives to ensure the quality and safety of their products by selecting good varieties, unifying the procurement of agricultural materials, and standardizing production management. It is worth noting that the monitoring sites and tracking time of waxy yam in this study were limited, and the current understanding of the quality properties and pesticide residue levels of waxy yam was not comprehensive enough. It is hoped that the existing study will be supplemented by more monitoring data in the future.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.3c09444.

2 year Wencheng waxy yam pesticide residue investigation and quality evaluation (PDF)

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Notes

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