agronomy

Communication

# Texture and Digestion Properties Based on Amylose Content and Gel Consistency in Landraces and Recently-Released Cultivars of *Indica* Rice in China

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**Abstract:** China has abundant rice landrace resources and has developed many new rice cultivars over the past several decades. To identify the differences in texture and digestion properties between landraces and recently-released cultivars of *indica* rice in China, this study estimated the hardness (Hd) and starch digestion rate (SDR) of cooked rice based on the amylose content (AC) and gel consistency (GC) of landraces and recently-released (2019–2021) cultivars of *indica* rice in eight provinces in southern China. The results demonstrated that AC ranged from 11.3% to 34.0% in landraces and from 10.0% to 28.6% in recently-released cultivars. The AC median was lower in recently-released cultivars than in landraces by approximately 40%. GC ranged from 21–100 mm in landraces and from 30–95 mm in recently-released cultivars. The GC median was about 130% higher in recently-released cultivars compared to landraces. Hd ranged from 720–1418 g in landraces and from 590–1244 g in recently-released cultivars. The Hd median was approximately 35% lower in recently-released cultivars compared to landraces. SDR ranged from 1.04–2.86 mg g min$^{-1}$ in landraces and from 1.71–3.37 mg g min$^{-1}$ in recently-released cultivars. The SDR median was higher in recently-released cultivars than in landraces by about 60%. The findings of this study suggest that recently-developed *indica* rice cultivars in China can cater to the preference of consumers for soft-texture rice but increase health risks due to a higher rate of digesting starch into glucose.

**Keywords:** grain quality; health risk; landraces; rice; starch digestion



**Citation:** Huang, M.; Xie, J.; Chen, J.; Zhao, C.; Liao, C.; Li, B.; Shu, A.; Chen, J.; Cao, F. Texture and Digestion Properties Based on Amylose Content and Gel Consistency in Landraces and Recently-Released Cultivars of *Indica* Rice in China. *Agronomy* **2022**, *12*, 2078. https://doi.org/10.3390/agronomy12092078

Academic Editor: Stephan M. Haefele

Received: 2 August 2022
Accepted: 30 August 2022
Published: 31 August 2022



## 1. Introduction

Rice has been domesticated in China for over 10,000 years [1], and it is the staple food for approximately 70% of the Chinese population [2]. Rice is cultivated in almost all provinces in China, except for Qinghai, with mainly *indica* cultivars in the south and japonica cultivars in the north [3]. As a source of cultivated rice, China is abundant in rice landraces [4]. To meet the growing demand for food as its population increases, new high-yielding rice cultivars, especially hybrid cultivars, have been continuously developed in China over the past several decades [5]. Consequently, high levels of cultivar diversity have been achieved in multiple major rice-producing provinces in China [6].

In recent years, improvements in economic and living standards have shifted Chinese consumer demand from high quantities of readily-available rice to higher-quality rice [7]. To meet this shift in demand, improving rice quality has become one of the most important objectives for Chinese breeders and a priority for Chinese agricultural production [8].

Rice quality has many traits, including milling recovery, overall appearance, nutritional value, and palatability [9]. Of these traits, palatability is generally considered the most important trait for rice consumer satisfaction [10]. Amylose content (AC) and gel consistency (GC) are two physicochemical parameters that significantly contribute to the palatability of rice [11]. In China, rice consumers generally preferer soft-texture rice with a low AC and high GC, and many rice breeders have dedicated themselves to developing new rice cultivars to cater to this consumer preference [12,13].

Improvements in economic and living standards have also increased demand for healthy food in China [14]. However, rice is generally considered a high-glycemic index food, and there is ample evidence that a high risk of type II diabetes is associated with high rice consumption in Asian populations, including in China [15–17]. Currently, China has the world's largest population of diabetics (mainly type II); around 141 million people suffered from diabetes in 2021 [18]. In addition, diets with a higher glycemic index can also increase the risk of other non-communicable diseases, such as cardiovascular disease and cancer [19,20], which have high mortality rates and are of increasing concern both domestically and international [21]. Therefore, it is important to consider a low glycemic index as a key target for rice production in China [22].

The glycemic index of rice is determined by starch digestion characteristics, which are closely related to the physicochemical properties of grain [23,24]. It has been well documented that there is a close negative relationship between the starch digestion rate (SDR, i.e., the rate of digestion of starch into glucose) and AC in rice [25,26]. Recently, Hu et al. [27] used a multiple-step regression analysis and variation partitioning analysis to identify the key physicochemical properties affecting SDR and quantify the contributions of the identified properties to SDR variation in rice. Their results demonstrated that AC and GC were the two most important physicochemical properties affecting SDR and explained approximately 80% of SDR variation.

In this study, we collected data of grain AC and GC and estimated the hardness (Hd) and SDR of cooked rice for landraces and recently-released cultivars of *indica* rice in eight provinces of southern China. The main objective of this study was to identify the differences in texture and digestion properties between landraces and recently-released cultivars of *indica* rice in China. This information provides an understanding of the changes in palatability and health risk of *indica* rice in China and contributes to the design of rational strategies for developing *indica* rice production in China.

## 2. Materials and Methods

### *2.1. Data Collection*

Data about the grain AC and GC of *indica* rice landraces were collected from the Chinese Crop Germplasm Information System (http://www.ricedata.cn, accessed on 3 July 2022), while those of *indica* rice cultivars released in 2019–2021 were collected from the China Rice Data Center (www.ricedata.com, accessed on 3 July 2022). The data covered eight major *indica* rice-producing provinces in southern China, including Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangxi, and Sichuan. The rice planting area of these eight provinces accounts for approximately 55% of all rice production in China (http://www.stats.gov.cn, accessed on 15 July 2022). Glutinous rice landraces or cultivars were excluded from the data collection. The total number of landraces and cultivars released in 2019, 2020, and 2021 for data collection were 706, 474, 645, and 717, respectively (Table 1).

**Table 1.** Number of landraces and recently-released cultivars of *indica* rice for data collection.

| Province | Landraces | Recently-Released Cultivars | | |
|---|---|---|---|---|
| | | 2019 | 2020 | 2021 |
| Fujian | 9 | 38 | 68 | 50 |
| Guangdong | 168 | 86 | 94 | 77 |
| Guangxi | 233 | 139 | 186 | 189 |
| Guizhou | 6 | 22 | 11 | 28 |
| Hubei | 3 | 36 | 78 | 89 |
| Hunan | 164 | 73 | 99 | 82 |
| Jiangxi | 2 | 57 | 50 | 77 |
| Sichuan | 121 | 23 | 59 | 125 |
| Total | 706 | 474 | 645 | 717 |

The Hd and SDR of cooked rice were estimated based on the grain AC and GC using the following equations:

$$Hd = 17.27AC - 7.024GC + 1040 \quad (1)$$

$$SDR = -0.080AC + 0.007GC + 3.550 \quad (2)$$

Equation (1) was established by the authors of this study using data from Hu et al. [27] with a multiple linear regression analysis (Statistix 8.0, Analytical Software, Tallahassee, FL, USA). Equation (2) was obtained from Hu et al. [27].

All collected and calculated data are provided in the Supplementary Materials (Spreadsheet S1).

### *2.2. Data Analysis*

The normality of the data was analyzed using the Shapiro–Wilk test. Since all data were not normally distributed (Table 2), we employed the non-parametric Kruskal–Wallis test to determine the significance of the differences in AC, GC, Hd, and SDR between landraces and recently-released cultivars. All statistical analyses were performed by Statistix 8.0.

**Table 2.** Shapiro–Wilk test of normality of data of amylose content (AC), gel consistency (GC), hardness (Hd), and starch digestion rate (SDR) in landraces and recently-released cultivars of *indica* rice in China.

| Variable | Statistic [a] | Landraces | Recently-Released Cultivars | | |
|---|---|---|---|---|---|
| | | | 2019 | 2020 | 2021 |
| AC | W | 0.926 | 0.948 | 0.905 | 0.897 |
| | $p$ | 0.000 | 0.000 | 0.000 | 0.000 |
| GC | W | 0.767 | 0.898 | 0.910 | 0.942 |
| | $p$ | 0.000 | 0.000 | 0.000 | 0.000 |
| Hd | W | 0.860 | 0.926 | 0.913 | 0.934 |
| | $p$ | 0.000 | 0.000 | 0.000 | 0.000 |
| SDR | W | 0.950 | 0.944 | 0.914 | 0.919 |
| | $p$ | 0.000 | 0.000 | 0.000 | 0.000 |

[a] W is the value of the test statistic. A significant test result ($p < 0.05$) means that the data are not normally distributed.

## 3. Results

The AC ranged from 11.3% to 34.0% in the landrace group, with a median of 26.3% (Figure 1a). In the groups of cultivars released in 2019, 2020, and 2021, the AC range was 10.3–25.3%, 10.0–26.6%, and 10.5–28.6%, with a median of 15.9%, 15.7%, and 16.2%, respectively. The medians of the groups of cultivars released in 2019, 2020, and 2021 were lower than that of the group of landraces by approximately 40% ($p < 0.000$). The GC range was 21–100 mm in the landrace group, with a median of 32 mm (Figure 1b). In the groups of cultivars released in 2019, 2020, and 2021, GC ranged from 30–90 mm, 30–95 mm, and 30–92 mm, with a median of 73, 74, and 74 mm, respectively. The medians of the groups of cultivars released in 2019, 2020, and 2021 were approximately 130% higher than that of the group of landraces ($p < 0.000$).

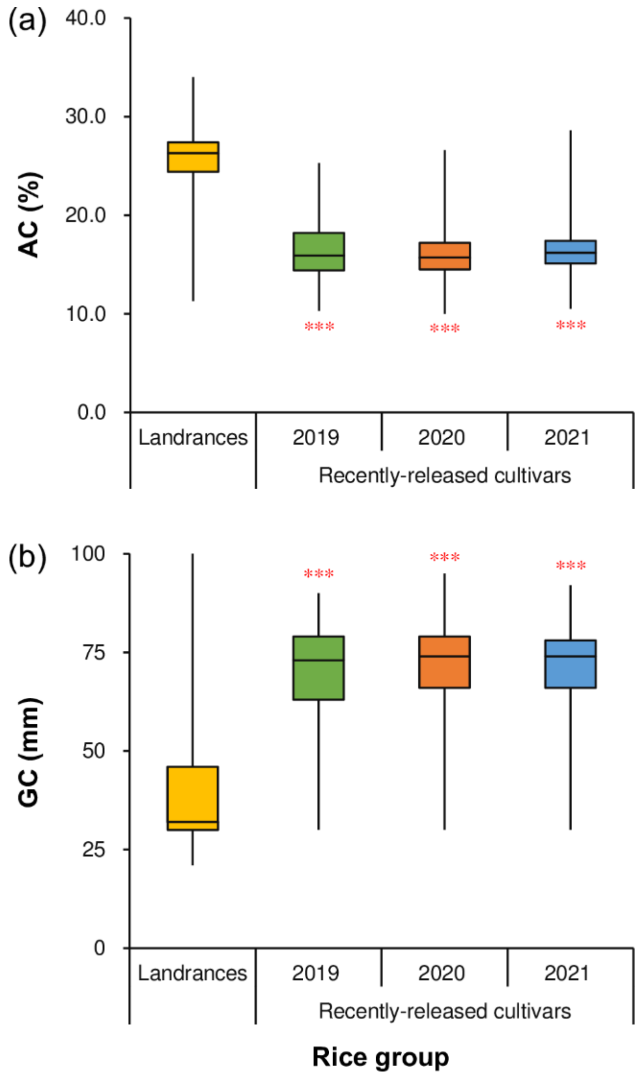


**Figure 1.** (**a**) Amylose content (AC) and (**b**) gel consistency (GC) in landraces and recently-released cultivars of *indica* rice in China. The box-and-whisker plot shows the minimum (end of the lower whisker), 25th percentile (lower edge of the box), median (horizontal line within the box), 75th percentile (upper edge of the box), and maximum (end of the upper whisker) values of the data ($n$ = 706, 474, 645, and 717 for landraces and cultivars released in 2019, 2020, and 2021, respectively). *** denotes a significant difference between recently-released cultivars and landraces at the 0.001 probability level.

In the group of landraces, the Hd range and median were 720–1418 g and 1237 g, respectively (Figure 2a). In the groups of cultivars released in 2019, 2020, and 2021, Hd ranged from 616–1238 g, 590–1244 g, and 607–1241 g, with a median of 808, 797, and 806 g, respectively. The Hd median was approximately 35% lower in the groups of cultivars released in 2019, 2020, and 2021 compared to the group of landraces ($p < 0.000$). SDR ranged from 1.04–2.86 mg g min$^{-1}$ in the group of landraces, with a median of 1.73 mg g min$^{-1}$ (Figure 2b). In the groups of cultivars released in 2019, 2020, and 2021, the SDR range was 1.84–3.30 mg g min$^{-1}$, 1.77–3.37 mg g min$^{-1}$, and 1.71–3.30 mg g min$^{-1}$, with a median of 2.77, 2.80, and 2.75 mg g min$^{-1}$, respectively. The medians of the groups of cultivars released in 2019, 2020, and 2021 exceeded that of the group of landraces by approximately 60% ($p < 0.000$).

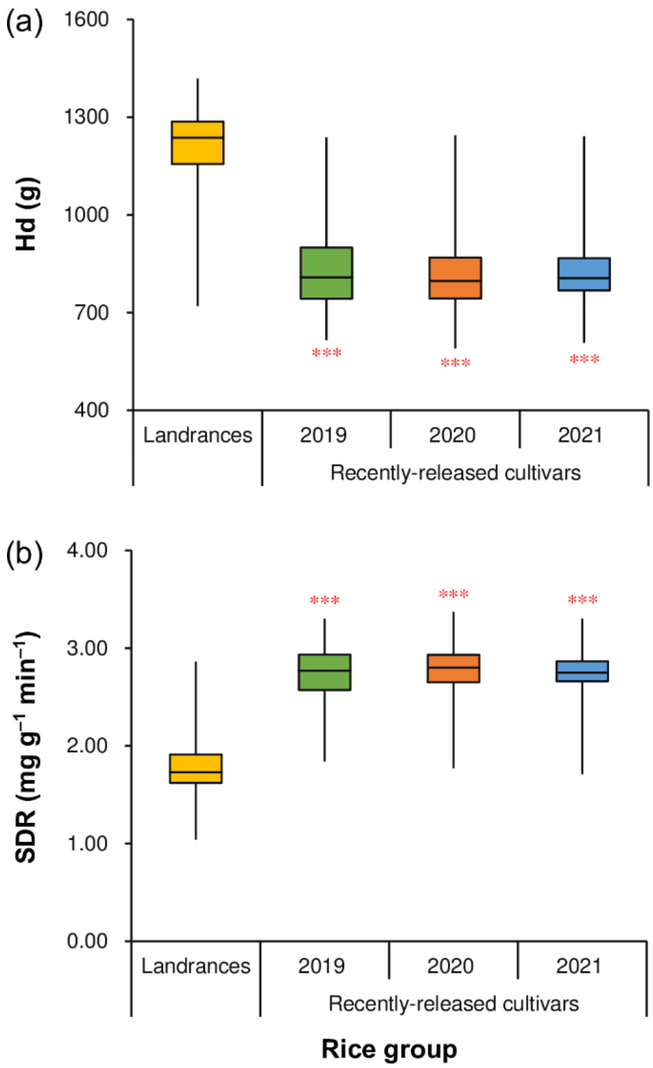


**Figure 2.** (**a**) Hardness (Hd) and (**b**) starch digestion rate (SDR) in landraces and recently-released cultivars of *indica* rice in China. The box-and-whisker plot shows the minimum (end of the lower whisker), 25th percentile (lower edge of the box), median (horizontal line within the box), 75th percentile (upper edge of the box), and maximum (end of the upper whisker) values of the data ($n$ = 706, 474, 645, and 717 for landraces and cultivars released in 2019, 2020, and 2021, respectively). *** denotes a significant difference between recently-released cultivars and landraces at the 0.001 probability level.

## 4. Discussion

The results of this study demonstrate that the texture and digestion properties have been substantially changed by changing the grain's physicochemical properties in recently-developed cultivars compared to landraces of *indica* rice in China. In particular, recently-developed cultivars have a much softer texture and a much faster rate of digestion of starch into glucose than landraces due to their considerably lower AC and higher GC. This finding is consistent with our recent studies [25,28], which showed that the development of soft-texture rice with a low AC can result in an acceleration in the rate of digestion of starch into glucose of cooked rice. Recently-developed cultivars have a softer texture because Chinese rice breeders have catered to the preferences of consumers in China [12,13], while the higher rate of digestion of starch into glucose in recently-developed cultivars was an unintentional result related to the development of soft-texture rice.

In general, a starch-rich food with a higher rate of digestion of starch into glucose has a higher glycemic index, which can lead to a higher risk of type II diabetes and other non-communicable diseases, such as cardiovascular disease and cancer [19,20]. Therefore, the recent development and consumption of soft-texture *indica* rice cultivars with a higher rate of digestion of starch into glucose increase health risks. While the high risk of type II diabetes is associated with rice consumption in China [15–17], the increased health risk of soft-texture *indica* rice has received little attention from the research community and the general public. We hope that our study will raise the scholarly and societal awareness of increased health risks due to the development and consumption of soft-texture *indica* rice and reconsider the development of *indica* rice in China.

In contrast to the recent development of high-quality, soft-texture rice with a low AC, high-quality *indica* rice developed in south Asia generally has a high AC. Therefore, introducing high-quality rice germplasms with a high AC from south Asia to Chinese rice breeding programs could relieve the contradiction between palatability and health risk in *indica* rice. This could be supported by the world-famous, high-quality Basmati rice that is produced in India and Pakistan, which has a high AC and a low glycemic index [29].

This study has certain limitations. The Hd and SDR data obtained in this study were estimated based on an in vitro study by Hu et al. [27]. However, there could be differences between the results obtained using in vitro and in vivo methods because it is difficult to accurately simulate the highly-complex physicochemical and physiological events occurring in human digestive tracts [30]. In addition, the digestion of starch-rich foods, including rice, can be slowed down by optimizing the cooking conditions [31] and food structure [32]. This highlights the need for interdisciplinary collaboration between crop and food scientists and the public health sector to comprehensively evaluate the health risks associated with the consumption of soft-texture *indica* rice in China.

## 5. Conclusions

Compared with *indica* rice landraces, recently-developed *indica* rice cultivars in China with a low AC and high GC can meet consumer demand for soft-texture rice, but the cultivars increase health risks due to a higher rate of digestion of starch into glucose. This study highlights the need to pay attention to the health risks of an accelerated rate of digestion of starch into glucose related to the development of soft-texture *indica* rice in China.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12092078/s1, Spreadsheet S1: Grain amylose content and gel consistency and estimated hardness and starch digestion rate of cooked rice in landraces and recently-released cultivars of *indica* rice in China.

**Author Contributions:** Conceptualization, M.H.; investigation, M.H., J.X., J.C. (Jiaxin Chen), C.Z., C.L., B.L., A.S., J.C. (Jiana Chen) and F.C.; funding acquisition, M.H.; writing—original draft preparation, M.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the National Key R&D Program of China, grant number 2016YFD0300509.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available in the Supplementary Materials.

**Conflicts of Interest:** The authors declare no conflict of interest.

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