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Analysis of Nutrient Composition of Purple Wheat

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To investigate the nutritional characteristics of purple wheat, 41 kinds of nutrients were measured in seven purple wheat lines using one white wheat variety as control sample. Correlation analysis of nutrient contents was performed. Results show that the amounts of 40 kinds of nutrients in the purple wheat lines are higher than those of the control. For example, the amounts of sodium (Na) and manganese (Mn) in purple wheat are higher than the standards by 311.77–2017.65% and 548.15–733.33%, respectively; the contents of $\beta + \gamma$-vitamin E is higher than the standards by 300%; and zinc (Zn), iron (Fe), magnesium (Mg), and potassium (K) are all higher than the control by 100%. Therefore, the purple wheat has obvious advantages in terms of the nutrient contents. Correlation analysis studies show that protein has significant positive correlations with Glu, Mo, Pro, Fe, Tyr and Ile. Anthocyanin has significant positive correlations with Mo and Glu, and significant negative correlations with free Trp and Ca. Carotenoid has significant positive correlations with His, Lys, Val, Leu, Arg, Gly and I, and significant negative correlations with Ca. This paper is a first report on comprehensive nutrients of several purple wheat lines. Our results suggest that purple wheat is rich in nutrients and there are many significant correlations among different nutrients. The valuable information is very useful in biofortification breeding and functional food development.

Keywords: purple wheat, nutrients, correlation analysis

Introduction

Micronutrient malnutrition or hidden hunger, afflicts billions of people. It is caused by a lack of micronutrients in the diet, as pointed out by HarvestPlus. The World Health Organization has also reported that 46% children aged from 5 to 14 years have iron deficiency anemia, 48% pregnant women are iron deficient (Kapur et al. 2002), more than 200 million people lack essential trace elements, and more than 160 million children have inadequate protein intake (Welch and Graham 2004). Many countries add nutrients to food in order to meet human needs. For example, Egypt adds folic acid and iron in wheat flour. But it is limited by some problems, such as nutrient absorption, enormous cost and security of added nutrients (Choia et al. 2007). If nutrient-rich crops can be bred and mass pro-

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duced, the problems mentioned above would be solved. Biofortification breeding will play an important role in supplying enough nutrients. Wheat is one of the world's major food crops, the nutritional quality of which has received more and more attention. For example, several research papers were published by HarvestPlus partners and collaborators in recent years demonstrating valuable sources, e.g. emmer and synthetic wheat, of increased concentrations of certain minerals, e.g. Zn (Rosado et al. 2009).

Colored wheats contain numerous nutrients which are beneficial to human health (Milder et al. 2005; Hosseinian and Beta 2007; Li and Beta 2011). Colored wheats are rich in anthocyanins, which display various biological activities including antioxidant, anti-inammatory, antimicrobial and anti-carcinogenic activities. In addition, anthocyanins have multiple effects on blood vessels and platelets that may reduce the risk of coronary heart disease (Zeven 1991; Mazza 2007; Hosseinian et al. 2008; Zheng et al. 2009). Li et al. (2003) found that contents of protein, total essential amino acids and total amino acids in Chinese black wheat were higher than those in white wheat varieties (Li et al. 2003). He and Ning (2003) found that black wheat "Qinhei No. 1" had higher contents of iron, zinc, manganese, copper, selenium, magnesium, potassium, phosphorus and some amino acids including lysine, methionine, isoleucine and glutamic acid, and the black wheat had low-sodium and low-fat characteristics. The organic chromium (trivalent chromium) content in black wheat "03Z4-439" was reported about four times that of common wheat, which characteristic can be used to treat diabetes. American scientists found that wild emmer wheat was rich in zinc and iron, and they increased contents of protein, zinc and iron by 10% to 15% through hybridization between wild wheat and common wheat (Reuters 2006).

Although various researches have investigated the nutrients of colored wheats, only one or several kinds of nutrients were studied in different wheat varieties with different methods. Different colored wheats have different genetic backgrounds, and hence the results are not consistent with each other. One could not find the adherent regularity among those results. In this paper, we report a comprehensive study of nutrients in purple wheat. We analyzed 41 kinds of nutrients in eight wheat cultivars including seven purple wheat lines derived from the same parents and one white wheat variety as control sample, trying to find more detailed information and nutrient constitution differences between purple wheat and white wheat, which may be useful in selecting and breeding nutrient-rich wheat and can provide more valuable information for functional food development.

Materials and Methods

Wheat samples

The seven colored wheat lines "ZY" used in this experiment were bred and selected by Dr. Zhengbin Zhang at Agricultural Resources Research Center, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences. These lines were F_7 generations derived from the outcross by mixed pollination with einkorn wheat (*Triticum boeoticum,* AA, white seed) and French rye (French *Secale cereale,* RR, blue seed) as male parents and with the high-quality bread wheat line “Y1642” (derived from common wheat and *Agropyron elongatum,* AABBDD) as the female parent (Guo et al. 2011). The name/code of original common wheat parent st2422/464 and its original seed color is white. These lines have independent genetic backgrounds from other colored wheat lines used in previous studies. One white-grained wheat variety SJZ8 provided by Shijiazhuang Academy of Agricultural Sciences was used as control sample from the same conditions, which has been planted for many years in north of China because of the high yield, good drought tolerance, and disease resistance. It should be mentioned that, since the blue aleurone trait originates from either *Triticum boeoticum* or *Agropyron elongatum* and the purple pericarp from Ethiopian tetraploid wheats, in the present material the anthocyanin pigmentation is of the blue aleurone type.

Nutrient tests

The nutrients were analyzed in Chinese National Analytical Center of Guangzhou, China. Amino acids were analyzed according to “Practical Food Nutrients Assay Vade Mecum” published by China Light Industry Printing Company, 2002. The typical procedure is described as following. Amino acid composition was determined by reversed-phase HPLC following hydrolysis with 6 N HCl at 110°C under nitrogen for 24 h and derivatization with phenylisothiocyanate. Sulfur-containing amino acids were converted into cysteic acid and methionine sulfone by pre-oxidation with performic acid prior to hydrolysis and derivatization. Amino acid standard from Sigma-Aldrich was used for calibration and α-amino *n*-butyric acid was used as an internal standard. The contents refer to 100 g seeds. Anthocyanin was measured according to the following procedures (Abdel-aal and Huel 1999). Typically, total anthocyanin content was measured with cyanidin-3-glucoside (Sigma-Aldrich) as a standard. A 2 g of sample was ground in a laboratory blender and extracted with 6 mL of acidified methanol solution (methanol/1 mol L^{-1} HCl, 85 : 15 v/v). The mixture was adjusted to pH 1 with 10 mol L^{-1} HCl and shaken in an oscillating shaker for 30 min. The extract was centrifuged at 2060 × *g* for 15 min. The absorbance of the supernatant was read at 535 nm against a reagent blank. All tests were performed in triplicate. The rest traits were analyzed according to Chinese National Standard (GB/T). All samples were analyzed with at least duplicate determinations and data were evaluated by analysis of variance (ANOVA) or Pearson correlation analysis. Values of the standards were from references (Jiang et al. 2000; Chen and Qin 2005; Guo et al. 2011).

Results

Contents of hydrolyzed amino acids in different wheat varieties

Purple wheat has obvious advantages over control samples in terms of contents of hydrolyzed amino acids (Table 1). Comparing with the standards, the amounts of 15 hydrolyzed amino acids are significantly higher in purple wheat ZY4, ZY5, ZY21 and ZY22, and 14 kinds significantly higher in ZY11, ZY17-1, and ZY17-2. For example, content of Trp in purple wheat is higher than that of the standards by more than 40%, Gly, His and Ile by

Table 1. Contents of hydrolyzed amino acids in different wheat varieties (g/100 g seeds)

Item	ZY4	ZY5	ZY11	ZY17-1	ZY17-2	ZY21	ZY22	Average of purple wheat	Standards	Control	PHS (%)	PHC (%)
Trp	0.14±0.01	0.15±0.01	0.16±0.01	0.16±0.01	0.16±0.01	0.15±0.01	0.14±0.01	0.15AB	0.10±0.00	0.12±0.01	40.0–60.0	16.67–33.33
Asp	0.75±0.01	0.74±0.01	0.72±0.01	0.73±0.03	0.67±0.01	0.76±0.01	0.77±0.02	0.73Ab	0.53±0.04	0.65±0.07	26.42–45.28	3.08–18.46
Glu	4.25±0.06	4.19±0.06	4.46±0.13	5.02±0.12	4.68±0.11	4.92±0.06	5.03±0.22	4.65AB	3.33±0.14	3.57±0.04	25.83–51.06	17.37–40.90
Ser	0.61±0.01	0.61±0.01	0.61±0.01	0.64±0.03	0.58±0.01	0.66±0.01	0.70±0.01	0.63AB	0.50±0.03	0.49±0.01	16.00–40.00	18.37–42.86
Gly	0.59±0.01	0.59±0.01	0.58±0.01	0.59±0.02	0.56±0.01	0.63±0.01	0.65±0.01	0.60AB	0.41±0.03	0.47±0.01	36.59–58.54	19.15–38.30
Thr	0.40±0.01	0.40±0.01	0.39±0.01	0.40±0.02	0.37±0.01	0.41±0.01	0.43±0.01	0.40AB	0.31±0.02	0.32±0.01	19.35–38.71	15.63–34.38
His	0.34±0.03	0.34±0.01	0.32±0.01	0.35±0.02	0.31±0.01	0.35±0.01	0.39±0.01	0.34Ab	0.23±0.02	0.27±0.01	34.78–69.57	14.81–44.44
Ala	0.52±0.01	0.52±0.01	0.50±0.01	0.51±0.01	0.47±0.01	0.53±0.01	0.54±0.01	0.51B	0.51±0.03	0.44±0.01	1.96–5.88	6.82–22.73
Arg	0.58±0.01	0.57±0.01	0.58±0.01	0.58±0.01	0.54±0.01	0.59±0.01	0.62±0.01	0.58a	0.50±0.04	0.52±0.02	8.00–24.00	3.85–19.23
Tyr	0.14±0.01	0.13±0.01	0.18±0.01	0.17±0.02	0.17±0.01	0.17±0.01	0.18±0.01	0.16A	0.32±0.03	0.14±0.01		21.43–28.57
Val	0.67±0.01	0.66±0.01	0.67±0.01	0.69±0.03	0.64±0.01	0.71±0.01	0.74±0.01	0.68AB	0.51±0.03	0.55±0.01	25.49–45.10	16.36–34.55
Met	0.09±0.01	0.09±0.01	0.10±0.01	0.10±0.01	0.09±0.01	0.10±0.01	0.11±0.01	0.097Ab	0.17±0.03	0.07±0.01		28.57–57.14
Phe	0.63±0.02	0.64±0.01	0.66±0.01	0.70±0.04	0.63±0.01	0.71±0.01	0.76±0.02	0.68AB	0.53±0.05	0.53±0.01	18.87–43.40	18.87–43.40
Ile	0.51±0.01	0.51±0.01	0.53±0.01	0.55±0.03	0.51±0.01	0.56±0.01	0.59±0.02	0.54AB	0.39±0.04	0.44±0.00	30.77–51.28	15.91–34.01
Leu	0.99±0.02	0.99±0.01	1.00±0.01	1.04±0.05	0.96±0.02	1.07±0.01	1.13±0.03	1.03AB	0.75±0.04	0.82±0.01	28.00–50.67	17.07–37.80
Lys	0.39±0.01	0.40±0.01	0.37±0.01	0.38±0.02	0.35±0.01	0.38±0.01	0.38±0.01	0.38A	0.29±0.03	0.36±0.01	20.69–37.93	2.78–11.11
Pro	1.14±0.01	1.36±0.31	1.57±0.02	1.70±0.03	1.65±0.01	1.60±0.03	1.63±0.48	1.52Ab	1.00±0.10	1.08±0.35	14.00–70.00	5.56–57.41
Total, c	12.6±0.23	12.7±0.38	13.2±0.08	14.2±0.45	13.2±0.11	14.2±0.16	14.7±0.40	13.54AB	10.57±0.27	10.70±0.28	19.21–39.07	17.76–37.38

Note: ZY, purple wheat lines; PHS, percentage of purple wheat higher than standards; PHC, percentage of purple wheat higher than control samples.
A, $P < 0.01$ vs. standards of common wheat; a, $P < 0.05$ vs. standards; B, $P < 0.01$ vs. control samples; b, $P < 0.05$ vs. control samples. c, Total Hydrolyzed Amino Acids.

Table 2. Contents of mineral elements in different wheat varieties

Item	Unit	ZY4	ZY5	ZY11	ZY17-1	ZY17-2	ZY21	ZY22	Average of purple wheat	Standards	Control	PHS (%)	PHC (%)
Mo	mg/kg	0.50±0.05	0.44±0.02	0.53±0.01	0.74±0.01	0.64±0.01	0.63±0.01	0.66±0.01	0.59b	0.48±0.05	0.82±0.01	4.17–54.17	
Zn	mg/kg	40.00±0.64	39.00±0.78	40.00±0.71	41.00±0.57	40.00±1.06	43.00±0.21	49.00±0.57	41.71AB	11.60±0.70	30.00±0.28	236.21–322.41	30.00–63.33
Fe	mg/kg	40.00±0.42	39.00±0.78	47.00±1.13	46.00±0.49	46.00±1.41	52.00±1.34	52.00±1.06	46.00A	18.50±3.10	43.00±0.92	81.08–110.81	6.98–20.93
Mg	%	0.13±0.01	0.14±0.01	0.14±0.01	0.14±0.01	0.14±0.01	0.15±0.01	0.15±0.01	0.14A	0.05±0.01	0.14±0.01	33.33–188.89	0.00–7.14
Na	%	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.038A	0.01±0.00	0.037±0.01	311.77–2017.65	0.00–10.81
K	%	0.38±0.01	0.39±0.01	0.36±0.01	0.34±0.01	0.34±0.01	0.38±0.01	0.34±0.01	0.36A	0.14±0.01	0.36±0.01	142.86–178.57	0.00–8.33
P	%	0.26±0.01	0.28±0.01	0.28±0.01	0.30±0.01	0.27±0.01	0.29±0.01	0.30±0.01	0.28A	0.15±0.01	0.27±0.01	68.83–94.81	3.70–11.11
Ca	mg/kg	436±3.54	439±9.19	447±4.95	366±6.36	407±2.12	425±2.83	417±1.41	419.57AB	340.00±20.00	258±5.66	7.65–31.47	41.86–73.26
I	mg/kg	0.04±0.01	0.04±0.01	0.04±0.01	0.05±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.04A	0.06±0.00	0.04±0.00		0.00–15.9
Mn	mg/kg	36.00±0.64	35.00±0.99	41.00±0.01	41.00±0.35	39.00±0.14	44.00±0.85	45.00±0.21	40.14A	5.40±0.30	37.00±1.27	548.15–733.33	5.41–21.62
Se	mg/kg	0.16±0.01	0.12±0.01	0.14±0.01	0.17±0.01	0.14±0.01	0.15±0.01	0.16±0.01	0.15AB	0.05±0.01	0.0018±0.001	126.42–220.75	566.67–844.44

Note: ZY, purple wheat lines; PHS, percentage of purple wheat higher than standards of common wheat; PHC, percentage of purple wheat higher than control samples. A, $P < 0.01$ vs. standards of common wheat; a, $P < 0.05$ vs. standards; B, $P < 0.01$ vs. control samples; b, $P < 0.05$ vs. control samples.

more than 30%, and Asp, Glu, Val, Leu and Lys by more than 20%. Comparing with the control, the contents of 17 kinds of hydrolyzed amino acids are higher in purple wheat ZY11, ZY17-1, ZY21 and ZY22, and 16 kinds higher in ZY4, ZY5 and ZY17-2. These results suggest that purple wheat ZY21 and ZY22 have advantages over other wheats in terms of contents of hydrolyzed amino acids.

Correlation analysis for contents of hydrolyzed amino acids in purple wheat

As shown in Table S1*, Val has positive correlations with 11 kinds of amino acids including Ser, Leu, Phe, Ile, Gly, Arg, Thr, His, Met, Ala and Asp. Ser has positive correlations with 10 kinds of amino acids including Leu, Val, Phe, Gly, Ile, His, Thr, Arg, Met and Ala. Gly has positive correlations with 9 kinds of amino acids including Val, Thr, Leu, His, Arg, Ala, Phe, Ile and Met. Thr has positive correlations with 7 kinds of amino acids including His, Arg, Ala, Val, Leu, Phe and Ile. Asp has positive correlations with 6 kinds of amino acids including Ala, Thr, Arg, Gly, His and Ser. These results suggest that, if we select some purple wheat lines with high contents of Val, Ser, Gly, Thr and Asp, we can obtain wheats rich in other amino acids.

Contents of mineral elements in different wheat varieties

Table 2 shows that purple wheat has obvious advantages in terms of contents of mineral elements over the control sample and standards. Comparing with the standards, the contents of 10 kinds of mineral elements are higher in purple wheat ZY4, ZY11, ZY17-1, ZY17-2, ZY21 and ZY22, and 9 kinds higher in ZY5. Meanwhile, comparing with the control, the contents of 9 kinds of mineral elements are higher in ZY21, 8 kinds higher in ZY17-1, 7 kinds higher in ZY11 and ZY22, 6 kinds higher in ZY5 and ZY17-2, and 5 kinds higher in ZY4. For example, content of Se in purple wheat is higher than the control by 126.42% to 220.75%. The purple wheat ZY21 has advantages over other wheats in terms of contents of mineral elements.

Correlation analysis of mineral element contents in purple wheat

We performed correlation analysis on the contents of 11 kinds of mineral elements in purple wheat. As shown in Table S2, Fe has positive correlations with Mn and Mg; Mg has positive correlations with Mn, and P; and Zn has positive correlations with Mn. Meanwhile, Na has negative correlations with Mn and Se; Mo has negative correlations with K and Ca; Ca has negative correlation with I.

Vitamin contents in different wheat varieties

Results of vitamin contents in different wheat varieties are shown in Table 3. Comparing with the standards, the contents of α-vitamin E, $\beta + \gamma$-vitamin E and total vitamin E are higher in purple wheat. For example, contents of $\beta + \gamma$-vitamin E in purple wheat are higher than the standards by 379.17% to 533.33%. Comparing with the control, 6 kinds

* Further details about the Electronic Supplementary Material (ESM) can be found at the end of the article.

Table 3. Vitamin contents in different wheat varieties

Item	Unit	ZY4	ZY5	ZY11	ZY17-1	ZY17-2	ZY21	ZY22	Average of purple wheat	Standards	Control	PHS (%)	PHC (%)
α-Vitamin E	mg/100 g	3.43±0.02	2.17±0.01	1.60±0.10	1.92±0.05	1.69±0.03	2.38±0.02	2.23±0.01	2.20	1.48±0.00	1.69±0.01	8.11–131.76	28.4–102.96
$\beta + \gamma$-Vitamin E		1.51±0.01	1.39±0.01	1.15±0.01	1.22±0.01	1.29±0.02	1.52±0.04	1.20±0.02	1.33A	0.24±0.00	1.44±0.02	379.17–533.33	4.86–5.56
Total vitamin E		4.94±0.02	3.56±0.01	2.75±0.11	3.14±0.06	2.98±0.01	3.90±0.06	3.43±0.04	3.53A	1.82±0.00	3.13±0.03	51.10–171.43	0.32–57.83
Vitamin B_1	mg/100 g	0.36±0.01	0.35±0.01	0.35±0.01	0.36±0.01	0.34±0.01	0.39±0.01	0.40±0.01	0.36		0.35±0.02		0.00–14.29
Vitamin B_2	μg/g	0.31±0.01	0.34±0.01	0.29±0.01	0.32±0.02	0.36±0.01	0.36±0.01	0.33±0.01	0.33B		0.25±0.01		16.00–44.00
Folic acid	μg/g	2.66±0.01	2.99±0.01	2.05±0.01	3.40±0.01	3.09±0.01	1.72±0.01	3.29±0.01	2.74B		0.96±0.01		79.17–254.17

Note: ZY, purple wheat lines; PHS, percentage of purple wheat higher than standards; PHC, percentage of purple wheat higher than control samples. A, $P < 0.01$ vs. standards of common wheat; a, $P < 0.05$ vs. standards; B, $P < 0.01$ vs. control samples; b, $P< 0.05$ vs. control samples.

Table 4. Contents of other nutrients in different wheat varieties

Item	Unit	ZY4	ZY5	ZY11	ZY17-1	ZY17-2	ZY21	ZY22	Average of purple wheat	Standards	Control	PHS (%)	PHC (%)
Fat	%	1.10±0.07	1.40±0.07	1.20±0.21	1.20±0.00	1.50±0.21	0.90±0.06	1.20±0.14	1.21b	1.16±0.19	0.88±0.05	7.69–15.38	2.27–70.45
Protein	g/100 g	13.90±0.04	13.70±0.40	14.60±0.10	16.20±0.20	15.70±0.12	15.60±0.08	16.50±0.10	15.17Ab	10.62±0.30	13.0±0.05	29.00–55.37	5.38–26.92
β-Carotene	μg/100 g	14.00±0.35	12.50±1.27	8.70±0.21	9.70±0.57	10.50±0.57	10.30±0.21	10.60±0.92	10.90b		7.50±0.00		16.00–86.67
Carotenoid	mg/kg	1.54±0.01	1.74±0.02	1.51±0.01	1.94±0.04	1.78±0.02	1.54±0.01	1.50±0.01	1.65b		1.38±0.02		8.70–40.58
Anthocyanin	antho-cyanin unit	1.86±0.00	1.54±0.01	2.15±0.01	4.17±0.01	2.60±0.01	3.07±0.01	3.02±0.01	2.63b		1.06±0.01		45.28–293.40
Insoluble dietary fiber	%	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30		11.30		

Note: ZY, purple wheat lines; PHS, percentage of purple wheat higher than standards; PHC, percentage of purple wheat higher than control samples. A, $P < 0.01$ vs. standards of common wheat; a, $P < 0.05$ vs. standards; B, $P < 0.01$ vs. control samples; b, $P < 0.05$ vs. control samples.

higher in ZY4 and ZY21, 5 kinds higher in ZY22 and ZY17-1, 4 kinds higher in ZY5, and 2 kinds higher in ZY11 and ZY17-2. Contents of all the 6 kinds of vitamins in purple wheat are higher than those in the control, and 3 kinds of vitamins are higher than the standards. The purple wheat ZY17-1 and ZY22 have advantages over other wheats in terms of vitamin contents.

Correlation analysis of vitamin contents in purple wheat

Table S3 shows the correlation analysis of vitamin contents in purple wheat. The total vitamin E has positive correlations with α-vitamin E and $\beta + \gamma$-vitamin E.

Contents of other nutrients in different wheat varieties

Contents of fat, protein β-carotene, carotenoid, anthocyanin and insoluble dietary fiber of purple wheat are shown in Table 4. Purple wheat has obvious advantages in terms of contents of these nutrients. Comparing with the standards, fat content is higher in ZY5 and ZY17-2, and protein content is higher in all purple wheat varieties. For example, protein content of purple wheat is higher than the standards by 29.00% to 55.37 %, and the fat content is higher than the standards by 7.69% to 15.38%. Comparing with the control, contents of anthocyanin, β-carotene, carotenoid, fat and protein are also higher in all the seven purple wheat lines. The purple wheat ZY17-1, ZY21 and ZY22 have advantages over other wheats in terms of contents of protein, fat, anthocyanin and other nutrients.

Correlation analysis for contents of other nutrients in purple wheat

Table S4 shows correlation analysis for contents of other nutrients such as fat, protein β-carotene, carotenoid, and anthocyanin. Protein has positive correlation with anthocyanin. It should be noted that, however, this correlation depends mainly on the present data and there is hitherto no evidence for a biological relationship.

Correlation analysis for contents of all nutrients in purple wheat

Besides correlation analysis on the same types of nutrients, a comprehensive correlation analysis for contents of different types of nutrients was also carried out in this study. VB1 has significant positive correlations with 12 kinds of amino acids including Gly, Val, Ser, Leu, Thr, Ile, Phe, His, Arg, Al, As and Met. Zn has significant positive correlations with 11 kinds of amino acids including Leu, Ile, Ser, Phe, Val, VB1, Gly, Met, His, Arg and Thr. It also has significant negative correlation with free Asp. Mn has significant positive correlations with 8 kinds of amino acids including Ile, Met, Phe, Glu, Tyr, Leu, Val and Ser. Carotenoid has significant positive correlations with 7 kinds of nutrients including His, Lys, Val, Leu, Arg, Gly and I, and has significant negative correlation with Ca. Protein has significant positive correlations with 6 kinds of nutrients including Glu, Mo, Pro, Fe, Tyr and Ile, and has significant negative correlations with Glu. Fe has significant positive correlations with 5 kinds of amino acids including Tyr, Glu, Ile, Met and Phe. P has significant positive correlations with 6 kinds of amino acids including Phe, Ile, Met, Leu, Glu and Ser. Ca has significant positive correlations with 2 kinds of nutrients including

Arg and His, and has significant negative correlations with carotenoid and anthocyanin. Mo has significant positive correlations with 3 kinds of nutrients including anthocyanin, Glu and Pro. Anthocyanin has significant positive correlations with Mo and Glu, and has significant negative correlations with free Trp and Ca. Na has significant positive correlations with Arg, and has significant negative correlations with Ile and Met. Mg has significant positive correlations with Pro, Ile and Leu. β-Carotene has significant positive correlations with total VE, Tyr and Pro. Iodine has significant positive correlations with carotenoid and folic acid. K has significant positive correlation with free Arg. Total VE has significant negative correlation with Pro.

Discussion

Relative anthocyanin content in different wheat and the distribution were measured and compared (Khlestkina et al. 2009). Other components such as phenolic acid content were determined in organically and conventionally grown winter wheat (Zuchowski et al. 2009). In this work, 41 kinds of nutrients were systematically measured and analyzed, which is different from most previous studies where only several limited kinds of nutrients were studied. We found that a wide range of nutrients contents in purple wheat are higher than the values of the control and those reported in literatures. Some results are consistent with those reported in literatures about nutrient contents of colored wheats. For example, it has been reported that purple and blue wheats were rich in anthocyanins (Abdel-aal and Hucl 2003; Hosseinian et al. 2008), which was also confirmed by our results. Li et al. (2003) studied 8 kinds of colored wheats and found that colored wheats with different genetic backgrounds had advantages over white wheat in nutrient contents. They also found that contents of melanoma, anthocyanin and polyphenol oxidase of blue and purple wheats were much higher than those of common wheat.

Some colored wheats have been actually bred, which are rich in nutrients. For example, black wheat "03Z4-439" has been bred by the Agriculture and Forestry Academy of Hebei Province in China, organic chromium content of which is four times higher than that of common wheat. In addition, it is also rich in selenium, zinc, dietary fiber and protein. Black wheat "Qinhei 1" has been bred by the Northwest Agriculture and Forestry University in China, the iron and zinc contents of which are found to be 19.2 and 4.1 times of those of common wheat, respectively, and contents of manganese, copper, selenium, magnesium, potassium, phosphorus, lysine, methionine, isoleucine and glutamic acid content are all higher than that of common wheat (He and Ning 2003).

In this work, we found that there are some correlations between different nutrients which have not been found in previous studies. We used wheats that have the same genetic background and nutrient contents, which are very high and stable. However, most materials reported in previous studies were from different genetic backgrounds, and the nutrient contents were unstable. Correlations between different nutrients in the purple wheats were analyzed. As far as we know, most previous correlation studies were focused on white wheat, instead of colored wheats. In addition, previous correlation studies were only about several limited nutrients. The analysis based on a wide range of nutrients may reveal comprehensive information of different nutrients. Some similar correlation analysis results have also been mentioned in previous studies (Mazza et al. 2004; Prior and Wu 2006; Choia et al. 2007; Hosseinian and Beta 2007). However, results in this work reveal more comprehensive information, which can be used to breed nutrient-rich wheat. For example, β-carotene has correlations with 3 kinds of nutrients including total VE, Tyr and Pro, which would contribute to breeding wheat rich in β-carotene, total VE, Tyr and Pro. Anthocyanin has correlations with 3 kinds of nutrients including Mo, Glu and Ca, which would contribute to breeding wheat rich in anthocyanin, Mo and Glu (free Trp and Ca). Correlation analysis of nutrient contents in purple wheat can help to find nutrient-controlling genes and improve nutrient contents in wheat.

In some cases, the present results are different from previous studies, which may require further research. Nandy et al. (2008) hybridized black wheat with blue wheat and purple wheat. Their results showed that protein contents of hybrids, which were higher than parents, were positively correlated with dietary fiber content and had high negative correlations with moisture and starch contents. In our experiment, insoluble dietary fiber content of purple wheat was almost the same as that of white wheat.

Forty-one kinds of nutrients have been measured in eight wheat cultivars including seven purple wheat lines and one white wheat variety as control sample. Results show that a wide range of nutrients contents in purple wheat are higher than the standards and the control. Correlation analysis for contents of 17 kinds of hydrolyzed amino acids and some other nutrients has also been performed for the purple wheats. It has been found that there are some correlations between different nutrients. The correlation analysis of nutrient contents may be helpful in finding nutrient-controlling genes and improving nutrient contents in wheat.

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Electronic Supplementary Material (ESM)

Electronic Supplementary Material (ESM) associated with this article can be found at the website of CRC at http://www.akademiai.com/content/120427/

Electronic Supplementary *Table S1*. Pearson correlation analysis for contents of hydrolyzed amino acids in purple wheat

Electronic Supplementary *Table S2*. Pearson correlation analysis for contents of mineral elements in purple wheat

Electronic Supplementary *Table S3.* Pearson correlation of vitamin contents in purple wheat

Electronic Supplementary *Table S4*. Pearson correlation analysis for contents of other nutrients in purple wheat