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Effects of plant density on grain yield, protein size distribution, and breadmaking quality of winter wheat grown under two nitrogen fertilisation rates

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ABSTRACT

Nitrogen (N) and plant density are two crucial factors that affect winter wheat (*Triticum aestivum* L.) yield and quality, but little is known regarding the effects of interactions between these two factors on the amount and size distribution of protein fractions and quality traits. We grew the bread wheat cultivar Jinan17 in two successive seasons (2012–2013 and 2013–2014) at three densities of 120 plants m^{-2} (low), 180 plants m^{-2} [the usual rate for a multiple-spike cultivar with high tillering ability in the North China Plain (NCP)], and 240 plants m^{-2} (high) and two levels of N fertilisation of 0 (low N availability treatment without N fertilisation) and 240 kg ha^{-1} (the usual N rate for winter wheat production in the NCP) to evaluate the effect of N level × plant density interaction on grain yield, grain protein concentration, the amount and composition of protein fractions, dough development time, dough stability time, and loaf volume. The effect of plant density on Jinan 17 grain yield and quality differed between the two N levels. As plant density increased, all the parameters listed above decreased under 0 kg ha^{-1} N fertilisation, but increased under 240 kg ha^{-1} N fertilisation. Stepwise regression analysis showed that the dough rheological properties and breadmaking quality of Jinan 17 were affected by plant density under both N levels, primarily through changes in the polymerisation degree of glutenins in the flour.

1. Introduction

Wheat is cultivated widely for its unique dough rheological properties conferred by gluten proteins which allow the processing of wheat into a range of foods including leavened breads and various derived end products that cannot be made from other cereals (Shewry et al., 1997). In general, wheat flour quality is strongly dependent on genotype, environmental factors including climate conditions, soil types and management practices involving nitrogen (N) fertiliser, irrigation, sowing date, and plant density and their complex interactions (Jia et al., 1996; Johansson et al., 2001; Zhu and Khan, 2001; Otteson et al., 2008). Genetic and environmental factors affect wheat quality mainly through their effects on grain protein content and composition (Dupont and Altenbach, 2003), which are the two most important determinants of quality (Weegels et al., 1996; Johansson et al., 2001; Zhu and Khan, 2001). Previous studies reported that polymeric glutenins and monomeric gliadins interact to form a highly cohesive and viscoelastic network, referred to as wheat gluten protein, which confers properties of elasticity and extensibility essential for the rheological and baking characteristics of wheat flour (Shewry et al., 1997; Singh and MacRitchie, 2001). The amount (Weegels et al., 1996) and size distribution of polymeric proteins (Shewry et al., 1997; Johansson et al., 2001; Singh and MacRitchie, 2001), the glutenin/gliadin (Glu/Gli) ratio (Fuertes-Mendizábal et al., 2010), and the proportion of sodium dodecyl sulphate (SDS)-insoluble glutenins among total glutenins (the polymerisation index; Jia et al., 1996; Zhu and

Abbreviations: GPC, grain protein concentration; TKW, thousand kernel weight; SE-HPLC, size exclusion high-performance liquid chromatography; SDS, sodium dodecyl sulfate; Glu/Gli, glutenin/gliadin ratio; RLD, root length density; AGN, aboveground nitrogen uptake; NHI, nitrogen harvest index; DDT, dough development time; DST, dough stability time.

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Khan, 2001; Fuertes-Mendizábal et al, 2010) all correlate strongly with dough-mixing properties and loaf volume.

Nitrogen (N) and plant density are two factors crucial to the successful implementation of crop management practices used in wheat production systems (Ellis et al., 1999; Otteson et al., 2008; Nakano et al., 2009). Numerous studies have reported the effects of N fertilisation on yield, the amount and composition of grain proteins, dough rheological properties, and breadmaking quality (Jia et al., 1996; Johansson et al., 2001; Fuertes-Mendizábal et al., 2010). Plant density also exerts a marked influence on wheat protein content and quality traits and should be considered a particularly important factor contributing to grain yield and quality. Geleta et al. (2002) reported that the grain protein concentration (GPC) decreased with increasing seeding rate and that the grain volume weight was lowest at a seeding rate of 16 kg ha^{-1}, but increased as the seeding rate was increased to 65 and 130 kg ha^{-1}. Samuel (1990) reported that the grain volume weight increased with an increase in the seeding rate from 90 to 270 kg ha^{-1}, although the effects were minimal. Moreover, the optimal plant densities for grain yield and quality traits were highly dependent on N availability (Gooding et al., 2002) indicating that interactive effects between the N fertilisation level and plant density were likely. Previous studies describing interactive effects focused mainly on growth and yield in winter wheat (Ellis et al., 1999; Gooding et al., 2002) or on the GPC (Gooding et al., 2002) and bread wheat loaf volume (Otteson et al., 2008). Available information on the effect of the interaction between the level of N fertilisation and plant density on the protein size distribution and its relationship with breadmaking quality is scarce. The objectives of this study were to investigate the effects of plant density combined with two levels of N fertilisation on grain yield, GPC, the amount and size distribution of protein fractions, dough development time (DDT), dough stability time (DST), and loaf volume and to document the effect of plant density on the degree of glutenins polymerisation under two levels of N fertilisation to explain variations in end-use quality.

2. Materials and methods

2.1. Materials

The bread winter wheat cultivar Jinan17, a multiple-spike cultivar with high tillering ability that is planted widely in the North China Plain (NCP), was grown in field trials in Dongwu Village (35°57′N and 117°3′E, Dawenkou Town, Tai'an City, Shandong Province, China) during 2012–2013 and 2013–2014. The area has a semi-humid continental temperate monsoon climate. The annual solar duration and cumulative temperature above 10 °C are at least 2627 h and 4213 °C, respectively, and the annual frost-free period is 195 days. The typical annual precipitation is 697 mm and the total rainfall from sowing to harvest in 2012–2013 (157.2 mm) and 2013–2014 (139.5 mm) were both below the 40-year average (188.31 mm). The monthly rainfall and mean temperature, which were obtained from a meteorological station located within 100 m of the experimental fields, are shown in Fig. 1. In general, total rainfall was slightly higher in the first season than in the second, when precipitation in April compensated for the scarcity of rainfall from December to the following March. Rainfall from flowering to harvest was roughly equal between the two growing cycles. The mean temperature during 2012–2013 was less than that during 2013–2014, except in March and April, when the mean temperatures were similar.

The soil type was sandy loam (Typic Cambisols; FAO/EC/ISRIC, 2003) with a pH of 8.25. Soil analyses were conducted prior to cultivation in both growing seasons. In 2012–2013, the top 40 cm

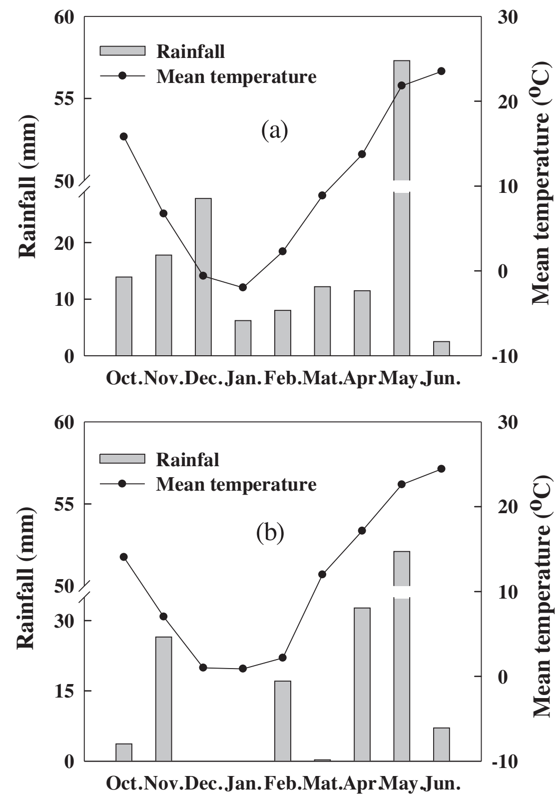

Fig. 1. Rainfall and mean temperature (°C) recorded during the period of wheat growth (October–June) in 2012–2013 (a) and 2013–2014 (b).

of the soil contained 1.53% organic matter (Walkley and Black, 1934), 0.12% total nitrogen (N) (semi-micro Kjeldahl method; Kjeltec 8200 Auto Distillation Unit, Foss, Hillerød, Denmark; Yuen and Pollard, 1953; Bremner, 1960), 30.02 mg kg^{-1} available phosphorus (P; Olsen method; Zandstra, 1968), and 65.92 mg kg^{-1} available potassium (K; Dirks-Sheffer method; Melich, 1953). The soil mineral N (NO_3^- and NH_4^+, Benesch and Mangelsdorf, 1972; Wagner, 1974) in the top 100 cm of soil depth was 116.15 kg ha^{-1}.

In 2013–2014, the organic matter, total N, available P, and available K in the top 40 cm of the soil were 1.51%, 0.09%, 32.88 mg kg^{-1}, and 68.23 mg kg^{-1}, respectively, in 0 kg ha^{-1} N fertilisation plots, and 1.54%, 0.13%, 30.69 mg kg^{-1}, and 66.89 mg kg^{-1}, respectively, in 240 kg ha^{-1} N fertilisation plots. The soil mineral N (NO_3^- and NH_4^+) in the top 100 cm of the soil was 76.79 and 119.56 kg ha^{-1} under 0 and 240 kg ha^{-1} N fertilisation, respectively.

2.2. Methods

2.2.1. Experimental design

The trials were conducted using a split plot design with three replicates, giving a total of 18 subplots. The main plots were assigned to two N fertilisation rates, 0 kg ha^{-1} (low N availability treatment without N fertilisation) and 240 kg ha^{-1} (the usual N rate for winter wheat production in the NCP; Wang et al., 2003; Zheng et al., 2013; Guo et al., 2014; Man et al., 2014), applied as urea, with a basal N fertilisation rate of 72 kg ha^{-1} plus a topdressing rate of 168 kg ha^{-1} at jointing (Feekes stage 6). Subplots were assigned to three plant densities; 120 plants m^{-2} (low), 180 plants m^{-2} (the usual rate for a multiple-spike cultivar with high tillering ability in the NCP, Guo et al., 2014; Man et al., 2014), and 240 plants m^{-2} (high). The size of each subplot was 30 × 1.5 m (6 rows, 25 cm between rows). A 0.75-m wide buffer plot with plastic film buried to a depth of 160 cm was arranged between