Plant Foods for Human Nutrition (2020) 75:169–176
https://doi.org/10.1007/s11130-020-00795-2

ORIGINAL PAPER

Comparative Study of the Nutritional Properties of 67 Potato Cultivars (*Solanum tuberosum* L.) Grown in China Using the Nutrient-Rich Foods ($NRF_{11.3}$) Index

Yu Wu[1] · Honghai Hu[1] · Xiaofeng Dai[1] · Hong Zhang[1,2] · Fen Xu[1] · Hanmin Hu[3] · Zhiqian Guo[4]

Published online: 2 March 2020

Abstract
The overall nutritional properties of tubers from 67 potato cultivars were systematically evaluated in this study by adopting the Nutrient-Rich Foods ($NRF_{11.3}$) Index Model. The macronutrients including dry matter, crude protein, total dietary fiber, and starch contents were found to be in the range of 14.8–30.5 g/100 g fresh weight, 5.71–12.0, 1.99–3.39, and 56.0–75.5 g/100 g dry weight, respectively. Additionally, the amounts of vitamin C, K and Fe were 22.6–86.6, 1457–3111, and 1.40–5.06 mg/100 g dry weight, respectively. The $NRF_{11.3}$ index model has a score of 66.4–102 *per* 100 kcal for male and 70.8–107 *per* 100 kcal for female over 18 years old. This model was utilized to determine the macrocomponents and micronutrients of diverse potato cultivars and aid in comprehensive nutritional study on potato as a desirable raw material for staple food processing to human nutrition and daily intake.

Keywords Potato (*Solanum tuberosum* L.) · Proximate analysis · Beneficial nutrients components · Limiting nutrients components · Nutrient-rich foods index

Introduction

As the worldwide top non-cereal food crop and the sole tuber crop, potatoes (*Solanum tuberosum* L.) produce high-quality proteins, more vitamins and minerals compared to cereals, as well as containing a wide array of health-promoting substances known as phytonutrients [1, 2]. Previous studies have proved the anti-obesity or prebiotic effects of ingesting the lyophilized potato powders or potato pulp [3, 4].

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11130-020-00795-2) contains supplementary material, which is available to authorized users.

✉ Hong Zhang
zhang.h07@hotmail.com

1 Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences/Key Laboratory of Agro-Products Processing, Ministry of Agriculture, Beijing 100193, China

2 Hefei CAAS Nutridoer Co. Ltd., Hefei 238000, China

3 Seed Administration Station of Anding District, Dingxi 743000, China

4 Guyuan Branch of Ningxia Academy of Agriculture and Forestry Sciences, Guyuan 756000, China

Investigating the nutritional characteristics of potatoes ahead of processing is vital to categorize potatoes and establish their processing aptitude [5]. The recommended daily intake (RDI) of nutrients can be fulfilled by consuming the tubers with a comprehensive chemical composition as the staple food and it can be a wise alternative option of traditional wheat or rice products for Chinese residents. Interestingly, the lyophilized potato powders with a nutrient-rich property might be featured in the staple food series products processing similar to milled wheat flour and long-grain nonglutinous rice flour, which could expand the categories of potato staple products matching the dietary habits of Chinese residents [6].

Science-based nutrient profiling models are adopted for grading individual food items in whole diet by assessing nutrient density as opposed to their energy density [7]. Among various practical profile algorithms, $NRF_{n.3}$ score was calculated by subtracting the daily values (DVs) for three-item disqualifying (negative) nutrients (LIM) from NRF_n, while NRF_n is an unweighted mean of percent DVs for n positive (beneficial) nutrients (generally 6–15) *per* 100 g, *per* 100 kcal (418 kJ), or *per* reference amount customarily consumed [8, 9]. LIM is defined by the US Food and Drug Administration (FDA) as commonly ground with saturated fat, added sugar (or total sugar instead), and sodium [7].

Nevertheless, $NRF_{n.3}$ Index model, an integrated nutrient profiling model, has been rarely implemented to assess the holistic nutritional scores of potatoes, especially the local Chinese cultivars. To this end, the proximate analysis has been firstly carried out including the determination of macronutrients and micronutrients in 67 potato cultivars grown at three different sites in China. The comprehensive nutritional value of 11 positive nutrients and three negative nutrients was then further evaluated using the $NRF_{n.3}$ Index model. Consequently, a large amount of data was obtained and systematically arranged to provide more scientific evidence that potato can be considered as a qualified and versatile substitute of traditional staple food for Chinese residents.

Materials and Methods

Potato Sample Preparation

A total of 67 mature potato tubers (*S. tuberosum* L.) varieties were collected from three different sites located in Gansu, Shaanxi, and Ningxia in China between October and November of 2015 and 2016. Table S1 showed the details regarding geographic coordinates, soil features, and fertilization system of each site. The samples were stored at 4 °C for 5 days after delivered to the lab. All the tested potatoes were gently rinsed with running tap water to remove soil and dried with paper towel. The samples were then peeled using a stainless vegetable scratcher, and subsequently cut into 2 cm^3 cubes, lyophilized, grounded to fine powder using a high-speed mill, and finally passed through a 70-mesh sieve. All the freeze-dried potato powders were collected, stored in zip-seal plastic bags, and placed in a desiccator at room temperature until further use.

Macronutrient Measurement

The content of potato dry matter (DM) was determined from the difference in the weights of tested samples before and after freeze-drying as described previously in other studies [10]. Starch and total dietary fiber (TDF) contents were estimated according to AOAC method 996.11 and 991.43 using commercial Total Starch and Total Dietary Fiber Assay Kits, respectively (K-TSTA and K-TDFR, Megazyme, Bray, Ireland). The calcination method was used to determine the ash content [11]. According to the automated Kjeldahl method [11], the content of crude protein was calculated by multiplying the nitrogen content with a conversion factor of 6.25. Crude fat content was measured using the Soxhlet extraction method [11].

Micronutrient Measurement

Vitamins B_1 and B_2 were executed extracted based on the enzymatic hydrolysis method. The contents were determined as outlined based on the enzymatic hydrolysis method. The contents were determined as outlined previously by Tuncel et al. [12]. Vitamin B_3 and C were analyzed by spectrophotometry [13] and spetrophotofluorimetry [11], respectively. Approximately 0.25 g of potato samples were mixed with 8 mL concentrated nitric acid and 3 mL hydrochloric acid and then digested using a Microwave Digestion System (MARS, CEM Corporation, Buckingham, UK). Inductively coupled plasma mass spectrometry (ICP-MS 7700, Agilent Technologies, Santa Clara, USA) was used for the determination of mineral contents (K, Ca, Mg, Na, Fe, and Zn).

Nutrient-Rich Foods Index Model ($NRF_{11.3}$)

In a modified $NRF_{11.3}$ model, 11 nutrients (protein, dietary fiber, vitamin B_1, vitamin B_2, vitamin B_3, vitamin C, calcium, potassium, magnesium, iron, and zinc) were defined as desired (recommended) components, whereas three nutrients (fat, added sugar, and sodium) were defined as undesired (restricted) components [14]. As described above, $NRF_{11.3}$ scores were calculated as the following formula:

$$NRF_{11.3} = 100 \times \left(\frac{\sum_{1-11} {}^{\text{Nutrient}_i}/_{\text{DV}_i}}{\text{ED}} - \frac{\sum_{1-3} {}^{L_i}/_{\text{MRV}_i}}{\text{ED}} \right)$$

where: Nutrient_i = content of nutrient i in 100 g edible part; DV_i = daily values for nutrient i; L_i = content of limiting nutrient i in 100 g edible part; MRV_i = maximum recommended values for limiting nutrient i; ED = energy density of each potato sample (kcal/g). ED was calculated by the formula as follows:

$$\begin{aligned} E = {} & [(\text{g Fat/g DW}) \times (9\ \text{kcal/g})] \\ & + [(\text{g Protein/g DW}) \times (4\ \text{kcal/g})] \\ & + [(\text{g Carbohydrate/g DW}) \times (4\ \text{kcal/g})] \\ & + [(\text{g Dietary fiber/g DW}) \times (2\ \text{kcal/g})] \end{aligned}$$

For male and female, the DVs for 11 recommended nutrients are listed as follows: protein (65 and 55 g), dietary fiber (25 g), vitamin B_1 (1.4 and 1.2 mg), vitamin B_2 (1.4 and 1.2 mg), vitamin B_3 (15 and 12 mg), vitamin C (100 mg), calcium (800 mg), potassium (2000 mg), magnesium (330 mg), iron (12 and 20 mg), and zinc (15 and 11.5 mg), whereas MRVs for three limiting nutrients (fat, added sugar, and sodium) were 62.5 g (50 g for female), 50 g, and 1500 mg, respectively. All $NRF_{11.3}$ indices were expressed as *per* 100 kcal of each potato sample. For male and female aged

≥18 years at light physical activity level, the nutrient reference intakes and maximum recommended values based on 2000 kcal diet were acquired from Chinese Dietary Reference Intakes (DRIs) [15]. In the present case, the contents of added sugars of potatoes were zero since raw potatoes do not contain any added sugars.

Statistical Analysis

All the experiments were performed in triplicate. Results were reported as the means with standard deviation. Statistics (Tukey's test and univariate analysis of variance, UNIANOVA) was conducted with statistically analyzed using statistical product and service solutions statistics software (SPSS version 19.0, IBM, Armonk, NY, USA). The correlations between $NRF_{11.3}$ scores, positive nutrients and negative nutrients were estimated using two-tailed Pearson correlation analysis. Statistical significant differences were set at $P < 0.05$.

Results and Discussion

Macronutrient Contents

The contents of macronutrients in 67 potato samples obtained from three different sites were shown in Figs. S1-S3 and significantly varied among cultivars. The maximum and minimum DM contents were observed in Longshu No. 8 (30.5 ± 0.7 g/100 g fresh weight, FW) and AGRICO8 (14.8 ± 1.9 g/100 g FW), respectively, which were both obtained from Dingxi, Gansu. Previous studies have demonstrated that several aspects including the type and phosphorus availability of soil, geographical location, cultivation techniques, variety differences, and maturity are involved in the determination of the DM content in potatoes [16]. Additionally, based on the correlation between DM contents and their processing aptitudes, it was speculated that Longshu No. 8 might be suitable for baking, while AGRICO8 was advisable for boiling [5]. As shown in Fig. S1, the numbers of starch contents between 63 and 71 g/100 g dry weight (DW) accounted for over 50% of the 67 varieties. L0527–2 (Dingxi, Gansu), Mccann No. 1 (Dingbian, Shaanxi), and GY06–1-4 (Guyuan, Ningxia) exhibited the highest starch content in each location, respectively. Several factors such as genotype, maturity, or nutrition feed especially micronutrients were considered to be the determinants for the starch content [17]. The ash content varied from 3.02 g/100 g DW in Jizhangshu No.12 from Dingxi, Gansu to 6.06 g/100 g DW in Dingshu No.1 from Dingbian, Shaanxi. In terms of fresh weight, the average content of ash (0.98 g/100 g) was similar to that reported previously in five traditional potato cultivars (1.01 g/100 g FW) [18]. The ash content in C3 species like wheat, potato, and leafy vegetable was influenced by species, microhabitation, and season of growth and positively correlated with carbon isotope discrimination or transpiration ratio [19].

Regarding the protein content in peeled potato samples, a variation of 5.71–12.0 g/100 g DW was obtained in the present study with the highest level of 12 g/100 g DW in LK-99 (Guyuan, Ningxia). Nevertheless, when expressed in FW, the protein content ranged from 1.46 to 3.21 g/100 g, where Longshu No.9 had the maximum value. A previous study reported similar results in the range from 0.85 to 4.2 g/100 g FW in Andean or exotic potatoes [20]. According to Chinese average daily consumption of potatoes (115 g FW) and RNI of protein for adult male (65 g), 6% of RNI for male could be satisfied by consuming 115 g FW of Longshu No.9. The nutritional content claim of "high in dietary fiber" can be attributed to the high resistant starch type 2 (RSII) levels in unprocessed potatoes [17]. It was well proved that dietary fiber could improve metabolic syndromes especially obesity, colon cancer, and type 2 diabetes [17]. Our present work revealed a variation of 1.99–3.39 g/100 g DW in regard to TDF content. The average content of TDF in various potato noodles (2.61 g/100 g DW) reported by Xu et al. [21] was close to our data (2.85 g/100 g DW). Potato should enjoy the "good" reputation due to the presence of high-value protein, essential amino acids, abundant vitamin C, antioxidants, and minerals including K and P, but without cholesterol, and only tiny quantities of fat and Na [20]. When expressed in FW, the mean value of crude fat content was 0.12 g/100 g FW and almost half of the value in sweet potato roots (0.33 g/100 g FW). 534–1 from Dingxi, Gansu with the highest content (1.08 ± 0.08 g/100 g DW) was 1.5 fold increased as compared to that of the advanced breeding clones AC-09 [22].

Vitamin and Mineral Contents

White potatoes, green peppers, spinach, and tomatoes are rich in vitamin C. On a fresh basis, the average levels of vitamins B_1, B_2, B_3, and C in the present study were 0.06, 0.05, 1.6, and 11.8 mg/100 g, respectively, which were similar to the results reported in earlier studies [17, 20]. As shown in Fig. S2, in terms of Guyuan, LK-99 exhibited the highest contents of vitamins B_1 and $B_3$with 0.45 and 9.2 mg/100 g DW, respectively, while the highest contents of vitamins B_2 and C were separately discovered in AGRICO6 from Dingxi, Gansu and Kexin No.1 from Dingbian, Shaanxi. Intake of 115 g FW of Kexin No.1 can provide a maximum contribution of 27.3% DV of vitamin C, close to the %DV served by consuming equivalent amounts of sweet potato or tomato [23]. Even considering the cooking losses (approximately 29% for boiled peeled), the cultivar was still comparable to asparagus, onion, and avocado [23].

Figure S3 illustrated the levels of six minerals evaluated in all potato samples. K and Fe dominated the most abundant

Table 1 The $NRF_{11.3}$ scores (*per* 100 kcal) of 67 potato (*S. tuberosum* L.) cultivars based on Chinese Dietary Reference Intakes 2013 for those age ≥ 18 years by gender[1]

No.	Cultivar	$NRF_{11.3}$ scores		No.	Cultivar	$NRF_{11.3}$ scores	
		Male	Female			Male	Female
Dingxi, Gansu							
1	AGRICO2	95.9 ± 0.2[a]	98.4 ± 0.2[a]	20	AGRICO10	78.1 ± 0.1	82.5 ± 0.1
2	AGRICO3	89.5 ± 0.1[b]	90.9 ± 0.1[b]	21	Longshu No.6	77.9 ± 0.3	82.4 ± 0.4
3	Xindaping	86.5 ± 0.1[c]	89.8 ± 0.1[b,c]	22	LY08104–12	77.7 ± 0.1	80.6 ± 0.2
4	AGRICO1	86.0 ± 0.2[c]	89.5 ± 0.2[c]	23	Longshu No.12	77.1 ± 0.1	79.3 ± 0.1
5	Zhongshu No. 19	84.3 ± 0.1[d]	87.2 ± 0.1[d]	24	Longshu No.8	76.3 ± 0.1	80.6 ± 0.2
6	L1039–6	84.2 ± 0.2[d]	87.1 ± 0.2[d]	25	Z2011–1	76.2 ± 0.5	78.9 ± 0.5
7	AGRICO5	83.3 ± 0.2	86.8 ± 0.2	26	Nongtian No.2	75.8 ± 0.3	79.2 ± 0.3
8	Zhongshu No. 21	83.3 ± 0.1	85.8 ± 0.1	27	AGRICO9	75.7 ± 0.2	80.6 ± 0.3
9	Longshu No.9	82.8 ± 1.2	87.0 ± 1.3	28	Longshu No.13	75.7 ± 0.3	78.4 ± 0.3
10	534–1	82.3 ± 0.5	86.7 ± 0.5	29	Zhuangshu No.3	75.5 ± 0.3	78.7 ± 0.3
11	Tianshu No.11	81.3 ± 0.1	83.8 ± 0.1	30	AGRICO6	74.9 ± 0.2	77.5 ± 0.2
12	Qingshu No.9	80.6 ± 0.2	81.1 ± 0.3	31	LY1011–15	74.8 ± 0.2	78.4 ± 0.2
13	Lishu No.10	80.4 ± 0.1	83.8 ± 0.1	32	Jizhangshu No.14	73.8 ± 0.1	77.0 ± 0.1
14	Jizhangshu No.12	80.3 ± 0.2	84.0 ± 0.2	33	Zhongshu No.901	73.4 ± 0.1	85.8 ± 0.1
15	AGRICO8	79.1 ± 0.1	81.4 ± 0.1	34	0422–19	72.3 ± 0.0	75.4 ± 0.0
16	AGRICO4	79.1 ± 0.2	80.8 ± 0.2	35	Zhongshu No.9	71.4 ± 0.1	74.5 ± 0.1
17	Lishu No.6	79.0 ± 0.2	81.9 ± 0.2	36	L0527–2	69.2 ± 0.2	72.6 ± 0.2
18	Yongfeng No.3	79.0 ± 0.3	82.0 ± 0.3	37	AGRICO7	66.4 ± 0.2	68.6 ± 0.2
19	0506–5	78.7 ± 0.2	83.4 ± 0.2				
Dingbian, Shaanxi							
1	Kexin No.1	102 ± 0.3[a]	107 ± 0.3[a]	13	Ganyin No.2	86.3 ± 0.1	90.4 ± 0.1
2	Shepody	94.2 ± 0.5[b]	98.7 ± 0.5[b]	14	Jizhangshu No.8	84.4 ± 0.3	88.7 ± 0.3
3	529–2	92.1 ± 0.3[c]	96.4 ± 0.3[c]	15	Qingshu No.168	82.7 ± 0.3	87.6 ± 0.3
4	948-A	91.3 ± 0.1[c,d]	94.2 ± 0.1[d]	16	Atlantic	81.9 ± 0.3	86.0 ± 0.3
5	Longshu No.7	90.9 ± 0.3[d]	94.9 ± 0.3[d]	17	Favorita	81.7 ± 0.3	85.0 ± 0.3
6	Qinzi No.1	89.0 ± 0.4	91.9 ± 0.4	18	Zhongshu No.18	81.6 ± 0.3	84.5 ± 0.3
7	L0527–7	89.0 ± 0.2	90.4 ± 0.2	19	L0527–4	81.3 ± 0.1	85.5 ± 0.1
8	Genyou No.5	88.1 ± 0.1	92.1 ± 0.1	20	Longshu No.11	79.3 ± 0.2	82.8 ± 0.3
9	Dingshu No.1	88.1 ± 0.2	91.4 ± 0.1	21	L0528–3	72.8 ± 0.1	75.3 ± 0.1
10	Longshu No.3	87.6 ± 0.3	91.6 ± 0.3	22	Mccann No.1	70.7 ± 0.2	74.4 ± 0.2
11	Longshu No.10	87.0 ± 0.1	91.4 ± 0.1	23	Genyou No.1	70.1 ± 0.2	73.7 ± 0.2
12	P-86	87.0 ± 0.4	90.9 ± 0.4	24	P-119	67.0 ± 0.2	70.8 ± 0.2
Guyuan, Ningxia							

Table 1 (continued)

No.	Cultivar	$NRF_{11.3}$ scores		No.	Cultivar	$NRF_{11.3}$ scores	
		Male	Female			Male	Female
62	GY08–50-2	102 ± 0.5^a	106 ± 0.5^a	65	LK-99	95.7 ± 0.7^b	101 ± 0.6^b
63	GY08–2-12	97.3 ± 0.4^b	102 ± 0.4^b	66	GY06–1-4	92.9 ± 0.3^c	97.8 ± 0.3^c
64	SM-3	96.2 ± 0.2^b	101 ± 0.2^b	67	GY08–6-30	91.4 ± 0.7^c	95.3 ± 0.8^d

[1] Values are average ± SD ($n = 3$). For each individual location for each gender, values within columns with different superscript letters are significantly different ($P < 0.05$). (letters a–d were marked). *NRF* Nutrient-rich foods

macro- and micro-mineral, respectively (mean values: 1987 and 2.40 mg/100 g DW). A lower average mineral content was detected in 37 samples from Dingxi, Gansu in comparison to those from other two sites. In light of large amounts of fertilizers applied in Dingxi (Table S1), other factors including potato genotypes, irrigation, climate, the phytoavailability of minerals in the soil, and the bioavailability of the fertilizer by potatoes might be the influencing factors of mineral elements levels and composition [17]. With regard to the contents of Na, the negative mineral nutrient in $NRF_{11.3}$ Index model, a variation of 1.28–56.4 mg/100 g DW was achieved in the tested potato samples, with the lowest in Nongtian No.2. The potassium content present in potatoes was higher than some vegetables and fruits such as mushrooms and bananas [24]. FDA and the American Heart Association (AHA) also recommend them as an excellent food for patients with hypertension or stroke because of the high K/Na ratio in potatoes [25].

$NRF_{11.3}$ Scores

Drewnowski [14] has calculated the nutrient-to-price ratios using NRF Index scoring system combined with a food prices database and finally identified that potatoes, citrus juices, cereals, and beans could be regarded as nutritious food at an affordable price. The $NRF_{11.3}$ scores of 67 potato samples based on Chinese DRIs for those over 18 years old by gender were shown in Table 1. For adult male/female, $NRF_{11.3}$ scores varied from 66.4/68.6 in AGRICO7 to 102/107 in Kexin No.1. Additionally, the average $NRF_{11.3}$ indices of six potato cultivars from Guyuan, Ningxia were 95.8 and 101 for men and women, respectively, which were double the values from other two sites. A majority of earlier studies focused on the $NRF_{9.3}$ model for estimating the nutritional quality of foods using 9 beneficial nutrients (protein, dietary fiber, vitamins A, C, E, iron, calcium, potassium, and magnesium) due to a higher percentage of variation (R^2) as explained by $NRF_{9.3}$ model in the validation procedure [9, 26]. The mean $NRF_{9.3}$ score in the present study (78.0, data not shown) was lower than that of potatoes and tubers for Chinese residents (88.4), while higher than that for Netherlandish residents (53.6) [26, 27]. Interestingly, as compared to those values based on US Department of Agriculture (USDA) nutrient composition, approximately three-fold increment was observed in the average $NRF_{11.3}$ indices of 67 potato cultivars (84.1) due to the different vitamins selected in our study [14]. Furthermore, 5.3- and 4.2-fold increases were also observed when compared with milled wheat flours and long-grain nonglutinous rice flour, respectively. It was demonstrated that the $NRF_{n.3}$ scores became less correlated with energy density as more nutrients employed in the model [7]. Therefore, an advisable selection of index nutrients should be considered deliberately prior to

Table 2 Pearson correlation coefficients of beneficial nutrients (protein, vitamin B_1, vitamin B_3, vitamin C, calcium, potassium, magnesium, iron and zinc), limiting nutrients (fat and sodium) and $NRF_{11.3}$ scores

Variables	Crude protein	VB_1	VB_3	VC	K	Mg	Ca	Fe	Zn	Crude fat	Na	$NRF_{11.3}$_male	$NRF_{11.3}$_female
Crude protein		−0.071	0.343^{**}	0.105	0.487^{**}	0.406^{**}	0.223	−0.058	0.577^{**}	0.194	0.129	0.568^{**}	0.589^{**}
VB_1	−0.071		−0.122	−0.156	−0.087	−0.055	−0.050	−0.050	0.093	-0.257^{*}	0.080	−0.026	−0.004
VB_3	0.343^{**}	−0.122		0.157	0.415^{**}	0.292^{*}	−0.213	−0.174	0.302^{*}	0.125	0.143	0.588^{**}	0.641^{**}
VC	0.105	−0.156	0.157		−0.066	0.078	0.039	0.032	0.007	0.298^{*}	0.208	0.489^{**}	0.471^{**}
Crude fat	0.194	-0.257^{*}	0.125	0.298^{*}	−0.049	−0.047	0.241^{*}	−0.140	0.056		−0.239	0.059	0.066
K	0.487^{**}	−0.087	0.415^{**}	−0.066		0.385^{**}	0.032	−0.075	0.374^{**}	−0.049	0.288^{*}	0.740^{**}	0.749^{**}
Mg	0.406^{**}	−0.055	0.292^{*}	0.078	0.385^{**}		0.108	0.252^{*}	0.431^{**}	−0.047	0.227	0.561^{**}	0.546^{**}
Ca	0.223	−0.050	−0.213	0.039	0.032	0.108		0.337^{**}	0.101	0.241^{*}	-0.398^{**}	0.109	0.068
Fe	−0.058	−0.050	−0.174	0.032	−0.075	0.252^{*}	0.337^{**}		−0.075	−0.140	−0.133	0.160	0.066
Zn	0.577^{**}	0.093	0.302^{*}	0.007	0.374^{**}	0.431^{**}	0.101	−0.075		0.056	0.175	0.455^{**}	0.482^{**}
Na	0.129	0.080	0.143	0.208	0.288^{*}	0.227	-0.398^{**}	−0.133	0.175	−0.239		0.316^{**}	0.328^{**}
$NRF_{11.3}$_male	0.568^{**}	−0.026	0.588^{**}	0.489^{**}	0.740^{**}	0.561^{**}	0.109	0.160	0.455^{**}	0.059	0.316^{**}		0.994^{**}
$NRF_{11.3}$_female	0.589^{**}	−0.004	0.641^{**}	0.471^{**}	0.749^{**}	0.546^{**}	0.068	0.066	0.482^{**}	0.066	0.328^{**}	0.994^{**}	

Only significantly correlated variables and coefficients are shown

** $P < 0.01$

* $P < 0.05$

VB_1 Vitamin B_1, *VB_2* Vitamin B_2, *VB_3* Vitamin B_3, *TDF* Total dietary fiber, *NRF* Nutrient-rich foods

establishing a complex nutrient profiling model. Potatoes were consequently recognized as one of the healthiest foods and the lowest-cost sources of potassium and dietary fiber based on nutrition economics [8].

Correlations Between Variables and $NRF_{11.3}$ Scores

As described in Table 2, among the 11 variables, a strong positive correlation was observed between crude protein and Zn (0.577) ($P = 0.000$), while with regard to vitamin B_3, minerals K and Mg, only a moderate correlation with crude protein was determined with r values of 0.343, 0.487, and 0.406, respectively ($P < 0.01$). Moderate positive correlations were observed between Mg and Zn (0.431), vitamin B_3 and K (0.415), K and Mg (0.385), K and Zn (0.374), Fe and Ca (0.337), and vitamin B_3 and Zn (0.302) in this study, while Na negatively correlated with Ca (−0.398, $P < 0.01$). According to Pearson correlation analysis, $NRF_{11.3}$ scores were highly associated with seven nutritional variables with the exception of VB_1, Ca, Fe, and crude fat. In addition, as the predominant component of the minerals, K was strongly correlated with $NRF_{11.3}$ indices as expected (0.740 for male and 0.749 for female, respectively).

There still existed some limitations of the present study. Cooking loss should be taken into account to verify the feasibility of $NRF_{11.3}$ model for the comprehensive nutritional assessment of raw potatoes or the potato staple products.

Conclusions

Generally, the proximate composition significantly varied among 67 potato cultivars. The highest DM content of 30.5 ± 0.7 g/100 g FW and dietary fiber content of 3.39 ± 0.05 g/100 g DW were observed in Longshu No.8 and Longshu No.6, respectively, both obtained from Dingxi, Gansu. LK-99 from Guyuan, Ningxia had the highest contents of crude protein, vitamins B_1 and B_3. The maximum $NRF_{11.3}$ scores in each location were found in AGRICO2 (Dingxi, Gansu), Kexin No.1 (Dingbian, Shaanxi), and GY08–50-2 (Guyuan, Ningxia), respectively. In conclusion, as a formal scoring system and the science of classifying foods tool, $NRF_{11.3}$ index model could be applied to determine the primary constitutes of various potato cultivars and promote comprehensive nutritional study on potatoes as a desirable raw material for staple food processing, contributing to human nutrition and daily diet.

Acknowledgements The authors acknowledge the financial support from Special Fund for Agro-scientific Research in the Public Interest (CN) (Grant No: 201503001-2) and Beijing Municipal Science and Technology Project (Grant No: 17110500190000).

Compliance with Ethical Standards

Conflict of Interest No potential conflicts of interest were declared by the authors.

References

1. Ezekiel R, Singh N, Sharma S et al (2013) Beneficial phytochemicals in potato — a review. Food Res Int 50:487–496
2. Turski MP, Kaminski P, Zgrajka W et al (2012) Potato- an important source of nutritional kynurenic acid. Plant Foods Hum Nutr 67:17–23
3. Wu Y, Hu H, Dai X et al (2019) Effects of dietary intake of potatoes on body weight gain, satiety-related hormones, and gut microbiota in healthy rats. RSC Adv 9:33290–33301. https://doi.org/10.1039/C9RA04867G
4. Hashimoto N, Nakamura Y, Noda T, Han KH, Fukushima M (2011) Effects of feeding potato pulp on cholesterol metabolism and its association with cecal conditions in rats. Plant Foods Hum Nutr 66:401–407
5. Ngobese NZ, Workneh TS, Alimi BA et al (2017) Nutrient composition and starch characteristics of eight European potato cultivars cultivated in South Africa. J Food Compos Anal 55:1–11
6. Zhang H, Xu F, Wu Y et al (2017) Progress of potato staple food research and industry development in China. J Integr Agric 16:2924–2932. https://doi.org/10.1016/S2095-3119(17)61736-2
7. Drewnowski A, Fulgoni VL, Young MK, Pitman S (2008) Nutrient-rich foods: applying nutrient navigation systems to improve public health. J Food Sci 73:H222–H228
8. Drewnowski A, Fulgoni V 3rd (2008) Nutrient profiling of foods: creating a nutrient-rich food index. Nutr Rev 66:23–39
9. Fulgoni VL, Keast DR, Drewnowski A (2009) Development and validation of the nutrient-rich foods index: a tool to measure nutritional quality of foods. J Nutr 139:1549–1554
10. Liu Q, Yada R, Arul J (2002) Characterization of thermal properties of potato dry matter–water and starch–water systems. J Food Sci 67:560–566
11. AOAC (Association of Analytical Chemists) (2000) Official methods of analysis (17th ed.). AOAC International, Gaithersburg
12. Tuncel NB, Yılmaz N, Kocabıyık H et al (2014) The effect of infrared stabilized rice bran substitution on B vitamins, minerals and phytic acid content of pan breads: Part II. J of Cereal Sci 59:162–166
13. AACC (American Association for Clinical Chemistry) (2000) Approved methods of american association of cereal chemists (10th ed.). American Association of Cereal Chemists, Inc., Eagan
14. Drewnowski A (2010) The nutrient rich foods index helps to identify healthy, affordable foods. Am J Clin Nutr 91:1095S–1101S
15. Chinese Nutrition Society (2013) Chinese dietary reference intakes (2013). Science Press, Beijing
16. Leonel M, Do Carmo EL, Fernandes AM et al (2017) Chemical composition of potato tubers: the effect of cultivars and growth conditions. J Food Sci Technol 54:2372–2378
17. Kaur L, Singh J (2009) Advances in potato chemistry and technology. Academic Press, London
18. Kaur S, Aggarwal P (2014) Studies on Indian potato genotypes for their processing and nutritional quality attributes. Int J Curr Microbiol App Sci 3:172–177
19. Zhao L, Xiao H, Liu X et al (2006) Correlations of foliar Δ with K concentration and ash content in sand-fixing plants in the Tengger Desert of China: patterns and implications. Environ Geol 51:1049–1056

20. Burlingame B, Mouillé B, Charrondière R (2009) Nutrients, bioactive non-nutrients and anti-nutrients in potatoes. J Food Compos Anal 22:494–502
21. Xu F, Hu H, Dai X et al (2017) Nutritional compositions of various potato noodles: comparative analysis. Int J Agric Biol Eng 10:218–225. https://doi.org/10.3965/j.ijabe.20171001.2287
22. Peña C, Restrepo-Sánchez L-P, Kushalappa A et al (2015) Nutritional contents of advanced breeding clones of *Solanum tuberosum* group Phureja. LWT-Food Sci Technol 62:76–82
23. Us Food and Drug Administration (2018) Nutrition information for raw fruits, vegetables and fish https://wwwfdagov/food/food-labeling-nutrition/nutrition-information-raw-fruits-vegetables-and-fish. Accessed 5 July 2019
24. McGill CR, Kurilich AC, Davignon J (2013) The role of potatoes and potato components in cardiometabolic health: a review. Ann Med 45:467–473
25. Appel LJ, Brands MW, Daniels SR, Karanja N, Elmer PJ, Sacks FM (2006) Dietary approaches to prevent and treat hypertension a scientific statement from the American Heart Association. Hypertension 47:296–308
26. Sluik D, Streppel MT, Van Lee L et al (2015) Evaluation of a nutrient-rich food index score in the Netherlands. J Nutr Sci 4:e14
27. Zhou SS, Li L, Zhang D et al (2014) Development and application of a new food nutrition evaluation index. Acta Nutrimenta Sinica 36:63–68. In Chinese. https://doi.org/10.13325/j.cnki.acta.nutr.sin.2014.01.016