Correlation of Plant Morphological and Grain Quality Traits with Mineral Element Contents in Yunnan Rice

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Abstract: Correlations between four grain quality, 24 plant morphological traits and eight element contents of 653 accessions from Yunnan rice were analyzed. P, K, Ca and Mg contents of core collection were closely correlated to the most plant morphological and grain quality traits, and there were highly significant correlations (\(P < 0.01\)) among some traits including P content to number of stems and tillers, K content and amylose content, Ca content and plant height, Mg content and protein content. Mn, Zn, Cu and Fe contents of core collection were closely related to a few traits, such as Fe content and gel consistency (-0.1121**), Zn content and seed setting rate (-0.1411**), Cu content and number of grains per panicle (-0.1398**), Mn content and plant height (-0.2492**).

Key words: mineral elements; morphological traits; cooking quality; core collection; Yunnan Province; rice

Mineral elements (P, Fe, Zn, Cu and Mn) are important compositions of the enzyme. K, Ca and Mg contents are the critical factors for the physical and biochemical reaction \([1]\). Zn and Cu are necessary in life activity and take part in the metabolism with minim-content \([2]\). Fe is the fourth element, following oxygen, silicon and aluminium \([3, 4]\). However Fe deficiency is the most popular and astonishing malnutrition (which affecting about 4-5 billion people), and 2 billion people had got anaemia mainly caused by Fe deficiency \([5]\). The deficiency of iron, zinc, selenium, and iodine affect 4-5 billion people in the world. Many diseases are attributed to the mineral element deficiencies. Among them, selenium and iodine content of grain can be increased by fertilizer, while increasing Fe, Zn and \(V_A\) contents of grain only by plant breeding and bio-engineering \([6, 7]\). Fe deficiency affects the human brain development, cognition and physical strength. Two point five to three billion people lack Zn, and the Zn deficiency affects infant diarrhea and children growing slowly. Ca deficiency leads to children growing slowly \([8]\). Increasing Fe and Zn contents of rice and wheat grain by genetic improvement is the key to solve the malnutrition problem facing 3.5 billion people \([9, 10]\).

More than 2.7 billion people rely on rice as their major source of food. So increasing nutrition element contents of rice can enhance nutrition uptake of human \([11, 12]\). However, N and P contents in brown rice of improved cultivars decreased by 14%, 15% respectively, Fe and Zn contents decreased by 17% compared with those of landraces (www.cseindia.org). P, Zn and N contents in brown rice of the improved cultivars of Yunnan decreased by 13.5%, 14.7% and 63.4% respectively compared with those of landraces. Some scholars at home and abroad considered that mineral element contents of different rice were controlled by environment and heredity \([6,12,14]\). For example, Fe content is quantitatively inherited and it’s very difficult to get the variety with high Fe content. Four QTL for high Fe content discovered is near to the fragrance gene, and N fertilizer can raise Fe content of grain \([6]\). Average Fe content (80.64 mg/kg) of fragrant rice of Yunnan is higher than that of common rice (49.61 mg/kg) and soft rice (23.68 mg/kg) \([13]\).

Yunnan is one of the largest genetic and ecological diversity centers for rice in the world \([15]\). So far, there is few available information on the relationship between 8 mineral elements and plant morphological, grain quality traits of core collection in Yunnan rice. Therefore, advance in understanding this relationship can provide reference for rice quality breeding and special rice industrialization.

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MATERIALS AND METHODS

Six hundred and fifty-three accessions of core collection in Yunnan rice were planted in Xingping County, Yunnan Province (500 m elevation). The field experiment management and determination of P, K, Ca, Mg, Fe, Zn, Cu and Mn by ICP-AES were according to the method depicted by Zeng et al [13]. Some traits of 10 plants for every variety were investigated, i.e. nine grain traits (1000-grain weight, grain length, grain width, grain thickness, glume length, rice length, rice width, rice thickness), eight panicle traits (panicle length, the 1-2 node length, awn length, number of filled grains per panicle, number of unfilled grains per panicle, total number of grains per panicle, seed setting rate, grain density), three plant traits (plant height, tiller number per stem, heading date) and three traits of ratooning rice (R-plant height, R-seed setting rate, ratooning coefficient). Ratooning coefficient can disclose the regenerative ability of rice. Calculated ratooning coefficient (Ri) of Yunnan rice with the formula:

\[ Ri = \frac{1}{3} (Hr - He + Lr - Le + Gr - Ge) \]

where \( Hr \), \( He \), \( Lr \), \( Le \), \( Gr \), and \( Ge \) indicate plant height, panicle length, total grain number per panicle of ratooning rice and initial rice, respectively.

The relationship between 4 quality traits, 9 grain traits, 8 panicle traits, 3 plant traits, 3 traits of ratooning rice and 8 mineral element contents of 653 accessions from core collection in Yunnan rice was analyzed by Excel.

RESULTS

Correlation between the grain quality and mineral element contents in brown rice

Correlation coefficients among grain quality traits and mineral element contents are shown in Table 1. Thirty-nine of all the 66 coefficients highlighted significant correlation. There were significant positive correlations among the macroelement contents (P and K, P and Mg, K and Mg), with higher correlation coefficient than those among microelement contents (Fe, Zn, Cu, Mn). Ca had a significant positive correlation with macroelements P and Mg, but the coefficient was lower than those of Ca and Fe, Ca and Mn, and had a negative correlation with Cu. In case of correlation between elements and grain quality traits, K content had a highly significant and positive correlation with protein content, gelatinization temperature, gel consistency, but had a significant negative correlation with amylose content. This may be because K is promoter of many enzymes for photosynthesis and sugar metabolism and protein synthesis. P, Mg, Cu were highly significantly and positively correlated with protein content, but not correlated with amylose content, gelatinization temperature, and gel consistency, possibly because P, Mg and Cu are activators of many enzymes and participate in nitrogen metabolism. Ca is also activator of many enzymes (e.g. amylases). Ca content had a significant correlation with amylose content.

Table 1. Correlation between grain quality traits and mineral element contents of core collection in Yunnan rice.

<table>
<thead>
<tr>
<th>Element or trait</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Zn</th>
<th>Cu</th>
<th>Mn</th>
<th>Protein content</th>
<th>Amylose content</th>
<th>Gelatinization temperature</th>
<th>Gel consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.4506**</td>
<td>0.1812*</td>
<td>0.6344**</td>
<td>0.0443</td>
<td>0.0670</td>
<td>0.1398**</td>
<td>0.4606**</td>
<td>0.2821**</td>
<td>-0.0763</td>
<td>-0.0230</td>
<td>0.0495</td>
</tr>
<tr>
<td>K</td>
<td>0.0530</td>
<td>0.5067**</td>
<td>0.0030</td>
<td>-0.0061</td>
<td>0.3744**</td>
<td>0.4748**</td>
<td>0.1334**</td>
<td>0.2394**</td>
<td>0.1119**</td>
<td>0.1793**</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>0.1997**</td>
<td>0.5306**</td>
<td>0.1467**</td>
<td>-0.0356</td>
<td>0.3079**</td>
<td>0.0302</td>
<td>0.1053**</td>
<td>0.2821**</td>
<td>0.1467**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>0.1296**</td>
<td>0.0585</td>
<td>0.1452**</td>
<td>0.4618**</td>
<td>0.2570**</td>
<td>0.0651</td>
<td>0.0495</td>
<td>0.0495</td>
<td>-0.0222</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>0.1012**</td>
<td>0.0260</td>
<td>0.2688**</td>
<td>0.0022</td>
<td>0.0778</td>
<td>0.0258</td>
<td>0.1121**</td>
<td></td>
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</tr>
<tr>
<td>Zn</td>
<td>0.1715**</td>
<td>0.0647</td>
<td>0.0255</td>
<td>0.0128</td>
<td>0.0299</td>
<td>0.0962*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.1862**</td>
<td>0.1151**</td>
<td>-0.0550</td>
<td>0.0396</td>
<td>0.0648</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.0908*</td>
<td>-0.1586**</td>
<td>-0.1050**</td>
<td>-0.1213**</td>
<td>0.1959**</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Protein content</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.4258**</td>
<td>-0.6901**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amylose content</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

*, ** Significant at 5% and 1% level, respectively; N=653, \( R_{0.05} = 0.080 \), \( R_{0.01} = 0.104 \). GT, Gelatinization temperature.
content, gelatinization temperature, respectively and the cooking quality of high Ca content grain is very poor. Fe, Zn were significantly and negatively correlated with gel consistency, but not correlated with the other 3 traits, which could be explained by the nutrition functions of Fe (the best activator for phosphsucrokinase) and Zn (promoting photosynthesis). Mn content was found to be positively correlated with protein content and gelatinization temperature, but negatively to amylose content, which can be partly explained by that Mn takes part in photosynthesis, respiratory and protein synthesis directly. To sum up, protein content was significantly and positively correlated with P, K, Mg, Cu and Mn contents; Gel consistency was significantly correlated with K, Ca, Fe, Zn contents; Amylose content was significantly correlated with K, Ca, Mn contents; Gelatinization temperature was also significantly positively correlated with K, Mn contents. The number of traits with significant correlation between grain quality and mineral element contents was in the following order: protein content > gel consistency > amylose content > gelatinization temperature, K>Mn>Ca>P, Mg, Cu, Fe and Zn.

Correlation between grain traits and mineral elements in brown rice

As shown in Table 2, P content in brown rice had a significant negative correlation with grain width, grain thickness and rice width, indicating that the larger grain had the lower P content. K content was significantly positively correlated with grain thickness, glume length, suggesting that high K content promote grain filling. Ca content had significant correlations with grain length or width, and rice length or width, thickness. Rice with large and well-filled grain had high contents of Ca. Mg contents had significant negative correlations with grain width and rice width, indicating that higher Mg content of brown rice was readily found in the cultivars with narrower grain. In addition, there is no correlation between microelements (Fe, Zn, Cu, Mn) and grain traits except Fe, Zn with rice thickness. As above-mentioned, P, K, Ca and Mg contents of brown rice had closer relationship with grain traits than microelements.

Correlation of panicle traits and mineral elements in brown rice

P content in brown rice had significant correlations with panicle length, awn length, filled grain number per panicle, seed setting rate and grain density (Table 3), indicating that P content was tightly associated with panicle traits. K content was significantly correlated with panicle length, but not with the other panicle traits. Ca content was found to be significantly correlated with panicle length, 1-2 node length, unfilled grain number per panicle, total grain number per panicle, seed setting rate, and grain density, implying that Ca content of brown rice was closely related with panicle traits, especially with seed setting rate. The contents of Mg, Zn, Cu in brown rice had significant negative correlations with number of filled grains per panicle and seed setting rate. Fe content in brown rice was not associated with panicle traits. To sum up, core collection in Yunnan rice with lower seed setting rate always had higher P, Mg, Zn and Cu contents and those with higher seed setting rate had higher Ca contents. We also found that seed setting rate was not correlated with K, Fe and Mn.

Table 2. Correlation between grain traits and mineral elements of core collection in Yunnan rice.

<table>
<thead>
<tr>
<th>Element</th>
<th>1000-grain weight</th>
<th>Grain length</th>
<th>Grain width</th>
<th>Grain thickness</th>
<th>Glume length</th>
<th>Glume width</th>
<th>Rice length</th>
<th>Rice width</th>
<th>Rice thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>-0.0349</td>
<td>-0.0529</td>
<td>-0.0816&quot;</td>
<td>-0.1057&quot;&quot;</td>
<td>0.0219</td>
<td>0.0317</td>
<td>0.0788</td>
<td>-0.0908&quot;</td>
<td>0.0058</td>
</tr>
<tr>
<td>K</td>
<td>0.0593</td>
<td>0.0270</td>
<td>-0.0228</td>
<td>0.1022&quot;</td>
<td>0.1296&quot;&quot;</td>
<td>0.0485</td>
<td>0.0183</td>
<td>-0.0538</td>
<td>-0.0161</td>
</tr>
<tr>
<td>Ca</td>
<td>-0.0102</td>
<td>0.0877&quot;&quot;</td>
<td>0.1336&quot;&quot;</td>
<td>0.2219&quot;&quot;</td>
<td>0.0446</td>
<td>0.0407</td>
<td>-0.2330&quot;&quot;</td>
<td>0.1464&quot;&quot;</td>
<td>0.1047&quot;&quot;</td>
</tr>
<tr>
<td>Mg</td>
<td>-0.0370</td>
<td>-0.0144</td>
<td>-0.0885&quot;</td>
<td>0.0352</td>
<td>0.0465</td>
<td>0.0249</td>
<td>-0.0367</td>
<td>-0.0921&quot;</td>
<td>-0.0505</td>
</tr>
<tr>
<td>Fe</td>
<td>-0.0064</td>
<td>-0.0037</td>
<td>-0.0602</td>
<td>-0.0104</td>
<td>-0.0044</td>
<td>-0.0009</td>
<td>0.0050</td>
<td>-0.0645</td>
<td>-0.0865&quot;&quot;</td>
</tr>
<tr>
<td>Zn</td>
<td>-0.0501</td>
<td>-0.0363</td>
<td>-0.0194</td>
<td>-0.0657</td>
<td>0.0168</td>
<td>0.0036</td>
<td>-0.0032</td>
<td>-0.0365</td>
<td>-0.0965&quot;&quot;</td>
</tr>
<tr>
<td>Cu</td>
<td>0.0403</td>
<td>0.0062</td>
<td>0.0376</td>
<td>-0.0367</td>
<td>0.0240</td>
<td>-0.0118</td>
<td>0.0778</td>
<td>0.0018</td>
<td>0.0257</td>
</tr>
<tr>
<td>Mn</td>
<td>-0.0232</td>
<td>0.0242</td>
<td>-0.0190</td>
<td>0.0795</td>
<td>0.0821&quot;</td>
<td>0.0376</td>
<td>-0.0352</td>
<td>-0.0530</td>
<td>-0.0204</td>
</tr>
</tbody>
</table>

*, **: Significant at 5% and 1% level, respectively; N=653. R_{0.05}=0.080, R_{0.01}=0.104.
Correlation between the plant traits and mineral element contents in brown rice

P content had significant correlations with plant height, R-plant height, seed setting rate, R-seed setting rate, number of stems and tillers and heading date, suggesting that P content of brown rice was linked with plant traits. K content was significantly and negatively correlated with plant height, R-plant height, number of stems and tillers and seed setting rate. Ca content had significant correlations with plant height, seed setting rate and R-seed setting rate. Mg content had significant negative correlations with plant height, R-plant height, number of stems and tillers and seed setting rate. Mn content had also significant negative correlations with plant height, number of stems and tillers, R-seed setting rate. In addition, Zn and Cu contents had non-significant correlations with plant traits. As aforementioned, we made the conclusion that P, K, Ca and Mg contents in brown rice had closer relation than microelement contents.

DISCUSSIN

P, K, Ca and Mg contents were related with the plant morphological and grain quality traits

P content in brown rice was correlated closely with plant, panicle and grain traits, revealing that P played an important role in rice growth. P content of brown rice had significant correlations with 15 traits, i.e. protein content, 4 grain traits (grain width and thickness, rice width and thickness), 5 panicle traits (panicle length, awn length, number of filled grains per panicle, number of unfilled grain per panicle, seed setting rate and heading date), 5 plant traits (plant height, number of stems and tillers, R-plant height, R-seed setting rate and heading date), and especially strongly correlated with tiller number and protein content. Relative tillering ability is the most reliable and convenient criterion for selection of P-deficiency tolerant genotype [1, 16]. Accordingly, corresponding lower P content in brown rice could be likely to one of the evaluation index for selecting P-deficiency tolerant genotypes in rice.
K content was significantly correlated with plant and grain quality traits, i.e. four grain quality traits (protein content, amylose content, gelatinization temperature and gel consistency) and 4 plant traits (plant height, R-plant height, number of stems and tillers and R-seed setting rate), especially strongly with amylose content, indicating that cultivars with lower K content of brown rice tended to have better rice quality. K is important to plant growth development and high quality.

Ca content was significantly correlated with amylose content, gel consistency, 6 grain traits (grain length and width and thickness, rice length and width and thickness), 6 panicle traits (panicle length, 1-2 node length, unfilled grain number per panicle, total grain number per panicle, seed setting rate, grain density), 2 plant traits (plant height and R-seed setting rate), and the highest correlation coefficient was found between Ca content and plant height. The results indicated that high Ca content in brown rice generally linked with large grain, high seed setting rate and dwarf plant. Ca is benefit for rice growth and quality.

Mg content had significant correlations with protein content, grain width, rice width, filled grain number per panicle, unfilled grain number per panicle, seed setting rate, plant height, R-plant height, tiller number, and especially strongly correlated with protein content resulting from that Mg takes part in nitrous metabolism directly. This showed that the cultivars with high Mg content have good nutrition quality.

Mn, Zn, Cu and Fe contents are related with morphological and grain quality traits

Mn content had significant correlation with protein content, amylose content, gelatinization temperature, glume length, panicle length, plant height, number of stems and tillers and R-seed setting rate. Mn content was connected with grain quality and plant traits. Zn content was significantly correlated with gel consistency, rice thickness, plant height, panicle length, filled grain number per panicle, unfilled grain number per panicle and seed setting rate. Zn content is related closely with panicle traits. Cu content has significant correlation with protein content, filled grain number per panicle, seed setting rate, grain density, R-plant height, indicating that Cu content was associated with panicle traits and had significant positive correlation with protein content, which was according with the findings made from the 166 kinds of botanies by Osaki et al [17]. There were significant negative correlations between Fe content and gel consistency, rice thickness. In a word, Mn, Zn, Cu contents of brown rice in core collection from Yunnan were more strongly correlated with morphological traits than Fe content.

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