Water irrigation management affects starch structure and physicochemical properties of *indica* rice with different grain quality

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Abstract

The effects of water irrigation management including conventional irrigation (CK), constant flooding irrigation (CFI) and alternate wetting and drying (AWD) on starch structure and physicochemical properties of two *indica* rice cultivars with good- and poor-quality were evaluated in the field condition with two years. The results showed that AWD could significantly increase peak viscosity, breakdown and gelatinization temperature, decreased setback and gelatinization enthalpy in two *indica* rice cultivars. However, starch granule size and amylopectin chain length distribution were differed the trends in the rice cultivars and treatments. AWD reduced starch granules size and amylopectin short chain, especially for large starch granules, but increased medium and long chain, which might contribute to better thermal stability and pasting viscosity for good-quality cultivar. Our study indicated that water irrigation management affected starch structure and physicochemical properties of *indica* rice starch, and would provide favorable information for improvement of rice starch in food industry.

Keywords： Good-quality *indica* rice; Alternate wetting and drying; Starch structure; Thermal properties; Pasting properties

1. Introduction

China with only about 6% of the global water and 9% of the arable land could feed 21% of the world's population (Zhang, 2011), which would be predicted for rising beyond 7.5 billion and additionally increasing food demand for 50% in 2030 (FAO, 2012). Arid and semi-arid areas account for 49% of the total land area of China (Li et al., 2014). We probably must use less arable and water to provide a secure safe and nutritious food. Although the rapid development of rice production in China in the past decades has made remarkable achievements, there are still some problems such as lower water use efficiency for limiting rice production, due to the unreasonable irrigation methods and the nonuniform distribution of water resources, or lack of water storage for farm irrigation in China (Bian et al., 2018). Therefore, the establishment of reasonable water-saving irrigation management will be greatly vital of crop production in current natural conditions.

Rice is hydrophilous plant, which needs sufficient water in the whole growth period, but the water demand for each growth stage is different. Previous studies showed that there were two sensitive growth periods under soil water stress, including young panicle initiation and heading stage, resulting in the serious reduction of grain yield (Lu, Gao, & Yong, 2004). Water management methods are commonly used in rice planting around the world include water-saving irrigation such as alternate wetting and drying irrigation (AWD), drip irrigation, and quantitative controlled irrigation, as well as traditional flooding irrigation such as continuous flooding irrigation (Gao et al., 2018). Traditional flooding irrigation mode can inhibit the respiration and growth of rice root system, leading to serious growth obstacle, for instance, premature senility of plant and leaf yellowed, and can also consume a large amount of water, decrease water use efficiency (Xiao et al., 2019). AWD for a water-saving irrigation technique that is conducive for rice cultivation is currently being used in many countries. Researchers reported that total water consumption of AWD was only 78.1-79.5% of constant flooding irrigation (Xiao et al., 2019). Water-saving irrigation can be considered for a promising method that can also regulate plant growth, improve plant root vitality, and delay leaf senescence, and increase photosynthesis time, enhance dry matter accumulation, not only save water (Li et al., 2018). There are some controversies whether AWD can increase rice yield. Some studies reported that AWD could increase grain yield (Yang, Zhou, & Zhang, 2017; Gao et al., 2018), but other research showed that AWD did not alter or slightly lower yield (Shaibu, Mloza, Makwiza, & Malunga, 2015). The reason might the difference on soil moisture content in AWD method, for instance, alternate moderate wetting and soil drying and alternate severe wetting and soil drying (Li et al., 2018). This indicates that soil moisture content during the alternate wet and dry periods is an important factor for ensuring the stability of rice yield. Water irrigation management not only affects the rice grain yield, but also alters the rice quality. Suitable drought for water content could decrease amylose content by inhibiting the gene expression of *Wx* gene (responsible for the synthesis of amylose) and reducing granules bound starch synthase activity, and increase milled rice and head rice (Fofana, Cherif, Kone, Futakuchi & Audebert, 2010). Whereas amylose content was increased and the protein content of rice was decreased by flooding irrigation (Yang et al., 2019).

Starch-related structure and physicochemical properties of rice affect grain quality (Tang et al., 2019). However, previous studies mainly underlined the effects of water stress on rice grain quality (i.e. processing, appearance, eating and nutritional quality), and were less concerned about the influences on the structure and function of rice starch (Bian et al., 2018). The internal components rice change (i.e. amylose content, protein content, amylopectin content, and amylopectin chain distribution) would alter the rice starch crystallinity and starch granule, thus significantly affecting the physical and chemical properties of starch such as thermal properties and pasting properties under different irrigation managements (Lin et al., 2016; Jeon, Ryoo, Hahn, Walia, & Nakamura, 2010). Lu, & Cai (2015) reported that drought during waxy maize grain filling deteriorated starch quality on pasting viscosities by reducing the starch granule size, proportion of amylopectin long chains, swelling power and crystallinity. Moreover, water-deficit stress during grain-filling could increase the starch branch degree and the proportion of short chains of amylopectin by enhancing starch branching enzyme and starch synthase activities (Zhang et al., 2017). Yang et al. (2019) reported that the average granule size and medium amylopectin branch of waxy maize starch were decreased by flooding during grain formation.

Recently, good-quality *indica* rice cultivars with low amylose content in South China have been widely planted and popularised in production, which can improve the economic benefits of farmers. However, insufficient water irrigation happens frequently during the growth period in late-season *indica* rice, affecting the improvement on grain quality of good-quality rice. The previous researches reported that flooding irrigation could affect the physical and chemical characteristics of crops starch, and the external environment contributed to the physiological and biochemical processes of starch endosperm cell formation (Lu, & Cai, 2015; Yang et al., 2019). Therefore, we hypothesize that water irrigation management changes the distribution of starch particle size, the degree of amylopectin polymerization, and affects the starch physicochemical properties such as the thermal stability and gelatinization characteristics in *indica* rice of different grain qualities. The results could provide a fundamental basis for improving the effective water utilization of farm by water irrigation management to face to the using of good-quality rice starch in food.

2. Materials and methods

2.1 Experimental design

Field experiments were conducted at Shanggao Experimental Base of Jiangxi Agricultural University (114°97′E, 28°23′N, and 93.4 m altitude) during the *indica* rice cultivation season in 2018 and 2019 from June to October. The two *indica* rice cultivars that Taiyou 871 (TY871) is good-quality rice with lower amylose content and Rongyouhuazhan (RYHZ) is poor quality rice with high amylose content were both used in this study, and provided by Jiangxi modern seed industry co. LTD. They are widely planted in the double-cropping rice system, which consists of early-season rice and late-season rice followed by winter fallow. And the early season rice is planted from March to July in the year, while the late season rice is planted from June to October. The soil type is river alluvial soil. The previous crop season for rice was planted early-season rice. The soil properties of 0-20cm layer was 5.32 pH, 33.4 $g{\cdot}kg^{-1}$ soil organic matter, 1.52 $g{\cdot}kg^{-1}$ total nitrogen, 176.5 $mg{\cdot}kg^{-1}$ alkaline hydrolyzable nitrogen, 15.3 $mg{\cdot}kg^{-1}$ available phosphorus, and 68.2 $mg{\cdot}kg^{-1}$ available potassium.

The experiment was established in a split plot design with three replications. The water irrigation management was as a main plot and the cultivars were as a split plot, and the area of split plot was 25m^2 (5m×5m). The seeds were sown on June 22 and breed in substrates, and the seedlings were transplanted manually on July 20. The transplanting density with the row spacing was 25 cm×14 cm, and two seedlings were as one hill. The total nitrogen (N) application rate was 165 kg N ha^{-1}, and the application ratio of nitrogen, phosphate (P_2O_5) and potassium (K_2O) fertilizer was 1:0.5:1. N was applied in four splits: 40% as basal fertilizer at transplanting period, 20% as tillering fertilizer at tillering stage, and 40% as panicle fertilizer at panicle initiation stage. Phosphate fertilizer was all applied as basal fertilizer. Potassium fertilizer was applied in two splits: 50% as basal fertilizer, and 50% as panicle fertilizer. There were no disease and pest during the rice growth.

The different water irrigation management of the field treatments was conducted as follows. (i) conventional irrigation (CK): in addition to drain for reducing invalid tiller at the tillering stage, the flooded layer about 2-4cm was maintained in the rice whole growth stage and the paddy water was drained naturally one week before harvesting; (ii) constant flooding irrigation (CFI): after rice seedlings transplanted, the field surface was always maintained 2-5cm water layer during the whole growth period regardless of tillering stage, and the paddy water layer was drained naturally one week before harvesting; (iii) alternate wetting and drying (AWD): since the seedlings were turned green and established after transplanted, the field was maintained a shallow layer of 0-4cm, followed by alternating dry and wet irrigation; When the soil water potential of paddy reached -15kPa, and then it was flooded with 1-2cm water depth, repeating it in this way. In addition, at the late tillering stage the field was drained to soil water potential for -15kPa, and to keep the 0-4cm shallow layer. The soil moisture content was determined for monitoring the soil water potential by negative pressure pot device (TRS-II, Guangzhou Hangxin Scientific Instrument Ltd, Guangdong, China). If the weather rains, water irrigation in the field will stop. The meteorological conditions from 2018 to 2019 are shown in Figure 1. The total water consumption (TWC), water irrigation efficiency (WIE), and total water use efficiency (WUE) were calculated according to the method of Howell (2001). Compared with CK and CFI, AWD decreased TWC, and significantly increased WIE by 20.8-54.2% and WUE by 11.3-45.4%, respectively (Data were not shown). The experiment requirements under the field conditions could obtain the expected results.

2.2 Rice grain amylose content, protein content

Amylose content was conducted according to the national standards of the rice quality evaluation GB/T 17871-2017, the People's Republic of China. The protein content was determined by Kjeldahl method, and the nitrogen content in milled rice flour was determined by Kjeldahl method, and then multiplied by the conversion coefficient of 5.95.

2.3 Starch extraction, dissolution

Rice grain sample were ground into flour by Freezer/Mill 6850 in the liquid nitrogen and sieved through 200-μm screen. The starch sample were dissolved in a DMSO/LiBr (0.5%, w/w) solution and centrifuged at 4000g for 10min, and then mixed with absolute ethanol. Protease and sodium bisulfite solution were used into the ethanol-precipitated samples. Ethanol and protease can remove the protein, fat, and non-starch polymer and is better than extracting starch using alkaline solution.

2.4 Starch granule size distribution

Starch granule size distributions were determined by matersizer (Matersizer 3000, Malvern Instruments Ltd, Worcestershire, UK). The average granule size was calculated as the volume weighted mean. Starch granule volume, surface area and number distribution were classified into two types: small & medium granules (d<10μm) and large granules (d>10μm) (Zhu, 2018).

2.5 Amylopectin chain distribution

Amylopectin chain distribution was analyzed by ion chromatography (HPAEC-ICS-5000, Thermo Fisher Scientific, Sunnyvale, America) equipped with a pulsed-amperometric detector according to the method of Zhang et al. (2016). Amylopectin were classified into four types depending on the chain length: A chain (6≤DP≤12), B1 chain (13≤DP≤24), B2 chain (25≤DP≤36), and B3 chain (DP≥37) (Hanashiro, Abe, & Hizukuri, 1996).

2.6 Thermal properties

The differential scanning calorimeter (DSC-Q2000, TA Instruments, USA) was used for determination of thermal properties. The flour 10 mg was mixed with 30 μL of distilled water in an aluminium oxide crucible and sealed hermetically. The contents were equilibrated for 24h at room temperature. The thermal properties included onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization ($\triangle H_{gel}$). In addition, the gelatinization temperature range (R) was computed as (T_c-T_o), the peak height index (PHI) was calculated by the equation: PHI=$\triangle H_{gel}$/ (T_p-T_o) (Kaur, & Singh, 2005).

2.7 Pasting properties

The pasting profiles of starch were estimated by rapid visco analyzer (RVA) (Starch Master TM 17133, Newport Scientific Pvt. Ltd, Warier Wood, Australia) according to the method of Bhat, & Riar (2019) with a minor modification. The flour 3g was mixed with 25g distilled water in an aluminum RVA canister; the pasting cycle was set in 12 min, starch sample will be heated at 50°C for 1 min and then heated from 50°C to 95°C at 12°C/min, and was cooled to 50°C at 12°C/min. The pasting properties included peak viscosity (PV), trough viscosity (TV), final viscosity (FV), breakdown viscosity (BD=PV-TV), setback viscosity (SB=FV-PV) and pasting temperature (PT). Viscosity values were recorded as centipoises (cP).

2.8 Statistical analysis

Data in this study are the average value of each treatment with three repeats, and the figure was prepared from SigmaPlot 14.0 ANOVA and the mean values were performed with SPSS 22.0 statistical software (SPSS Inc, Chicago, USA) to determine the least significant difference (LSD) at $p< 0.05$ level.

3 Results and discussions

3.1 Amylose content, protein content and starch granule size distribution

The amylose content in grain was increased but the protein content was significantly decreased by AWD in the two years, compared with CFI (Table 1). Granules bound starch synthase (GBSS) is the most critical enzyme in amylose synthesis, and AWD increases the activity of GBSS, thus increasing amylose content (Zhang et al., 2017), especially for TY 871 in 2019. CFI reduces oxygen content and microorganisms in the root system, resulting in a significant increase in protein content (Yang et al., 2019). Starch granule structure was described in terms of amorphous and semicrystalline growth rings, and the amorphous region mainly contains amylose and less ordered amylopectin (Morrison, 1995). Higher amylose in amorphous region increased the degree of crystallization and made the starch granules structure more closely (Wani et al., 2012), resulting in poor rheological property and increased hardness of rice flour (Lii, Tsai, & Tseng, 1996). Although protein is not the main component of starch granules, protein and lipids are easy to form complexes and link to the surface or insert to the starch granules, thereby affecting the properties of starch granules (Martin, & Fizgeral, 2002).

The rice starch granule volume size distribution of the two cultivars was similar with a peak value at 7μm and a low peak value at 20μm, while the surface area and number distribution showed a single-peak curve, which the peak was 5μm and 3.5μm, respectively (Figure 2). For RYHZ, compared with CK and CFI, the average starch granules volume and surface area of AWD were increased by 13.8-33.5% and 9.2-25.8% in the two years, respectively; however, they were decreased by 18.3-27.7% and 4.8-17.1% under AWD for TY 871, respectively. The average number distribution did not differ among the treatments in the cultivars. The reason for the lower average starch granules under CK and CFI in RYHZ may be caused by the flooding weakening the grain filling plumpness, thereby inhibiting the development of starch granules to form large granules (Lu, & Cai, 2015). The research reported that flooding during grain filling could destroy the grain endosperm structure and reduce enzyme activities related to starch synthesis, resulting in abnormal starch granule development (Zhu, 2018). But AWD in RYHZ facilitates the formation of endosperm cells and promotes the absorption of nutrients by the surviving starch granules (Wang, Mao, Huang, Lu & Lu, 2020).

In addition, the trends of starch granule size distribution among the treatments were completely opposite between the two cultivars (Table 1). For RYHZ, compared to CK and CFI, AWD significantly decreased the starch volume percentage of small & medium granule (d<10μm) by 11.6-14.9% in the two years, but significantly increased the starch volume percentage of large granule (d>10μm) by 13.3%-19.7%. However, for TY 871, AWD significantly increased the small & medium granule by 10.3-15.1%, and decreased the large granule by 15.1-19.2%. And surface area and number distribution of rice starch granule had the same trends with the volume distribution. These results might be because the amylose content in TY 871 was lower than that of RYHZ. Low amylose content (Table 1) and amylopectin short chain length (Figure 3) are unable to form a double helix structure that spans the entire crystal lamellae, which will lead to the defects of the crystal region and instability of the crystal structure, and the starch granules finally become loose (Wang et al., 2012).

3.2 Degree of polymerization

The distribution of chain fractions in debranched amylopectin was determined by Ion Chromatography. There was significant difference on amylopectin degree of polymerization of rice starch between the cultivars under water irrigation management, but the trends of the amylopectin chain length distribution in two years were similar with the same results (Figure 3). For RYHZ, the increasing of A chain (6≤DP≤12) and B1 chain (13≤DP≤24) under AWD might be caused by the increased activity of starch branching enzyme (Timabud, & Yin, 2016), but CFI increased the A chain and significantly decreased B1 chain, implying the starch branching enzyme activity being disorderly.

Furthermore, short & medium chains is higher, and long chains is lower, eating quality is better (Tao, Li, Yu, Gilbert, & Li, 2019); therefore, CFI may deteriorate rice eating quality for high amylose content cultivar (RYHZ). Different with the cultivar RYHZ, compared with CK, CFI and AWD had both decreased A chain and increased B1, B2 chain (25≤DP≤36) and B3 chain (DP≥37) for TY 871 that the influences under AWD were relatively obvious. The results showed that AWD could better improve the formation of medium chains. The difference in amylopectin chain length distribution has a significant impact on the structure and physicochemical properties of starch granules (Perez, & Bertoft, 2010). Starch granules are mainly composed of amylose and amylopectin, and amylopectin determines the basic structure of starch granules (Kaur, & Singh, 2005). The medium and long chain of amylopectin can form a double helix structure that spans the crystalline region, which is conducive to the crystallization of starch granules (Smith, Denyer, & Martin, 1997). However, CFI decreased the expression of the soluble starch synthase encoding genes, and amylopectin content was further reduced and unable to form the well-developed crystalline lamellae (Jeon, Ryoo, Hahn, Walia, & Nakamura, 2010), leading to significantly decrease the large starch granule in RYHZ (Table 1). Additionally, the distribution of amylopectin large chains length is highly positive correlated with the enthalpy of gelatinization (Lin et al., 2016). This indicated CFI might require more and higher enthalpy of gelatinization than that of AWD, while polished rice was cooked (Lu, & Cai, 2015).

3.3 Thermal properties

Water irrigation managements have significant effects on the thermal properties of rice starch (Table 2). Gelatinization is a 2-step endothermic process: firstly starch granules swell due to breakage of hydrogen bonds in the amorphous portions of the starch, and next undergo hydration resulting in swelling of the amorphous regions (Blazek, & Gilbert, 2011). In the two years, AWD in RYHZ had significantly highest gelatinization temperatures (T_o, T_p) among the treatments. And the trends were similar in TY 871; moreover, the relatively lowest gelatinization temperatures were observed for the cultivars under CFI, especially in 2019. High gelatinization temperatures under AWD indicate higher stability of starch structure (Wani et al., 2012). Therefore, AWD could improve starch structure stability of the two cultivars.

Compared with CK, AWD decreased the gelatinization enthalpy (ΔH_{gel}) in the cultivars, whereas CFI might increase the ΔH_{gel}, especially for 2019. That might be attributed to the difference distribution of starch granules, starch crystallinity and amylopectin chain length distribution (Bao, Sun, Zhu, & Corke, 2004), and the increase of large starch granule in RYHZ and long-chain amylopectin in TY 871 might be the main reason for the increase of ΔH_{gel} under CFI (Bhat, & Riar, 2019; Wani et al., 2012; Vandeputte, Vermeylen, Geeroms, & Delcour, 2003). However, amylose content (absolute and free amylose content) did not affect the gelatinization temperatures of waxy rice starches (Vandeputte, Vermeylen, Geeroms, & Delcour, 2003), and small variation in amylose contents due to the treatments had no significant effects on thermal properties (Raina, Singh, Bawa, & Saxena, 2007). This might be the reason that the thermal properties had the similar trends regardless of the high- or low-amylose rice cultivar. The gelatinization temperature range (R) was positively correlated with amylose content, suggesting that high amylose content cultivar increased R (Bhat, & Riar, 2019). Our results also verified it. Furthermore, compare with CFI, AWD could decrease R of the cultivars with a significant effect on TY 871 in 2019. Peak height index (PHI) is an indicator of the uniformity of starch swelling and splitting to form a paste solution at high temperature (Kaur, & Singh, 2005). The PHI is lower, and the gelatinization is more uniform, the gelatinization enthalpy is lower (Zhang et al., 2016). However, although the differences on PHI were not significant among the treatments in the two cultivars, except for that was significantly lower under AWD for TY 871 in 2019, AWD could overall decrease the PHI in the two years.

3.4 Pasting properties

The pasting properties of rice starch are shown in Table 3. Compared with CFI, AWD increased the pasting viscosity (PV, TV and FV) in the two cultivars for two years. Pasting properties of starch are determined by amylose content, amylopectin chain length distribution, and starch granule size distribution (Bhat, & Riar, 2016). The lowest pasting viscosity for CFI may be due to amylopectin branch long chains in TY 871, large starch granule in RYHZ and high crystallinity value, resulting in inhibiting the starch swelling (Bhat, & Riar, 2019). Altogether, CFI increased the average pasting temperature in the cultivars. Generally, AWD might improve the cohesiveness and stickiness of rice starch and reduce the hardness of rice starch, resulting in lower rice cooking temperature (Falade, & Christopher, 2015). The results indicated that CFI could not conducive to starch dissolution and worsen grain quality, especially for cooking quality. High peak viscosity, large breakdown and low setback could form good taste value for rice RVA flour (Han, Xu, Liu, Yan, & Schuyler, 2004). In this study, AWD had higher breakdown and lower setback in the cultivars with the two years field experiments, implied the improvement on the cooking and eating quality, especially for the cultivar

TY 871. The present study suggested that AWD could also improve the eating palatability of cooked rice for good quality rice cultivar, not only for poor quality rice cultivar.

4. Conclusions

Our study results showed that AWD had better thermal stability (i.e. higher gelatinization temperature and lower gelatinization enthalpy) and pasting properties whether high- or low-amylose *indica* rice cultivar, but CFI significantly increased protein content. Starch granule size and amylopectin distribution under AWD were differed the trends in the two cultivars due to amylose content. For good quality rice cultivar TY871, AWD increased small & medium starch granules (i.e. volume, surface area and number) and medium and long chain whereas reduced average & large starch granules, contributing to gelatinization temperature; however, for poor quality cultivar RYHZ, AWD increased average starch granules size by increasing large granules, and short & medium amylopectin chains, being conducive to decrease enthalpy of gelatinization. The field experiments results provide some useful information for the processing and improvement of rice starch in food industry through water irrigation managements.

5. Conflict of interest

The authors have declared on conflicts of interest.

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Table 1. Effects of different water irrigation management on starch granule size distribution.

Years	Cultivars	Irrigation management	Amylose content (%)	Protein content (%)	Volume percentage (%)		Surface area percentage (%)		Number percentage (%)	
					<10μm	>10μm	<10μm	>10μm	<10μm	>10μm
2018	RYHZ	CK	20.4a	6.2b	65.9a	34.1b	86.7a	13.3c	98.56b	1.44b
		CFI	20.0a	7.0a	66.2a	33.8b	85.9b	14.1b	98.66a	1.34c
		AWD	20.7a	6.0b	58.0b	42.0a	79.6c	20.5a	98.54c	1.46a
	TY 871	CK	16.4a	6.9b	56.0b	44.0a	84.2b	15.8b	98.53b	1.47b
		CFI	16.2a	7.7a	56.6b	43.4b	82.1c	17.9a	98.50c	1.50a
		AWD	16.9a	6.8b	63.1a	36.9c	85.0a	15.0c	98.63a	1.37c
2019	RYHZ	CK	20.0a	6.4b	59.7b	40.3b	85.5b	14.5b	98.53b	1.47a
		CFI	18.0a	7.2a	61.4a	38.6c	86.1a	14.0c	98.65a	1.35b
		AWD	21.1a	6.1b	53.5c	46.5a	82.9c	17.1a	98.52b	1.48a
	TY 871	CK	15.7b	7.0b	50.7c	49.3a	82.3c	17.8a	98.47c	1.53a
		CFI	14.5c	7.8a	52.2b	47.8b	83.4b	16.6b	98.49b	1.51b
		AWD	16.4a	6.3c	58.4a	41.6c	85.8a	14.2c	98.62a	1.38c

Different lowercase letters between different management under the same cultivars in the same year in the same column are significant at $p<0.05$.

RYHZ, Rongyouhuazhan; TY 871, Taiyou 871.

CK, conventional irrigation; CFI, constant flooding irrigation; AWD, alternate wetting and drying.

Table 2 Thermal properties of rice starch.

Years	Cultivar	Irrigation management	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH_{gel} (Jg^{-1})	R	PHI
2018	RYHZ	CK	67.9b	74.4b	82.0a	9.4ab	14.1a	1.4a
		CFI	68.3b	73.9b	82.2a	10.0a	13.9a	1.8a
		AWD	69.3a	76.4a	81.9a	9.0b	12.6a	1.3a
	TY 871	CK	62.3ab	68.7a	72.8b	9.2a	10.5a	1.4a
		CFI	61.5b	67.9b	73.2ab	8.3b	11.7a	1.3a
		AWD	63.1a	69.3a	73.8a	7.8b	10.7a	1.3a
2019	RYHZ	CK	69.5b	73.3b	81.7b	9.7b	12.2a	2.6a
		CFI	67.5c	72.6b	80.1c	10.7a	12.6a	2.1a
		AWD	70.7a	75.1a	83.1a	8.6c	12.4a	2.0a
	TY 871	CK	64.7b	68.9b	74.2b	8.3b	9.5ab	2.0a
		CFI	63.3c	67.9c	73.4c	9.7a	10.1a	2.1a
		AWD	66.7a	72.5a	75.5a	7.4c	8.8b	1.3b

Different lowercase letters between different management under the same cultivars in the same year in the same column are significant at $p<0.05$.

RYHZ, Rongyouhuazhan; TY 871, Taiyou 871.

CK, conventional irrigation; CFI, constant flooding irrigation; AWD, alternate wetting and drying; T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; $\triangle H_{gel}$, enthalpy of gelatinization; R, gelatinization temperature range; PHI, peak height index.

Table 3 Pasting properties of rice starch.

Years	Cultivars	Irrigation management	PV (cP)	TV (cP)	FV (cP)	BD (cP)	SB (cP)	PT (^{o}C)
2018	RYHZ	CK	2825a	1799ab	3275a	1026a	450b	78.5b
		CFI	2760b	1787b	3231b	973b	471a	80.3a
		AWD	2833a	1818a	3267a	1015a	434c	79.3ab
	TY 871	CK	2891a	1573a	2813a	1318b	-78b	83.2a
		CFI	2687b	1532b	2728b	1155c	41a	83.8a
		AWD	2895a	1551ab	2809a	1344a	-86b	78.5b
2019	RYHZ	CK	2946a	1838b	3350a	1108a	404b	79.8a
		CFI	2760b	1751c	3261b	1009b	501a	80.3a
		AWD	2999a	1893a	3358a	1106a	359c	80.3a
	TY 871	CK	3169b	1677b	3011ab	1492b	-158b	75.1a
		CFI	3044c	1604c	2941b	1440c	-103a	75.5a
		AWD	3260a	1742a	3046a	1518a	-214c	75.6a

Different lowercase letters between different management under the same cultivars in the same year in the same column are significant at $p<0.05$.

RYHZ, Rongyouhuazhan; TY 871, Taiyou 871.

CK, conventional irrigation; CFI, constant flooding irrigation; AWD, alternate wetting and drying.

PV, peak viscosity; TV, trough viscosity; FV, final viscosity; BD, breakdown viscosity; SB, setback viscosity; PT, pasting temperature.

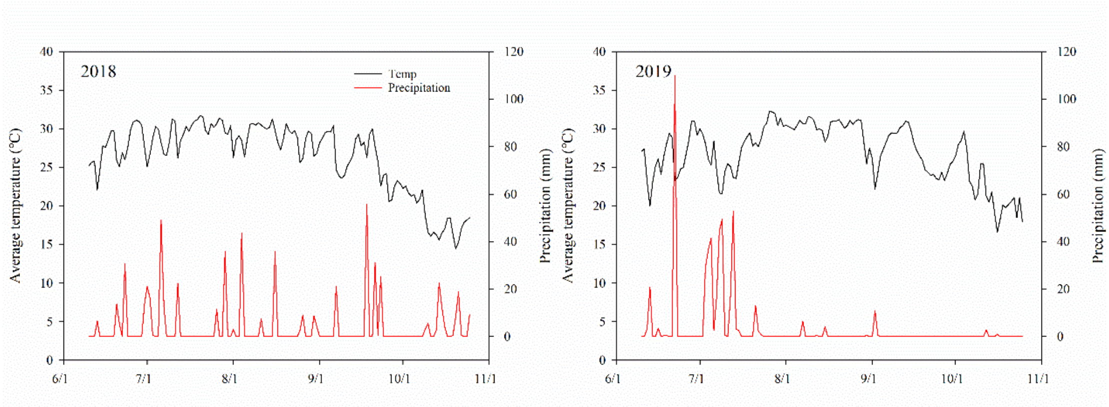
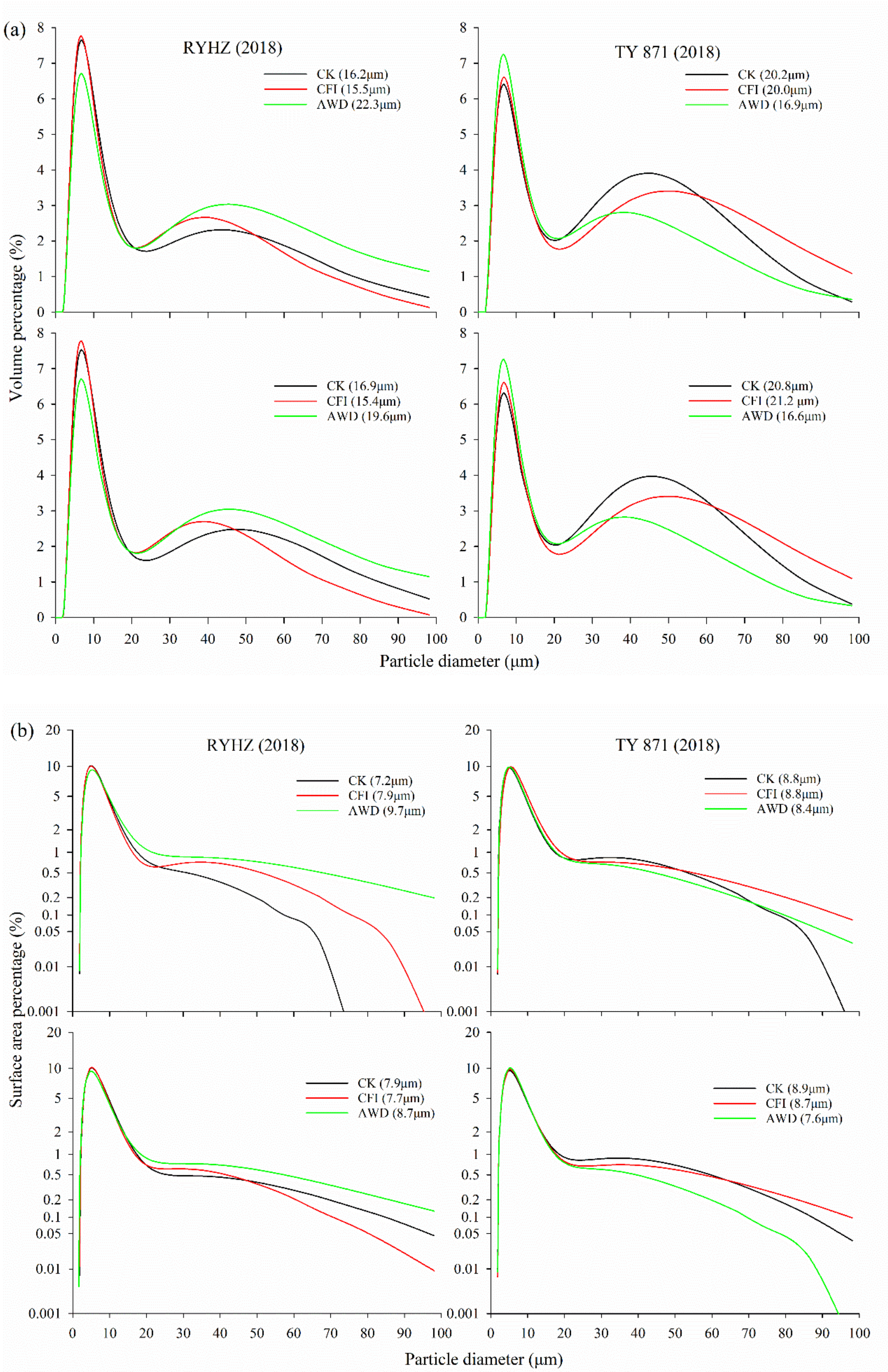


Fig.1 Meteorological conditions in the field experiments from 2018 to 2019.


(a)
RYHZ (2018)
CK (16.2μm)
CFI (15.5μm)
AWD (22.3μm)
TY 871 (2018)
CK (20.2μm)
CFI (20.0μm)
AWD (16.9μm)
CK (16.9μm)
CFI (15.4μm)
AWD (19.6μm)
CK (20.8μm)
CFI (21.2 μm)
AWD (16.6μm)
Volume percentage (%)
Particle diameter (μm)
(b)
RYHZ (2018)
CK (7.2μm)
CFI (7.9μm)
AWD (9.7μm)
TY 871 (2018)
CK (8.8μm)
CFI (8.8μm)
AWD (8.4μm)
CK (7.9μm)
CFI (7.7μm)
AWD (8.7μm)
CK (8.9μm)
CFI (8.7μm)
AWD (7.6μm)
Surface area percentage (%)
Particle diameter (μm)

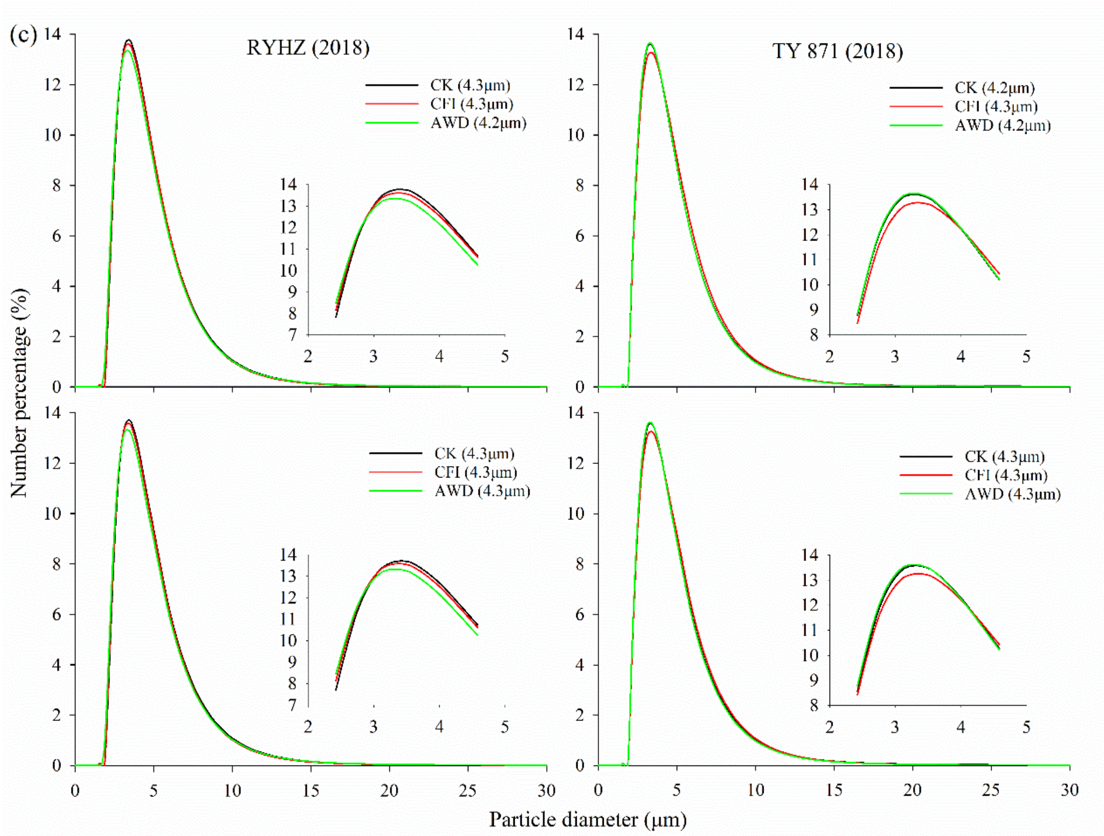


Figure 2. Rice starch granule volume size distribution (a), surface area distribution (b) and number distribution (c) under difference water irrigation management. The values in brackets represent the average starch volume, surface area and number granule size under difference water irrigation management, respectively.

RYHZ, Rongyouhuazhan; TY 871, Taiyou 871.

CK, conventional irrigation; CFI, constant flooding irrigation; AWD, alternate wetting and drying.

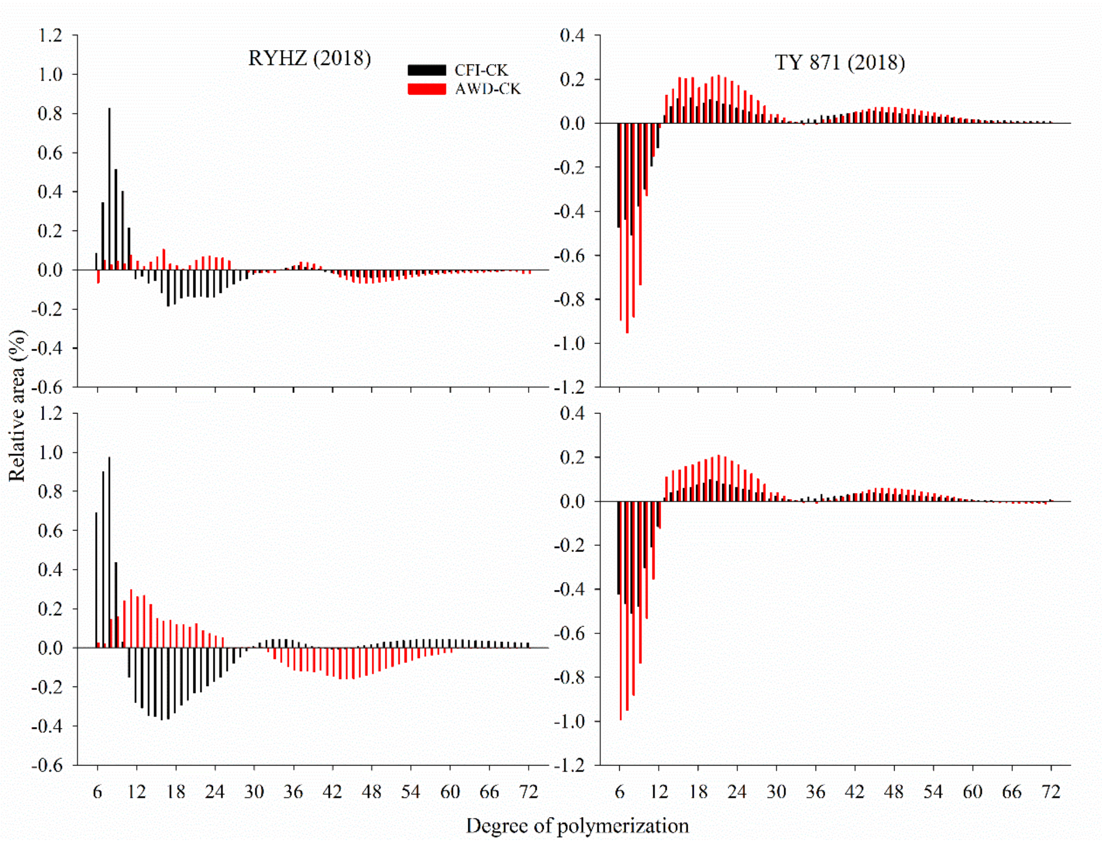


Figure 3. Amylopectin degree of polymerization of rice starch under difference water irrigation management.

RYHZ, Rongyouhuazhan; TY 871, Taiyou 871.

CK, conventional irrigation; CFI, constant flooding irrigation; AWD, alternate wetting and drying.