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Effects of Different Variety and Phosphorus Fertilizer Applications on Grain Starch Characteristics and Nutrient Composition of Winter Wheat (*Triticum aestivum* L.) in Shanxi Province Taigu China

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Abstract Wheat (*Triticum aestivum* L.). It plays an important role in ensuring food security and improving people's living standards in China. Few studies have been conducted on how to get high yield and efficient resource use efficiency simultaneously Therefore, field experiment with treatments using three varieties, Yangnong-1212 (YN1212), Shannong-29 (SN-29), Jimai-44 (JM-44) and three phosphorus (P) application rates (0, 150, and 300 kg ha−1, represented as P0, P150, and P300, respectively) were conducted from 2019 to 2020. The results showed that the yield with P application had an increase by 2.0%–4.8% compared to P0 treatment, however, there was no significant increase with further increase in P application. Grain yield was 33.6% and 14.1% higher in YN-1212 than that in SN-29 and JM-44, respectively. The longer growth duration, higher leaf area index at anthesis and stronger P uptake capacity led to higher dry matter accumulation for YN-1212. Higher dry matter production of YN-1212 was attributed to increased pre-anthesis dry weight and post-anthesis dry weight. YN-1212 had higher P use efficiency for grain production than SN-29 by 25.0% and JM-44 by 6.7%, respectively. Higher total P quantity of YN-1212 was observed than that in SN-29 and JM-44, which was due to higher pre-anthesis P uptake and post-anthesis P uptake. Therefore, YN-1212 could exhibited both high PUE and grain yield simultaneously with P application of 150 kg ha^{-1} in Middle Shanxi, China.

Keywords: *amylopectin content, albumin, globulin, protein, wheat*

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1. Introduction

Wheat is a staple food for approximately 30% of the world population [1]. Keeping a continuing increase in wheat production is essential to sustain the food supply needed for the growing population [2]. The largest producer of wheat in the world is China. The top wheat production regions in China are located in The North China (NCP), accounting for 25% of Chinese food production [3]. It has been suggested that most of increase in wheat production only come from the existing farmland [4]. Because the area of arable land used for wheat planting is hard to expand [5]. Thus, how to increase wheat production will have an important influence on food security for the world and China.

Phosphorus (P) is one of the indispensable nutrients for growth and production of wheat crops [6]. However, P deficiency in soil restricts wheat yields worldwide [7]. To alleviate the lack of P in soil required in wheat production, a large increase in P fertilizer input is required to increase agricultural production, particularly in China [8]. While, only part of P fertilizer is uptaken and utilized by wheat plants. The efficiency of P use (PUE) in wheat production is, however, only about 10-25 % of applied P [9]. That a large amount of P is lost from agricultural fields. Most of the applied P is fixed in soil or lost through gaseous plant emission and leaching [10,11]. Furthermore, excessive P input also leads to overexploitation in global phosphate rock, which may be completely depleted after 50 years [12]. Therefore, it is widely recognized that enhancing PUE is an important issue for sustainable agricultural development [6,13]. The PUE can be enhanced by the improvement of P management strategies [14]. Other effective approach is to breed new varieties that achieve both high yield and high PUE [15]. Previous studies demonstrated that different wheat varieties differ in total P accumulation and PUE in low P-supply environments, and high PUE varieties had higher total P accumulation and PUE low. Other studies also indicated that there were significant differences in PUE of wheat regardless of P fertilizer application, and the differences of varieties were more obvious under low and high P-supply environments [16,17]. Thus, it has great significance for the sustainable development of current agriculture to explore and utilize the genetic potential of crops, improve the nutritional traits of current wheat varieties, and screen varieties with higher utilization efficiency of nutrient resources. Middle Shanxi is located in the Starch Characteristic. The main objectives of this study were to (1) clarify the effects of P fertilizer application rate under different variety on population development and yield formation, and (2) determine high-yielding varieties whether could help improve both yield and starch characteristic simultaneously.

2. Materials and Methods

2.1. Site description

Field experiment was conducted at the wheat agriculture station of Shanxi Agricultural University (37°26′N, 112°32′E), Taigu County, Shanxi Province, China in 2019-2020. This site has a typical, semi-arid, warm temperature and continental monsoon climate (Köppen classification) with an average precipitation of 185.5 mm, average daily temperature of 8.0°C, and 3185.5 MJ m^{-2} of total solar radiation during the wheat growing season (from mid–October to early June) from 2006 to 2016. Soil samples from 0–20 cm layer were randomly collected with six replicates for soil analysis in 2019. The soil type at the field experimental site was classified as clay loam (Typic Hapli-Udic Agrosols) with a pH of 8.51, organic matter of 12.95 g kg^{-1}, total N of 1.02 g kg^{-1}, alkaline N of 37.06 mg kg^{-1}, Olsen P of 9.63 mg kg^{-1}, and available K of 150.17 mg kg^{-1}.The cropping pattern at the field experimental site is a winter wheat–summer maize double–cropping system. The climate parameters including daily minimum temperature, maximum temperature, solar radiation, and precipitation were collected from a weather station (Watchdog 2000 Series, Spectrum Technologies Inc, Aurora, USA), approximately 100–meters from the experimental field.

2.1.1. Experimental Design and Crop Management

The experiment was arranged in a split-plot design with the variety as the main plot and P application rate as a subplot with three replicates. Three varieties, Yannong1212 (YN1212), Jimai44 (JM44) and Shanong29 (SN29), and three P application rates, 0 kg ha^{-1}, 150 kg ha^{-1}, 300 kg ha^{-1} (represented as P0, P150, and P300, respectively) were applied in this study. YN1212 was approved by National Crop Variety Approval Committee in 2020 (Ministry of agriculture and rural development of the People's Republic of China, 2020), which has high yield potential good grain quality. Jimai44 and Shanong29 have been widely grown in the NCP because of their high yield, and good grain quality. Each subplot was 5 m in length and 3.5 m in width with a 1.0 m buffer zone between subplot s to minimize the effects of adjacent subplots. Wheat seeds were planted on 25th September, 2019, with a plant density at the three-leaf stage (Zadoks code 13) of 300 plants m^{-2}.N fertilizer was applied as urea (46% N), with 120 kg N ha^{-1} being applied before sowing, and 80 kg N ha^{-1} as topdressing fertilizer during jointing (Zadoks code 32); P fertilizer was applied as urea calcium super-phosphate (16% P_2O_5) and 90 kg K_2O ha^{-1} in the form of potassium chloride (52% K_2O) were applied before sowing. Experimental plots were irrigated with 60mm (1.05 m^3/plot) of water each in the wintering (Zadoks code 26), jointing (Zadoks code 32), and anthesis (Zadoks code 65). Irrigation water was supplied by a movable sprinkler system using a flow meter to measure the amount of water applied. The field was kept free of pests and diseases using pesticides 2 or 3 times in experimental year.

2.1.2. Sampling and Measurements

The wheat plants in the central row of 1m length were selected to record the stem number (sum of main stems and tillers) at jointing. The maximum stems number at jointing was defined as the highest value across the growing season. The productive stem percentage was calculated as the ratio of ear number to the maximum stems number.

The samples of wheat plants were selected in a row of 0.5 m length at anthesis and maturity (Zadoks code 91). At anthesis, the green leaf area of wheat plants was measured using a leaf area meter (LI–3000C, LI–COR, Lincoln, NE, USA) to calculate the leaf area index. All samples were then divided into vegetative parts (leaves, stems plus sheaths) and ear. At maturity, the samples were divided into straw (sheaths, stems, leaves, rachis plus chaff) and grain after counting the ear number.

All samples at anthesis and maturity were oven–dried for 30 min at 105°C and then at 70°C for 48 h to constant weight to determine the aboveground total dry weight. The 1000-grain weight and grain number per ear were calculated using the grain samples above. At maturity, a 5 m^2 random samples were harvested to estimate grain yield (adjusted to moisture content of 0.125 g H_2O g^{-1} fresh weight). Grain moisture content was measured with a digital moisture tester (PM8188A, Kett Electric Laboratory, Tokyo, Japan). All the oven–dried samples were were finally pulverized in anball mill (Jxfstprp-32F, Jingxin Co Ltd, Shanghai, China) for P concentration measurement.

$$Post-anthesis\ dry\ matter\ production\ \left(DM_{post},\ t\ ha^{-1}\right)$$
$$= total\ dry\ weight\ at\ maturity - total\ dry\ weight\ at\ anthesis$$
$$Harvest\ index\ (\%)$$
$$= grain\ yield\ /\ total\ dry\ weight\ at\ maturity$$
$$Post-anthesis\ accumulated\ P\ \left(Ppost,\ kg\ ha^{-1}\right)$$
$$=\ TP - TPas$$
$$P\ harvest\ index\ (PHI,\ \%) = GP / TP$$

Where TP (kg ha^{-1}) and TP_{as} (kg ha^{-1}) are the total P quantity at maturity and anthesis, respectively. GN (kg ha^{-1}) is grain P content.
Phosphorus use efficiency for grain production (PUEg, kg where P_f is the total input of P fertilizer (kg ha^{-1}).

2.1.3. Statistical Analysis

Analysis of variance was performed using Statistix 8.0 (Analytical Software, Tallahassee, FL, USA), and the means of treatments were compared based on the Tukey's honestly significant difference (HSD) test at the 0.05 probability level. Figures were created using Origin Lab pro 2021b (OriginLab Corporation, Northampton, MA, USA).

3. Results

3.1. Effects of Variety and Phosphorus Application Amount on Starch Characteristics

The variety and phosphorus application had significant effects on the contents of total starch and amylopectin in grains, but there was no significant interaction between them (Table 1). Compared to JM-44 and YN1212, the total starch content of SN-29 was increased by 3.9% and 2.6% on average (P<0.05), and the amylopectin content was increased by 3.2%, and 2.3% on average (P<0.05), respectively. The amount of phosphorus application had a significant effect on amylose content, but the variety had no significant effect, and there was no significant interaction between the two. The contents of total starch, amylose and amylopectin without phosphorus application were significantly higher than those of 300 kg phosphorus ha^{-1} treatment, but there was no significant difference between the above three indexes of 150 kg phosphorus ha^{-1} treatment and other treatments. The ratio of amylose to amylopectin was significantly affected variety and phosphorus application amount, and there was a significant interaction between the two. The direct support ratio of JM-44 was significantly higher than that of SN-29, and YN-1212. For SN-29, phosphorus application significantly reduced the direct branching ratio compared with no phosphorus application, but there was no significant difference in direct branching ratio under different phosphorus application levels. For JM-44, there was no significant difference in the direct branch ratio between the treatment of 150 kg ha^{-1} and no phosphorus application, but the direct branch ratio decreased significantly when the phosphorus application rate reached 300 kg ha^{-1}. YN-1212, there was no significant difference in starch direct branch ratio among the three phosphorus treatments.

3.2. Effects of Variety and Phosphorus Application Amount on Nutrient Quality

The Variety had a significant effect on albumin and globulin contents, while phosphorus application had no significant effect on them, and there was no significant interaction between them (Table 2). The albumin content of JM-44 and YN-1212 was 28.3% and 21.5% higher than that of SN-29, respectively. The globulin content of JM-44 and YN-1212 was 20.2%, and 19.1% higher than that of SN-29, respectively.

3.3. Effects of Variety and phosphorus Application Amount on Processing Quality

Variety and phosphorus application had significant effects on the content of glycolin and gluten, but there was no significant interaction between them. The content of glycolin among the three varieties was JM-44, YN-1212, SN-29, and the difference among the three treatments was significant (Table 3). The gluten content of JM-44 and YN1212 was 18.7% and 16.5% higher than that of SN-29, respectively (P<0.05). For the three cultivars, phosphorus application could increase the contents of glycine and gluten by 3.6-9.6%, and 9.7%-14.3%, respectively (P<0.05), but there was no significant difference in the contents of glycine and gluten between 150 kg ha-1 and 300 kg ha-1 treatments. Variety and phosphorus application had significant effects on total protein content, but there was no significant interaction between them. The total protein content of the three varieties was JM-44, YN-1212, SN-29, and the difference among the three treatments was significant. For the three varieties, phosphorus application could increase the total protein content by 4.2%-8.2% (P<0.05). The difference in total protein content was mainly due to changes in the content of glycolin and gluten, rather than albumin and globulin.

Table 1. Grain starch characteristic of the experimental varieties at different P_2O_5 rate

Variety	P_2O_5 rate kg ha^{-1}	Total starch content %	Amylose content %	Amylopectin content %	Ratio of amylose to amylopectin
SN29	0	76.85 a	8.88 a	67.97 a	0.136 a
	150	75.11 ab	8.36 ab	66.75 ab	0.126 b
	300	74.04 b	7.76 a	66.28 a	0.127 b
	Mean	**75.33 A**	**8.33 A**	**67.00 A**	**0.130 B**
JM44	0	73.58 a	8.01 a	65.57 a	0.139 a
	150	72.69 ab	7.61 ab	65.08 ab	0.143 a
	300	71.22 b	7.12 b	64.10 b	0.131 b
	Mean	**72.50 B**	**7.58 A**	**64.92 B**	**0.138 A**
YN1212	0	74.57 a	8.49 a	66.08 a	0.129 a
	150	73.37 ab	7.89 ab	65.48 ab	0.127 a
	300	72.35 b	7.49 b	64.86 b	0.125 a
	Mean	**73.43 B**	**7.96 A**	**65.47 B**	**0.127 B**
ANOVA					
Variety (V)		**	ns	*	*
Phosphate (P)		*	**	*	*
V×P		ns	ns	ns	**

Within a column for each variety, means followed by different lower-case letters are significantly different according to Tukey's HSD test (0.05). Within a column, upper-case letters indicate comparisons among three varieties. * and **, significant at 0.01 and 0.05 probability levels, respectively; ns, indicates not significant at 0.05 probability level.

Table 2. Grain nutritional quality of the experimental varieties at different P_2O_5 rate

Variety	P_2O_5 rate kg ha^{-1}	Albumin %	Globulin %	Gliadin %	Glutenin %	Total protein %
SN29	0	2.21 a	1.86 a	4.96 b	2.99 a	12.02 b
	150	2.24 a	1.89 a	5.24 a	3.35 b	12.72 a
	300	2.24 a	1.90 a	5.14 a	3.28 b	12.56 a
	Mean	**2.23 B**	**1.88 B**	**5.11 C**	**3.21 B**	**12.43 C**
JM44	0	2.76 a	2.15 a	5.66 b	3.49 a	14.37 b
	150	2.89 a	2.28 a	5.87 b	3.94 b	14.98 a
	300	2.93 a	2.35 a	5.93 b	3.99 b	15.20 a
	Mean	**2.86 A**	**2.26 A**	**5.82 A**	**3.81 A**	**14.85 A**
YN1212	0	2.65 a	2.18 a	5.19 a	3.49 a	13.51 b
	150	2.71 a	2.24 a	5.60 b	3.85 b	14.40 a
	300	2.77 a	2.29 a	5.69 b	3.88 b	14.63 a
	Mean	**2.71 A**	**2.24 A**	**5.49 B**	**3.74 A**	**14.18 B**
				ANOVA		
Variety (V)		**	**	**	**	**
Phosphate (P)		ns	ns	**	**	**
V×P		ns	ns	ns	ns	ns

Within a column for each variety, means followed by different lower-case letters are significantly different according to Tukey's HSD test (0.05). Within a column, upper-case letters indicate comparisons among three varieties. * and **, significant at 0.01 and 0.05 probability levels, respectively; ns, indicates not significant at 0.05 probability level.

Table 3. Grain processing quality of the experimental varieties at different P_2O_5 rate

Variety	P_2O_5 rate kg ha^{-1}	Sedimentation volume mL	Wet gluten content %	Water absorption %	Dough stability time min
SN29	0	23.71 b	27.66 b	55.63 b	4.70 b
	150	26.16 a	29.29 a	57.51 a	5.43 a
	300	26.53 a	29.40 a	57.52 a	5.50 a
	Mean	**25.47 B**	**28.78 C**	**56.89 C**	**5.21 B**
JM44	0	31.50 b	35.56 b	67.56 b	6.85 b
	150	33.00 a	37.03 a	69.52 a	8.11 a
	300	33.19 a	37.86 a	69.63 a	8.19 a
	Mean	**32.56 A**	**36.82 A**	**68.90 A**	**7.72 A**
YN1212	0	25.30 b	31.91 b	57.66 b	4.74 b
	150	28.16 a	33.46 a	59.91 a	5.35 a
	300	28.62 a	33.73 a	60.10 a	5.55 a
	Mean	**27.36 B**	**33.03 B**	**59.22 B**	**5.21 B**
ANOVA					
Variety (V)		**	**	**	**
Phosphate (P)		**	**	**	**
V×P		ns	ns	ns	ns

Within a column for each variety, means followed by different lower-case letters are significantly different according to Tukey's HSD test (0.05). Within a column, upper-case letters indicate comparisons among three varieties. * and **, significant at 0.01 and 0.05 probability levels, respectively; ns, indicates not significant at 0.05 probability level.

Table 4. Yield and yield components of the experimental varieties at different P_2O_5 rate

Variety	P_2O_5 rate kg ha^{-1}	Yield kg ha^{-1}	Spike per m^1 Spike m^1	Grain per spike	1000-grain weight g
SN29	0	5693 b	602 b	20.5 a	45.4 b
	150	6050 a	621 a	20.2 a	49.0 a
	300	6008 a	620 a	20.4 a	48.1 a
	Mean	**5917 C**	**614 B**	**20.4 C**	**47.5 A**
JM44	0	6611 b	567 b	29.7 a	39.2 b
	150	7092 a	586 a	29.5 a	41.9 a
	300	7081 a	591 a	29.2 a	42.0 a
	Mean	**6928 B**	**581 C**	**29.5 A**	**41.0 C**
YN1212	0	7596 b	744 b	24.5 a	41.5 b
	150	8072 a	771 a	24.3 a	43.8 a
	300	8056 a	782 a	24.0 a	44.2 a
	Mean	**7908 A**	**766 A**	**24.3 B**	**43.2 B**
ANOVA					
Variety (V)		**	**	**	**
Phosphate (P)		**	**	**	**
V×P		ns	ns	ns	ns

Within a column for each variety, means followed by different lower-case letters are significantly different according to Tukey's HSD test (0.05). Within a column, upper-case letters indicate comparisons among three varieties. * and **, significant at 0.01 and 0.05 probability levels, respectively; ns, indicates not significant at 0.05 probability level.

3.4. Grain Yield and Component Factors of Wheat

Both varieties and phosphorus application had significant effects on grain yield, but there was no significant interaction between them (Table 4). YN-1212 had the highest yield, followed by JM-44. Compared with SN-29 with the lowest yield, YN-1212 and JM-44 had an average increase of 33.6% and 17.1%, respectively. For the three cultivars, phosphorus application significantly increased grain yield by 5.5-7.2%, but there was no significant difference in grain yield between 150 kg ha^{-1} and 300 kg ha^{-1} treatments.

3.5. Yield and Yield Related Attributes

The maximum stem number of YN-1212 was significantly higher than SN-29 and JM-44, while no significant difference was observed in productive stem percentage among three varieties (Figure 1; Figure 2). Therefore, the ear number advantage of YN-1212 over SN-29 and JM-44 resulted from higher maximum stem number, rather than productive stem percentage. A significant rate of maximum stem number increase was observed by 9.0%-10.9% with the P application applied across varieties, while there was no significant difference in maximum stem number between 150 kg P ha^{-1} and 300 kg P ha^{-1}. No significant difference was observed in productive stem percentage among three P application rates. Averaged across P application rates, the leaf area index at anthesis was significantly 11.6% and 8.3% higher in YN-1212 than that in SN-29 and JM-44 respectively (Figure 3). The P application had a significant increase in leaf area index at anthesis across varieties, while there was no significant difference in leaf area index at anthesis between 150 kg P ha^{-1} and 300 kg P ha^{-1}. Averaged across P application rates, the total dry weight at maturity of YN-1212 was significantly higher than that in SN-29 and JM-44 by 14.4% and 17.0%, respectively, whereas no significant difference was observed between SN-29. With an increase in the P application rate, the total P quantity at maturity of wheat increased across varieties. The P harvest index was significantly higher in JM44 than that in SN-29 and YN-1212, but the increase was less than two percentage points (only 3% increase). When the P fertilizer was applied, the P harvest index significantly decreased by 4.7%-7.8%, while there was no significant difference between the treatments of 150 kg ha^{-1} and 300 kg ha^{-1} of P application. YN-1212 had higher Pre-anthesis P uptake and post-anthesis P uptake than SN-29 and JM-44, which accounts for the advantage in total P quantity at maturity in YN-1212 over SN-29 and JM-44. With an increase in the P application rate, both pre-anthesis P uptake and post-anthesis P uptake significantly and continuously increased across varieties.

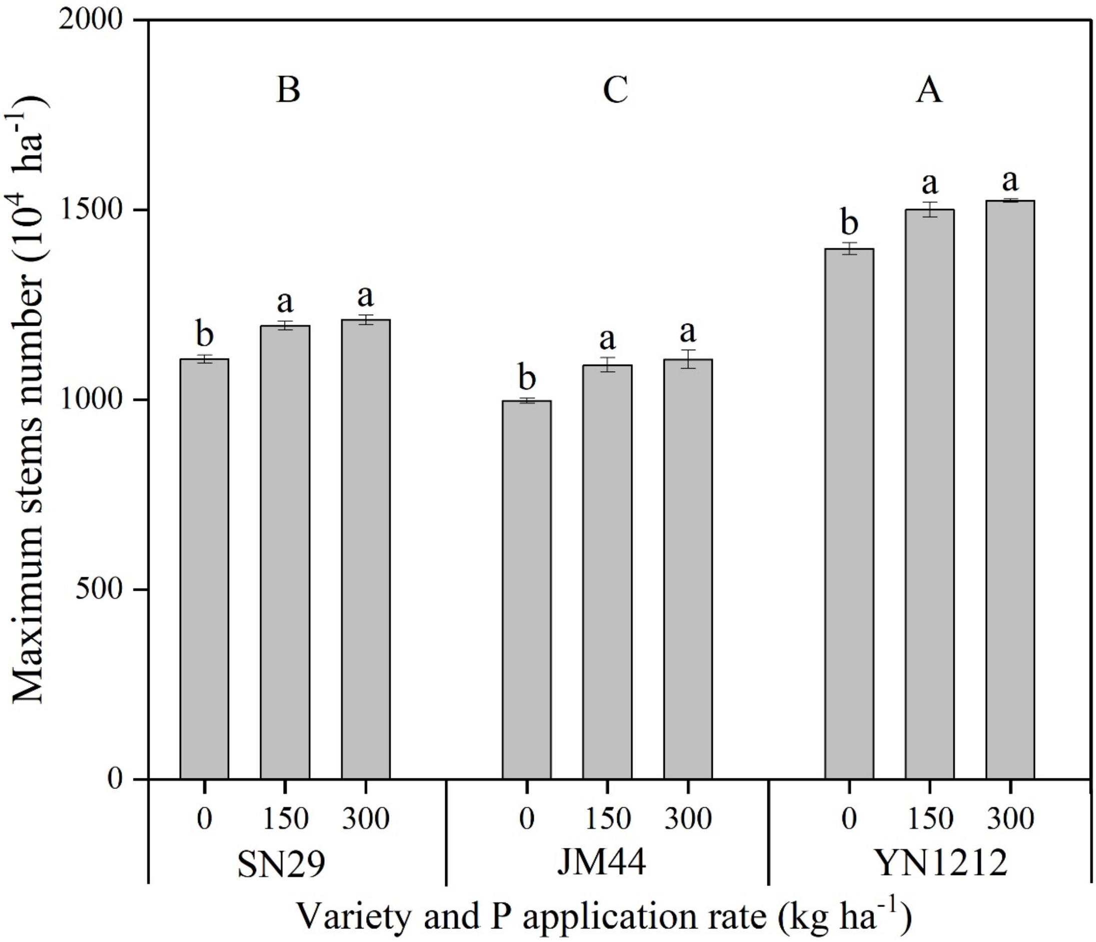

Figure 1. Maximum stem number of winter wheat under different variety and P application rate. SN-29, Shangnong-29; JM-44, Jimai-44; YN-1212, Yannong-1212. Different upper-case letters indicate significant difference among three varieties according to Tukey's HSD test (α=*0.05*). Within each variety, different lower-case letters above bars indicate significant difference among three P application rates according to Tukey's HSD test (α=*0.05*). error bar, the standard deviation (± SD)

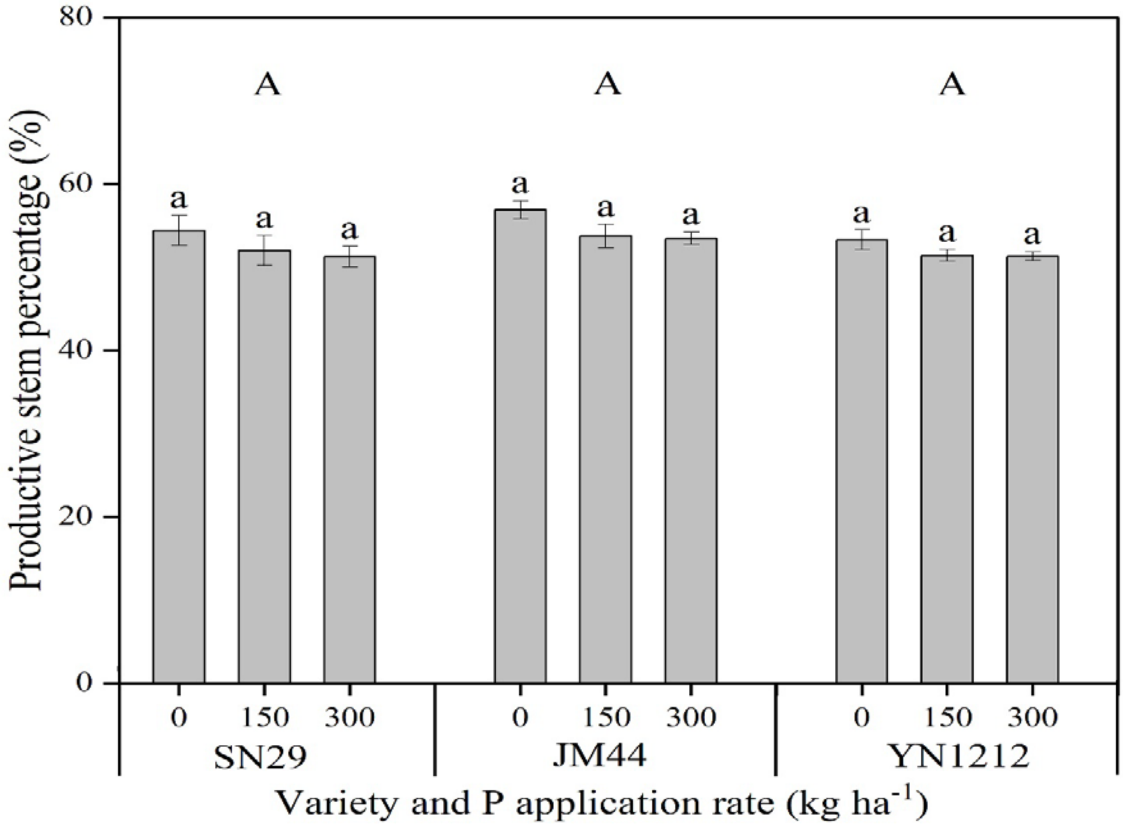

Figure 2. Productive stem percentage of winter wheat under different variety and P application rate. SN-29, Shangnong-29; JM-44, Jimai-44; YN-1212, Yannong-1212. Different upper-case letters indicate significant difference among three varieties according to Tukey's HSD test (*α=0.05*). Within each variety, different lower-case letters above bars indicate significant difference among three P application rates according to Tukey's HSD test (*α=0.05*). error bar, the standard deviation (± SD)

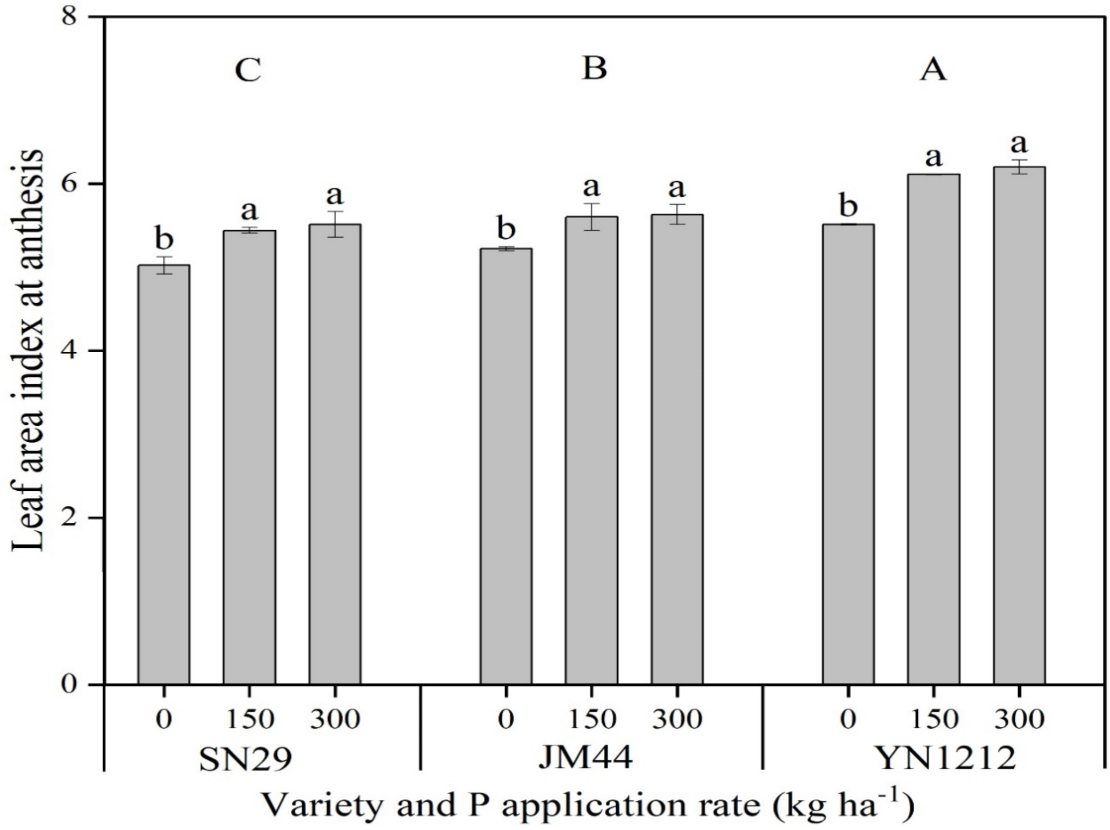

Figure 3. Leaf area index at anthesis of winter wheat under different variety and P application rate. SN-29, Shangnong-29; JM-44, Jimai-44; YN-1212, Yannong-1212. Different upper-case letters indicate significant difference among three varieties according to Tukey's HSD test (*α=0.05*). Within each variety, different lower-case letters above bars indicate significant difference among three P application rates according to Tukey's HSD test (*α=0.05*). error bar, the standard deviation (± SD)

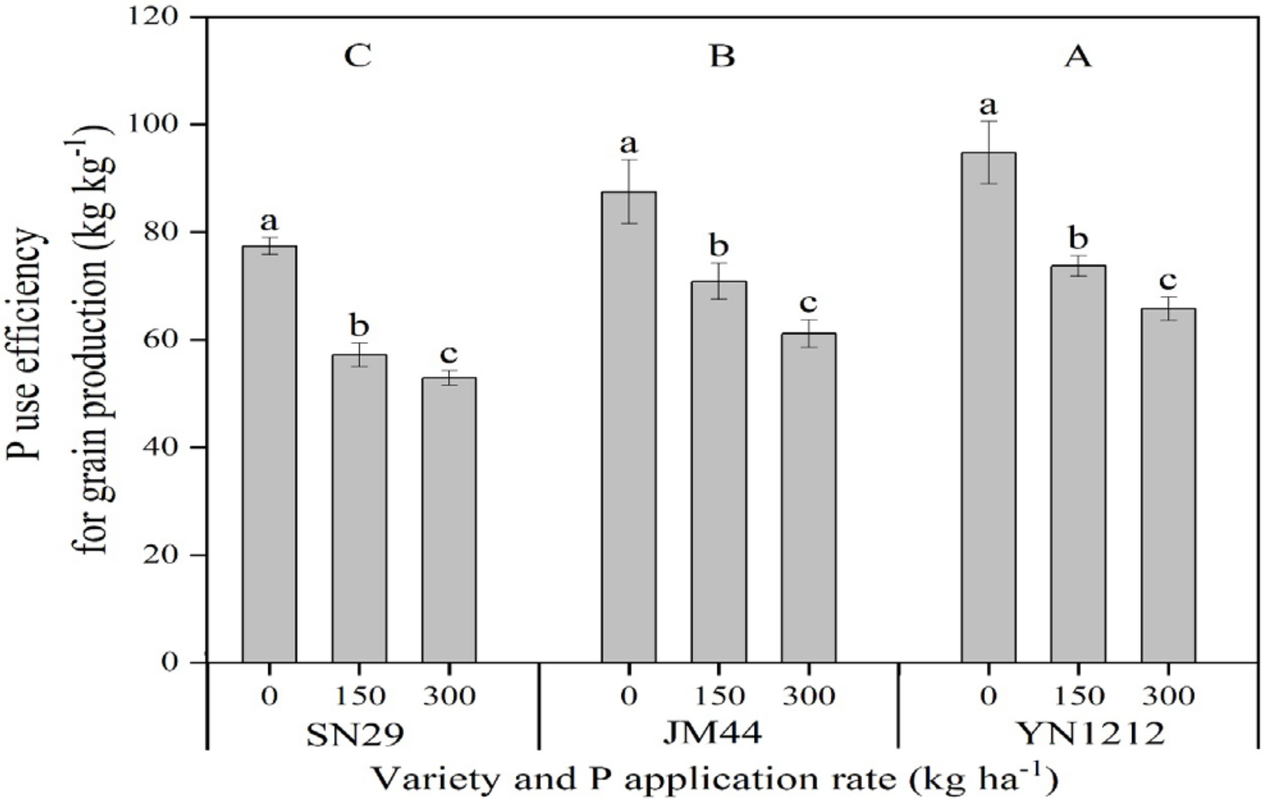

Figure 4. P use efficiency for grain production (PUEg) of winter wheat under different variety and P application rate. SN-29, Shangnong-29; JM-44, Jimai-44; YN-1212, Yannong-1212. Different upper-case letters indicate significant difference among three varieties according to Tukey's HSD test (*α=0.05*). Within each variety, different lower-case letters above bars indicate significant difference among three P application rates according to Tukey's HSD test (*α=0.05*). error bar, the standard deviation (± SD)

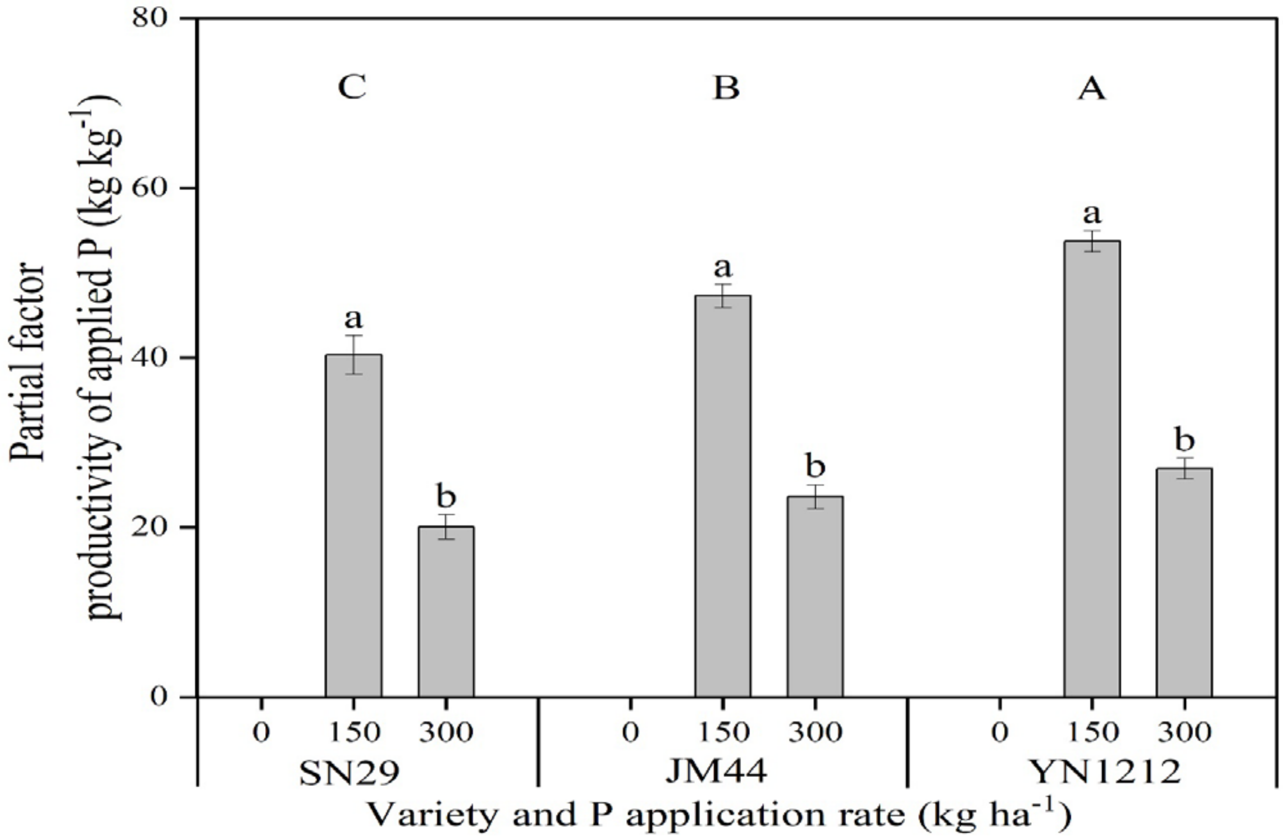

Figure 5. Partial factor productivity of applied P (PFP_p) of winter wheat under different variety and P application rate. SN-29, Shangnong-29; JM-44, Jimai-44; YN-1212, Yannong1212. Different upper-case letters indicate significant difference among three varieties according to Tukey's HSD test (*α=0.05*). Within each variety, different lower-case letters above bars indicate significant difference among three P application rates according to Tukey's HSD test (*α=0.05*). error bar, the standard deviation (± SD)

The wheat crop of YN-121exhibited a higher PUEg than SN-29 and JM-44 by 25.0% and 6.7%, averaged across P rates, respectively (Figure 4). The recorded PUEg decreased with increases in P fertiliser administration across varieties. The PFP_p of YN-1212 was significantly higher than SN-29 and JM-44 by 33.6% and 13.7%, averaged across P application rates, respectively (Figure 5). With an increase in the P application rate, PFP_p decreased across varieties.

4. Discussion

4.1. Effects of Phosphorus Application Amount and Variety on Grain Protein Content

Many research results show that applying phosphorus fertilizer is helpful to improve grain quality. Most of the research results believed that phosphorus application was helpful to improve grain protein content, and grain protein content increased with the increase of phosphorus application [18]. That phosphate fertilizer could significantly improve the quality of corn grains, and with the increase of phosphorus application, the protein content in corn grains significantly increased [19]. The research results of Fu Guozhan showed that with the increase of phosphate fertilizer application amount, starch content in grains first increased and then decreased [20]. The increase of phosphorus application, the relative content of starch and the ratio of amylose and amylopectin decreased significantly [21]. In this study, under the phosphorus application treatment, the grain protein content was significantly increased, and the starch content and starch direct branch ratio were significantly decreased. The quality of different wheat varieties was controlled by genotype and influenced by environmental factors. Before 2000, wheat breeding focused on improving yield and rust resistance, and after 2000, quality improvement also became one of the important breeding goals [22]. Under the conditions of this experiment, the grain quality of the three main varieties in Jinzhong showed great differences, and the total protein content of Jimai-44 and Yannong-1212 was significantly higher than that of Shannong-29. The total starch content of Shannong-29 was significantly higher than that of Jimai-44 and Yannong-1212. The starch direct branch ratio of Jimai-44 was significantly higher than that of Shannong-29 and Yannong-1212. These results showed that the wheat yield and quality could be improved synchronously by choosing varieties with higher grain protein content and applying appropriate amount of phosphate fertilizer in Jinzhong area.

4.2. Effects of Phosphorus Application Rate and Variety on Dry Matter Production, Transport and Distribution of Wheat

Compared to zero N treatment (N0), the P application rate of 150 kg ha^{-1} significantly increase grain yield across varieties, while there was no significant increase in grain yield as the P application rate increased to 300 kg ha^{-1}. Similar effects of P application on grain yield have been reported in previous studies [23]. These results indicate that a moderate amount of P application was sufficient to meet the demand for P fertilizer in wheat productivity, and that excessive application of P fertilizer not only had no significant effect on grain yield improvement, but also increased cost for the grower and caused waste of resources. In the present study, the P application had the greatest effect on ear number, followed by 1000-grain weight, and the least effect on the grain number per ear, among the three yield related attributes, similar results were reported in a previous study [24]. That P application promoted the produce of tillers and did not reduce the productive stem percentage meanwhile, significantly increasing the ear number, which was the reason why P application can improve the grain yield. Additionally, the application of P fertilizer enhanced photosynthesis, and the sufficient carbohydrates promoted the filling of the grain and significantly increased the 1000-grain weight. The length of crop growth duration has an important influence on yield formation. A longer growth duration of wheat is beneficial for capturing more radiation and thermal resources, promoting dry matter accumulation and yield formation [23]. There was no significant difference between different P application rates within a variety, while significant difference was observed among three varieties, mainly in the reproductive growth stage.

YN-1212 had the higher grain yield, maturing 2 and 7 days later than SN-29 and JM-44, respectively, with 4 and 6 days longer grain filling periods, which was conducive to dry matter accumulation and yield formation. These results suggest that selecting varieties with appropriately longer duration, especially with relatively longer grain filling periods, is an effective way to achieve high yield.

Crop yield is determined by dry matter production and harvest index [24]. Thus, crop yield can be increased by increasing the dry matter accumulation, harvest index or both [25]. In the present study, the P application significantly increased the total dry weight at maturity, whereas no significant difference in harvest index was recorded among three P treatments. This result suggests that the wheat crop with P application showed greater total dry weight instead of higher biomass partitioning efficiency compared to that in P0 treatment. Additionally, pre-anthesis and post-anthesis dry matter production were both significantly higher with P application than those in P0 treatment. Similar results were reported in a previous study [26]. These results suggest that selecting varieties with strong dry matter accumulation, combined with appropriate P fertilizer application, is conducive to achieving high yield.

5. Conclusions

In this study wheat production area with similar soil type and environmental conditions, Yannong-1212 could obtain higher grain yield and good grain quality under the condition of 150 kg ha^{-1} phosphorus application, while JM-44 could increase the supply of high-quality wheat while ensuring a certain yield level. The contents of glycine, and total protein in wheat grains, reduced the total starch content and the ratio of amylose to amylopectin, improved the processing quality of wheat grains. Among the three varieties in this experiment, Yannong-1212 showed the highest yield level, and its yield advantage was due to its strong tiller ability to obtain higher spike number per area.

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References

[1] FAO (2016) World Food Situation. http://www.fao.org /worldfoodsituation/csdb/en/
[2] Manschadi AM, Soltani A "Variation in traits contributing to improved use of nitrogen in wheat: Implications for genotype by environment interaction" Field Crops Research 270. 108211, 2021.
[3] Duan JZ, Shao YH, He L, Li X, Hou GG, Li S, Feng W, Zhu YJ, Wang Y, Xie Y "Optimizing nitrogen management to achieve high yield, high nitrogen efficiency and low nitrogen emission in winter wheat" Science of the Total Environment 697:134088, 2019.
[4] Ray DK, Foley JA "Increasing global crop harvest frequency: recent trends and future directions" Environ. Res. 8, 044041. 2013.
[5] FAOSTAT.2020.FAOStatisticYearbook2020(http://www.fao.org/faostat/en/#data).
[6] Oldroyd GE D and Leyser O "A plant's diet, surviving in a variable nutrient environment" Science, 368: 6486, 2020.
[7] Wang Q, Xu L, Guo D, Wang G, Song X, Ma Y. "The continuous application of biochar in field: effects on P fraction, P sorption and release" Chemosphere 263,128084, 2021.
[8] Du Y, Cui B, zhang Q, Wang Z, Sun J, Niu W "Effects of manure fertilizer on crop yield and soil properties in China: a meta-analysis. Catena 193, 104617, 2020.
[9] Zhu J, Li M, Whelan M P "Phosphorus activators contribute to legacy phosphorus availability in agricultural soils" a review. Science of the Total Environment, 612: 522-537, 2018.
[10] Yang Y, Zhang H, Qian X, Duan J, Wang G. "Excessive application of pig manure increases the risk of P loss in calcic cinnamon soil in China" Sci. Total Environ. 609, 102-108, 2017.
[11] Koch M, Kruse J, Eichler-L¨obermann B, Zimmer D, Willbold S, Leinweber P, Siebers N "Phosphorus stocks and speciation in soil profiles of a long-term fertilizer experiment: Evidence from sequential fractionation, P K-edge XANES, and 31P NMR spectroscopy" Geoderma 316, 115-126, 2018.
[12] Liu C, Jin Y, Liu C "Phosphorous fractions in soils of rubber-based agroforestry systems: Influence of season, management and stand age" Sci. Total Environ. 1576-1588, 2018.
[13] Liu P, Yan H, Xu S "Moderately deep banding of phosphorus enhanced winter wheat yield by improving phosphorus availability, root spatial distribution, and growth" Soil and Tillage Research, 220: 105388, 2022.
[14] Dai J, Wang Z, Li M "Winter wheat grain yield and summer nitrate leaching: Long-term effects of nitrogen and phosphorus rates on the Loess Plateau of China" Field Crops Research, 196: 180-190, 2016.
[15] He WT, Chen SS, Kang JH "Genotypic differences in phosphorus utilization efficiency among spring wheat varieties in Ningxia" Soils, (06):500-505, 2003. (in Chinese, with English abstract).
[16] Laza MR, Peng SB, Akita S, Saka H "Contribution of Biomass Partitioning and Translocation to Grain Yield under Sub-Optimum Growing Conditions in Irrigated Rice" Plant Production Science 6:28-35, 2003.
[17] Man J, Yu Z, Shi Y "Radiation interception, chlorophyll fluorescence and senescence of flag leaves in winter wheat under supplemental irrigation" Scientific Reports 7:7767, 2017.
[18] Rivera-Amado C, Trujillo-Negrellos E, Molero G, Reynolds MP, Sylvester-Bradley R, Foulkes MJ "Optimizing dry-matter partitioning for increased spike growth, grain number and harvest index in spring wheat" Field Crops Research 240: 154-167, 2019.
[19] Takahashi S, Anwar M R "Wheat grain yield, phosphorus uptake and soil phosphorus fraction after 23 years of annual fertilizer application to an Andosol" Field Crops Res, 101(2): 160-171, 2007.
[20] Wang K, Cui K, Liu "Low straw phosphorus concentration is beneficial for high phosphorus use efficiency for grain production in rice recombinant inbred lines" Field Crops Research, 203: 65-73. 2017.
[21] Wang Y C, Zheng C, Xiao S "Agronomic responses of ratoon rice to nitrogen management in central China" Field Crops Res, 241: 107569, 2019.
[22] Yu X, Qi C, Shi W "Interactions between phosphorus availability and microbes in a wheat–maize double cropping system: A reduced fertilization scheme" Journal of Integrative Agri, 21(3): 840-854, 2022.
[23] Zhu X, Li C, Jiang Z "Responses of phosphorus use efficiency, grain yield, and quality to phosphorus application amount of weak-gluten wheat" Journal of Integrative Agri, 11(7): 1103-1110, 2012.
[24] Wang Y, Chi SY, Ning TY "Coupling effects of irrigation and phosphorus fertilizer applications on phosphorus uptake and use efficiency of winter wheat" Journal of Integrative Agri, 12(2): 263-272, 2013.
[25] Mazlouzi El M, Morel C, Robert T "Phosphorus uptake and partitioning in two durum wheat cultivars with contrasting biomass allocation as affected by different P supply during grain filling" Plant and Soil, 449(1): 179-192, 2020.
[26] Korkmaz K, İbrikçi H, Karnez E "Phosphorus use efficiency of wheat genotypes grown in calcareous soils" Journal of Plant Nutrition, 32(12): 2094-2106, 2009.