Effects of Shading on Starch Pasting Characteristics of Indica Hybrid Rice (Oryza sativa L.)

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Abstract

Rice is an important staple crop throughout the world, but environmental stress like low-light conditions can negatively impact crop yield and quality. Using pot experiments and field experiments, we studied the effects of shading on starch pasting viscosity and starch content with six rice varieties for three years, using the Rapid Visco Analyser to measure starch pasting viscosity. Shading at different growth stages and in different rice varieties all affected the starch pasting characteristics of rice. The effects of shading on starch pasting viscosity at middle and later growth stages were greater than those at earlier stages. Shading enhanced breakdown but reduced hold viscosity and setback at tillering-elongation stage. Most pasting parameters changed significantly with shading after elongation stage. Furthermore, the responses of different varieties to shading differed markedly. The change scope of starch pasting viscosity in Dexiang 4103 was rather small after heading, while that in Ilyou 498 and Gangyou 906 was small before heading. We observed clear tendencies in peak viscosity, breakdown, and pasting temperature of the five rice varieties with shading in 2010 and 2011. Correlation analysis indicated that the rice amylose content was negatively correlated with breakdown, but was positively correlated with setback. Based on our results, Ilyou 498, Gangyou 906, and Dexiang 4103 had higher shade endurance, making these varieties most suitable for high-quality rice cultivation in low-light regions.

Introduction

Rice (Oryza sativa L.) is the staple food for over half of the global population [1] and for about 60% of the population in China [2]. Furthermore, more than 90% of the world’s rice is produced in Asian countries like China, India, Indonesia, Bangladesh, and Viet Nam [3]. However, crop production is affected by environmental stresses, such as heat, drought, salt, and shading. Rice, as a photophophilic crop, often encounters low-light stress during the growth stage, particularly in Sichuan, China; the Sichuan Basin receives fewer than 1200 hours of sunshine annually, and only 3345 MJ m⁻² y⁻¹ of annual solar radiation [4].

Light intensity is one of the most important requirements for plant growth, affecting growth, development, survival, and crop productivity. Because of the difficulty of controlling light intensity [5], researchers have evaluated the effects of shading on morphological characteristics, physiological characteristics, yield, and quality of agricultural crops. Multiple studies [6,7,8,9] have shown that the morphological changes resulting from shading included increases in leaf width, length, and area index, and decreases in leaf thickness due to the reduction of palisade layer number, palisade cells, and spongy parenchyma length. Shading also increased thylakoid number in grana and stroma, but reduced trichome density, plastoglobuli, and stomata number [6]. Under the shading treatment applied, the peduncle internode length and plant height increased [7,10]. Shading generally reduced tiller number and delayed tiller appearance and growing period [11,12].

In plant photosynthesis, chlorophyll is the most important photosynthetic pigment, and shading also affected the chlorophyll content of plants. Shading altered light-use efficiency by increasing leaf chlorophyll a, chlorophyll b, and chlorophyll a+b, and decreasing chlorophyll a/b ratios [6,7,9]. However, differences among plant species exist; for some turfgrass species, chlorophyll content increased in Lolium perenne L., decreased in Poa pratensis L., but remained unchanged in red fescue (Festuca rubra L.) [8]. Furthermore, light intensity changed the rate of non-photochemical quenching, electron transport rate between PSII and PSI, and quantum yield of PSII (Φ PSII) [13].

Shading applied during developmental stages could reduce the plant dry matter accumulation and disturb the redistribution of photosynthetic products from vegetative organs into grains. Ultimately, this could affect total grain yield by reducing panicles, spikelets, filled grains, and grain weight [7,11,14]. However, shade before booting stage of rice mainly decreased tiller number and effective panicle number, and little reduction in rice yield was observed [15,16]. When shade occurred after booting stage, the filled grain percentage and 1000-grain weight decreased, which decreased overall rice yield [16,17].
To be successful staple crops, crops need to be resistant to varying growing conditions, providing consistent yield and quality under a range of environmental conditions. Starch pasting viscosity, which is tested using a Rapid Visco Analyser (RVA), has long been used in estimating the eating, cooking, and processing quality of rice [18,19,20]. While many previous studies focused on shading effects on rice morphology, physiology, and yield, the responses of starch quality to shading in indica hybrid rice are unclear. Therefore, we examined the effects of shading on starch content and starch pasting viscosity in rice genotypes. These research results may lay a theoretical foundation for the selection of shade-tolerant varieties of rice and the improvement of cultivation technologies.

Materials and Methods

Plant Materials and Experimental Conditions

The experiments were conducted on the farm of Sichuan Agricultural University in 2009–2011, Ya’an (29°58′N and 102°59′E), Sichuan Province, P. R. China, in a humid monsoon climate. The mean annual accumulated temperature is 6030.4 °C, with rainfall of about 1798.6 mm and sunshine hours of about 944.0 h (Tables 1, 2). The soil type of pot and field experiments is a heavy loam (Table 3).

The results of preliminary experiment led to the selection of five rice varieties for the pot experiments in 2009: Iyou 498, Gangyou 188, Gangyou 527, Chuanxiang 9838, and Gangyou 906 (Table 4). On May 23, three similar seedlings (at age of 50 days) were transplanted to pots (25 cm in height and 30 cm in diameter). Each pot contained 10 kg of soil previously fertilized with 0.3 g N, 0.3 g P2O5, and 0.3 g K2O. After transplant, N was split-applied, 0.6 g pot−1 at elongation stage (from 30 June to 21 July 2009), 0.18 g pot−1 at mid-tillering and 0.12 g pot−1 at panicle initiation. K was applied 0.6 g pot−1 at panicle initiation.

In Experiment 1, one-layer and two-layer white cotton yarn screens, which shaded about 53% and 73% of the full radiation, respectively, covered the top of Gangyou 906 at tillering-elongation stage (TE; from 23 May to 29 June 2009), elongation-booting stage (EB; from 30 June to 21 July 2009), booting-heading stage (BH; from 22 July to 8 August 2009), and heading-maturity stage (HM; from 14 August to 6 September 2009). In Experiment 2, we studied the responses to shading of stalk and shoot of Iyou 498, Gangyou 188, Gangyou 527, and Chuanxiang 9838 from tillering stage (23 May 2009) to elongation stage (from 30 June to 1 July 2009) and from booting stage (from 22 to 24 July 2009) to heading stage (from 9 to 13 August 2009), by covering with one-layer white cotton yarn screen, which shaded about 53% of the full radiation.

On 20 May 2010 and 25 May 2011, fifty-day-old seedlings were transplanted at a spacing of 33.3 cm × 20.0 cm, with two seedlings per hill using plot size of 14.00 m2; Iyou 498, Gangyou 188, Gangyou 527, Chuanxiang 9838, and Dexiang 4103 were selected (Table 4). Fertilizer was applied at a rate of 180 kg ha−1 of N as urea, 90 kg ha−1 of P2O5 as single superphosphate, and 180 kg ha−1 of K2O as potassium chloride. N was split-applied at multiple growing stages: 75.6 kg ha−1 at basal, 32.4 kg ha−1 at mid-tillering, 43.2 kg ha−1 at panicle initiation, and 28.8 kg ha−1 at booting. P was applied at basal, and K application was split equally at basal and panicle initiation. One-layer white cotton yarn screen, which shaded about 53% of the full radiation, covered the top of the rice canopy from heading (5 August 2010) to maturity (26 September 2010), and from heading (8 August 2011) to 30 d after heading (7 September 2011).

The shading screens were more than 2.0 m above the ground to ensure good ventilation and were large enough to fully cover the shaded plants. Plants without covers were set as controls (CK). The pot experiments were conducted using a randomized design, and all field experiments were in randomized block designs, with three replications. In the rice paddy field, we used a high-efficiency irrigation technique of damp irrigation before booting, rational irrigation during booting, and wetting-drying alternation irrigation after heading. Insects, weeds, and diseases were controlled when required. The water level of each pot was maintained at 1–2 cm in depth, and other rice management actions were similar to those used in the paddy field.

Seed Collection for Physicochemical Properties Analysis

At maturity, the seeds from the field experiments were randomly selected from five hills in the center of each block; seeds from the pot experiments were randomly selected from three pots with nine plants. All seeds were dried and stored at room temperature for about three months until the physicochemical properties became stable. Then the seeds were shelled, milled, ground to rice flour using CT410 (FOSS SCINO Co., Ltd., China), and sifted through a 0.5-mm screen.

Starch Pasting Viscosity

Starch pasting viscosity of milled rice flour was determined with the Rapid Visco Analyser using the Super-3, running with Thermal Cycle for Windows software (Newport Scientific Pvt., Ltd., Australia), according to American Association of Cereal Chemists Standard Method 61-02.01 [21]. 3.00 g rice flour (12% moisture) was mixed with 20 ml deionized water, and the mixture was heated from 50 °C to 95 °C at a rate of 1 °C/minute, then kept at 95 °C for 2 minutes, and finally cooled (to 50 °C) at a rate of 0.3 °C/minute. The samples were analyzed with three different runs: (1) a cooling run (CR), (2) a heating run (HR), and (3) a second heating run (SHR). All pasting parameters were calculated using Thermal Cycle for Windows software (Newport Scientific Pvt., Ltd., Australia). The pasting parameters included viscosity (peak, trough, and final), peak time, and setback time. The peak viscosity is the highest value of the pasting viscosity during the heating cycle. The final viscosity is the value of the pasting viscosity at the end of the heating cycle. The peak time is the time at which the peak viscosity is reached. The setback time is the time at which the pasting viscosity is reduced to half of its peak value.
moisture basis) was weighed into a new test canister, and then 25.0 ml ultrapure water was added to the flour in the canister. The instrument mixed the flour and water by rotating a paddle at 960 rpm for the first 10 s of the test, after which viscosity was sensed using a constant paddle rotation speed of 160 rpm. The test profile for rice used the following time/temperature cycle [21]: (1) set the idle temperature to 50°C; (2) hold at 50°C for 1.0 min; (3) increase the temperature to 95°C in 3.8 min; (4) hold at 95°C for 2.5 min; (5) decrease the temperature to 50°C in 3.8 min; (6) then hold at 50°C for 1.4 min. Heating and cooling were linearly increased or decreased between profile set points. The instrument was allowed at least 30 min to warm up before being used.

Starch pasting viscosities were described by six parameters: peak viscosity (PKV), hold viscosity (the minimum hold viscosity, HPV), final viscosity (the viscosity achieved at the end of the test, CPV), breakdown (peak viscosity minus hold viscosity, BDV), setback (final viscosity minus peak viscosity, SBV), and pasting temperature (PaT) [21]. All the viscosity parameters were expressed in rapid visco units (RVU).

### Starch Contents of Rice Flour in 2011

The starch contents of rice flour were determined by dual-wavelength spectrophotometry [22,23]. The amylose wavelengths of 565 nm and 743 nm were selected as measuring wavelengths. The total starch content was the sum of amylose and amylopectin contents. The results were reported on a dry weight basis.

### Statistical Analyses

All data were analyzed using the two-way analysis of variance (ANOVA) and the Fisher’s protected least significance difference (LSD) test at p = 0.05 and p = 0.01 [24] for comparisons between growth stages, light intensities, and varieties using SPSS 16.0 (SPSS, Chicago, USA). Correlation analysis was carried out using MS Excel 2003 and SPSS 16.0.

### Results and Discussion

#### Effect of Shading on Starch Pasting Viscosity of Rice Flour at Different Growth Stages

We quantified the starch pasting parameters, PKV, HPV, CPV, SBV, BDV, and PaT, of rice at different growth stages (Tables 5, 6). The difference of starch pasting viscosity of Gangyou 906 was caused by light intensity and growth stage; the interaction between these factors had significant (p<0.01) effects on all starch pasting parameters in Experiment 1 (Table 5). Growth stage significantly affected PKV, HPV, SBV, and PaT, while the effect of light intensity was significant for all starch pasting parameters except for HPV (p<0.01). At TE, shading reduced PKV and HPV, but increased CPV, SBV, and BDV. Furthermore, there were significant differences observed in HPV, SBV, and BDV between 73%-shade treatment and the control (CK). PKV and BDV with 53%-shade, and PaT with 73%-shade were higher than the values for CK by 6.1%, 23.9%, and 1.4%, respectively. SBV was 13.1% lower than CK under 53%-shade, but it was 12.7% higher than CK under 73%-shade at 14 August–06 September (p<0.05). 53%-shade at BH increased BDV by 10.6% (p<0.05), but decreased PKV, HPV, and CPV. At HM, shading substantially affected the starch pasting viscosity of rice flour, and there were significant (p<0.05) differences between the majority of treatments.

In Experiment 2, the variety, growth stage, and the interactions of these factors had highly significant (p<0.01) effects on all starch pasting parameters (Table 6). At TE, shading significantly (p<0.05) reduced SBV of Gangyou 188 and Gangyou 527 by 56.2% and 49.0%, respectively. However, shading increased BDV (15.0%) of Gangyou 188, and CPV (5.0%) and SBV (46.3%) of Chuanxiang 9838. The influence of shading at BH was greater than CK under 73%-shade, but it was 12.7% higher than CK under 73%-shade at 14 August–06 September (p<0.05).

### Table 2. Sunshine hours (h) during different growth stages of rice varieties (2009).

| Varieties   | TE (shading time) | EB (shading time) | BH (shading time) | HM (shading time) |
|-------------|-------------------|-------------------|-------------------|-------------------|
|             | (23 May–29 June.) | (30 June–21 July.) | (22 July–08 Aug.) | (14 Aug–06 Sept.) |
| Gangyou 906 | 111.5             | 52.3              | 45.0              | 81.6              |
| Ilyou 498   | 115.8             | –                 | 46.1              | –                 |
| Gangyou 188 | 115.8             | –                 | 56.6              | –                 |
| Gangyou 527 | 119.3             | –                 | 45.0              | –                 |
| Chuanxiang 9838 | 119.3 | – | 41.8 | – |

TE, tillering-elongation stage; EB, elongation-booting stage; BH, booting-heading stage; and HM, heading-maturity stage.

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### Table 3. Soil chemical characteristics of experiments in 2009–2011.

| Soil chemical indexes          | 2009     | 2010     | 2011     |
|-------------------------------|----------|----------|----------|
| Organic matter (g kg⁻¹)       | 29.60    | 19.74    | 29.52    |
| Total N (g kg⁻¹)              | 0.82     | 2.14     | 1.38     |
| Total P (g kg⁻¹)              | 0.36     | 0.24     | 0.37     |
| Total K (g kg⁻¹)              | 11.44    | 27.60    | 27.06    |
| NaOH hydrolysable N (mg kg⁻¹) | 165.38   | 161.47   | 161.02   |
| Olsen-P (mg kg⁻¹)             | 25.34    | 82.24    | 58.37    |
| NH₄OAc extractable K (mg kg⁻¹)| 74.70    | 97.61    | 118.84   |

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than that at TE. For Gangyou 188, Gangyou 527, and Chuanxiang 9838, shading reduced PKV, HPV, CPV, and BDV by 5.7% to 41.7%, but significantly increased SBV and PaT by 0.9% to 68.2% (p < 0.05). Shading at a later growth stage (after heading) may have greater influence than at an earlier stage. Therefore, shading treatments at heading-maturity stage in 2010 and 30 d after heading in 2011 were studied to clarify the responses of starch pasting viscosity to shading.

**Response of Starch Pasting Viscosity to Shading in Different Rice Varieties**

During plant growth and development, environmental conditions could impact rice quality [25]. At heading-maturity stage, the changes of starch pasting viscosity were controlled by heredity and environment (Table 7). BDV is related to the starch stability to heat and shear stress, and SBV is related to the recovery of the viscosity during cooling of the heat [21, 25, 26]. The rice with lower SBV and higher BDV showed good eating quality [18, 27]. The effect of variety was significant (p < 0.01) for all starch pasting parameters, and the effect of light intensity was significant for all parameters except SBV. There were significant (p < 0.05) or highly significant (p < 0.01) interactions between light intensity and variety on PKV, HPV, and CPV. The results showed significant (p < 0.05) decreases in PKV and BDV of IIyou 498 (2.7% and 10.1%, respectively), but increases in PaT by 1.5%. For Gangyou 188 with shading, PKV, HPV, CPV, and BDV significantly (p < 0.05) decreased by 14.5% to 19.8%, PKV, HPV, and CPV of Gangyou 527 were lower (p < 0.05) than controls by 4.4% to 5.7%, but PaT was higher. PKV, CPV, and BDV reduced 4.8%, 2.7%, and 11.4%, respectively, in Chuanxiang 9838. In Dexiang 4103, only PKV significantly (p < 0.05) increased with shading (1.9%). Shading at heading-maturity stage (after heading) could significantly decrease BDV of IIyou 498, Gangyou 188, and Chuanxiang 9838, and the rice viscosity was hard. Compared with other rice varieties, Gangyou 527 and Dexiang 4103 were less affected by shading, as their SBV and BDV had no significant differences among different treatments.

**Table 4.** Introduction of indica hybrid rice varieties used in the study.

| Varieties | Parents | Breeding institutes |
|-----------|---------|---------------------|
| IIyou 498 | II-32A × Shuhui 498 | Rice Research Institute of Sichuan Agricultural University |
| Gangyou 527 | Gang 46A × Shuhui 527 | Rice Research Institute of Sichuan Agricultural University |
| Gangyou 906 | Gang 46A × Ronghui 906 | Chengdu Academy of Agriculture and Forestry Sciences |
| Dexiang 4103 | Dexiang 074A × Leuhu H103 | Sichuan Academy of Agricultural Sciences |
| Gangyou 188 | Gang 46A × Leuhu 188 | Leshan Agriculture and Animal Husbandry Science Research Institute |
| Chuanxiang 9838 | Chuanxiang 29A × Fuhui 838 | Sichuan Tianyu Seed Co., Ltd, Crop Research Institute of Sichuan Academy of Agricultural Sciences |

**Table 5.** Effects of shading on starch pasting viscosity of rice flour of Gangyou 906 in Experiment 1 (2009).

| Stages | Treatments | PKV (RVU) | HPV (RVU) | CPV (RVU) | SBV (RVU) | BDV (RVU) | PaT (°C) |
|--------|------------|-----------|-----------|-----------|-----------|-----------|----------|
| TE     | CK         | 370.07±8.27 | 259.44±12.22 | 478.40±12.73 | 108.33±6.10 | 110.63±5.57 | 76.43±0.44 |
|        | 50%-shade  | 368.21±10.6 | 353.69±8.34 | 487.56±9.14 | 115.46±5.13 | 118.52±9.20 | 76.61±0.21 |
|        | 50%-shade  | 351.29±2.88 | 240.23±6.30 | 578.40±1.48 | 119.21±2.70 | 121.26±6.61 | 76.54±0.34 |
| EB     | CK         | 370.07±8.27 | 259.44±12.22 | 478.40±12.73 | 108.33±6.10 | 110.63±5.57 | 76.43±0.44 |
|        | 50%-shade  | 387.47±1.50 | 255.44±2.16 | 486.60±2.96 | 94.13±2.80 | 137.03±2.85 | 76.64±0.33 |
|        | 70%-shade  | 369.24±7.82 | 267.96±7.03 | 491.36±13.26 | 122.13±7.47 | 101.28±6.12 | 77.50±0.25 |
| BH     | CK         | 370.07±8.27 | 259.44±12.22 | 478.40±12.73 | 108.33±6.10 | 110.63±5.57 | 76.43±0.44 |
|        | 50%-shade  | 361.25±12.40 | 238.90±11.25 | 477.11±10.36 | 115.86±3.23 | 122.35±1.15 | 76.43±0.09 |
|        | 70%-shade  | 360.54±6.44 | 253.21±5.40 | 477.93±6.28 | 117.39±1.02 | 107.33±5.90 | 75.92±0.26 |
| HM     | CK         | 370.07±8.27 | 259.44±12.22 | 478.40±12.73 | 108.33±6.10 | 110.63±5.57 | 76.43±0.44 |
|        | 50%-shade  | 410.88±6.20 | 278.56±8.25 | 510.58±1.02 | 99.71±7.03 | 132.32±3.10 | 76.42±0.50 |
|        | 70%-shade  | 338.94±0.73 | 278.56±8.25 | 437.10±5.53 | 98.15±4.83 | 94.72±2.95 | 77.65±0.02 |

| F-value | G | 6.79** | 10.76** | 1.99 | 10.56** | 0.94 | 5.57** |
|         | L | 41.88** | 0.45 | 11.48** | 7.17** | 1.09 || 6.25** |
|         | G×L | 17.58** | 4.10** | 12.44** | 7.51** | 2.04 || 6.39** |

TE, tillering-elongation stage; EB, elongation-booting stage; BH, booting-heading stage; HM, heading-maturity stage; G, growth stage; L, light intensity; PKV, peak viscosity; HPV, hold viscosity; CPV, final viscosity; SBV, setback; BDV, breakdown; PaT, pasting temperature; and RVU, rapid visco units.

Values in columns represent the significant differences between CK and shading treatments, (p < 0.05). Means ± standard. n = 3.

**significant at 0.01 level.

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The analysis of variance showed that the effect of variety during 30 d after heading was significant (p<0.01) for starch pasting parameters; light intensity also caused significant differences (Table 8). The interactive effects of light intensity and variety had significant influence on starch pasting parameters (p<0.01), except for HPV. For Iyou 498, shading increased SBV by 15.5%, and it decreased PKV (9.2%), HPV (6.5%), CPV (1.9%), and BDV (12.8%). PKV and BDV of Gangyou 188 with shading were significantly (p<0.05) lower than these of controls by 13.4% and 29.7%, respectively, but the other parameters were higher by 3.2% to 101.8%. In Gangyou 527, shading significantly (p<0.05) decreased PKV, HPV, and BDV by 5.0% to 15.3%, and shading increased SBV and PaT by 30.3% and 1.0%, respectively. PKV, HPV, CPV, and SBV of Chuanxiang 9838 were significantly (p<0.05) lower than CK by 2.3% to 12.0%, but PaT was higher by 1.3%. For Dexiang 4103, shading significantly (p<0.05) decreased PKV (8.1%), HPV (5.5%), CPV (4.1%), and BDV (9.9%), but increased SBV by 18.0%. With shading during 30 d

The effects of shading on starch pasting characteristics of rice flour are summarized in Table 6. The interactive effects of light intensity and variety had significant influence on starch pasting parameters (p<0.01), except for HPV. For Iyou 498, shading increased SBV by 15.5%, and it decreased PKV (9.2%), HPV (6.5%), CPV (1.9%), and BDV (12.8%). PKV and BDV of Gangyou 188 with shading were significantly (p<0.05) lower than these of controls by 13.4% and 29.7%, respectively, but the other parameters were higher by 3.2% to 101.8%. In Gangyou 527, shading significantly (p<0.05) decreased PKV, HPV, and BDV by 5.0% to 15.3%, and shading increased SBV and PaT by 30.3% and 1.0%, respectively. PKV, HPV, CPV, and SBV of Chuanxiang 9838 were significantly (p<0.05) lower than CK by 2.3% to 12.0%, but PaT was higher by 1.3%. For Dexiang 4103, shading significantly (p<0.05) decreased PKV (8.1%), HPV (5.5%), CPV (4.1%), and BDV (9.9%), but increased SBV by 18.0%. With shading during 30 d
Table 8. Effects of shading on starch pasting viscosity of rice flour during 30 d after heading (2011).

| Varieties | Treatments | PKV (RVU) | HPV (RVU) | CPV (RVU) | SBV (RVU) | BDV (RVU) | PaT (°C) |
|-----------|------------|-----------|-----------|-----------|-----------|-----------|---------|
| IIyou 498 | CK         | 258.08±2.34a | 148.47±2.79a | 279.58±3.98a | 21.50±2.30b | 109.61±1.57a | 77.55±0.05a |
| Shading   |            | 234.42±2.73b | 138.89±6.77b | 274.31±3.90b | 39.89±5.19a | 95.53±8.56b | 77.57±0.10a |
| Gangyou 188 | CK     | 223.06±2.96a | 136.50±4.33a | 281.44±2.04b | 58.39±0.92b | 86.56±2.28a | 78.28±0.03b |
| Shading   |            | 193.14±2.12b | 132.25±4.45a | 310.97±1.93a | 117.83±3.99a | 60.89±6.56b | 80.78±0.03a |
| Gangyou 527 | CK     | 211.75±2.82a | 118.75±6.17a | 264.67±3.84a | 52.92±3.06b | 93.00±4.45a | 79.95±0.05b |
| Shading   |            | 191.58±0.29b | 112.83±3.56b | 260.56±2.36a | 68.97±2.56a | 78.75±3.77b | 80.78±0.03a |
| Chuanxiang 9838 | CK       | 228.64±1.55a | 130.17±7.30a | 292.61±7.68a | 63.97±6.78a | 98.47±6.84a | 78.32±0.03b |
| Shading   |            | 223.31±1.75b | 122.28±1.35b | 279.58±1.61b | 56.28±2.80b | 101.03±2.03a | 79.37±0.03a |
| Dexiang 4103 | CK     | 247.03±2.95a | 97.78±6.83a | 175.14±7.17a | −71.89±4.25b | 149.25±3.90a | 71.80±0.09a |
| Shading   |            | 226.92±3.17b | 92.42±1.96b | 167.94±1.73b | −58.97±1.54a | 134.50±1.23b | 72.10±0.56a |
| F-value   | L          | 623.92**   | 46.55**    | 0.00       | 271.52**   | 92.30**    | 181.55** |
|           | V          | 449.79**   | 298.79**   | 1951.51**  | 1966.68**  | 278.84**  | 1842.82** |
|           | L × V      | 25.90**    | 0.97       | 54.96**    | 82.61**    | 10.74**    | 38.21**  |

L, light intensity; V, variety; PKV, peak viscosity; HPV, hold viscosity; CPV, final viscosity; SBV, setback; BDV, breakdown; PaT, pasting temperature; and RVU, rapid viscosity units.

Values in columns represent the significant differences between CK and shading treatments, (p<0.05). Means ± standard, n = 3.

**significant at 0.01 level.

Table 9. Effects of shading on starch content of rice flour (2011).

| Varieties | Treatments | Amylose (%) | Amylopectin (%) | Total starch (%) |
|-----------|------------|-------------|-----------------|-----------------|
| IIyou 498 | CK         | 30.52±0.96a | 46.64±1.13a     | 77.17±2.07a     |
| Shading   |            | 30.09±0.60a | 44.36±2.78a     | 74.46±2.43a     |
| Gangyou 188 | CK       | 31.29±0.25b | 43.59±1.21b     | 74.89±1.44b     |
| Shading   |            | 33.07±0.82a | 57.12±1.83a     | 90.19±1.45a     |
| Gangyou 527 | CK       | 27.36±0.37a | 52.23±2.10a     | 79.58±1.87a     |
| Shading   |            | 26.30±1.04b | 54.25±5.65a     | 80.54±4.77a     |
| Chuanxiang 9838 | CK       | 28.87±0.45a | 57.67±2.37b     | 86.54±2.82b     |
| Shading   |            | 28.56±0.45a | 64.59±2.82a     | 93.13±3.17a     |
| Dexiang 4103 | CK     | 20.96±0.48b | 42.04±0.93b     | 63.00±1.41b     |
| Shading   |            | 22.98±0.60a | 70.19±2.38a     | 93.18±2.66a     |
| F-value   | L          | 3.92        | 100.12**        | 109.48**        |
|           | V          | 283.27**    | 29.41**         | 24.21**         |
|           | L × V      | 9.30*       | 30.41**         | 32.43**         |

L, light intensity; V, variety.  
Values in columns represent the significant differences between CK and shading treatments, (p<0.05). Means ± standard, n = 3.  
**significant at 0.01 level;  
*significant at 0.05 level.

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differences manifested themselves at different growth stages in the different rice varieties. At tillering-elongation stage, shading had more influence on Gangyou 188 with lower SBV and higher BDV, and Chuanxiang 9838 with higher SBV and lower BDV (Tables 5, 6). When shading occurred at booting-heading stage, the rice viscosity of Gangyou 188, Gangyou 527, Chuanxiang 9030, and Gangyou 906 was hard, with higher SBV and lower BDV (Tables 5, 6). After heading, BDV of IIyou 498, Gangyou 188, and Gangyou 527 decreased, and the rice viscosity was hard (Tables 7, 8).

The starch pasting viscosity of rice flour, a pasting curve, is generated in a standard temperature program of “heat-hold-cool-breakdown; and PaT, pasting temperature.

| Items       | PKV  | HPV  | CPV  | SBV  | BDV  | PaT  |
|-------------|------|------|------|------|------|------|
| Amylose     | -0.228 & 0.899** | 0.928** | 0.846** | -0.817** | 0.747** |
| Amylopectin | -0.362 | -0.409 | -0.126 | 0.027 | -0.010 | 0.008 |
| Total starch| -0.443 | -0.049 | 0.238 | 0.356 | -0.328 | 0.299 |

PKV, peak viscosity; HPV, hold viscosity; CPV, final viscosity; SBV, setback; BDV, breakdown; and PaT, pasting temperature.

**Significant at 0.01 level.

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