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REGULAR ARTICLE

Changes in the content and influence factors of α-solanine in potato during storage

Xiaolong Chen[1], Yongbo Ding[1], Jianquan Kan[1,2]*

[1]College of Food Science, Southwest University, Chongqing 400715, China, [2]Laboratory of Quality & Safety Risk Assessment for Agro-products on Storage and Preservation (Chongqing), Ministry of Agriculture, 400715, China

ABSTRACT

This paper presents a study on storage of three species of potato: Ruby, Black Beauty and Favorita. By using of high-performance liquid chromatography, the study investigated their variation pattern of α-solanine in different storage conditions including greenhouse with fluorescent lamp, greenhouse without fluorescent lamp, cold storage (4°C) and shaded, machine-damaged and shaded, and machine-damaged with fluorescent lamp. The experimental results showed that the content of α-solanine in Ruby is higher than Favorita and Black Beauty under the same conditions; and the content of α-solanine in peels is generally higher than tubers among the same specie; the following storage conditions influenced the content of α-solanine in potatoes to varying degrees: machine-damaged with fluorescent lamp > machine-damaged and shaded > greenhouse with fluorescent lamp > greenhouse without fluorescent lamp > cold storage (4°C) and shaded; and the content of α-solanine presented a trend of increasing firstly and then decreasing under the greenhouse with fluorescent lamp, greenhouse without fluorescent lamp, machine-damaged and shaded and machine-damaged with fluorescent lamp, but it nearly remains unchanged in the cold storage (4°C) and shaded. This study provides a useful reference to the proper storage of potatoes.

Keywords: Potato; α-solanine; Machine-damaged; Light; Storage

INTRODUCTION

Potato (*Solanum tuberosum*), which belongs to the solanaceae, is one of the four major food crops in worldwide, and it is rich in starch, protein, carbohydrate, a variety of vitamins and inorganic salts (Deng et al., 2012). Nowadays, the amount of potato-derived food and products have increased rapidly which has provided a good chance for the development of potato industry (Diaztoledo et al., 2016; Jochym et al., 2017; Van et al., 2017). α-Solanine, which is formed by sugar chain and solanidine, is one kind of poisonous glycoalkaloid in potato (Søren et al., 2012; Jens et al., 2009; Jacques et al., 2012). α-Solanine has the effect of hematolysis and it can inhibit the activity of cholinesterase which may induce the nerve-related symptoms. There often accompanied by nausea, vomiting, abdominal pain, diarrhea, dizziness, and other symptoms after solanism (Shiro et al., 2013; Romanucci et al., 2016). However, current studies reveal that the α-solanine have some beneficial effects, such as anti-cancer (Zhang et al., 2016; Shin et al., 2016), anti-bacterial (Tatiana et al., 2014) and anti-diabetic (Camire, 2009). In mature potato, the content of α-solanine is generally low (Ping et al., 2017), but there are lots of α-solanine in green or gemmiparous potato because of the improper storage, especially the site of green or germination (Affleck et al., 2017). It may cause poisoning or death once humans have consumed the green or sprouted potato, and some cases of poisoning accidents have been reported (Koffi et al., 2017; Dong et al., 2013). Nowadays, the studies of α-solanine in potato have mostly focused on the determination of its content but rarely investigated its influencing factors and the variation pattern of α-solanine's content in potatoes under different storage conditions. Therefore, it has a great significance to research on its influencing factors and the variation pattern of the α-solanine's content in potatoes under different storage conditions.

In this study, high-performance liquid chromatography (HPLC) was performed to determine the content of α-solanine in different varieties potato under different storage conditions such as greenhouse with fluorescent

***Corresponding author:**
Jianquan Kan, College of Food Science, Southwest University, Tiansheng Road 1, Chongqing, 400715, PR China. Tel.: +86 23 68 25 03 75. Fax: +86 68 25 19 47 E-mail: kanjianquan@163.com

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lamp, greenhouse without fluorescent lamp, cold storage (4°C) and shaded, machine-damaged and shaded, and machine-damaged with fluorescent lamp. The experimental have obtained an ideal result which may provide a useful reference to the proper storage of potatoes.

MATERIALS AND METHODS

Chemicals and materials

Different varieties potato (namely Favorita, Black Beauty and Ruby) were provided by Potato Research Institute of Guizhou Academy of Agricultural Sciences, China. Standard of α-Solanine was purchased from Sigma Chemical Co. (St. Louis, MO, USA). Sodium hypochlorite (99%), ethanol, acetic acid, concentrated sulfuric acid (98%), and concentrated ammonia water (25%–28%) were of analytical grade, purchased from Chengdu Kelong Chemical Reagent Factory, China. Acetonitrile and methanol were of chromatographic grade, purchased from Chengdu Kelong Chemical Reagent Factory, China.

Simulated storage experiments

Firstly, the surface of Ruby, Black Beauty and Favorita were washed with water, and then immersed to 200 μg/L aqueous sodium hypochlorite solution for about 3 minutes. Then gently wiped the surface water with gauze. Finally, divided the whole potatoes into five groups. One group was placed in greenhouse with fluorescent lamp (2 meters from a fluorescent lamp, illuminated at 60 W for approximately 24 h/d). One group was placed in greenhouse without fluorescent lamp. One group was placed in cold storage (4°C) and shaded. The other two groups were cut with a fruit knife to make 2 to 3 wounds with a size of 1 cm^2 and then respectively placed in shaded or fluorescent lamp (2 meters from a fluorescent lamp, illuminated at 60 W for approximately 24 h/d). Its content of α-solanine was measured each 7 days, and each measurement was repeated three times. Pictures were regularly obtained each 7 days and the temperature and humidity in the storage environment were recorded in each afternoon (Meng et al., 2012).

Determination of α-Solanine

Took out 3 or 4 potatoes, respectively collected and smashed them in a pulverizer after their peels and tubers had been separated by peelers. Then put the potato peels and tubers into valve bag.

Weighed 10.000 g above sample in a 250 mL conical bottle, then added 100 mL ethanol and acetic acid (100:30, V/V), magnetically stirred for 8 h at 50°C, then dried by a rotary evaporator after it had been filtered. Used 30 mL 1% H_2SO_4 to mix and dissolve the target substance, sonicated for 45 min, and filtered again. Adjusted the pH to 10.5 by concentrated aqueous ammonia. The mixture was then placed at 4°C to pass the night, after it, centrifuged at 2795 g for 15 min, discarded the supernatant and washed the precipitate with 1% aqueous ammonia until to the liquid was clear. Used chromatographic grade methanol to dissolve the precipitate and then fixed it to 5 mL. The mixture was placed in liquid vials after it had been filtered by a 0.22 μm organic membrane filter for HPLC (Agilent Science and Technology Ltd., Germany) analysis (Abdul et al., 2012; Marcela et al., 2014).

The liquid chromatography conditions was as flows: a C_{18} stainless steel column (4.6 mm × 150 mm, 5 μm) was used as a chromatographic column. The acetonitrile/phosphoric acid (0.4%; 25:75) was used as the mobile phase. The column temperature was 30°C, and the sample size was 10 μL. The detection wavelength was detected at 208 nm with a flow rate of 0.8 mL/min.

Accurately weighed 20.000 mg α-Solanine standard, dissolved and fixed it to a 50 mL capacity bottle with methanol. Afterward, took out 0.00, 1.00, 2.00, 3.00, 4.00, 5.00 and 6.00 mL sample and then fixed it to 10 mL. Took 1 mL sample, used HPLC to measure it after it had been filtered by a 0.22 μm organic membrane filter. A standard curve was drawn by using α-solanine concentration (g/L) as the X coordinate and the peak area as the Y coordinate. The linear regression equation was $Y=1637.8X-3.5301$ ($R^2=0.9995$). Linear relationship was considered good when α-solanine ranged from 0.04 g/L to 0.4 g/L. The obtained chromatogram is consistent with that of Xiao et al. (Xiao et al., 2011; Kodamatani et al., 2005).

Statistical analysis

Experimental data were analyzed using Origin 8.0 and Microsoft Excel 2007. Experiments were repeated thrice in parallel. Results were expressed as mean ± standard deviation.

RESULTS AND DISCUSSIONS

Simulated storage experiment of potato

The variation pattern of α-solanine in greenhouse with fluorescent lamp

From Fig 1, the content of α-solanine in different species potato peels and tubers presented a trend of increasing firstly and then decreasing under the greenhouse with fluorescent lamp. Ruby started to turn green and even sprout when it had been stored for approximately 21 days, and the content of α-solanine in sprouted and greened potato peels and tubers increased rapidly until it had been stored for approximately 42 days while the potato had

basically completed germination. After that, the content of α-solanine reached to its maximum when it had been stored for approximately 56 days, and its maximum is: 153.41mg/100g in peels, 95.16 mg/100g in tubers. But the content of α-solanine gradually decreased from then on due to the potato's nutrient had been depleted (Mäder et al., 2009). Black Beauty also started to turn green and even sprout when it had been stored for approximately 21 days, but it needed to be stored for approximately 35 days when the potato had basically completed germination, and it reached its maximum when it had been stored for approximately 56 days, the maximum is: 105.35mg/100g in peels, 51.25 mg/100g in tubers. However, the Favorita started to sprout and turn green when it had been stored for about 28 days which may attributed to its longer dormancy, and its content of α-solanine began to increased slowly when it had been stored about 49 days. It reached to its maximum when it had been stored for approximately 70 days, and the maximum is: 123.12mg/100g in peels, 75.11 mg/100g in tubers.

The variation pattern of α-solanine in greenhouse without fluorescent lamp

From Fig 2, the content of α-solanine in different species potato peels and tubers presented a trend of increasing firstly and then decreasing under the greenhouse without fluorescent lamp. Ruby sprouted but didn't turn green when it had been stored for approximately 21 days, its content of α-solanine in peels and tubers increased rapidly until it had been stored for approximately 35 days while the potato had basically completed germination, and it reached its maximum when it had been stored for approximately 49 days, the maximum is: 78.16 mg/100g in peels, 32.11 mg/100g in tubers. Black Beauty also sprouted and completed its sprout when it had been stored for 21 days and 35 days, but it reached the maximum when it had been stored for approximately 42 days, the maximum is: 41.02mg/100g in peels, 16.24 mg/100g in tubers. Favorita sprouted at 35 days, completed sprouted at 56 days, and reached its maximum at 70 days, the maximum is: 123.12mg/100g in peels, 75.11 mg/100g in tubers.

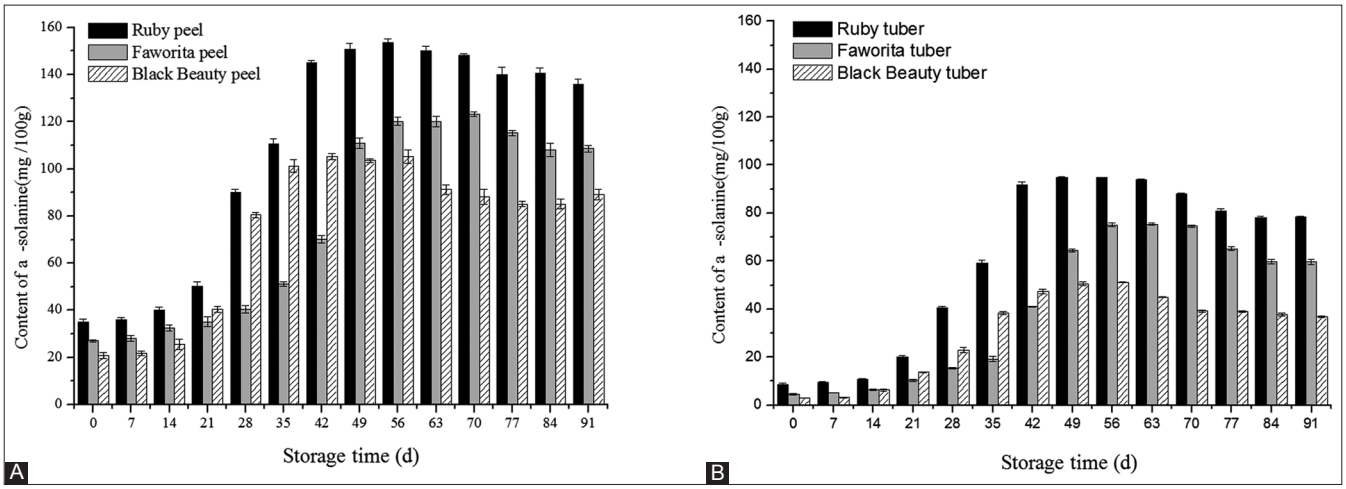

Fig 1. The variation pattern of α-solanine in greenhouse with fluorescent lamp (A:peel, B:tuber)

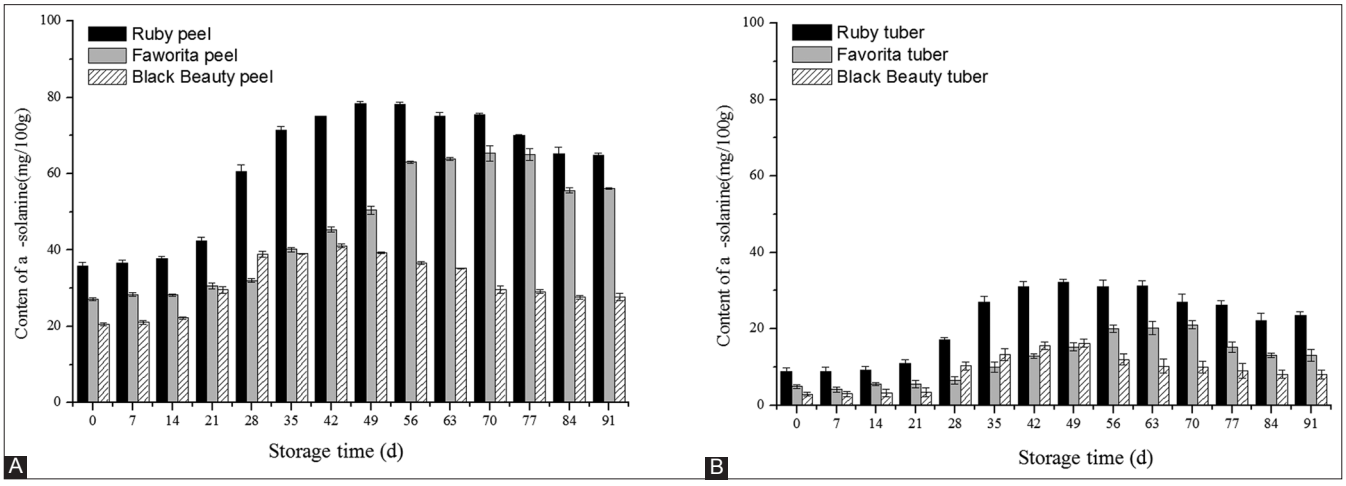

Fig 2. The variation pattern of α-solanine in greenhouse without fluorescent lamp (A:peel, B:tuber)

The variation pattern of α-solanine in cold storage (4°C) and shaded

From Fig 3, the content of α-solanine in different species potato peels and tubers nearly remained constant under the cold storage (4°C) and shaded, which is due to the physiological activity of potato is very low in this conditions, and the potato enter into the dormant, neither sprout nor turn green (Ping et al., 2017).

The variation pattern of α-solanine in machine-damaged and shaded

From Fig 4, the content of α-solanine in different species potato peels and tubers presented a trend of increasing firstly and then decreasing under the machine-damaged and shaded. When potato had been suffered from mechanical damage, it will enhance its respiration action and increase its enzyme activity to repair the damage which will lead to a rapid rise of α-solanine in potato (Ping et al., 2017). We can see from Fig 4 that there is a rapid rise of α-solanine in Ruby, Black Beauty and Favorita when they had been stored for 14 days. After that, Ruby's content of α-solanine increased slowly when it had been stored for approximately 49 days and it reached its maximum when it had been stored for approximately 70 days, the maximum is: 240.99mg/100g in peels, 115.62 mg/100g in tubers. Black Beauty's content of α-solanine increased slowly when it had been stored for approximately 35 days and it reached the maximum when it had been stored for approximately 63 days, the maximum is: 200.22mg/100g in peels, 110.65 mg/100g in tubers. Favorita's content of α-solanine increased slowly when it had been stored for approximately 56 days and it reached the maximum when it had been stored for approximately 63 days, the maximum is: 234.52mg/100g in peels, 110.25 mg/100g in tubers.

The variation pattern of α-solanine in machine-damaged with fluorescent lamp

From Fig 5, the content of α-solanine in different species potato peels and tubers presented a trend of increasing firstly and then decreasing under the machine-damaged

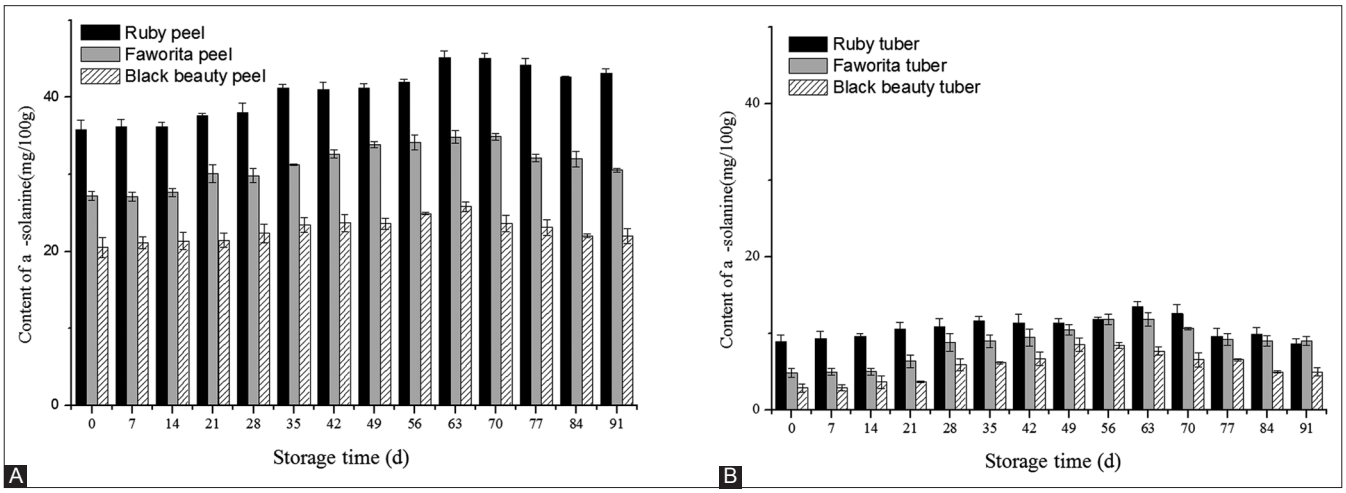

Fig 3. The variation pattern α-solanine in cold storage (4 °C) and shaded (A:peel, B:tuber)

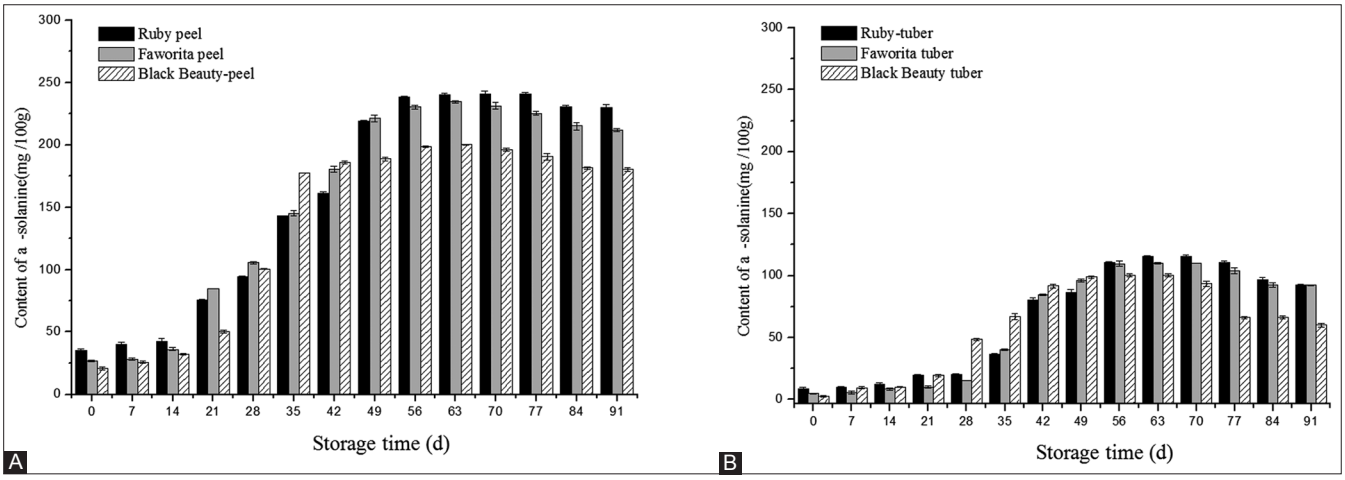

Fig 4. The variation pattern of α-solanine in machine-damaged and shaded (A:peel, B:tuber)

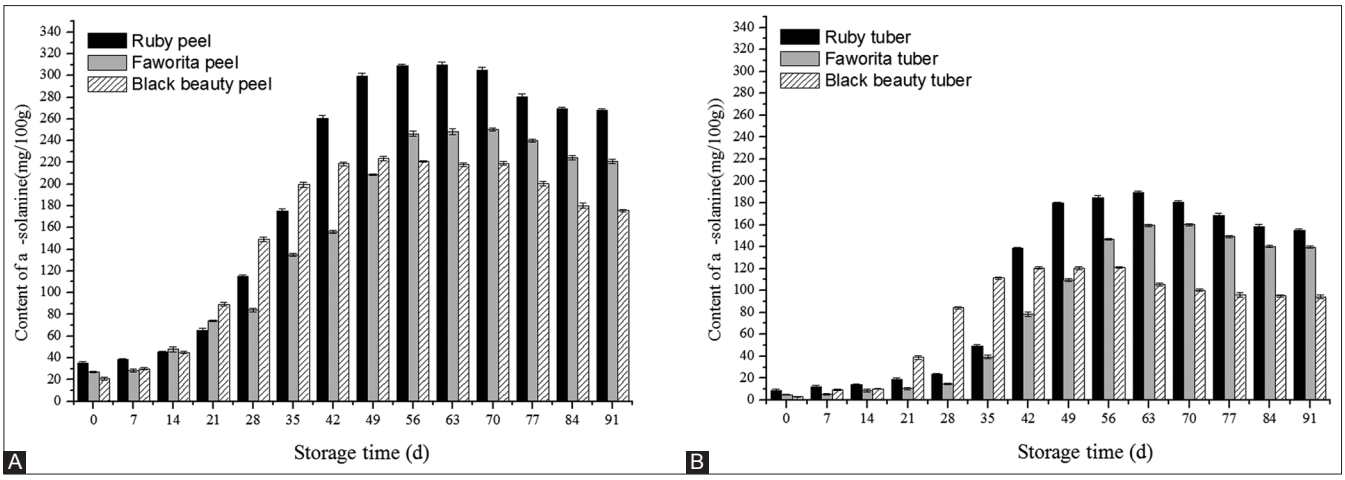

Fig 5. The variation pattern of α-solanine in machine-damaged with fluorescent lamp (A:peel, B:tuber)

with fluorescent lamp. We fond that Ruby, Black Beauty and Favorita sprouted and turned green when they had been stored for approximately 14 days, and its content of α-solanine increased rapidly in this period. Thereafter, Ruby's content of α-solanine increased slowly when it had been stored for approximately 49 days and reached its maximum when it had been stored for approximately 56 days, the maximum is: 309.41mg/100g in peels, 189.32 mg/100g in tubers. Black Beauty's content of α-solanine increased slowly when it had been stored for approximately 56 days and reached its maximum when it had been stored for approximately 63 days, the maximum is: 223.64mg/100g in peels, 121.12 mg/100g in tubers. Favorita's content of α-solanine increased slowly when it had been stored for approximately 42 days and it reached its maximum when it had been stored for approximately 70 days, the maximum is: 250.36mg/100g in peels, 160.11 mg/100g in tubers.

A comparative study on the content of α-solanine in different species potato peels and tubers under different storage conditions

A comparative study on the content of α-solanine in different species potato peels and tubers under different storage conditions. From Table 1 and Table 2, we can see that the content of α-solanine in different species potato is different, in general, Ruby is higher than Favorita and Black Beauty; the content of α-solanine in peels is generally higher than tubers under the same conditions, and this difference is related to varieties; the following storage conditions influenced the content of α-solanine in potatoes to varying degrees: machine-damaged with fluorescent lamp > machine-damaged and shaded > greenhouse with fluorescent lamp > greenhouse without fluorescent lamp > cold storage (4°C) and shaded, and the content of α-solanine presented a trend of increasing firstly and then decreasing under the greenhouse with fluorescent lamp, greenhouse without fluorescent lamp, machine-damaged and shaded, and machine-damaged with fluorescent lamp, but it nearly remains unchanged in the cold storage (4°C) and shaded. This may due to the potato which we stored in greenhouse with fluorescent lamp, greenhouse without fluorescent lamp, machine-damaged and shaded, and machine-damaged with fluorescent lamp will sprout or turn green, which makes the content of α-solanine increased significantly, while the potato which we stored in cold storage (4°C) and shaded, will not sprout and turn green because of the low temperature, as a result, the content of α-solanine remained nearly unchanged. When compared the machine-damaged with fluorescent lamp to no machine-damaged with fluorescent lamp, machine-damaged and shaded to no machine-damaged and shaded, found that the content of α-solanine in potato peels and tubers which had machine-damage was higher than that the potato which had no machine-damage, this is due to the potato with machine-damage will enhance its respiration action and increase its enzyme activity to repair its wound, as a result, its content of α- solanine would rise obviously (Huang et al., 2011).

CONCLUSIONS

The experimental results concluded that the content of α-solanine in different species potato is different under the same storage conditions, in general, Ruby is higher than Favorita and Black Beauty; the content of α-solanine in peels is generally higher than tubers, and this difference is related to varieties; the following storage conditions influenced the content of α-solanine in potatoes to varying degrees: machine-damaged with fluorescent lamp > machine-damaged and shaded > greenhouse with fluorescent lamp > greenhouse without fluorescent lamp > cold storage (4°C) and shaded, and the content of α-solanine presented a trend of increasing firstly and then decreasing

Table 1: Content of α-solanine in different species potato peels under different storage conditions

Variety	Storage conditions	Start	Max	Over
	Greenhouse with Sunshine		153.41±1.89^{c}	135.89±2.11^{c}
	Greenhouse without Sunshine		78.16±1.45^{d}	65.03±2.06^{d}
Ruby	Cold Storage (4°C) and Shaded	35.12±1.21	45.15±0.88^{e}	43.14±0.55^{e}
	Machine-damaged and Shaded		240.99±2.00^{b}	230.11±2.05^{b}
	Machine-damaged with Sunshine		309.41±2.97^{a}	268.15±1.56^{a}
	Greenhouse with Sunshine		123.12±0.99^{c}	108.61±1.52^{c}
	Greenhouse without Sunshine		65.14±1.00^{d}	56.12±1.99^{d}
Favorita	Cold Storage (4°C) and Shaded	27.02±0.58	34.89±0.44^{e}	30.55±0.24^{e}
	Machine-damaged and Shaded		234.52±0.84^{b}	211.85±1.20^{b}
	Machine-damaged with Sunshine		250.36±1.64^{a}	220.03±1.99^{a}
	Greenhouse with Sunshine		105.35±2.85^{c}	89.12±2.31^{b}
	Greenhouse without Sunshine		41.02±0.88^{d}	28.15±0.95^{c}
Black Beauty	Cold Storage (4°C) and Shaded	20.75±1.32	25.84±0.65^{e}	22.01±0.99^{c}
	Machine-damaged and Shaded		200.22±0.15^{b}	180.22±1.51^{a}
	Machine-damaged with Sunshine		223.64±2.16^{a}	175.62±1.25^{a}

Statistical comparisons were performed within varieties and columns different superscripts indicate differences with each other ($p<0.05$)

Table 2: Content of α-solanine in different species potato tubers under different storage conditions

Variety	Storage conditions	Start	Max	Over
	Greenhouse with Sunshine		95.16±1.74^{c}	78.01±1.21^{b}
	Greenhouse without Sunshine		32.11±0.85^{d}	23.51±0.84^{c}
Ruby	Cold Storage (4°C) and Shaded	8.88±0.95	13.51±0.65^{e}	8.65±0.65^{d}
	Machine-damaged and Shaded		115.62±0.51^{b}	82.54±0.68^{b}
	Machine-damaged with Sunshine		189.32±1.79^{a}	155.31±1.09^{a}
	Greenhouse with Sunshine		75.11±1.22^{c}	60.89±1.12^{c}
	Greenhouse without Sunshine		21.03±1.11^{d}	13.02±1.54^{d}
Favorita	Cold Storage (4°C) and Shaded	4.84±0.54	11.85±0.25^{e}	9.00±0.62^{e}
	Machine-damaged and Shaded		110.25±0.24^{b}	92.21±0.11^{b}
	Machine-damaged with Sunshine		160.11±1.01^{a}	139.68±0.99^{a}
	Greenhouse with Sunshine		51.25±2.22^{c}	38.12±1.25^{c}
	Greenhouse without Sunshine		16.24±0.99^{d}	8.00±1.14^{d}
Black Beauty	Cold Storage (4°C) and Shaded	2.88±0.51	8.55±0.85^{e}	5.00±0.55^{d}
	Machine-damaged and Shaded		110.65±1.26^{b}	70.12±1.48^{b}
	Machine-damaged with Sunshine		121.12±0.89^{a}	94.11±1.74^{a}

Note: Statistical comparisons were performed within varieties and columns different superscripts indicate differences with each other ($p<0.05$)

under the greenhouse with fluorescent lamp, greenhouse without fluorescent lamp, machine-damaged and shaded, and machine-damaged with fluorescent lamp, but it nearly remains unchanged in the cold storage (4°C) and shaded.

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Author Contributions

In this study, Xiaolong Chen designed the experimental scheme and did the experiment, Jianquan Kan guided it. Yongbo Ding corrected it.

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