



Lysine content and its relationship with protein content in *indica* rice landraces of China

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ABSTRACT

Lysine is a limiting essential amino acid in rice. This study determined the variation in lysine content and evaluated the relationship between lysine and protein content in *indica* rice landraces of four provinces (Guangdong, Guangxi, Hunan, and Sichuan) in China by using the data ($n = 654$) collected from the Chinese Crop Germplasm Information System. Results showed that grain lysine content ranged from 0.25 % to 0.54 %, with 139 landraces having a grain lysine content of more than 0.40 %. Lysine content of protein ranged from 28.4 to 48.1 mg g⁻¹, with 20 landraces having a lysine content of protein of more than 45.0 mg g⁻¹. Guangdong had 5–21 % higher median of grain lysine content and 3–6 % higher median of lysine content of protein than the other three provinces. Lysine content of protein was significantly negatively related to protein content across four provinces.

Introduction

More than half of the population in the world relies on rice as a staple food (Muthayya et al., 2014). Rice is not only an energy source but also an important nutritional source for rice consumers, especially for those living in poverty, who have diets that are largely restricted to rice (Bhullar & Grussem, 2013). Therefore, improving the nutritional quality in rice will make a great contribution to the human well-being.

Grain amino acid content is an important nutritional trait in rice, but the essential amino acid lysine is present at limiting content in rice grains (Kumamaru et al., 1997). Hence, increasing grain lysine content is a major goal for breeders aiming to improve the nutritional value of rice (Yang et al., 2021). The search for rice germplasms with high grain lysine content is critical for achieving this goal.

Lysine content is also an important measure of the quality of protein in cereals including rice (Shewry, 2007), which plays a key role in design of healthy diets and sustainable food systems (Adhikari et al., 2022). It has been reported that lysine content of protein (i.e., lysine content in protein basis) is negatively related to grain protein content in cereal crops such as wheat, barley, and triticale (Brandt et al., 2000; Rharrabi et al., 2001), indicating a contradiction between the quality and quantity of protein in these crops. However, there is limited information available on this aspect in rice.

Landraces are an important component of crop germplasm resources and often genetically diverse (Barba-Espin & Acosta-Motos, 2022). China is rich in crop landraces including rice landraces (Cao et al., 1997). The objectives of this study were to (1) determine the amplitude of variation in lysine content and (2) evaluate the relationship between lysine and protein content in *indica* rice landraces of China.

Materials and methods

We collected data ($n = 654$) of grain lysine and protein content (dry-weight basis) in *indica* rice landraces from the Chinese Crop Germplasm Information System (<https://www.cgris.net>). The data covered four major *indica* rice-producing provinces of China with abundant *indica* rice landraces, including Guangdong ($n = 168$), Guangxi ($n = 226$), Hunan ($n = 149$), and Sichuan ($n = 111$). Lysine content of protein was calculated by dividing grain lysine content by grain protein content. All collected and calculated data are provided in the [Supplementary Material \(Spreadsheet S1\)](#).

Box-and-whisker plots were employed to summarize the data and identify outliers. The identified outliers were excluded from subsequent analyses. Because more than half of the data sets were abnormally distributed (Table S1), comparisons among four provinces were performed using Kruskal-Wallis test. Relationships between grain lysine

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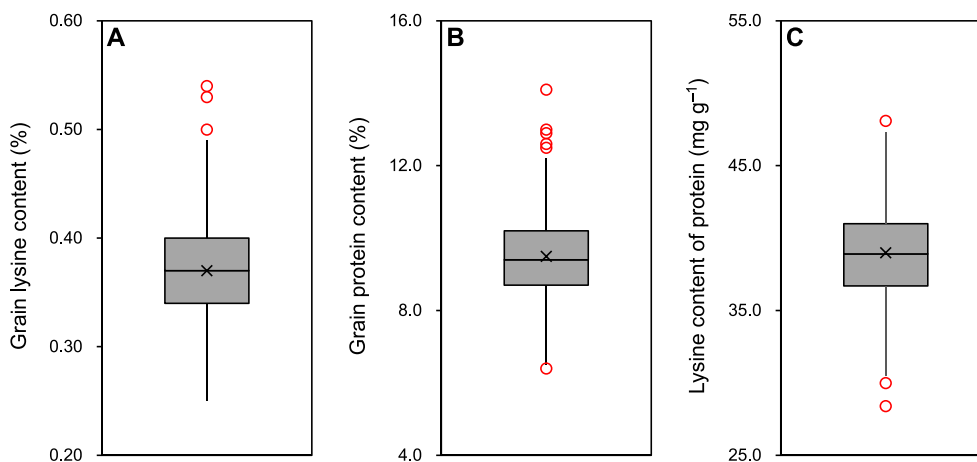


Fig. 1. Grain lysine content (A), grain protein content (B), and lysine content of protein (C) in *indica* rice landraces across four provinces (Guangdong, Guangxi, Hunan, and Sichuan) in China. The box-and-whisker plot shows the 50 % interquartile range (box), the mean (cross within the box), the median (horizontal line within the box), and the minimum and maximum value (end of the whiskers) without considering outliers (open red circles) of the data ($n = 654$).

Table 1
List of *indica* rice landraces with high lysine content of protein in China.

Province	Landrace	Lysine content of protein (mg g^{-1})
Guangdong	Jinyinzao	45.2
	Shijiaozhan	45.5
	Mizhan	45.5
	Toujiangzao	45.5
	Nandongzhong	46.0
	Jinfengzao	46.3
	Changwei	47.3
Guangxi	Hanhongpibayuegu	45.5
Hunan	Mazaohu	45.6
	Maguzinuo	45.7
	Bianganzhan	45.8
	Sanbaili	45.8
	Qitouwang	46.1
	Jiajiahe	46.2
	Aizibai	46.6
	Changshazao	46.8
	Dayezao	46.9
	Baizaohu	48.1
Sichuan	Nanjizao	46.6
	Jiangjindao	46.8

and protein content and between lysine content of protein and grain protein content were analyzed across four provinces using linear regression analysis. All data analysis was performed using Statistix 8.0 (Analytical Software, Tallahassee, FL, USA).

Results and discussion

Grain lysine content ranged from 0.25 % to 0.54 % (Fig. 1A). This range is broader than that (0.26–0.40 %) reported in a review by Zhao et al. (2020). There were 139 landraces from Guangdong ($n = 70$), Guangxi ($n = 11$), Hunan ($n = 26$), and Sichuan ($n = 32$) with a grain lysine content of more than 0.40 % (Spreadsheet S1), which is the previously reported upper limit of grain lysine content in rice (Zhao et al., 2020). Of those, Bashiri, Nahuoxianluozhan, and Tongweiheilian from Guangdong had a grain lysine content of more than 0.50 %. These findings suggest that *indica* rice landraces of China are highly diverse in grain lysine content and are important germplasm resources for increasing grain lysine content in rice.

The range of grain protein content was 6.4 % to 14.1 % (Fig. 1B).

Lysine content of protein ranged from 28.4 to 48.1 mg g^{-1} (Fig. 1C). There were 20 landraces from Guangdong ($n = 7$), Guangxi ($n = 1$), Hunan ($n = 10$), and Sichuan ($n = 2$) with a lysine content of protein of 45.2–48.1 mg g^{-1} (Table 1), which exceeds the requirement for adults (45.0 mg g^{-1}) recommended by WHO/FAO/UNU (2007). These findings indicate that *indica* rice landraces of China are richly diverse in lysine content of protein, and it is possible to achieve a satisfactory protein quality in terms of lysine content in rice through efficient utilization of landraces in breeding programs.

Grain lysine and protein content and lysine content of protein significantly varied with province (Fig. 1A–C). The median of grain lysine content in Guangdong was 5–8 % higher than those in Hunan and Sichuan and 21 % higher than that in Guangxi (Fig. 2A). Guangdong and Sichuan had the similar grain protein content, and the average median of grain protein content across these two provinces was 7 % higher than that in Hunan and 14 % higher than that in Guangxi (Fig. 2B). Guangdong had 3–6 % higher median of lysine content of protein than Hunan, Guangxi, and Sichuan (Fig. 2B). These results suggest that there are geographical variations in both grain lysine content and lysine content of protein in *indica* rice landraces of China, with higher in Guangdong than in Guangxi, Hunan, and Sichuan. This finding highlights the need for further investigations to explain the geographical variation in lysine content in *indica* rice landraces of China.

There was a significantly positive relationship between grain lysine and protein content ($p = 0.0000$); grain lysine content increased by approximately 0.03 % for each 1 % increase in grain protein content (Fig. 3A). On the contrary, lysine content of protein was significantly negatively related to grain protein content ($p = 0.0000$), although the coefficient of determination ($r^2 = 0.0711$) was small (Fig. 3B). Lysine content of protein decreased by about 0.8 mg g^{-1} for each 1 % increase in grain protein content. This finding is similar to that observed in other cereal crops including wheat, barley, and triticale (Brandt et al., 2000; Rharrabti et al., 2001), and suggests that there is also a contradiction between the quality and quantity of protein in rice.

Conclusions

This study shows that *indica* rice landraces of China are diverse and geographical variations in both grain lysine content and lysine content of protein, including some germplasms with high grain lysine content and/or high lysine content of protein. This study also indicates that the quality of lysine based on the lysine content is contradicted with the quantity of protein in rice.

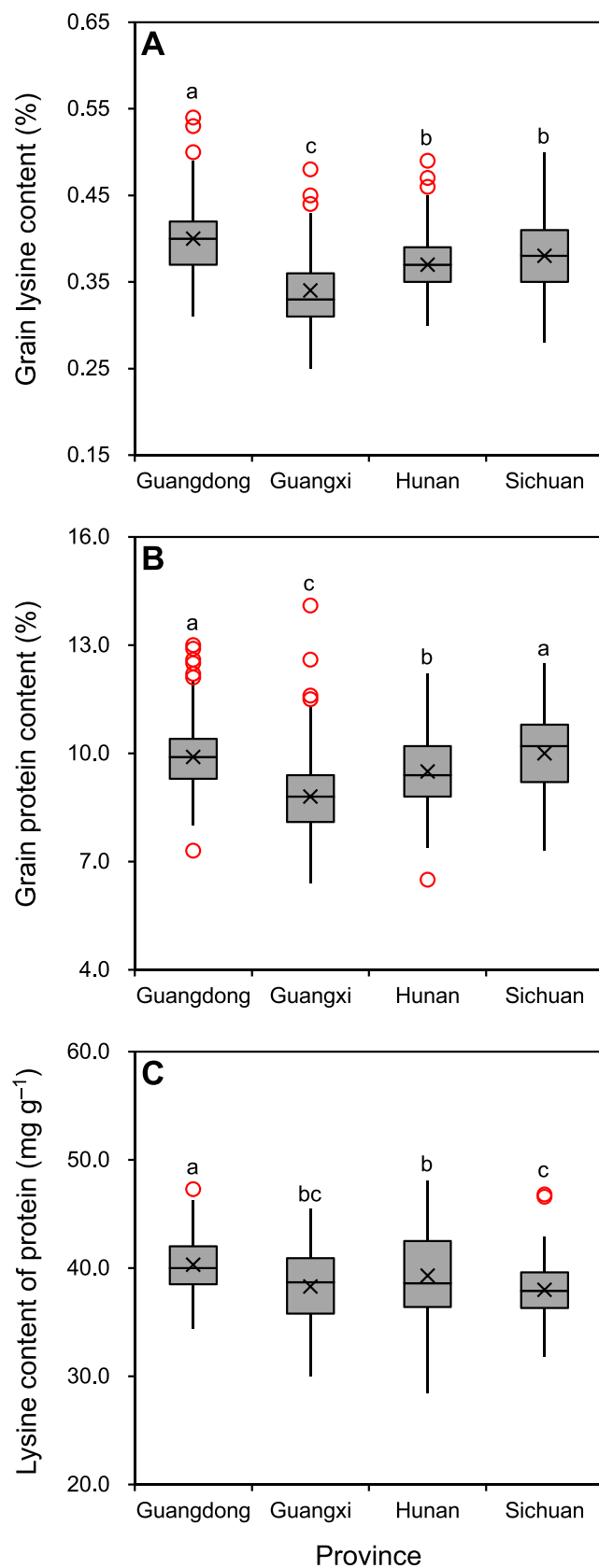


Fig. 2. Comparisons of grain lysine content (A), grain protein content (B), and lysine content of protein (C) in *indica* rice landraces among four provinces (Guangdong, Guangxi, Hunan, and Sichuan) in China. The box-and-whisker plot shows the 50 % interquartile range (box), the mean (cross within the box), the median (horizontal line within the box), and the minimum and maximum value (end of the whiskers) without considering outliers (open red circles) of the data ($n = 168, 226, 149,$ and 111 for Guangdong, Guangxi, Hunan, and Sichuan, respectively). Within a subfigure, data sharing the same lowercase letters are not significantly different at the 0.05 probability level.

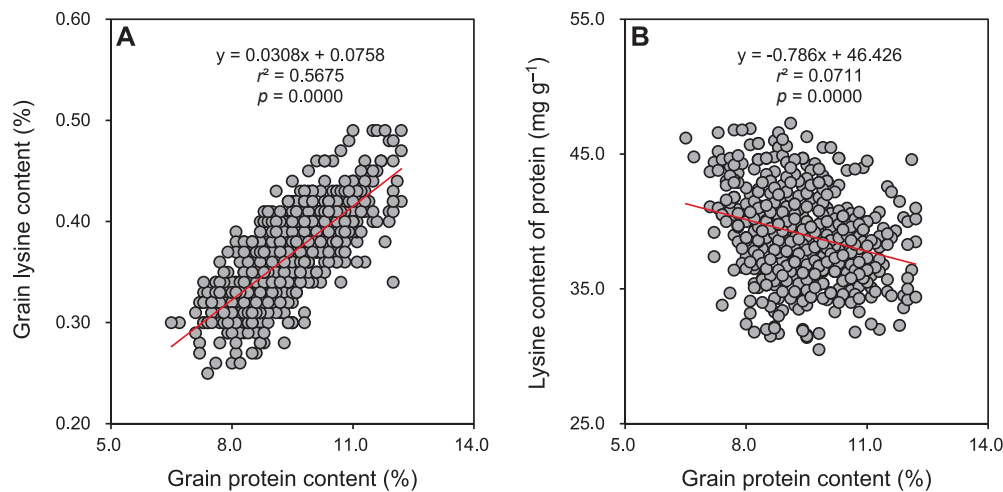


Fig. 3. Relationships between grain lysine and protein content (A) and between lysine content of protein and grain protein content (B) in *indica* rice landraces across four provinces (Guangdong, Guangxi, Hunan, and Sichuan) in China.

CRediT authorship contribution statement

Min Huang: Conceptualization, Formal analysis, Writing – original draft, Funding acquisition. **Chengjing Liao:** Investigation. **Jiixin Xie:** Investigation. **Jiana Chen:** Investigation. **Fangbo Cao:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.fochx.2022.100549>.

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