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Effects of potassium fertilization on potato starch physicochemical properties

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ABSTRACT

Potato starch serves as an excellent raw material or food additive in the food industry. With the advancement of the potato staple food strategy in China, improving the potato starch yield and quality has attracted more and more attention. Potassium is an essential nutrient for potato due to its direct effects on the yield and quality of potato tubers. Here, the effects of three different potassium levels on potato starch physicochemical properties were evaluated by field experiments. With increasing potassium fertilization rates, the amylose content, phosphorus content and particle size decreased, thereby resulting in low gelatinization temperature, breakdown and setback viscosity, and high swelling power, relative crystallinity and transparency. Our study indicated that enhanced potassium fertilization improved the resistance to heat and shear stress and decreased the retrogradation of starch, and the 270 kg/ha potassium fertilization rate could obtain the highest tuber and starch production with desirable starch physicochemical properties. The integrated results also provide some novel insights into the management of the fertilization conditions to obtain native starches with special properties.

1. Introduction

Potato is one of the most important food crops in the world, with an annual production of >380 million tonnes [1]. When compared with corn, rice and wheat starches, potato starch, the main carbohydrate of potato tubers, has a lower gelatinization temperature, higher transparency and viscosity [2]. Therefore, potato starch serves as an excellent raw material or food additive in the food industry [3].

China is the world's largest potato producer [1]. With the advancement of the potato staple food strategy in China, the market demand for starch is increasing, and the related food products have attracted more and more attention [4]. However, their applications are closely related with potato starch physicochemical properties. For instance, amylose as the most important factor significantly affects the starch pasting properties [5]. A high amylose content may affect food stability and quality by increasing starch retrogradation [6–8]. Thus, improving the yield and quality of potato starch is the focus of attention in the Chinese potato staple food strategy.

The physicochemical properties of potato starch are not only related to cultivars, but also to temperature, fertilization, etc. [8–10]. Potassium (K) is a mineral nutrient with the largest demand for potatoes, with about 4.4 kg K removed per 1000 kg of tubers, and proper potassium management is extremely important for sustaining high tuber yield and quality [11,12]. Studies of rice starch showed that K fertilizer reduced the amylose and breakdown, and improved the cooking quality of rice [13]. Dai et al. [14] have also reported that K fertilizer promoted the accumulation of amylopectin and improved the physicochemical properties of wheat starch. Unfortunately, many of the potato growing areas in China are in poor mountainous regions with inadequate K fertilization [11,15,16]. The lack of K would lead to a decline not only in potato production, but also in starch content [16,17]. However, most previous studies are concentrated on the effect of K fertilization rates on tuber yield and starch content, and rare studies have been performed about its effects on the physicochemical properties of starch. In this study, the effects of potassium fertilization on potato starch physicochemical properties were investigated by a field experiment with two potato cultivars grown under different potassium fertilization rates. Our field research is of critical importance for establishing the relationship between K fertilization rates and potato starch quality.

2. Materials and method

2.1. Plant material and experimental design

The field experiment was conducted at Huazhong Agricultural University, Hubei Province, China (30°28′N, 114°21′E) in 2017. The soil in

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Table 1
Effect of potassium application on tuber yield, dry matter content, starch content and yield.

Cultivar	Potassium rate	Tuber yield	Dry matter content	Starch content in dry matter	Starch content in fresh tuber	Starch yield
	(kg/ha)	t/ha	g/100 g	g/100 g	g/100 g	t/ha
Zhongshu 5	135	28.4 ± 1.7 b	19.9 ± 0.5 a	70.4 ± 2.1 b	14.0 ± 0.3 ab	4.0 ± 0.3 c
	270	37.0 ± 1.8 a	19.6 ± 0.5 a	74.5 ± 1.7 a	14.6 ± 0.5 a	5.4 ± 0.3 a
	405	34.4 ± 1.4 a	18.2 ± 0.6 b	75.1 ± 1.8 a	13.7 ± 0.4 b	4.7 ± 0.3 b
Atlantic	135	24.1 ± 1.6 b	26.3 ± 0.5 a	72.6 ± 1.9 b	19.1 ± 0.5 ab	4.6 ± 0.4 c
	270	30.6 ± 1.7 a	25.8 ± 0.6 a	75.8 ± 1.6 ab	19.6 ± 0.6 a	6.0 ± 0.2 a
	405	28.7 ± 1.9 a	24.1 ± 0.7 b	76.8 ± 2.2 a	18.5 ± 0.5 b	5.3 ± 0.3 b

Data are means ± standard deviations. Values in the same column with different letters are significantly different ($p < 0.05$). Starch yield = Tuber yield × Starch content in fresh tuber.

the experimental field is yellow brown earth with the following basic physic-chemical properties: pH 7.08, organic matter 10.62 g/kg, available nitrogen 48.36 mg/kg, available phosphorus 9.03 mg/kg, available potassium 116.95 mg/kg. Two varieties (Zhongshu 5 and Atlantic) used in this study are widely extended in Hubei Province.

In this study, three potassium fertilization rates including 135, 270, and 405 kg/ha (low, medium, and high K) were repeated three times in a random block design with a plot area of 30 m^2. All the groups were treated with nitrogen 210 kg/ha, and phosphorus (P) 120 kg/ha. Urea was used as N fertilizer, potassium sulfate as K fertilizer, and calcium phosphate as P fertilizer. All the P, 50% K and 70% N were applied as a basal dressing at sowing, and the remaining fertilizers were used as top dressing during tuber formation. Potatoes were planted on January 3 and harvested on May 16. Other field management measures were consistent with local production. When harvesting, the potato yield was measured for each plot and the tubers of a similar size were selected for starch content determination and starch extraction.

2.2. Potato dry matter

Potato tubers were washed, peeled, cut into cubes, then dried at 65 °C until a constant weight. Dry matter content was determined from the difference in the weight of potato samples before and after drying. Finally, the sample was milled and passed through a 100-mesh sieve for starch content determination.

2.3. Starch content of potato tuber

Starch content was determined based on potato dry matter as well as fresh tuber weight. The potato dry matter sample was hydrolyzed with hydrochloric acid according to the Chinese standard method GB/T 5009.9-2008 [18] for starch content analysis. Then, the percentage of total reducing sugars was determined with dinitrosalicylic acid reagent (DNS) according to the Miller method [19]. Starch content in potato dry matter was expressed as glucose equivalents multiplied by 0.9. Finally, starch content in fresh tubers was expressed by multiplying dry matter content by starch content in dry matter.

2.4. Isolation of starch

Potato starch was isolated according to the method of Huang et al. [20]. A composite sample of at least 8 potato tubers was used for isolation of starch. Potatoes were washed, peeled and cut into cubes. The small pieces of potato were soaked in 0.1% (w/v) sodium bisulfite solution for 10 min, then smashed with a low speed blender containing sodium bisulfite solution. The resulting slurry was passed through 100-mesh sieve to remove the debris, and the suspension was filtered three times using a 120-mesh sieve, followed by standing at room temperature for 2 h. The precipitated starch was suspended in distilled water and precipitated again. This procedure was repeated until the color of the precipitated starch was pure white. The starch layer was dried at 45 °C for 24 h in a drying oven. Finally, the starch was milled and passed through a 100-mesh sieve.

2.5. Composition of starch

The amylose content of potato starches were determined according to the method of Morrison and Laignelet [21]. The amylose content (%) was calculated from the blue value (defined as the absorbance of 10 mg anhydrous starch in 100 mL of diluted I_2-KI solution at 635 nm and 20 °C) according to the following equation: Amylose (%) = (28.414 × Blue Value) - 6.218. The phosphorus content of potato starch samples were measured according to the method of Thomas, Sheard, and Moyer [22]. Briefly, approximately 200 mg of starch sample was placed in a 50-ml volumetric flask. Then, the sample was digested with H_2SO_4-H_2O_2 at about 225 °C. Finally, the phosphorus content in the digestion solution was determined using the molybdenum-blue colorimetric method.

2.6. Particle size distributions

The potato starch sizes were determined using a laser diffraction particle size analyzer (Malvern Mastersizer 3000, Malvern Instruments Ltd., Malvern, UK). The size distribution was expressed in terms of the volumes of equivalent spheres. The D [3,4] (De Brouckere diameter) was reported as the volume mean diameter.

2.7. Swelling power

The swelling power of potato starches were determined according to the method of Noda et al. [23] with some modifications. Briefly, starch suspensions (2%, w/v, d.b.) were added to a screw-cap test tube and heated at 70 °C for 30 min with frequent mixing by inverting at 2 min intervals. The tubes were then cooled to room temperature and centrifuged at 5000*g* for 15 min, and the supernatant was removed with suction. The swelling power was calculated as the weight of the swelled starch residue per 1 g of dry starch.

2.8. X-ray diffraction analysis

X-ray diffraction patterns of potato starches were obtained with a D8 ADVANCE X-ray diffractometer (Bruker, Germany). An accelerating voltage and current of 40 kV and 40 mA were used. The diffractograms were recorded in a 2θ between 4° and 40° with a scanning rate of 4.0°/min. Relative crystallinity (%) was calculated by using software (MDI Jade 6).

Table 2
Effect of potassium application on amylose and phosphorus content of potato starches.

Cultivar	Potassium rate (kg/ha)	Amylose (%)	Phosphorus (mg/kg)
Zhongshu 5	135	30.2 ± 0.9 a	755 ± 28 a
	270	28.5 ± 0.6 b	692 ± 23 b
	405	27.6 ± 0.7 b	644 ± 20 c
Atlantic	135	28.1 ± 0.8 a	957 ± 33 a
	270	27.2 ± 0.5 ab	884 ± 28 b
	405	26.3 ± 0.7 b	842 ± 37 b

Data are means ± standard deviations. Values in the same column with different letters are significantly different ($p < 0.05$).