EFFECTS OF TRANSPLANTING CONDITIONS AND WATER MANAGEMENT ON THE YIELD, QUALITY AND AROMA OF FRAGRANT RICE

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Abstract. To explore the effects of transplanting conditions and water treatments on the yield, quality and aroma of fragrant rice, a field experiment was conducted with conventional fragrant rice cultivars, “Meixiangzhan 2”and “Xiangyaxiangzhan”, as plant materials. Four treatments were designed: (DR) dry transplanted + rainfed, (DC) dry transplanted + conventional irrigation treatments, (WR) water transplanted + rainfed, (WC) water transplanted + conventional irrigation treatments. The highest 1000-grain weight were recorded under the WR treatment, and this treatment was more beneficial to the export and accumulation of assimilates during rice growth. The average yield of the two fragrant rice cultivars in both seasons were WC > WR > DR > DC. The milled rice rate and head rice rate were maximized in WR treatment, also minimized in chalkiness and chalky grain rate in the case of all except WC treatments in the early season. Compared with WC and DC treatments, average content of 2-acetyl-1-pyrroline (2-AP) under WR and DR treatments increased by 24.11%. In conclusion, we considered WR treatment as the optimum water saving treatment for yield increase and quality improvement, as well as for increasing the aroma of fragrant rice grains.
Keywords: *rice, rainfed, aroma-related enzymes, 2-acetyl-1-pyrroline, yield*

Introduction

Rice (*Oryza sativa* L.), as an important food crop, is consumed by more than half of the world’s population, and the main rice cultivars are only grown in Asia (Abid et al., 2015).

Due to its unique flavor and superior grain qualities, the fragrant rice fetches premium prices in international markets and demands are grown dramatically in recent years (Deng et al., 2018). Among the more than 100 volatile components, the aromatic compound 2-acetyl-1-pyrroline (2-AP) is the main reason for the aroma of fragrant rice (Hashemi et al., 2013). Relevant studies have confirmed that the aroma of fragrant rice is not only affected by the genetics of fragrant rice itself, but also has an important relationship with its growth and cultivation environment. The yield formation and 2-AP biosynthesis of fragrant rice were affected by many environmental factors and agronomic measures (Kong et al., 2020). In various cultivation measures, water management as an important cultivation and management measure has been concerned

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by predecessors, in which dry-wet alternative irrigation, as a new irrigation technique, has been adopted by many countries (Marchesi et al., 2019; Graham Acquaah et al., 2019). Dry-wet alternative irrigation regulated the precursors' accumulation, enzymes activities and genes expression of the enzymes that regulate the production of 2AP in both rice cultivars (Bao et al., 2018a).

Related studies have shown that light water-controlled irrigation can increase the aroma content of fragrant rice grains and decrease the chalky grain rate, and it is the best cultivation measure for high yield and high quality of fragrant rice (Tian et al., 2018). Strong water stress affected the physiological activity of rice in the later stage and reduced the synthesis and accumulation of 2-AP in fragrant rice, so water had a great influence on the aroma of fragrant rice (Wang et al., 2013).

Predecessors had a detailed description of intermittent irrigation and water-saving irrigation, but there were few reports on the effects of water treatment before sowing and the whole cultivation process of fragrant rice on the yield, quality and aroma of fragrant rice. To explore the differences in yield, quality and aroma of fragrant rice, two fragrant rice cultivars, "Meixiangzhan-2"and "Xiangyaxiangzhan", which were widely planted in South China, were used as experimental materials. The purpose of this study is to provide a theoretical basis for high yield, quality and more aroma of fragrant rice.

Materials and methods

Experimental details

A two-season field experiment was conducted in the Experimental Research Farm, College of Agriculture, South China Agricultural University, Guangzhou (23°09' N, 113°22' E and 11 m from mean sea level), in China in 2019. The physical and chemical properties of soil in the early season were as follows: pH 6.5, organic matter content 22.63 g/kg, total nitrogen 1.56 g/kg, total phosphorus 1.43 g/kg, total potassium 23.97 g/kg, available potassium 90.32 mg/kg, available phosphorus 75.70 mg/kg; Physical and chemical properties of soil in late season: pH 6.2, organic matter content 25.63 g/kg, total nitrogen 1.66 g/kg, total phosphorus 1.57 g/kg, total potassium 22.83 g/kg, available potassium 92.32 mg/kg, available phosphorus 45.63 mg/kg.

Two fragrant rice cultivars, "Meixiangzhan 2" (Lemont × Fengaozhan) and "Xiangyaxiangzhan" (Xiangsimiao 126× Xiangyaruanzhan), were used as materials in the experiment. Those cultivars are well-known and widely grown in South China. The split zone test design is adopted in the experiment.

The soil conditions at transplanting were set as: dry transplanted treatment (D): the former cropping was not soaked after harvest. 5 days after harvest, rotary tillage machine was used for dry rotary tillage once and the second dry rotary tillage was carried out 3 days before transplanting rice seedlings. Water transplanted treatment (W): irrigation was carried out 3-4 cm in the field 10 days before transplanting. After keeping water for 3 days, the rotary tillage was used to rotate once. The water treatments were set as: rainfed (R), if there is no wilting of the seedlings after transplanting, no artificial irrigation was carried out. If wilting occurred, irrigation was carried out to ensure that the rice would not die. In conventional irrigation treatments (C) shallow water was maintained at the early stage, then drained and exposed the field after enough seedlings, 3-4 cm irrigation was carried out at the beginning of young panicle differentiation, then kept dry and wet alternately from booting stage to breaking stage, then kept in shallow water layer after heading to facilitate filling and fruiting, and water was cut off 5-6 days before harvest. The plot sizes of the four

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treatments were 10.5 × 7 m^2. Each treatment special fertilizer was applied for fragrant rice ($N + P_2O_5 + K_2O \geq 6\%$, organic matter ≥ 25%) 750 kg/hm^2 at the tillering stage, and ridges were built between plots (40 cm wide and wrapped in plastic) to keep water and fertilizer. The seeds of both rice cultivars were surface sterilized with a 5% sodium hypochlorite solution and then immersed in water for 12 h and allowed to germinate in a dark thermostatic incubator at 38 °C for 12 h. The germinated seeds were sown in PVC trays for nursery raising, then, PVC trays were placed in puddled field and covered with a plastic sheet. 15-day-old seedlings were transplanted to the field. Geminated seeds of both cultivars were sown on the 9th March, 2019 (early season) and the 15th July 2019 (late season) for nursery rising. Seedlings were transplanted in puddled field on the 26th March and the 2nd August, 2019 for early and late season, respectively, and harvested on 14th July (early season) and 7th November (late season) (*Fig. 1*).

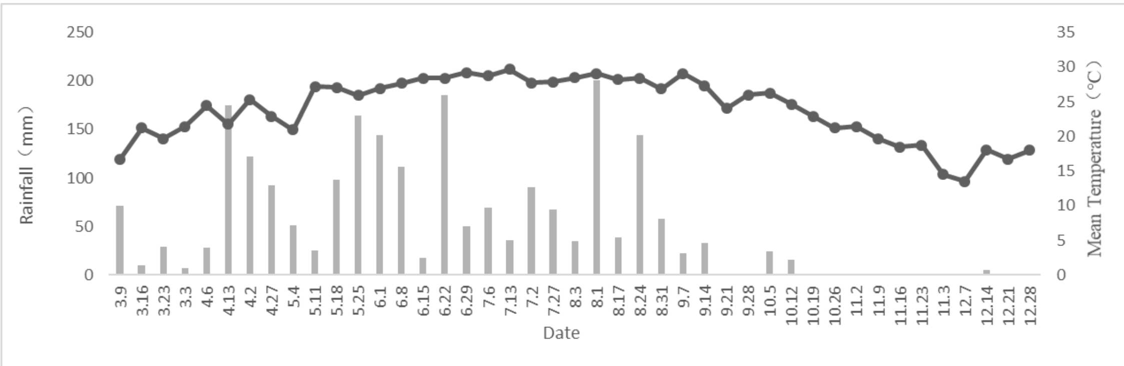

Figure 1. *Mean weekly temperature and rainfall during the experiment*

Treatments and plant sampling

Experimental treatments were carried out as described:

- DR: dry transplanted + rainfed,
- DC: dry transplanted + conventional irrigation treatments,
- WR: water transplanted + rainfed,
- WC: water transplanted + conventional irrigation treatments.

Nine random rice plants from each plot were collected for estimation of accumulation and assimilation of photosynthetic matter, aroma-related enzymes and 2-acetyl-1-pyrroline (2-AP) in grains in the tillering stage (early season April on 26th, late season on September 5th), booting stage (early season on the 19th May, late season on the 24th September), full heading stage (early season on the 11th June, late season on the 10th October), 15 days after heading (early season on the 26th June, late season on the 25th October), and mature stage (early season on the 4th July, late season on the 13th November).

Accumulation and assimilation of photosynthetic matter

The leaf area was measured according to the methods of Tao et al. (2006). According to the average tiller number of the community, 6 hills of rice plants with the same growth pattern were taken. The leaf area of rice samples was measured by the product of length and width of 15 flag leaves. Then the tissues of different parts of rice were cut and dried at 105 °C for 30 min and dried in oven at 80 °C for 30 min. The dry matter

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mass was measured to determine the community growth rate (CGR) and net assimilation rate (NAR).

$$CGR(g/(m^2 \cdot d)) = (W2\text{-}W1)/(t2\text{-}t1)$$

$$NAR(g/(m^2 \cdot d)) = [(\ln LAI\ 2\text{-}\ln LAI\ 1)/(LAI\ 2\text{-}LAI\ 1)]\times[(W2 - W1)/(t2 - t1)]$$

where LAI1 and LAI2 are the leaf area index measured before and after, t1 and t2 are the time of the two measurements, and W1 and W2 are the dry matter mass measured before and after the two measurements.

Aroma-related enzymes and 2-acetyl-1-pyrroline (2-AP) in grains

According to the average number of tillers of the population, 3 hills of rice samples with the same growth were taken back to the laboratory, the tissues of different parts (including the leaves, stems and grains) of rice were quickly separated and placed in liquid nitrogen. The leaves, stems and grains were placed in the refrigerator at -80 °C.

The determination method of proline refers to the method of Huang et al. (2012). The contents of pyrroline-5-carboxylic acid (P5C) were measured according to the method of Luo et al. (2019). Ornithine aminotransferase (OAT) activity was assayed according to the method devised by Bao et al. (2018b), the measurement of methylglyoxal refers to the method of Hasanuzzaman et al. (2019), and the determination method of aroma (2-AP) in grains refers to the method of Du et al. (2019). The measurements were repeated in triplicate and averaged.

Measurement of yield and yield-related traits

One community sample area (1 m^2) from each experimental plot was harvested at maturity, then threshed manually and sun-dried. 30 random hills of rice plants in each plot were sampled for calculating the average effective panicle number per hill. The above measures have been repeated thrice. According to the average number of effective panicles, 5 representative plants were randomly selected to determine the number of grain count per panicle, seed setting rate and 1000-grain weight.

Measurement of grain quality

After sun-dried, grains were stored at room temperature for at least three months to determine grain quality attributes. Rice grains from each treatment was taken from storage and brown rice rate was estimated using a rice huller (Jiangsu, China) while milled rice and head rice recovery rates were calculated by using a Jingmi testing rice grader (Zhejiang, China). Grains with chalkiness and chalky grain rate were estimated by using an SDE-A light box (Guangzhou, China) while an Infratec-1241 grain analyzer (FOSS-TECATOR) was used to determine the grain amylose and protein contents.

Statistical analyses

All statistical analyses were performed by using Statistix 8 (Analytical software, Tallahassee, Florida, USA). Two factors (transplanting conditions and water management) and their interactions had been tested. The data were analyzed by one-

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way analysis of variance and the differences amongst means were separated by using least significant difference (LSD) test at 5% significance level.

Results

Community growth rate and net assimilation rate

As shown in *Table 1*, for Meixiangzhan 2, the highest community growth rate (CGR) was recorded under the WR treatment, in all except for WC treatment from booting stage to 15 days after heading in the early season, and the trend of net assimilation rate (NAR) from booting stage and 15 days after heading in early season were the same: WR > WC = DC > DR. In late season, the CGR under WR treatment was the highest at tillering stage, and the NAR had the same trend. For Xiangyaxiangzhan, there was no significant regular change in the treatments in the early season, and the CGR was the highest under WR treatment at tillering stage, and the NAR under WR treatment was also significantly higher than that of DC and WC treatment at tillering stage.

Table 1. *Effects of transplanting conditions and water management on CGR and NAR of fragrant rice*

Season	Cultivar	Treatment	CGR/($g \cdot m^{-2} \cdot d^{-1}$)			NAR/($g \cdot m^{-2} \cdot d^{-1}$)		
			T-B	B—H	H-HA	T-B	B—H	H-HA
Early	*Meixiangzhan 2*	DR	14.23±2.59b	10.53±2.51b	8.89±2.99b	4.74±1.36b	1.98±0.47b	2.21±0.74b
		DC	15.43±1.89b	8.36±3.39b	10.76±2.91ab	4.83±1.13b	2.38±1.51ab	2.83±0.76ab
		WR	14.27±3.45b	17.98±0.31a	14.09±3.29a	3.69±1.46c	3.72±0.06a	3.08±0.72a
		WC	21.55±2.52a	23.41±3.19a	10.76±2.15ab	5.28±1.31a	2.44±0.6ab	2.42±0.48ab
	Xiangyaxiangzhan	DR	14.17±3.45ab	8.24±4.85c	9.43±4.44b	5.32±1.32a	1.98±0.98b	2.74±1.05a
		DC	11.61±2.58b	25.87±3.28a	3.49±0.89c	4.53±1.41a	4.87±1.29a	1.35±0.77b
		WR	17.32±1.18a	9.82±0.14c	9.09±4.32b	5.75±0.39a	3.85±1.47ab	2.17±0.36a
		WC	12.29±1.59b	17.11±2.26b	18.26±4.65a	4.55±1.01a	4.62±1.47a	2.23±1.32a
Late	*Meixiangzhan 2*	DR	12.61±1.17ab	21.59±0.26a	13.48±1.97b	5.21±0.68a	5.08±0.08b	3.69±0.65a
		DC	13.16±2.59ab	22.21±0.56a	16.21±4.41a	3.74±0.74b	6.82±1.04a	3.05±0.51a
		WR	16.56±1.44a	15.26±4.92b	13.57±4.55b	5.01±0.44a	2.62±0.51c	3.31±0.94a
		WC	10.56±4.54b	20.42±1.62a	17.58±2.81a	2.31±0.71c	3.92±1.05b	3.37±0.71a
	Xiangyaxiangzhan	DR	19.13±4.79a	9.98±2.24c	16.03±4.36b	4.27±0.73a	2.19±0.55c	3.28±1.23b
		DC	18.56±4.96ab	8.28±4.74c	20.01±2.62b	4.01±1.07a	3.41±1.11bc	3.24±1.33b
		WR	12.86±1.98bc	26.23±0.55a	30.78±0.93a	4.13±0.41a	5.23±0.94a	4.18±1.67a
		WC	9.48±3.39c	14.6±2.06b	19.59±3.85b	2.52±0.14b	3.77±0.74ab	3.22±0.27b

(DR) dry transplanted + rained irrigation, (DC) dry transplanted + conventional irrigation treatments, (WR) water transplanted + rainfed irrigation, (WC) water transplanted + conventional irrigation treatments. T-B: Tillering stage to booting stage, B-H: Booting stage to heading stage, H-HA: Heading stage to Heading after 15 days. Small alphabetical letters above means indicate the differences ($P < 0.05$) among different management treatments

Yield and yield-related traits

As shown in *Table 2*, for Meixiangzhan 2, The trend of fertile panicle was: WR = WC > DR = DC in both early and late season. Also the highest 1000-grain weight was recorded with WR treatment in the early season. For Xiangyaxiangzhan, in the early season, the trend of fertile panicle was the same as Meixiangzhan 2. Compared with C treatments, R

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treatments could also increase the 1000-grain weight of these cultivars, and the highest yield was recorded under the WR treatment in the early season. The varieties and the experiments did not influence the yield significantly, so the average yield of the two fragrant rice cultivars in both seasons were WC > WR > DR > DC.

***Table 2.** Effects of transplanting conditions and water management yield and yield-related traits*

Season	Cultivar	Treatment	Fertile panicle (m^{-1})	Grain count per panicle	Seed setting rate (%)	1000-grain weight (g)	Actual yield ($t\ ha^{-1}$)
Early	Meixiangzhan 2	DR	257.11 ± 0.43b	131.39 ± 6.89b	82.63 ± 3.92b	18.80 ± 0.60ab	3.25 ± 0.28b
		DC	252.33 ± 1.22b	151.90 ± 5.72a	82.57 ± 8.33b	17.55 ± 1.25b	3.33 ± 0.11b
		WR	261.42 ± 0.45a	148.32 ± 8.29a	87.91 ± 3.46a	19.36 ± 1.52a	3.48 ± 0.21a
		WC	260.22 ± 0.22a	153.04 ± 2.59a	86.91 ± 5.51a	18.82 ± 0.72ab	3.23 ± 0.43b
	Xiangyaxiangzhan	DR	252.22 ± 0.11b	124.94 ± 3.63b	82.81 ± 5.17ab	20.44 ± 0.62a	2.72 ± 0.49b
		DC	252.12 ± 1.22b	129.83 ± 8.73b	79.95 ± 1.36b	20.50 ± 0.40a	2.97 ± 0.11ab
		WR	275.94 ± 0.23a	142.16 ± 6.16a	85.31 ± 2.42a	19.66 ± 0.36ab	3.55 ± 0.43a
		WC	272.77 ± 0.32a	133.30 ± 3.02b	86.42 ± 2.44a	19.01 ± 1.40b	3.35 ± 0.28ab
Late	Meixiangzhan 2	DR	246.13 ± 1.22b	140.27 ± 19.13ab	89.12 ± 1.03a	19.11 ± 1.22b	5.68 ± 0.49a
		DC	242.22 ± 0.32b	152.75 ± 23.16a	86.89 ± 0.03a	20.79 ± 1.23a	4.64 ± 0.23b
		WR	276.58 ± 1.01a	122.45 ± 15.35b	90.13 ± 2.02a	19.21 ± 0.21b	4.80 ± 0.52b
		WC	270.13 ± 0.31a	137.95 ± 20.83ab	88.32 ± 0.05a	20.21 ± 0.93ab	5.52 ± 0.68a
	Xiangyaxiangzhan	DR	255.12 ± 1.21b	138.86 ± 11.29a	84.24 ± 1.06b	18.88 ± 0.57b	5.52 ± 0.39b
		DC	268.21 ± 0.22ab	130.70 ± 5.74b	83.33 ± 0.36b	20.28 ± 0.44a	5.62 ± 0.30a
		WR	285.54 ± 1.11a	143.27 ± 6.20a	88.29 ± 1.24ab	20.04 ± 0.66a	5.68 ± 1.19a
		WC	281.12 ± 1.65a	125.63 ± 14.95b	91.25 ± 0.33a	18.96 ± 1.55b	5.42 ± 0.85c
Early	C		1.43	1.43	13.36*	1.25	3.94
	T		0.03	0.03	12.18*	2.47	1.05
	C×T		1.66	1.66	11.17*	0.34	3.64
Late	C		16.03*	5.28*	1.46	0.81	3.19
	T		15.03*	12.22*	2.62	2.42	0.81
	C×T		5.01*	20.86*	2.01	1.65	1.74

(DR) dry transplanted + rained irrigation, (DC) dry transplanted + conventional irrigation treatments, (WR) water transplanted + rainfed irrigation, (WC) water transplanted + conventional irrigation treatments. Small alphabetical letters above means indicate the differences ($P < 0.05$) among different management treatments. *, ** Significantly different at 0.05 and 0.01 probability levels, respectively. C: Cultivar; T: Treatment; C×T: Cultivar- Treatment interaction. The same as below

Quality of fragrant rice

As shown in *Table 3*, for Meixiangzhan 2, there was no significant difference among the four treatments in the early season on the rate of brown rice and milled rice of this cultivar. The head rice rate maximized in WR treatment. And maximized in DR treatment in the early and late season. For Xiangyaxiangzhan, WR treatment had the highest milled rice rate and head rice rate and the lowest chalkiness and chalky grain rate in all except WC treatments in the early season, while the four treatments had no significant effect on the brown rice rate and milled rice rate of this cultivar in the late season. Each of the treatments had little effect on the length-width ratio of the two fragrant rice cultivars.

Proline content

The effects of different transplanting conditions and water management on the proline content in the leaves of fragrant rice was shown in *Table 4*. For Meixiangzhan,

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the trend of proline contents was: DR = DC > WR = WC at tillering stage and booting stage. And the proline content in leaves had the same trend in late season. For Xiangyaxiangzhan, DR and DC treatments maximized the leaf proline content of this cultivar at four stages (except heading after 15 days) in the early season, and the trend in the late season was similar.

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Table 3. *Effects of transplanting conditions and water management on quality of fragrant rice*

Season	Cultivar	Treatment	Brown rice rate (%)	Milled rice rate (%)	Head rice rate (%)	Protein	Amylose	Akali	Chalkiness (%)	Chalky grain rate (%)	The ratio of length to width (%)
Early	*Meixiangzhan 2*	DR	74.19 ± 1.69a	61.09 ± 1.57a	55.76 ± 1.35ab	7.43 ± 0.05a	19.97 ± 0.69a	5.61 ± 0.08b	1.45 ± 0.11b	5.05 ± 1.13b	2.92 ± 0.19a
		DC	74.01 ± 0.49a	64.22 ± 0.87a	52.26 ± 1.14b	6.17 ± 0.09d	19.67 ± 0.12ab	5.53 ± 0.05bc	1.46 ± 0.03b	5.12 ± 2.29b	2.77 ± 0.05ab
		WR	76.16 ± 0.21a	63.52 ± 0.43a	57.98 ± 1.06a	6.87 ± 0.05b	18.60 ± 0.51b	5.90 ± 0.10a	2.39 ± 0.65a	5.63 ± 3.35a	2.66 ± 0.12b
		WC	75.71 ± 0.08a	66.05 ± 1.14a	57.23 ± 1.66a	6.37 ± 0.05c	19.80 ± 0.71a	5.37 ± 0.12c	1.58 ± 0.18b	5.17 ± 3.26ab	2.81 ± 0.11ab
	Xiangyaxiangzhan	DR	73.13 ± 0.09a	58.52 ± 1.85b	55.93 ± 1.19ab	7.33 ± 0.05a	17.30 ± 0.67a	5.73 ± 0.05a	1.06 ± 0.63ab	4.35 ± 3.22b	3.14 ± 0.21a
		DC	72.58 ± 0.42a	62.46 ± 0.24ab	54.63 ± 0.21ab	7.07 ± 0.05c	18.50 ± 1.28a	5.63 ± 0.05ab	2.08 ± 0.89a	5.66 ± 3.84a	3.03 ± 0.22a
		WR	72.49 ± 3.35a	63.25 ± 0.86a	56.52 ± 0.72a	7.17 ± 0.05bc	18.93 ± 0.05a	5.63 ± 0.05ab	0.75 ± 0.09b	3.69 ± 2.26c	2.84 ± 0.14a
		WC	72.94 ± 0.48a	61.88 ± 0.37ab	53.51 ± 0.46b	7.23 ± 0.05ab	17.10 ± 0.90a	5.60 ± 0.08b	1.49 ± 0.77ab	4.41 ± 3.13b	3.14 ± 0.15a
Late	*Meixiangzhan 2*	DR	76.76 ± 0.21a	67.48 ± 0.91a	65.22 ± 0.85a	8.27 ± 0.12a	19.13 ± 0.54a	6.67 ± 0.12a	0.61 ± 0.69c	3.12 ± 2.66b	2.67 ± 0.12a
		DC	76.66 ± 0.35a	65.62 ± 0.88a	62.19 ± 0.57b	7.97 ± 0.12b	19.07 ± 0.41a	6.72 ± 0.08a	0.78 ± 0.24b	3.37 ± 5.36b	2.74 ± 0.11a
		WR	76.58 ± 0.69a	65.56 ± 1.05a	63.24 ± 1.34ab	7.81 ± 0.08b	19.51 ± 0.43a	6.63 ± 0.12a	1.06 ± 0.68a	4.54 ± 5.21a	2.72 ± 0.09a
		WC	76.86 ± 0.11a	66.66 ± 0.48a	63.66 ± 0.48ab	8.41 ± 0.08a	18.77 ± 0.12a	6.73 ± 0.17a	0.79 ± 0.23b	3.41 ± 5.71b	2.71 ± 0.13a
	Xiangyaxiangzhan	DR	75.36 ± 0.37a	62.03 ± 0.54a	56.32 ± 0.21b	8.21 ± 0.08a	18.70 ± 0.08b	6.83 ± 0.12a	0.58 ± 0.48ab	4.13 ± 2.82a	2.67 ± 0.12a
		DC	74.91 ± 0.49a	62.65 ± 1.64a	55.06 ± 1.62b	7.97 ± 0.12ab	19.63 ± 0.05a	6.67 ± 0.12a	1.23 ± 0.66a	3.76 ± 2.87ab	2.77 ± 0.09a
		WR	75.05 ± 0.81a	63.76 ± 1.16a	59.57 ± 0.88a	7.92 ± 0.08b	18.92 ± 0.22b	6.67 ± 0.12a	0.16 ± 0.06b	3.59 ± 2.68b	2.81 ± 0.11a
		WC	75.55 ± 0.69a	64.51 ± 1.47a	59.84 ± 1.13a	7.97 ± 0.12ab	18.21 ± 0.36c	6.63 ± 0.12a	0.55 ± 0.11ab	3.45 ± 1.49b	2.92 ± 0.21a
Early	C		8.44**	9.75**	2.51	16.45**	20.61**	2.12	3.01	23.788**	15.98**
	T		2.04	1.79	14.68**	12.15**	4.53*	12.31**	0.92	6.99**	3.67*
	C*T		0.72	2.589	8.52**	15.73**	16.95**	10.12**	4.738*	19.58**	0.28
Late	C		11.18**	12.43**	35.46**	3.6	2.52	0.07	0.85	0.11	2.25
	T		0.74	1.22	7.27**	11.77**	5.47**	0.44	1.51	0.36	1.41
	C*T		0.17	2.29	9.38**	4.87*	2.91	0.81	1.69	1.38	0.63

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Table 4. *Effects of transplanting conditions and water management on proline content in leaves of fragrant rice (μg/g)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15 d
Early	*Meixiangzhan 2*	DR	38.11 ± 1.29a	41.81 ± 0.84a	31.77 ± 1.91b	20.49 ± 2.49a
		DC	40.33 ± 1.86a	52.43 ± 3.72a	28.71 ± 1.14b	12.76 ± 2.62bc
		WR	29.79 ± 1.63b	37.52 ± 7.22b	24.65 ± 1.26c	17.21 ± 1.62ab
		WC	30.79 ± 1.22b	34.07 ± 7.55b	40.35 ± 1.41a	11.83 ± 0.84c
	Xiangyaxiangzhan	DR	30.68 ± 2.88a	35.39 ± 3.54a	26.27 ± 1.38a	9.51 ± 1.06b
		DC	32.11 ± 4.66a	38.41 ± 4.18a	26.31 ± 1.72a	5.29 ± 0.51c
		WR	17.13 ± 5.21c	19.12 ± 7.48b	21.73 ± 2.07ab	14.71 ± 1.64a
		WC	21.22 ± 6.33b	24.01 ± 0.81b	19.43 ± 3.37b	3.01 ± 1.11c
Late	*Meixiangzhan 2*	DR	50.73 ± 4.66a	58.51 ± 3.66a	36.92 ± 0.61a	79.13 ± 2.68a
		DC	50.66 ± 2.54a	52.51 ± 1.33a	31.69 ± 1.33b	51.36 ± 3.49b
		WR	42.49 ± 1.33c	34.98 ± 1.92c	26.13 ± 2.57c	42.52 ± 1.43c
		WC	44.51 ± 3.05b	46.62 ± 4.39b	25.06 ± 4.13c	31.73 ± 0.82d
	Xiangyaxiangzhan	DR	53.54 ± 0.91a	38.84 ± 2.33a	20.48 ± 0.85a	33.48 ± 3.45a
		DC	40.97 ± 4.48b	22.67 ± 2.23b	14.35 ± 2.07b	20.98 ± 4.15bc
		WR	30.44 ± 1.02c	22.03 ± 0.77b	15.48 ± 2.41b	26.93 ± 4.54ab
		WC	36.09 ± 4.31b	18.52 ± 3.13b	12.76 ± 0.39b	20.43 ± 0.74c

As shown in *Table 5,* for Meixiangzhan 2, the trend of proline content in stem was similar to that in leaves in the early season. There was no remarkable difference among the four stages. But tillering stage, the content of proline in DR and DC treatments were significantly higher than in WR and WC treatments. For Xiangyaxiangzhan, the content of proline in DR and DC treatments were significantly higher than in WR and WC treatments among the four stages in the early season and the trend in the late season was similar.

Table 5. *Effects of transplanting conditions and water management on proline content in the stem of fragrant rice (μg/g)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	*Meixiangzhan 2*	DR	24.13 ± 4.02a	16.12 ± 2.09b	9.45 ± 0.42a	11.26 ± 0.99ab
		DC	15.99 ± 1.14b	21.36 ± 0.66a	8.45 ± 0.89bc	14.17 ± 3.70a
		WR	12.42 ± 1.37c	9.98 ± 0.71c	9.71 ± 1.22b	9.48 ± 1.02bc
		WC	12.65 ± 1.17c	13.12 ± 1.75bc	4.47 ± 0.40c	5.24 ± 0.70c
	Xiangyaxiangzhan	DR	15.09 ± 1.21a	11.83 ± 1.25a	3.68 ± 0.75a	5.59 ± 3.04a
		DC	16.28 ± 3.77a	11.25 ± 1.02a	2.98 ± 1.09a	4.03 ± 1.77ab
		WR	7.66 ± 1.66b	6.71 ± 1.97b	3.34 ± 1.14a	0.98 ± 0.34c
		WC	11.82 ± 2.3ab	3.44 ± 0.61c	3.31 ± 0.36a	2.53 ± 0.14b
Late	*Meixiangzhan 2*	DR	38.53 ± 4.44a	23.38 ± 1.46b	13.62 ± 1.05a	19.86 ± 3.82b
		DC	33.23 ± 3.57a	24.71 ± 3.6ab	14.58 ± 2.16a	26.91 ± 2.20a
		WR	23.31 ± 1.63b	23.62 ± 4.15b	16.30 ± 1.20a	13.40 ± 2.77c
		WC	27.59 ± 2.98b	29.94 ± 2.67a	16.82 ± 3.45a	24.31 ± 2.49ab
	Xiangyaxiangzhan	DR	25.49 ± 3.91a	18.91 ± 3.11a	11.14 ± 2.42a	15.84 ± 1.44a
		DC	19.39 ± 2.37b	6.57 ± 2.66bc	7.08 ± 3.27ab	10.36 ± 1.32b
		WR	14.83 ± 2.11c	7.18 ± 1.33b	5.52 ± 1.27b	5.02 ± 1.79c
		WC	18.55 ± 2.05b	3.05 ± 0.56c	4.11 ± 0.85b	3.30 ± 2.38c

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Ornithine aminotransferase activities

As shown in *Table 6*, for Meixiangzhan 2, the highest Ornithine aminotransferase (OAT) activity was recorded in DC treatment from heading stage to 15 days after heading (except WC treatment at heading stage) in the early season. OAT activity in the leaves of this cultivar under WR treatment was the highest at four stages (except heading stage) in the late season. For Xiangyaxiangzhan, compared with C treatments, R treatments enhanced OAT activity in leaves from tillering stage to booting stage.

Table 6. *Effects of transplanting conditions and water management on OAT activity in the leaves of fragrant rice (U·g-1·min-1·FW)*

Season	Cultivar	Treatments	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	Meixiangzhan 2	DR	115.77 ± 3.66a	114.58 ± 4.75a	71.72 ± 1.43b	81.23 ± 8.83ab
		DC	113.87 ± 3.44a	110.96 ± 1.12a	76.05 ± 1.63a	89.07 ± 7.66a
		WR	111.29 ± 1.04a	114.87 ± 3.77a	71.78 ± 1.15b	74.70 ± 1.76b
		WC	110.69 ± 4.64a	110.63 ± 1.53a	74.88 ± 0.87a	73.41 ± 1.40b
	Xiangyaxiangzhan	DR	113.31 ± 4.12a	110.72 ± 2.04a	73.16 ± 0.69b	75.82 ± 2.83a
		DC	112.23 ± 3.13ab	107.47 ± 7.87b	74.66 ± 0.97b	73.52 ± 2.64a
		WR	111.59 ± 2.00ab	112.08 ± 1.73a	74.35 ± 2.18b	74.26 ± 2.64a
		WC	105.34 ± 3.82b	113.27 ± 1.71a	85.62 ± 12.20a	73.57 ± 0.70a
Late	Meixiangzhan 2	DR	97.97 ± 0.99b	94.39 ± 1.30a	87.90 ± 1.70a	82.99 ± 1.39a
		DC	94.47 ± 0.58c	88.98 ± 3.10b	86.25 ± 0.98a	82.56 ± 1.60a
		WR	101.20 ± 1.28a	94.47 ± 2.91a	85.64 ± 2.35a	83.33 ± 2.85a
		WC	94.51 ± 0.92c	86.21 ± 2.79b	84.25 ± 4.73a	82.33 ± 0.84a
	Xiangyaxiangzhan	DR	96.53 ± 2.22a	89.12 ± 1.01ab	82.72 ± 2.12a	81.90 ± 2.21ab
		DC	102.07 ± 4.53a	87.83 ± 1.46b	83.65 ± 4.94a	86.33 ± 1.30a
		WR	99.25 ± 2.51a	87.86 ± 3.03b	85.35 ± 1.82a	84.02 ± 2.6ab
		WC	97.03 ± 1.78a	92.71 ± 2.51a	83.32 ± 4.52a	81.04 ± 3.32b

As shown in *Table 7*, for Meixiangzhan 2, the highest OAT activity in stems was recorded under the WC treatment at tillering stage and full heading stage in the early season, and the stems of OAT activity under DC treatment was the highest in the late season except for booting stage and 15 days after heading. For Xiangyaxiangzhan, the trend of OAT activity in the early season was the same as that of Meixiangzhan 2, and the OAT activity was highest under WC treatment at 15 days after heading in the late season.

Pyrroline-5-carboxylic acid content

As shown in *Table 8*, for Meixiangzhan 2, the highest content of Pyrroline-5-carboxylic acid (P5C) in leaves was recorded under the WR treatment at four stages of the early season (except heading after 15 days). Compared with WC and DC treatments, DR and WR treatments could significantly increase the content of P5C in leaves of this cultivar in the late season. For Xiangyaxiangzhan, in the early season, compared with WC and DC treatments, WR and DR treatments could increase P5C content at tillering stage and booting stage, and P5C content under WR treatment was significantly higher than that of other treatments (except WC treatment) at tillering stage in the late season. There was no significant difference among the treatments in the other three periods.

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Table 7. *Effects of transplanting conditions and water management on OAT activity in the stem of fragrant rice (U·g-1·min-1·FW)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	*Meixiangzhan 2*	DR	110.21 ± 0.73b	113.11 ± 3.75a	72.69 ± 2.95a	74.29 ± 2.01a
		DC	109.94 ± 2.83b	114.05 ± 3.36a	71.63 ± 1.54ab	73.51 ± 0.41a
		WR	112.20 ± 4.58ab	108.65 ± 0.76b	70.61 ± 0.67b	72.66 ± 1.03a
		WC	115.59 ± 0.71a	112.80 ± 1.25a	74.38 ± 1.41a	73.13 ± 2.70a
	Xiangyaxiangzhan	DR	111.18 ± 0.68a	113.62 ± 3.37a	71.47 ± 0.72b	73.53 ± 2.06b
		DC	109.81 ± 1.40a	110.13 ± 4.57b	71.27 ± 2.81b	76.05 ± 1.55a
		WR	110.02 ± 3.26a	114.86 ± 1.41a	70.23 ± 0.72b	73.51 ± 2.53b
		WC	112.61 ± 5.26a	113.46 ± 4.20a	74.03 ± 1.69a	73.93 ± 2.54ab
Late	*Meixiangzhan 2*	DR	80.74 ± 3.11b	87.19 ± 2.25a	90.44 ± 4.38a	93.27 ± 4.02a
		DC	83.65 ± 2.36a	83.01 ± 2.68b	91.07 ± 4.02a	88.59 ± 0.81b
		WR	82.31 ± 4.19a	84.96 ± 3.00b	89.79 ± 3.02a	91.47 ± 2.88a
		WC	82.38 ± 3.18a	84.30 ± 3.20b	88.63 ± 3.82a	92.87 ± 4.17a
	Xiangyaxiangzhan	DR	80.98 ± 3.64a	80.53 ± 3.43b	88.67 ± 0.70a	89.47 ± 4.68ab
		DC	79.52 ± 4.62a	85.17 ± 3.35a	87.47 ± 2.26a	88.26 ± 3.66ab
		WR	82.86 ± 2.95a	86.43 ± 2.52a	86.42 ± 2.45a	87.77 ± 4.90b
		WC	83.31 ± 2.50a	81.31 ± 3.57b	88.30 ± 1.36a	93.16 ± 1.84a

Table 8. *Effects of transplanting conditions and water management on the content of P5C in the leaves of fragrant rice (u mol/g·FW)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	*Meixiangzhan 2*	DR	1.48 ± 0.02b	1.70 ± 0.06a	1.96 ± 0.01ab	2.09 ± 0.10ab
		DC	1.44 ± 0.15b	1.55 ± 0.08b	2.04 ± 0.04ab	2.23 ± 0.11a
		WR	1.52 ± 0.02a	1.71 ± 0.10a	2.07 ± 0.08a	2.20 ± 0.05a
		WC	1.58 ± 0.04a	1.58 ± 0.05b	1.95 ± 0.01b	1.97 ± 0.01b
	Xiangyaxiangzhan	DR	1.65 ± 0.02ab	1.56 ± 0.02a	1.68 ± 0.02b	2.21 ± 0.06a
		DC	1.42 ± 0.07b	1.42 ± 0.04b	1.63 ± 0.01b	2.12 ± 0.09a
		WR	1.72 ± 0.05a	1.54 ± 0.02a	1.69 ± 0.01b	1.72 ± 0.02c
		WC	1.47 ± 0.19b	1.48 ± 0.03b	1.75 ± 0.04a	1.92 ± 0.09b
Late	*Meixiangzhan 2*	DR	1.80 ± 0.02a	2.24 ± 0.04a	2.12 ± 0.06b	2.84 ± 0.12a
		DC	1.66 ± 0.08a	2.15 ± 0.06a	2.30 ± 0.1ab	2.86 ± 0.17a
		WR	1.72 ± 0.04a	2.23 ± 0.14a	2.38 ± 0.13a	2.57 ± 0.17b
		WC	1.63 ± 0.26a	2.20 ± 0.15a	2.15 ± 0.11b	2.38 ± 0.05b
	Xiangyaxiangzhan	DR	1.71 ± 0.06b	2.07 ± 0.06a	2.08 ± 0.08a	2.68 ± 0.23a
		DC	1.67 ± 0.04b	1.99 ± 0.06a	2.11 ± 0.05a	2.43 ± 0.37a
		WR	1.84 ± 0.06b	2.07 ± 0.07a	2.22 ± 0.09a	2.55 ± 0.19a
		WC	1.87 ± 0.09a	2.07 ± 0.11a	2.16 ± 0.08a	2.55 ± 0.06a

As shown in *Table 9*, for Meixiangzhan 2, the content of P5C in the stem of Meixiangzhan 2 was the highest under WC treatment at four stages in the early season, and the highest content of P5C in the stem of this cultivar was recorded in WR treatment at tillering stage and 15 days after heading in the late season. For Xiangyaxiangzhan, there is no significant difference among the four treatments in the early season, but the content of P5C in WC treatment is the highest at tillering stage and heading stage.

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Table 9. *Effects of transplanting conditions and water management on the content of P5C in the stem of fragrant rice (umol/g·FW)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	*Meixiangzhan 2*	DR	1.01 ± 0.09a	1.15 ± 0.01b	1.19 ± 0.01b	1.21 ± 0.02b
		DC	1.01 ± 0.02a	1.14 ± 0.01bc	1.27 ± 0.02a	1.29 ± 0.02a
		WR	1.03 ± 0.03a	1.12 ± 0.01c	1.21 ± 0.02b	1.32 ± 0.05a
		WC	1.08 ± 0.05a	1.18 ± 0.01a	1.32 ± 0.03a	1.28 ± 0.02a
	Xiangyaxiangzhan	DR	1.01 ± 0.02a	1.13 ± 0.02a	1.26 ± 0.09a	1.20 ± 0.03a
		DC	1.01 ± 0.07a	1.14 ± 0.01a	1.21 ± 0.06a	1.17 ± 0.03a
		WR	0.98 ± 0.01a	1.17 ± 0.01a	1.18 ± 0.03b	1.17 ± 0.02a
		WC	1.08 ± 0.03a	1.14 ± 0.04a	1.20 ± 0.03a	1.15 ± 0.01a
Late	*Meixiangzhan 2*	DR	1.42 ± 0.05b	1.19 ± 0.03a	1.44 ± 0.05a	1.46 ± 0.06b
		DC	1.18 ± 0.03c	1.26 ± 0.06a	1.36 ± 0.08a	1.58 ± 0.04a
		WR	1.73 ± 0.04a	1.27 ± 0.08a	1.39 ± 0.04a	1.65 ± 0.05a
		WC	1.39 ± 0.05b	1.18 ± 0.01a	1.42 ± 0.08a	1.59 ± 0.08a
	Xiangyaxiangzhan	DR	1.39 ± 0.19b	1.16 ± 0.05b	1.27 ± 0.02b	1.48 ± 0.01b
		DC	1.57 ± 0.06b	1.24 ± 0.02a	1.30 ± 0.01b	1.70 ± 0.08a
		WR	1.41 ± 0.06b	1.20 ± 0.04ab	1.23 ± 0.01c	1.56 ± 0.10b
		WC	1.89 ± 0.14a	1.22 ± 0.04ab	1.36 ± 0.02a	1.43 ± 0.07b

Methylglyoxal content

As shown in *Table 10*, for Meixiangzhan 2, the methylglyoxal content in the leaves of this cultivar under DC treatment was the highest at booting stage in the early season, and there was no significant difference in methylglyoxal content among the treatments except for DR treatment at full heading stage. From tillering stage to heading stage in the late season, WR treatment maximized content of methylglyoxal in leaves of this cultivar. For Xiangyaxiangzhan, in the tillering stage of the early season, the content of methylglyoxal was the highest recorded under the WR treatment.

Table 10. *Effects of transplanting conditions and water management on methylglyoxal in the leaves of fragrant rice (μmol/g·FW)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	*Meixiangzhan 2*	DR	21.24 ± 0.37c	21.15 ± 0.73b	23.54 ± 0.45b	24.17 ± 1.54a
		DC	25.09 ± 0.43a	21.95 ± 0.75b	28.12 ± 1.74a	22.25 ± 0.89a
		WR	23.76 ± 0.40b	20.60 ± 0.34b	26.27 ± 0.37a	22.26 ± 2.33a
		WC	21.74 ± 0.39c	24.53 ± 0.72a	26.13 ± 0.71a	21.43 ± 0.27a
	Xiangyaxiangzhan	DR	24.50 ± 2.23b	22.42 ± 0.20a	22.08 ± 0.93a	21.53 ± 1.04a
		DC	27.64 ± 2.21ab	19.90 ± 0.56b	22.05 ± 1.51a	22.21 ± 1.10a
		WR	30.76 ± 1.42a	21.44 ± 1.05a	22.10 ± 1.09a	17.64 ± 1.17b
		WC	26.15 ± 0.56b	21.66 ± 0.56a	22.79 ± 1.75a	20.13 ± 0.76a
Late	*Meixiangzhan 2*	DR	23.39 ± 0.44bc	21.66 ± 0.60b	24.63 ± 0.90a	31.02 ± 1.92a
		DC	22.40 ± 2.19c	19.92 ± 1.30b	24.81 ± 0.39a	28.23 ± 1.78a
		WR	26.01 ± 0.93a	23.85 ± 1.40a	26.01 ± 1.02a	28.24 ± 0.17a
		WC	25.59 ± 1.02ab	21.22 ± 1.11b	22.26 ± 1.22b	28.38 ± 1.48a
	Xiangyaxiangzhan	DR	24.98 ± 0.37ab	24.34 ± 0.79a	25.94 ± 0.74b	26.95 ± 0.66a
		DC	23.83 ± 0.32b	21.22 ± 1.40b	26.48 ± 0.33ab	26.87 ± 1.87a
		WR	25.55 ± 0.77a	21.62 ± 1.29b	25.57 ± 1.17b	27.65 ± 2.08a
		WC	25.83 ± 1.13a	24.45 ± 2.98a	27.43 ± 0.55a	26.93 ± 0.64a

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As shown in *Table 11*, for Meixiangzhan 2, the highest content of methylglyoxal in the stem was recorded under the DR treatment at 15 days after heading in the early season. For Xiangyaxiangzhan, there were no remarkable trends in the early season. And in the late season, the content of methylglyoxal trend was: DR = WR > WC > DC.

Table 11. *Effects of transplanting conditions and water management on methylglyoxal in the stem of fragrant rice (mol/g·FW)*

Season	Cultivar	Treatment	Tillering stage	Booting stage	Heading stage	Heading after 15d
Early	*Meixiangzhan 2*	DR	14.40 ± 0.61a	14.46 ± 0.24a	12.64 ± 0.52ab	16.77 ± 0.33a
		DC	14.37 ± 0.34a	14.96 ± 0.50a	12.13 ± 0.23b	15.67 ± 0.08ab
		WR	14.45 ± 0.34a	14.74 ± 0.69a	11.93 ± 0.01b	14.81 ± 0.35b
		WC	14.60 ± 0.50a	15.23 ± 0.28a	13.08 ± 0.51a	14.73 ± 1.20b
	Xiangyaxiangzhan	DR	13.14 ± 0.52a	12.44 ± 0.04a	11.81 ± 0.28ab	14.39 ± 0.53b
		DC	13.38 ± 0.88a	13.23 ± 1.27a	12.28 ± 0.55a	15.74 ± 0.10a
		WR	13.11 ± 0.24a	13.94 ± 0.60a	11.75 ± 0.49ab	14.95 ± 0.8ab
		WC	13.06 ± 0.64a	13.73 ± 1.29a	10.33 ± 1.49b	15.85 ± 0.42a
Late	*Meixiangzhan 2*	DR	13.95 ± 0.65ab	11.29 ± 1.16b	13.18 ± 0.58ab	14.63 ± 0.18a
		DC	13.17 ± 0.60b	12.75 ± 0.41a	12.03 ± 0.73b	15.27 ± 0.33a
		WR	13.51 ± 0.33ab	13.63 ± 0.8a	13.91 ± 0.51a	14.86 ± 0.71a
		WC	14.28 ± 0.44a	12.97 ± 0.36a	12.41 ± 1.36ab	15.31 ± 0.88a
	Xiangyaxiangzhan	DR	13.25 ± 0.44a	13.01 ± 0.22a	12.54 ± 1.54a	15.79 ± 0.73b
		DC	12.66 ± 0.54ab	13.03 ± 0.30a	12.78 ± 0.22a	16.78 ± 0.35a
		WR	13.13 ± 0.30a	13.55 ± 0.89a	12.45 ± 0.51a	16.21 ± 0.60ab
		WC	11.95 ± 0.13b	13.81 ± 0.07a	12.57 ± 0.17a	16.15 ± 0.08ab

2-acetyl-1-pyrroline content in grains

As shown in *Table 12*, for *Meixiangzhan 2*, at the mature stage of the early season, the trend of 2-Acetyl-1-Pyrroline (2-AP) content was: WR = DR > WC > DC. But at the mature stage of late season the trend of 2-AP was: WC > WR = DC > DR. For *Xiangyaxiangzhan*, the trend of grain aroma content in mature stage was consistent with that of *Meixiangzhan 2*, and compared with C treatments, the average aroma content of R treatments was increased by 5.24% in the early season, and the highest aroma at mature stage was recorded under the WR treatment in the late season.

Discussion

Various yield components act comprehensively and coordinate with each other to form the yield of rice. Water management, as an important measure to increase yield, has been concerned by predecessors. With the decrease of irrigation water, the number of effective panicles of direct seeding rice increased at first and then decreased (Wu et al., 2019). Water-saving irrigation could increase the number of tillers in the middle and early stage, also it increased the number of effective tillers in the later stage as well as the panicle rate of tillers (Zhao et al., 2018). Light dry-wet alternative irrigation can effectively control ineffective tillers, and significantly increased panicle rate (Zhao et al., 2015). The results showed that the fertile panicle number of the two fragrant rice had no significant difference between WR and WC treatment, but were higher than DR and DC treatments which prove that water-saving irrigation maybe not only saving the resource but also can enhance or keep the fertile panicle number. Under the condition of

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alternating dry and wet irrigation, it was helpful to the construction of high yield population, the coordination of nitrogen accumulation and distribution of rice plant (Peng, 2014). The results showed that the highest grain count per panicle, seed setting rate and 1000-grain weight of two fragrant rice cultivars were recorded in WR treatment (except WC treatment) which means that WR treatment was more beneficial to the export and accumulation of assimilates during rice growth, and made the yield composition more reasonable. On the other hand, compared to conventional irrigation treatment in WC treatment no extra water was applied in the rice production, thus WR treatment is beneficial to water conservation. We observed that there was no significant difference between WR and WC treatment of average yield in both seasons. Thus, WR treatment could be a water-saving cultivation.

Table 12. *Effects of transplanting conditions and water management on the aroma (2-AP) content of fragrant rice seeds*

Season	Cultivar	Treatment	HA 15d	Maturity stage
Early	*Meixiangzhan 2*	DR	258.44 ± 5.77bc	252.02 ± 5.4a
		DC	251.39 ± 8.02c	169.60 ± 5.00c
		WR	298.40 ± 5.79a	252.10 ± 8.88a
		WC	280.62 ± 8.24ab	230.56 ± 5.85b
	Xiangyaxiangzhan	DR	152.77 ± 4.19d	307.08 ± 16.72a
		DC	175.20 ± 15.13c	245.19 ± 4.49b
		WR	246.21 ± 7.50b	301.06 ± 15.65a
		WC	276.11 ± 3.65a	286.36 ± 12.95ab
Late	*Meixiangzhan 2*	DR	264.83 ± 11.09b	140.65 ± 6.85c
		DC	141.07 ± 8.46c	174.52 ± 10.54b
		WR	300.29 ± 14.30ab	181.79 ± 9.61b
		WC	349.02 ± 25.49a	235.11 ± 11.17a
	Xiangyaxiangzhan	DR	252.17 ± 4.39c	135.59 ± 5.43c
		DC	254.88 ± 5.13c	232.88 ± 14.71b
		WR	313.17 ± 10.93b	265.59 ± 8.48a
		WC	363.78 ± 22.33a	232.03 ± 3.27b

Water stress at different stages had significant effects on the quality of rice, such as chalky grain rate, protein content and fat content. Water stress treatment from flowering to 15 days after anthesis significantly reduced the head rice rate of rice, but had relatively little effect on other quality factors (Zheng et al., 2017). The results showed that there was no significant difference in brown rice rate and milled rice rate between the two fragrant rice cultivars under different treatments, while the highest head rice rate was recorded in R treatments which proved that the processing quality of rice could be improved under this treatment. The milled rice rate and head rice rate were maximized in WR treatment, also minimized in chalkiness and chalky grain rate in all except WC treatments in the early season of Xiangyaxiangzhan, and the four treatments had little effect on the length-width ratio of the two fragrant rice cultivars.

As the aroma characteristic substance, 2-acetyl-1-pyrroline (2-AP) of fragrant rice can form pyrroline-5-carboxylic acid by proline as nitrogen source and catalyzed by proline oxidase. Ornithine aminotransferase can also catalyze ornithine to form

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pyrroline 5-carboxylic acid, decarboxylate to form 1-pyrroline, and finally combine with acetyl CoA. Under the action of pyrroline acetyltransferase to form the aroma of 2-acetyl-1-pyrroline (Yoshihashi et al., 2002). This study showed that compared with other treatments, WR treatment increased P5C content in both early and late seasons, and the content of 2-AP in grains of two fragrant rice cultivars treated with WR was enhanced, indicating that WR treatment had the effect of increasing aroma.

Conclusions

The average yield of WR treatment was similar to WC treatment, since the varieties and the treatments did not influence the yield significantly. Furthermore, WR treatment had the highest milled rice rate and head rice rate and the lowest chalkiness and chalky grain rate all except WC treatments in the early season. WR treatment increased P5C content of two fragrant rice cultivars in both early and late seasons, and the content of 2-AP in grains of two fragrant rice cultivars under WR treatment was enhanced. Hence, WR treatment had the effect of increasing aroma. In conclusion, WR treatment could be a water-saving cultivation, and the optimum treatment for increasing yield and improving quality, also it increases the aroma of fragrant rice grains. Although, further research is required at molecular and physiological level.

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APPENDIX

Instruments used to measure the content of aroma in fragrant rice

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