

## Article

# Effect of Steaming on Vitamin Retention in Tubers from Eight Cultivars of Potato (*Solanum tuberosum* L.)

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**Abstract:** As the fourth largest staple crop in China, potatoes are a significant source of food and revenue, and provide diverse vitamins to human. However, the variation of vitamin retention in tubers after cooking were seldom evaluated. In this study, we evaluated the effects of steaming on water-soluble vitamins (vitamin B9 and vitamin C) and liposoluble vitamin (vitamin E) in tubers from eight potato cultivars grown in northern China. We found that these cultivars contained wide ranges of vitamin B9 (8.60–19.93 µg/100 g FW), vitamin C (46.67–155.44 mg/100 g FW), and vitamin E (15.34–33.82 mg/kg FW), with the highest vitamins B9, C, and E content in cultivars V7, XinDaPing, and QingShu 9, respectively. After steaming, vitamin contents decreased in most cultivars; levels of these three vitamins in tubers of cultivars ‘Tianshu11’ and ‘XinDaPing’ were higher than others, indicating that these two cultivars could be better sources among the detected ones for multiple vitamins after steaming.

**Keywords:** steaming; vitamin retention; vitamin B9; vitamin C; vitamin E; potatoes; thermal processing



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## 1. Introduction

Potatoes (*Solanum tuberosum* L.) are annual herbaceous tubers of plant family Solanaceae. China is the world's largest potato producer, and potato has become the fourth largest staple crop in China, representing 30% of all food consumed due to adjustments in the agricultural structure of regions where irrigated wheat is grown on the North China Plain [1]. Potatoes are widely planted in north China due to their good drought resistance and water use efficiency [2]. Based on the 5th China total diet study, generally around 450 g per day was consumed in 2017, and the consumption increased gradually in China from 2002 [3]. Potatoes are a significant source of food and revenue, containing essential carbohydrates (starch content: 9–21%), protein (1.5–2.3%), amino acids (including eight essential amino acids), dietary fiber (crude fiber content: 0.6–8%), and minerals such as calcium, iron, potassium, magnesium. Potatoes contain around 80% water and contain diverse vitamins, including carotenoids, vitamin B9 (folate; vitB9), vitamin C (ascorbic acid; vitC), vitamin E (tocopherol and tocotrienol; vitE), pyridoxine, and thiamine [4,5]. Half of the human body's daily thiamine requirements and one-quarter of those for vitC and pyridoxine are met in a 100 g potato [6,7]. Potato is also an important dietary folate donor in Europe. Historically, potatoes provided 7–12% of the Neanderthal diet, which is similar to that of present-day Norwegians [5]. Thus, potatoes could be a good source of multiple vitamins due to the diverse vitamins.

However, levels of vitamins in vegetables generally decrease during thermal processing, resulting in the inadequate intake of vitamins from the diet [8–11]. VitB9, including

tetrahydrofolate and its derivatives, is an important coenzyme involved in the one carbon unit transfer reaction; it plays an important role in the biosynthesis of purine, thymidylate, DNA, amino acid, and proteins, as well as in the methyl cycle. Folate deficiency leads to severe human diseases such as neural tube defects and anemia [12]. VitC, also known as L-ascorbic acid, is a highly effective antioxidant in the human body that is involved in scavenging free radicals and preventing oxidative stress. VitC deficiency can cause anemia and other symptoms [13]. VitE comprises liposoluble components including tocopherol and tocotrienol; its deficiency can lead to diseases related to the reproductive system [14]. One strategy for addressing vitamin deficiencies in the human diet is to screen germplasms that contain multiple micronutrients in staple crops and analyze their content after cooking. Steaming is a common cooking (thermal processing) method in northern China [1]. However, few studies have evaluated the effects of steaming on the vitamins of potatoes. In this study, we examined the effects of steaming on the content of water-soluble (vitB9 and vitC) and liposoluble (vitE) vitamins in eight common potato cultivars grown in northern China. The results showed that these cultivars contained wide ranges of vitB9, vitC, and vitE, and levels of these three vitamins in tubers of ‘Tianshu11’ and ‘XinDaPing’ were higher than others after steaming, indicating that these two cultivars could be better sources among the detected ones for multiple vitamins after steaming.

## 2. Material and Methods

### 2.1. Samples

Potato cultivars were obtained from the Hulunbeier Agricultural Research Institute, Inner Mongolia Autonomous Region, and Gansu Provincial Agricultural Technological Extension Station, China. The former provided tubers from the ‘YouJin, V7’, and ‘L8’ cultivars, and the latter provided tubers from the ‘Tianshu 11’, ‘Tianshu 12’, ‘XinDaPing’, ‘Qingshu 9’, and ‘Xisen 6’ cultivars [15–17] (Figure 1; Table 1). The tubers were harvested and maintained at room temperature from harvest until treatment within 1 week.

**Table 1.** Basic information of potato cultivars used in this study.

Cultivar Name	Approval Number	Yield (kg 667 m <sup>-2</sup> )	Starch Content (%)	Resources
‘L8’	Application approved in Heilongjiang province in Dec. 2020	2226.89	18.95	Personal communicated with G.W.
‘V7’	Personal provided by G.W.	None	9.20	Personal provided by G.W.
‘YouJin’	Jishenshu2015001	2397–2813	14.33	<a href="http://www.baidu.com">www.baidu.com</a> [15]
‘TianShu 11’	Guoshenshu20014006	2043–2522	16.05	<a href="http://www.baidu.com">www.baidu.com</a> [15]
‘XiSun 6’	Mengshenshu2016003	2191–3617	15.10	<a href="http://www.baidu.com">www.baidu.com</a> [15] Ren et al., 2020 [16]
‘XinDaPing’	Ganshenshu2005004	929–1383	20.19	<a href="http://www.baidu.com">www.baidu.com</a> [15] Liu et al., 2021 [17]
‘QingShu 9’	Qingshenshu200600	2250–4200	19.76	<a href="http://www.baidu.com">www.baidu.com</a> [15]
‘TianShu 12’	Ganshenshu2005003	1279	16.05	<a href="http://www.baidu.com">www.baidu.com</a> [15]

### 2.2. Samples Preparation

In this study, steaming was chosen because it is a common household potato preparation method in northern China [1]. The potato tubers were washed carefully by hand under running water to remove dirt from the surface without peeling. Four tubers of each potato cultivar were used in the experiment. Each tuber was cut in two; one half was treated with steam, and the other was kept raw as a control. These half tubers in the raw group were cut into pieces, and the center part was used to measure water and vitamin content. The other half tubers in the steamed group were placed in a steamer basket for 25 min above boiling water until fully cooked and then cooled to room temperature and cut into pieces for water and vitamin content measurements. For vitamin measurements, fresh samples

were frozen in nitrogen, grounded into powder, and then stored at  $-80\text{ }^{\circ}\text{C}$  until analyses. We performed 4 biological repeats of all vitamin content measurements.



**Figure 1.** Photos of tubers of potato cultivars used in this study. (a), ‘L8’; (b), ‘V7’; (c), ‘YouJin’; (d), ‘TianShu 11’; (e), ‘XiSun 6’; (f), ‘XinDaPing’; (g), ‘QingShu 9’; (h), ‘TianShu 12’. Bar = 5 cm.

### 2.3. VitB9 Content Measurement

For vitB9 content measurement, each sample was mixed with the extract buffer, boiled for 10 min, and cooled on ice for 10 min. Next, 20  $\mu\text{L}$   $\alpha$ -amylase (40 mg/mL) was added to the mixture, which was incubated at  $37\text{ }^{\circ}\text{C}$  for 30 min. Subsequent parts of the procedure until supernatant collection were previously described [18,19]. The resulting supernatant was subjected to 3 kDa ultra-filtration and then used for high-performance liquid chromatography–mass spectrometry (HPLC–MS). Chromatographic analyses were performed using a 1260 HPLC system (Agilent) with an Akzo Nobel analytical column (Kromasil 100–5 C18,  $50 \times 2.1\text{ mm}$ ) at a flow rate of 0.30 mL/min. The mobile phases were 0.1% formic acid in water (phase A) and 0.1% formic acid in acetonitrile (phase B). The mobile phase volumes changed in the following time intervals: 0–2 min (95% phase A, 5% phase B; flow rate: 0.3 mL/min); 2–7.9 min (91% phase A, 9% phase B; flow rate: 0.3 mL/min); 7.9–8.2 min (90.5% phase A, 9.5% phase B; flow rate: 0.3 mL/min); 8.2–11.2 and 11.2–11.4 min (80% phase A, 20% phase B; flow rate: 0.6 mL/min); 11.4–14.4 min (95% phase A, 5% phase B; flow rate: 0.6 mL/min); and 14.4–14.5 min (95% phase A, 5% phase B; flow rate: 0.3 mL/min). An Agilent 6420 triple–quadruple tandem MS system coupled to an electron spray ionization interface was used for mass analyses and quantification of target analytes. The mass spectrometer was operated in positive ion mode. The parameters were optimized for target analyses at a gas temperature of  $350\text{ }^{\circ}\text{C}$ , drying gas flow of 11 L/min, nebulizer pressure of 35 psi, and capillary voltage of 3500 V (+). System operation, data acquisition, and data analyses were performed using the Agilent MassHunter soft-

ware (Beijing, China, [www.agilent.com/zh-cn/promotions/masshunter-mass-spec](http://www.agilent.com/zh-cn/promotions/masshunter-mass-spec)). We purchased H<sub>2</sub>folate (*m/z*: 444.2–178, 20 eV), 5,10-CH = THF (*m/z*: 456–412, 30 eV), 5-CH<sub>3</sub>-H<sub>4</sub>folate (*m/z*: 460–313, 20 eV), 5-CHO-H<sub>4</sub>folate (*m/z*: 474–327, 20 eV), and H<sub>4</sub>folate (*m/z*: 446–299, 20 eV) from Schircks Laboratories (Jona, Switzerland, <http://www.schircks.ch/>).

#### 2.4. VitC Content Measurement

VitC content was measured using a phosphomolybdic acid colorimetry kit (Shanghai Yuanye Biotechnology Co., Ltd., Shanghai, China), following the manufacturer's instructions.

#### 2.5. VitE Content Measurement

VitE content was measured following the method of Konda et al., (2020) with modifications [20]. Tocopherols and tocotrienols were extracted from freshly ground bulk tubers and analyzed using high performance liquid chromatography (HPLC) and reverse-phase HPLC. We resolved 50 mg samples in 1 mL methanol/di-chloromethane (9:1, *v/v*); prior to homogenization, we added 100 µL internal standard (Rac-5,7-dimethyltolcol, Abcam, ab143879) at a concentration of 1.5 ng/µL. Chromatographic analyses were performed using a HPLC-10AVP system with RF-10AXL fluorescence detector (Shimadzu Corporation, Kyoto, Japan, [www.shimadzu.com](http://www.shimadzu.com)), using an Agilent analytical column (ZORBAX Eclipse XDB-C18, 4.6 × 250 mm, 5µm).

#### 2.6. Data Analyses

VitB9, vitC, and vitE content data are reported as means ± standard deviation (stdv) of 4 biological replicates. The student's *t*-test was used to evaluate significant differences in vitamin content using Excel 2019 (Microsoft). Correlation analyses were conducted using the R software ver. 4.0.3 (R Core Team; Auckland, New Zealand, [www.datavis.ca/R/](http://www.datavis.ca/R/)).

### 3. Results

#### 3.1. VitB9, VitC, and VitE Content

Raw potato tubers contained around 80% water (Table 2), and more vitC than either vitE or vitB9 (Table 2). The contents of vitC and each derivative of vitB9 and vitE in raw potato tubers were calculated for each raw sample on a fresh-weight (FW) basis first (Tables 3 and 4). Different variations among vitamins were observed. Among the tubers of these cultivars, the highest vitB9 content was found in 'V7' tubers, which was about 2-fold higher than that of 'XiSen 6' tubers, with 5-CH<sub>3</sub>-H<sub>4</sub> folate as the dominant form (45.6–59.0%; Tables 2 and 3). VitC showed 3.3-fold variation among cultivars with 'V7' as the lowest levels detected, and 'XinDaPing' contained the highest vitC level (Tables 2 and 3). VitE includes tocopherol and tocotrienol, which occurred at varying rates among cultivars. For example, the proportion of tocotrienol within vitE content was 68.5% in 'QingShu 9', and 42.8% in 'V7' (Table 4). The highest total vitE content was observed in 'QingShu 9' tubers, which was 2.2-fold that in 'L8' tubers (Tables 2 and 4).

**Table 2.** The range of water and vitamin content among raw potato cultivars.

Compound	Minimum Content	Maximum Content
Water (%)	77.47	84.86
Vitamin B9 (µg/100 g FW)	8.60 ± 2.25	19.93 ± 3.83
Vitamin C (mg/100 g FW)	46.67 ± 1.39	155.44 ± 7.33
Vitamin E (mg/kg FW)	15.34 ± 2.11	33.82 ± 1.17

Note: FW, fresh weight.

**Table 3.** The content of water-soluble vitamins among raw tubers of potato cultivars on a fresh-weight basis.

Cultivar Name	5-CH <sub>3</sub> -H <sub>4</sub> folate (µg/100 g FW)	Proportion of 5-CH <sub>3</sub> -H <sub>4</sub> folate (%)	5-CHO-H <sub>4</sub> folate (µg/100 g FW)	Proportion of 5-CHO-H <sub>4</sub> folate (%)	5,10-CH=H <sub>4</sub> folate (µg/100 g FW)	Proportion of 5,10-CH=H <sub>4</sub> folate (%)	H <sub>2</sub> folate (µg/100 g FW)	Proportion of H <sub>2</sub> folate (%)	H <sub>4</sub> folate (µg/100 g FW)	Proportion of H <sub>4</sub> folate (%)	Total Vitamin B9 (µg/100 g FW)	Vitamin C (mg/100g FW)
'V7'	10.09 ± 1.73	50.7	6.28 ± 1.77	31.5	1.31 ± 0.08	6.6	0.54 ± 0.10	2.7	1.70 ± 0.13	8.5	19.92 ± 0.09	46.67 ± 1.40
'L8'	5.62 ± 0.17	49.9	3.09 ± 0.79	27.5	0.98 ± 0.05	8.7	0.34 ± 0.25	3.0	1.23 ± 0.19	10.9	11.26 ± 0.62	74.27 ± 3.58
'YouJin'	7.57 ± 0.05	45.6	5.33 ± 0.82	32.1	1.42 ± 0.21	8.6	0.35 ± 0.09	2.1	1.93 ± 0.11	11.6	16.60 ± 0.93	50.79 ± 0.55
'TianShu 11'	6.28 ± 0.25	41.5	5.08 ± 0.13	33.6	1.36 ± 0.05	9.0	0.61 ± 0.04	4.0	1.80 ± 0.34	11.9	15.15 ± 0.63	109.80 ± 12.20
'XiSen 6'	4.28 ± 1.24	49.8	2.29 ± 0.42	26.6	0.87 ± 0.37	10.1	0.11 ± 0.09	1.3	1.05 ± 0.12	12.2	8.60 ± 2.05	102.86 ± 52.24
'XinDaPing'	6.58 ± 0.62	59.0	2.72 ± 0.94	24.4	0.85 ± 0.14	7.6	0.13 ± 0.10	1.2	0.87 ± 0.36	7.8	11.16 ± 1.96	155.44 ± 7.33
'QingShu 9'	5.74 ± 0.75	54.3	2.93 ± 0.77	27.7	0.94 ± 0.19	8.9	0.00 ± 0.00	0.0	0.96 ± 0.01	9.1	10.58 ± 1.73	105.44 ± 7.33
'TianShu 12'	4.70 ± 0.03	43.5	3.98 ± 0.71	36.8	0.97 ± 0.01	9.0	0.07 ± 0.10	0.7	1.08 ± 0.32	10.0	10.80 ± 1.11	65.74 ± 4.12

Note: FW, fresh weight.

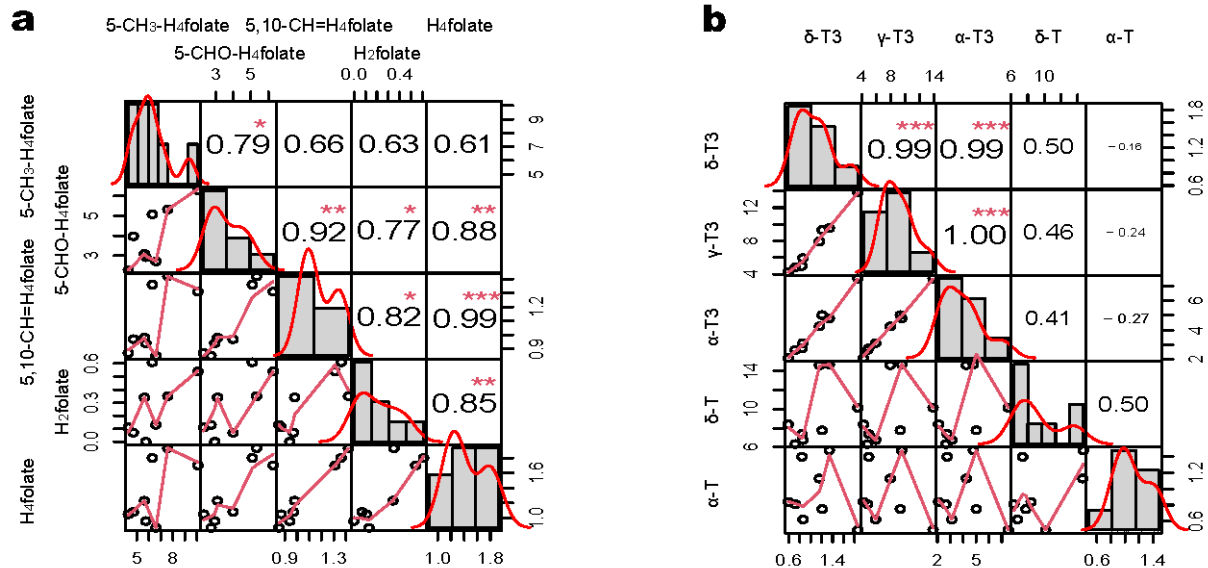
**Table 4.** The content of each derivative of vitamin E among raw tubers of potato cultivars.

Cultivar Name	δ-T3 (mg/kg FW)	Proportion of δ-T3 (%)	γ-T3 (mg/kg FW)	Proportion of γ-T3 (%)	α-T3 (mg/kg FW)	Proportion of α-T3 (%)	Total T3 (mg/kg FW)	Proportion of total T3 (%)	δ-T (mg/kg FW)	Proportion of δ-T (%)	α-T (mg/kg FW)	Proportion of α-T (%)	Total T (mg/kg FW)	Proportion of Total T (%)	Total Vitamin E (mg/kg FW)
'V7'	0.60 ± 0.05	3.7	4.24 ± 0.08	26.2	2.10 ± 0.32	13.0	6.93 ± 0.45	42.9	8.40 ± 3.55	51.9	0.84 ± 0.04	5.2	9.24 ± 3.51	57.1	16.17 ± 3.07
'L8'	0.72 ± 0.25	4.7	4.82 ± 1.16	31.4	2.66 ± 0.56	17.3	8.20 ± 1.96	53.5	6.33 ± 0.06	41.3	0.81 ± 0.08	5.3	7.14 ± 0.14	46.5	15.34 ± 2.11
'YouJin'	1.34 ± 0.15	4.2	9.52 ± 0.65	29.9	4.79 ± 0.49	15.0	15.66 ± 0.32	49.2	14.70 ± 1.66	46.2	1.48 ± 0.53	4.7	16.18 ± 1.23	50.8	31.83 ± 0.80
'TianShu 11'	0.86 ± 0.74	5.0	5.93 ± 4.18	34.3	3.12 ± 2.27	18.1	9.91 ± 7.19	57.4	6.75 ± 0.30	39.1	0.62 ± 0.04	3.6	7.37 ± 0.34	42.6	17.28 ± 7.53
'XiSen 6'	1.16 ± 0.3	4.0	7.94 ± 1.58	27.3	4.25 ± 1.20	14.6	13.35 ± 3.07	45.9	14.62 ± 1.11	50.2	1.13 ± 0.32	3.9	15.75 ± 1.43	54.1	29.10 ± 1.64
'XinDaPing'	1.21 ± 0.02	5.0	9.32 ± 0.60	38.7	5.02 ± 0.20	20.9	15.55 ± 0.82	64.6	7.77 ± 0.06	32.3	0.75 ± 0.04	3.1	8.52 ± 0.02	35.4	24.07 ± 0.80
'QingShu 9'	1.86 ± 0.23	5.5	13.82 ± 0.01	40.9	7.50 ± 0.21	22.2	23.18 ± 0.01	68.5	10.15 ± 1.17	30.0	0.49 ± 0.00	1.4	10.65 ± 1.16	31.5	33.83 ± 1.17
'TianShu 12'	0.84 ± 0.74	4.8	4.97 ± 1.58	28.6	2.76 ± 0.82	15.9	8.57 ± 2.48	49.4	7.39 ± 0.81	42.6	1.40 ± 0.03	8.1	8.79 ± 0.78	50.6	17.37 ± 3.26

Note: FW, fresh weight; T, tocopherol; T3, tocotrienol; Total T3, the sum of α-, γ-, and δ-tocotrienol; Total T, the sum of α- and δ-tocopherol; Total vitamin E includes both tocopherol and tocotrienol.



The content of all vitB9 derivatives was significantly correlated among all potato cultivars ( $p < 0.01$ ; Table 3; Figure 2a). Among tocotrienol derivatives,  $\alpha$ -,  $\gamma$ -, and  $\delta$ -tocotrienol content levels were significantly correlated ( $p < 0.01$ ; Table 4; Figure 2b). No significant correlation was found between  $\alpha$ - and  $\delta$ -tocopherol or between tocopherol and tocotrienol (Figure 2b). There was no significant correlation among vitB9, vitC, and vitE levels among cultivars (data not shown).



**Figure 2.** Correlation among the derivatives of vitB9 and vitE, respectively, in tubers of potato cultivars before steaming. (a) Correlation results among derivatives of vitB9; (b) Correlation results among derivatives of vitE. \*,  $p < 0.01$ ; \*\*,  $p < 0.001$ ; \*\*\*,  $p < 0.0001$ .

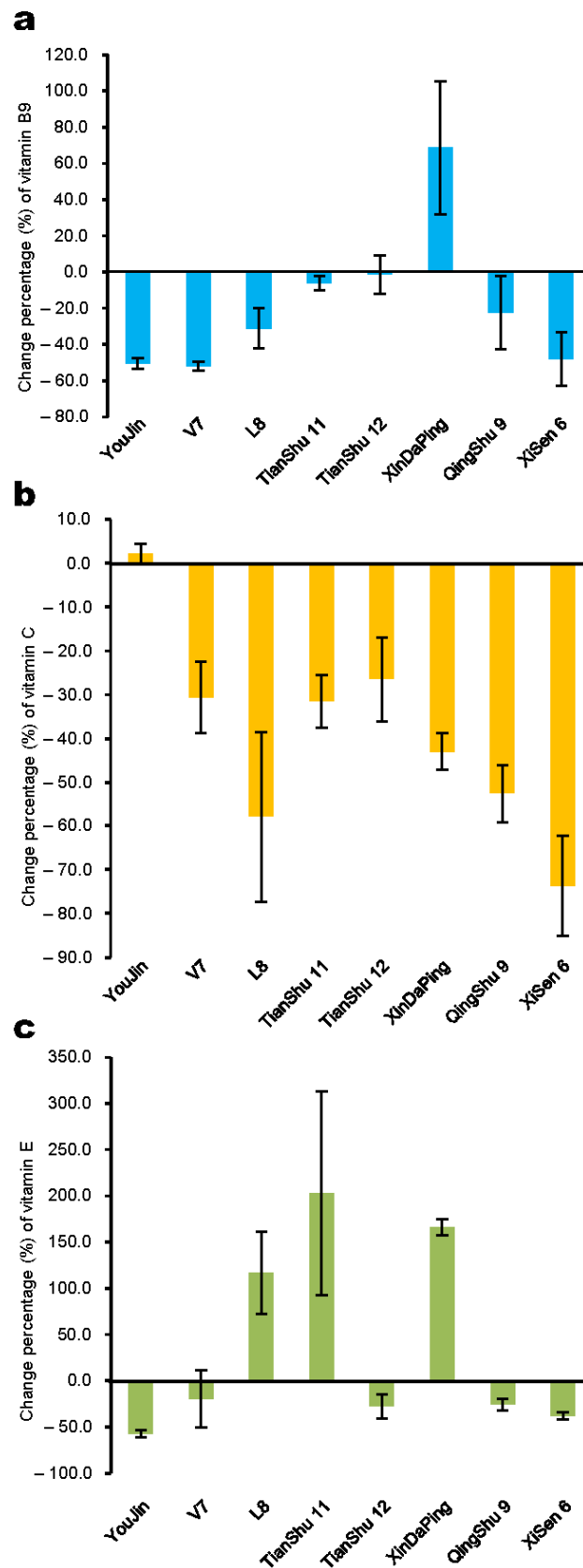
### 3.2. Effect of Steaming On Vitamin Retention in Potato Tubers

For the calculation of vitamin retention in steaming treatment, the vitamin contents of each potato cultivar were calculated on a dry-weight (DW) basis and the change percentages were compared (Table 5). Water content did not change significantly after steaming (78.3–82.9%). Prior to steaming, the three cultivars with the highest vitB9 levels were ‘YouJin’, ‘V7’, and ‘TianShu 11’ (Table 3). After steaming, vitB9 levels decreased over  $-50\%$  in most cultivars. Whereas those in ‘TianShu 11’ and ‘TianShu 12’ did not change much after steaming (Table 5; Figure 3a). Notably, the vitB9 content in steamed tubers of ‘XinDaPing’ increased significantly to  $17.83 \pm 3.53 \mu\text{g}/100 \text{ g FW}$ , which was over 2-fold of that of YouJin ( $8.74 \pm 1.17 \mu\text{g}/100 \text{ g FW}$ ;  $p < 0.01$ ; Table 6; Figure 3a). Before steaming, ‘TianShu 11’, ‘XinDaPing’, ‘QingShu 9’, and ‘XiSen 6’ contained more vitC than the other cultivars (Table 3). The vitC levels of all cultivars except ‘YouJin’ decreased over  $-26.4\%$  after steaming, with the greatest decrease ( $-73.8\%$ ) observed in ‘XiSen 6’ (Table 5; Figure 3b). Compared with ‘XiSen 6’, the decrease in ‘TianShu 11’ ( $-31.5\%$ ) and ‘XinDaPing’ ( $-26.4\%$ ) were significantly less, resulting as  $76.03 \pm 0.85 \text{ mg}/100 \text{ g FW}$  and  $85.24 \pm 6.36 \text{ mg}/100 \text{ g FW}$  in steamed tubers, respectively (both  $p < 0.01$ ; Figure 3b; Table 6). The top three cultivars for vitE were ‘YouJin’, ‘QingShu 9’, and ‘XiSen 6’ before steaming (Table 4). In most cultivars, vitE levels decreased after steaming (Table 5; Figure 3c). However, those of ‘L8’ (155.5%), ‘TianShu 11’ (277.7%), and ‘XinDaPing’ (286.5%) significantly increased compared with that of ‘YouJin’ ( $-57.5\%$ ), resulting as  $33.42 \pm 7.21 \text{ mg}/\text{kg FW}$ ,  $48.03 \pm 6.51 \text{ mg}/\text{kg FW}$ , and  $61.71 \pm 9.11 \text{ mg}/\text{kg FW}$  in steamed tubers, respectively (all  $p < 0.01$ ; Tables 5 and 6; Figure 3c). After steaming, vitB9, vitC, and vitE levels were consistently higher in ‘TianShu 11’ and ‘XinDaPing’ than in all other cultivars (Table 6), which suggests that they are better sources among the detected ones of multiple vitamins in steamed potatoes.

**Table 5.** The content of total vitamin B9, vitamin C, and vitamin E among raw and steamed tubers of potato cultivars on a dry-weight basis.

Cultivar Name	Total Vitamin B9 in Raw Tubers (µg/100 g DW)	Total Vitamin B9 in Steamed Tubers (µg/100 g DW)	Folate CP (%)	Vitamin C in Raw Tubers (mg/100g DW)	Vitamin C in Steamed Tubers (mg/100g DW)	Vitamin C CP (%)	Total Vitamin E in Raw Tubers (mg/kg DW)	Total Vitamin E in Steamed Tubers (mg/kg DW)	Vitamin E CP (%)
'Youjin'	96.66 ± 5.44	47.87 ± 1.93	−50.4 ± 2.8	295.78 ± 3.18	301.88 ± 8.63	2.1 ± 2.3	184.45 ± 4.79	78.41 ± 8.63	−57.5 ± 3.9
'V7'	131.68 ± 0.62	63.29 ± 4.14	−51.9 ± 2.6	308.33 ± 9.21	214.06 ± 30.61	−30.5 ± 8.1	105.93 ± 20.35	83.70 ± 36.27	−19.5 ± 31.4
'L8'	53.02 ± 2.9	36.49 ± 6.97	−31.1 ± 11.2	349.41 ± 16.82	146.71 ± 89.02	−58.0 ± 19.5	72.47 ± 10.01	155.48 ± 32.35	116.6 ± 44.3
'TianShu 11'	89.34 ± 3.73	83.99 ± 2.54	−5.9 ± 4.0	647.31 ± 71.46	440.97 ± 4.92	−31.5 ± 6.0	101.21 ± 43.81	277.70 ± 27.29	202.8 ± 110.0
'TianShu 12'	63.33 ± 6.48	62.14 ± 5.29	−1.4 ± 10.7	385.47 ± 24.16	283.03 ± 47.24	−26.4 ± 9.6	101.21 ± 19.08	71.94 ± 7.24	−27.6 ± 12.7
'XinDaPing'	49.56 ± 8.72	82.31 ± 16.27	68.7 ± 36.6	690.12 ± 32.56	393.50 ± 29.38	−42.9 ± 4.2	107.70 ± 3.57	286.48 ± 6.79	166.1 ± 8.9
'QingShu 9'	48.84 ± 8.00	37.43 ± 10.21	−22.3 ± 20.3	488.87 ± 60.16	229.66 ± 35.11	−52.7 ± 6.6	157.06 ± 5.54	116.65 ± 11.73	−25.7 ± 6.5
'XiSen 6'	55.32 ± 13.21	27.99 ± 6.88	−47.9 ± 14.7	661.99 ± 336.25	151.24 ± 28.06	−73.8 ± 11.4	185.76 ± 10.16	115.28 ± 6.22	−37.9 ± 3.9

Note: DW, dry weight. CP, the change percentage of vitamins (%) is equal (nutrient contents after steaming − nutrient contents before steaming)/nutrient contents before steaming \*100.



**Figure 3.** Change percentages of vitB9, vitC, and vitE in tubers of potato cultivars after steaming, respectively. (a) Change percentage of vitB9; (b) change percentage of vitC; (c) change percentage of vitE.



**Table 6.** Profiles of vitB9, vitC, and vitE among tubers of steamed potato cultivars on a fresh-weight basis.

Cultivar	Vitamin B9 ( $\mu\text{g}/100\text{ g FW}$ )	Vitamin C ( $\text{mg}/100\text{ g FW}$ )	Vitamin E ( $\text{mg}/\text{kg FW}$ )
'V7'	$10.91 \pm 0.71$	$36.9 \pm 5.27$	$14.50 \pm 6.29$
'L8'	$7.80 \pm 1.49$	$31.37 \pm 19.03$	$33.11 \pm 6.87$
'YouJin'	$8.74 \pm 0.35$	$55.11 \pm 1.58$	$14.34 \pm 1.57$
'TianShu 11'	$14.48 \pm 0.44$	$76.03 \pm 0.85$	$48.03 \pm 4.71$
'XiSen 6'	$5.62 \pm 1.38$	$30.39 \pm 5.64$	$23.13 \pm 1.25$
'XinDaPing'	$17.83 \pm 3.53$	$85.24 \pm 6.36$	$61.71 \pm 1.43$
'QingShu 9'	$8.27 \pm 2.26$	$50.74 \pm 7.76$	$25.57 \pm 2.57$
'TianShu 12'	$10.60 \pm 0.91$	$48.3 \pm 8.06$	$12.35 \pm 1.25$

Note: FW, fresh weight.

#### 4. Discussion

Potatoes have high nutritional value, such as diverse vitamins [5]. The study evaluated levels and retention upon steaming of vitamins in potatoes tubers within one week after the harvest because the storage under low temperature caused the decrease of vitC and the increase of pyridoxine and vitB9 [21]. In raw tubers of potato cultivars grown in northern China, vitB9 levels ( $48.84\text{--}131.68\ \mu\text{g}/100\text{ g DW}$ ) were at a similar range to those of cultivars grown in the Americas [22] ( $46.3\text{--}233.7\ \mu\text{g}/100\text{ g DW}$ ; Table 5); VitC levels were slightly higher ( $46.47\text{--}155.44\ \text{mg}/100\text{ g FW}$ ) than those of American cultivars [23] ( $10\text{--}40\ \text{mg}/100\text{ g FW}$ ; Table 2); VitE levels ( $15.34\text{--}33.84\ \text{mg}/\text{kg DW}$ ; Table 5) were lower than those reported in seeds of species including barley [24,25] ( $50\text{--}55\ \text{mg}/\text{kg DW}$ ), black sweet corn [26] ( $74.14\ \text{mg}/\text{kg DW}$ ), and soybean [20] ( $266\text{--}421\ \text{mg}/\text{kg DW}$ ; Table 5). Similar to that tocotrienol is the main form of vitE in most monocotyledons, and some dicotyledons [4], the proportion of tocotrienol was  $42.9\text{--}68.5\%$  (Table 5). Due to limitations in vitE measurement techniques, only  $\alpha$ -,  $\gamma$ -, and  $\delta$ -tocotrienol and  $\alpha$ - and  $\delta$ -tocopherol were detected in this study (Table 4). The levels of  $\alpha$ -tocopherol in potatoes ( $0.49\text{--}1.48\ \text{mg}/\text{kg FW}$ ) in this study were lower than those previously reported from India [27] ( $18.4\ \text{mg}/\text{kg FW}$ ; Table 4). The different levels of vitB9, vitC and vitE could be due to the materials with different genetic backgrounds, the different grown regions, and the different types of cultivation during tuber development [28].

Since the potatoes could not be freshly eaten, the study on vitamin retention upon the thermal processing is important in the screen for better germplasm. Plant folate content varies according to cooking method and species. For example, in a study on wheat-based foods, boiling, steaming, and baking led to folate losses of 13%, 16%, and 11%, respectively [29]. As folates are soluble in water, their levels decrease significantly during boiling, with losses of 50.8% and 56.5% reported for spinach and broccoli, respectively, but only losses of 17.8% for potato. In a study on the leaves of wild edible Mediterranean plants, significant losses (31.4–80.3%) in folate content was observed after boiling [30]. Similarly, a maximum loss of 47% was reported in steamed sweet potato [10] (*Ipomoea batata*). Steaming has a weaker impact on folate levels, with a 15.3% increase reported for spinach and a 9.2% loss for broccoli [31]. In this study, we observed an average decrease in potato folate levels of about  $-50\%$  after steaming; however, there was a wide variation, and also the increase in tubers of 'XinDaPing' was observed (Table 5; Figure 2). Even though folate content in 'XinDaPing' was the highest among the cultivars detected, the 450 g per day of 'XinDaPing' consumed only met one-fifth of folate recommended day intake [3,32] ( $400\ \mu\text{g}/\text{day}$ ).

The loss of vitC in potato tubers was normally observed, and much less during microwaving or baking than during boiling or frying in oil [11,33–35]. In this study, after steaming, vitC levels decreased by  $> -30\%$  in most cultivars (Table 5; Figure 2), similar to those observed in cooked potatoes from Poland or cooked cauliflower [11,34]. Among the cultivars tested, 'XinDaPing' showed the highest vitB9 and vitC contents after steaming, which met the vitC recommended daily intake in 100 g [32] ( $75\ \text{mg}/\text{day}$ ; Table 6). This phenomenon was similar to what had been reported in *Asparagus acutifolius*, indicating that

higher folate retention could be associated with higher vitC content in some plant species or varieties [30].

The increase or decrease of vitE after cooking depended on the type of vegetables, for example, thermal treatment increased the contents of vitE in detected broccoli after some cooking methods, but that decreased in detected potato [28,35]. Previous studies have also reported that potato  $\alpha$ -tocopherol levels were not significantly affected by boiling, with a 2% decrease observed in wild-type tubers and a 2.8–5.5% increase in “golden” potatoes [36]. As also shown in our vitE retention results, vitE levels after steaming decreased over –19.5% in some potato cultivars and increased by >100% in others (Table 5), indicating a dependence on genotype.

Folate content was also dependent on the stability of its polyglutamylated forms and folate binding proteins in materials [37]. As vitE is liposoluble, tocopherols, and tocotrienols usually scavenge the lipid peroxy radical as free-radical scavengers to form tocotrienoxyl radical and can be recycled back by vitC [38]. Upon the heat, the scavenge of vitE could be inactive due to the destruction of enzymes involved in the scavenge and recycle, and more VitE could also be released from lipids by the cell disruption [28,35]. Consequently, more screening of the potato germplasm and the genetic analysis could be carried to figure out the mechanism on the release of vitB9 and vitE upon thermal processing based on either folate binding proteins or enzymes involved in the scavenge and recycle, such as tocopherol oxidase [35,37,38].

## 5. Conclusions

We examined the effects of steaming on water-soluble (folates and L-ascorbate acid) and liposoluble (tocopherol and tocotrienol) vitamins in eight potato cultivars commonly planted in northern China. Steaming resulted in vitC loss in almost all varieties, whereas vitB9 and vitE retention depended on the germplasm. Two cultivars, ‘TianShu 11’ and ‘XinDaPing,’ adequately retained vitB9 and vitE during steaming, resulting in the highest levels of vitB9, vitC, and vitE after the treatment. Our results suggest that these two cultivars could be better sources among the detected ones for multiple vitamins after steaming. Future studies should elucidate the genetic backgrounds of these cultivars to provide a deeper understanding of the mechanisms underlying the stability of vitB9, vitC, and vitE levels to improve nutritional fortification and food processing methods.

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## Abbreviations

5-CH <sub>3</sub> -H <sub>4</sub> folate	5-methyl-tetrahydrofolate
5-CHO-H <sub>4</sub> folate	5-formyl-tetrahydrofolate
H <sub>4</sub> folate	tetrahydrofolate
H <sub>2</sub> folate	dihydrofolate
5,10-CH=H <sub>4</sub> folate	5,10-methenyl-tetrahydrofolate
α-T	α-tocopherol
α-T3	α-tocotrienol
β-T3	β-tocotrienol
γ-T3	γ-tocotrienol
δ-T	δ-tocopherol
δ-T3	γ-tocotrienol
VitC	L-ascorbic acid
VitB9	tetrahydrofolate and its derivatives
VitE	tocopherol and tocotrienol
HPLC–MS	high-performance liquid chromatography–mass spectrometry
FW	fresh weight
DW	dry weight
stdv	standard deviation

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