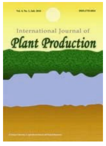

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Assessing variety mixture of continuous spring wheat (*Triticum aestivum* L.) on grain yield and flour quality in Northeast China

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Abstract

Wheat (*Triticum aestivum* L.) variety mixtures represent a relatively unexplored avenue for maintaining yield and improving flour quality. A field experiment was conducted to examine the responses of three spring wheat varieties in pure variety and in variety mixtures under continuous cropping in Northeast China. Three modern spring wheat varieties, along with a three-variety mixture and a two-variety mixture of equal proportions, were planted during the growing seasons of 2006 to 2009. The mixtures were chosen mainly to have complementary traits of yield potential and grain quality. Wheat yield was not affected by continuous cropping but by growing conditions, varieties and variety mixture. Yield stability of 3-variety mixture exceeded that of the pure varieties. The 3-variety mixture consistently out-yielded the means of the respective components (mid-components), with a mean advantage of 0.17 t ha^{-1} over the different growing conditions. Variety mixture offers greater yield advantages over lower-yield but good-quality variety and improves dough rheological properties and some chemical properties over the higher-yield variety. The 1:1:1 variety mixtures have greater environmental plasticity and potential application in improving flour quality than pure varieties and are therefore recommended for use to Northeast China’s wheat growers even in the absence of severe disease.

Keywords: *Triticum aestivum*; Cultivar blends; Yield stability; Flour quality; Test weight; Sedimentation value.

Introduction

Variety mixtures refer to mixtures of cultivated varieties growing simultaneously on the same parcel of land with no attempt to breed for phenotypic uniformity (Vandermeer et al., 1998; Mundt, 2002). Wolfe (1985) defined variety mixtures as mixtures of cultivars that vary for many characters including disease resistance, but have sufficient similarity to be grown together. It is only in the last hundred years or so that crop pure variety has become predominant in industrialized agriculture for field and plantation crops. The reasons were for simplicity of planting, harvesting and other operations, which could all be mechanized and for uniform quality of the crop product. However, pure variety produced severe disadvantages, such as vulnerability to diseases, pests and weeds and yield instability, which necessitated, for example, the large-scale use of pesticides, fertilizers and growth regulators (Browning, 1988; Wolfe, 2001). The use of variety mixtures (mechanical mixtures of different varieties of the same species at seed level) has been demonstrated as a potential means of increasing as well as stabilizing crop yield, reducing insect and disease damage or outbreaks over varied environments (Finckh and Mundt, 1992; Akanda and Mundt, 1997; Finckh et al., 2000), minimizing risk and maximizing exploitation of limited resources such as moisture, nutrients or space and increasing soil organic matter levels through greater above-ground biomass production (Smithson and Lenne, 1996; Sarandon and Sarandon, 1995; Kiær et al., 2009). Variety mixtures can be produced commercially or by the farmer at low cost, to produce good disease control and yield stability (Essah and Stoskopf, 2001). The main disadvantage is that the quality of the mixture may not be acceptable to the end-user of the crop product. Composition of mixtures can be changed to delay selection of pathogen races able to overcome more than one component of each mixture. This is main purpose of our research.

Variety mixtures have been used extensively in small grain production in several European countries (Wolfe, 2001) and 6 to 15% of the wheat production area in the states of Washington, Oregon and Kansas was planted to blends every year (NASS, 2007). Wheat variety mixtures may involve any combination of two or more varieties, in any ratio and may offer the benefits of the strengths of each component variety while compensating for weaknesses of each variety (Ciha, 1984; Gupta and Virk, 1984). Since varieties perform differently in mixtures than in pure variety, greater gains in stability would occur from a systematic search for component varieties that exhibit a high degree of buffering capacity when mixed, rather than composing variety mixtures based on yield capability alone (Aslam and Fischbeck, 1993; Manthey and Fehrmann, 1993; Sharma and Dubin, 1996). However, variety mixtures or blends of spring wheat are unknown in northeastern China wheat production.

Spring wheat (*Triticum aestivum* L.) is planted on approximately 0.2 million hectares in Northeastern China annually and is often regarded as a relatively low profit crop mainly due to lower yield and poor competitiveness of flour quality in the market. However, growers have no choice but planting wheat because of shorter frost-free period in some areas. This paper compared pure varieties, two-variety mixtures and three-variety mixtures of spring wheat for their capacity to cope with yield and end-product quality in a continuous cropping system. The objective of the research was to determine if the mixture of wheat varieties differing in yield potential and flour quality would produce high yields of grain with acceptable flour quality, or if mixtures could be grown without reducing flour quality of some variety, while the grain yield of the crop could be improved for field production.

Materials and Methods

Experiments were conducted during the growing seasons of 2006, 2007, 2008 and 2009 at National Observation Station of Hailun Agroecosystem, Chinese Academy of Sciences, where the soil is the typical Chinese Mollisol. This station is located at 47°21′N, 126°49′E, altitude 128 m, Heilongjiang Province, Northeast China, in the continental monsoon area, which is cold and arid in winter and hot and rainy in summer. The annual average temperature is 1.6 °C, ranging from 33 °C in summer to -38 °C in winter. Three varieties were grown as a three-variety mixture, a two-variety mixture and pure varieties under continuous wheat cultivation conditions. The genotypes chosen for mixture were based on their complementarities for yield, quality, plant height and disease resistance and with good adaptation and of similar maturity in the local region of Heilongjiang Province. These varieties were selected without any prior knowledge of their performance in a mixture.

The variety Long Mai 26 (LM26) has a relatively short-culm (85 cm) and excellent protein quality (strong gluten). Its weakness is lower grain yield. The variety Long Fu Mai 16 (LFM16) is a tall (100 cm) and a widely adapted cultivar with high grain yield potential, medium-gluten strength and good stand ability. The third variety Long Fu Mai 9 (LFM9) is a medium-height (95 cm), higher yield and good quality. Its weakness is lodging. Since all wheat varieties released are required to pass the test of disease resistance in Northeast China, disease control was not the priority in this study.

The experimental design was a randomized complete block design with three replications. Mixtures were prepared with equal proportions of seed number of each variety at a seeding rate of 600 seeds per m^2. All plots were seeded manually. The 3-variety mixture was LM26, LFM16 and LFM9, the 2-variety mixture was LM26 and LFM16 and pure varieties were LM26, LFM16 and LFM9. Added fertilizer was 37.5 kg ha^{-1} of urea, 112.5 kg ha^{-1} of di-ammonium phosphate and 25 kg ha^{-1} of K_2SO_4 applied at seeding based on soil fertility and normal recommended rate by local extension scientist there. Each plot consisted of 16 rows with 0.30 m between rows. The row length was 8.0 m. The plots were maintained weed-free by hand weeding. No growth regulators were used. All plots were hand-harvested and threshed using a stationary thresher. Yields were determined by adjusting the grain weight of samples to a moisture content of 14%.

In order to level out differences in productivity among years for absolute values of yield in mixture and pure variety plots, a relative measure of mixing effect (ME) in reference to the method of Kiær et al. (2009) was developed in calculating each mixture in each year, the ME was calculated as:

$$ME_i = (A_i-B_i)/ B_i$$

where A is the mean yield of all varieties grown in the given mixture in the environment, B is the mean yield of the component variety in pure variety in the given environment and *i* refers to each component variety being considered. $ME_{(mean)}$ is calculated from the mean yield of all varieties grown in the given mixture and the average yield of the varieties when grown as pure varieties.

Four quality tests were performed on each sample. Samples were milled using a Perten Laboratory Mill 3100. Test weight, flour yield, Zeleny sedimentation test, Farinograph and Extensograph parameters were performed according to AACC methods 55-10, 26-10A, 56-63, 54-21, 54-10, respectively (AACC International 2000). All reported values are the mean values of three replicates. Data of yield, test weight, vitreousness, wet gluten content, dry gluten content, Zeleny sedimentation value, were analyzed at 0.05 probability level by LSD (SAS Institute, Inc. 1996).

Results

Growing conditions and yield

Conditions for wheat growth in the 4-year experiment were different (Figure 1). The average temperature in April (sowing and emergence period) was 3.26, 5.06, 7.78 and 7.6 °C while the total rainfall was 433 mm, 494 mm, 302 mm and 411 mm for the whole growing period each year (2006 to 2009) respectively. The 30-year average rainfall for the whole wheat growing period was 297 mm, close to the rainfall in 2008, thus 2006, 2007 and 2009 can be regarded as a wetter year.

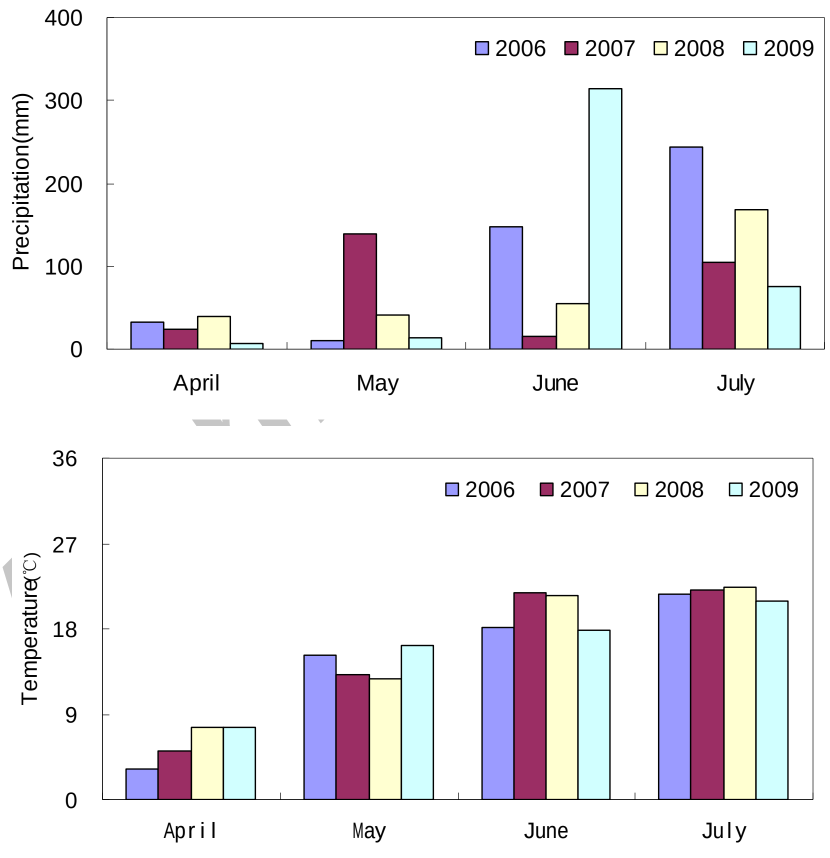

Figure 1. Average monthly rainfall and temperature during wheat growth in 2006 to 2009.

Continuous wheat did not affect yield over this four-year study (Figure 2). Yield of variety LM26 in a pure variety range from 3.12 t ha^{-1} to 3.35 t ha^{-1}, while that of varieties LFM16 and LFM9 in pure varieties ranged from 3.23 t ha^{-1} to 4.72 t ha^{-1} and 3.22 t $ha^{-1}$to 4.25 t ha^{-1} respectively over the four years. Thus LM26 was a variety with lower yield but with greater yield stability over different environments. The 3-variety mixture consistently out-yielded the means of their respective components (mid-components), with a mean advantage of 0.17 t ha^{-1} (3.8% yield increase) over the four-years of continuous cropping (Table 1, Figure 2). The 2-vareity mixture out-yielded the means of their respective components only in the first two-year continuous wheat and had negative impact on yield afterwards (Table 2, Figure 2). The individual mixing effects varied significantly among varieties. The relative mixing effect of the 3-variety mixture was 18%, 8%, 6% and 23% over variety LM26, -6%, 10%, -3% and -12% over variety LFM16 and 14%, 11%, 4% and -3% over variety LFM9 in the first, second, third and fourth year continuous wheat, respectively (Table 1). The relative mixing effect of the 2-variety mixture was 30%, 4%, -1% and 10% over variety LM26 and 3%, 6%, -10% and -21% over variety LFM16 in the first, second, third and fourth year continuous wheat, respectively (Table 2). The individual mixing effects ranged from -12 to 23% for 3-variety mixture with these extreme values occurring in the fourth year. For the 2-variety mixture the mixing effect ranged from -21 to 30% with the extreme negative value in the fourth year while the extreme positive value occurred in the first year.

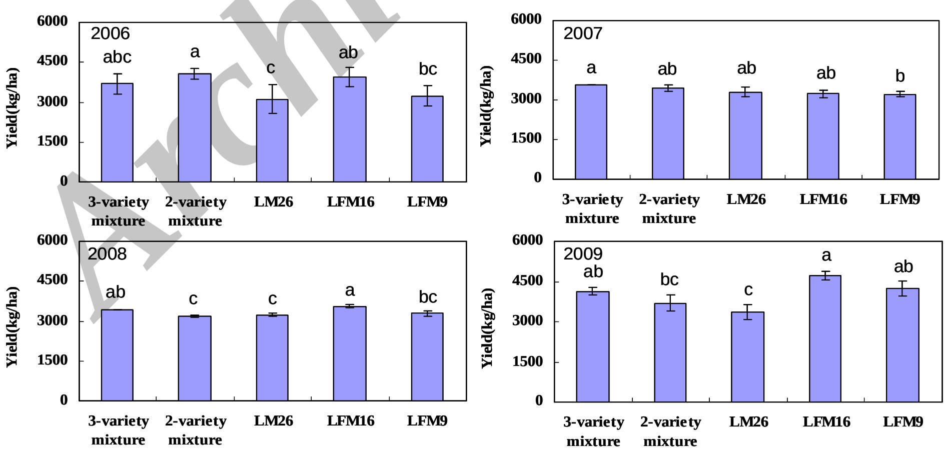

Figure 2. Yield of variety mixture and pure variety cultivation in 4-yr continuous wheat Values followed by different letters are significantly different at the 0.05 probability level by LSD analysis.

Table 1. Relative mixing effect of three variety mixture compared to each cultivar and the three variety mixture mean mixing effect.

	2006	2007	2008	2009
LM26	0.18*	0.08	0.06	0.23*
LFM16	-0.06	0.10	-0.03	-0.12
LFM9	0.14*	0.11	0.04	-0.03
Mean	0.05	0.07	0.02	0.01

* indicates significant difference to the variety at the 0.05 probability level by LSD analysis.

Table 2. Relative mixing effect of two variety mixture compared to each cultivar and the two variety mixture mean mixing effect.

	2006	2007	2008	2009
LM26	0.30*	0.04	-0.01	0.10
LFM16	0.03	0.06	-0.10	-0.21*
Mean	0.15	0.05	-0.06	-0.08

* indicates significant difference to the variety at the 0.05 probability level by LSD analysis.

Changes of dough rheological and chemical properties after 4-year continuous wheat

Dough rheological properties except weakness in variety LM26 pure varieties were significantly greater than other treatments after 4-yr continuous wheat, while no differences were found between 3-variety mixture and 2-variety mixture except weakness and extensibility (Table 3). The development time, stability time, Farinograph quality number, Valorimeter values, extensibility and extension area of the 3-variety mixture were significantly higher than those of variety LFM9 in pure variety. Lower resistance to extension, extensibility and extension area were only found in variety LFM16 in pure variety compared to the 3-variety mixture (Table 3).

No differences were found among variety LM26 in pure variety, 3-variety mixture and 2-variety mixture for flour water content, water absorption, test weight and flour yield, while the vitreousness, wet and dry gluten content and Zeleny sedimentation value were significantly reduced by 3-variety mixture compared to those of LM26 in pure variety (Table 4). However, the Zeleny sedimentation values, water absorption as well as flour yield in 2-variety mixture and 3-variety mixture were significantly higher than that of variety LFM16 in pure variety.

Table 3. Effect of variety mixture and pure variety cultivation on dough rheological properties after 4-yr continuous wheat.

	Valorimeter value					Extensibility value				
	Development time min	Stability time min	Farinograph Quality Number (FQN)	Weakness F.U	Valorimeter value of dough	Resistance to extension 50 mm	Max stretch force (Rm, 135 E.U)	Extensibility (E,135) cm	Extension area (cm^2)	R/E Rate
3-variety mixture	4.2^{b}	4.0^{b}	70^{b}	97^{a}	53^{b}	105^{c}	140^{b}	25.3^{a}	57.5^{b}	0.6^{b}
2-variety mixture	4.2^{b}	3.8^{b}	72^{b}	90^{b}	54^{b}	115^{bc}	140^{b}	23.8^{b}	49.2^{c}	0.6^{b}
LM26	5.7^{a}	5.1^{a}	93^{a}	75^{c}	61^{a}	125^{a}	205^{a}	26.7^{a}	74.6^{a}	0.8^{a}
LFM16	3.8^{bc}	3.8^{b}	69^{b}	84^{b}	53^{b}	85^{d}	85^{c}	20.5^{c}	26.3^{d}	0.4^{c}
LFM9	3.2^{c}	2.6^{c}	51^{c}	107^{a}	48^{c}	112^{bc}	142^{b}	24.3^{b}	48.7^{c}	0.6^{b}

Values followed by different letters are significantly different for one variable within the same column at the 0.05 probability level by LSD analysis.

Table 4. Effect of variety mixture and pure variety cultivation on dough chemical properties after 4-yr continuous wheat.

	Water content %	Water absorption mL/100g	Test weight g/L	Vitreousness %	Flour yield %	Wet gluten content %	Dry gluten content %	Zeleny sedimentation value (mL)
3-variety mixture	12.7[b]	62.5[a]	780[a]	88[b]	71.2[a]	33.4[b]	10.7[b]	55[b]
2-variety mixture	13.0[b]	64.5[a]	771[a]	99[a]	71.8[a]	35.9[b]	11.6[ab]	61[ab]
LM26	13.0[b]	61.8[ab]	776[a]	97[a]	73.0[a]	39.2[a]	12.4[a]	67[a]
LFM16	14.4[a]	67.2[a]	784[a]	99[a]	73.2[a]	34.8[b]	11.1[b]	49[c]
LFM9	13.0[b]	58.3[b]	782[a]	85[b]	66.9[b]	32.2[b]	9.80[c]	52[bc]

Values followed by different letters are significantly different for one variable within the same column at the 0.05 probability level by LSD analysis.

Discussion

Variety mixtures are not only being used extensively in small-scale subsistence agriculture worldwide but also in large-scale systems. One of the most remarkable examples of the large-scale use of variety mixtures in industrialized agriculture was the development during the 1980's of the use of spring barley mixtures in the former German Democratic Republic (Wolf et al., 2001). Jackson and Wennig (1997) proposed that wheat cultivar blends can provide a measure of disease control and are useful for improving agronomic performance and end-product quality. The present study showed that average grain yield ranged from 3.12 t ha^{-1} to 4.72 t ha^{-1} for the pure varieties, with LM26 the lowest yielding pure variety and LFM16 the highest, reflecting the differences in potential yields of these varieties. Among the pure varieties, two-variety mixtures and three-variety mixtures, variety LM26 in pure variety and the 3-variety mixture had greater yield stability over the different growing conditions. The average mixing effect of 3-variety mixture on yield was 3.8% (an average increase of 0.17 t ha^{-1}), while individual mixing effects ranged from -12 to 23%, varying significantly among varieties. Smithson and Lenne (1996) summarized the yield results from more than 100 studies of intraspecific field crop blends, and concluded that on average blend yields exceeded their mid component varieties by a small but significant amount and the advantage was greater for wheat (5.4%) than other field crops. Greater yield stability as an important benefit of blends compared to sole crop cultivars was strongly recommended since blends produce stable and acceptable yields (Dubin and Wolfe, 1994; Kessler, 1997; Swallow and Abel, 2002). Greater blend yield advantages with more than two component varieties than with just two (Newton et al., 1997; Nitzsche and Hesselbach, 1983; Stuke and Fehrmann, 1987) and three to five component varieties were more efficient for disease reduction and yield increase than two-component variety mixtures (Gacek et al., 1996). Stability of yield is extremely important for the farmer. Because of environmental variation among years, it is not possible to forecast which component variety will give the best yield in the next season, the safest option, therefore, is always to grow the mixture. Because of this and other interactions among the component varieties, mixtures provide a buffer against environmental variation so that yield is stable across environments and years. We also observed healthier crops and greater lodging resistance in 3-variety mixture in 2009 (data were not shown), where greater rainfall occurred during heading to early anthesis. Varietal complementarity reducing the tendency to lodge under adverse weather conditions may allow more sturdy varieties to support the weaker erect growth of others (Smithson and Lenne, 1996). Differences in competitive ability among component varieties in a blend have resulted in changes in their relative proportions over time (Akanda and Mundt, 1996). Thus, spring wheat variety mixtures are promising in enhancing competitive ability and may provide greater stability and may have positive, neutral, or negative effects on yield over individual component varieties. Different mixtures vary in the degree to which they reduce disease or generate increased yield, making them equal to, better, or worse, than the mean of the individual cultivar components grown in pure varieties (Finckh and Mundt, 1992).

The general experimental evidence of more stable yields of mixtures than the average of their pure variety component varieties may justify large-scale cultivation of variety mixtures in variable environments as reported in current study. However, mixtures would be even more advantageous to farmers in general if, in addition, mixture yields were comparable to the highest yields of the component varieties. Cultivar mixtures offer the advantage of different components complementing one another in their adaptation to yield limiting factors and environmental variation and with increased yield (Finckh and Wolfe, 1997; Wolfe, 2000; Biabani et al., 2008). Variety mixtures are thus expected to minimize the risk of reduced yield under stress conditions and may thus contribute to yield stability across varying growth environments.

In wheat cultivated without nitrogenous fertilizers, Sarandon and Sarandon (1995) found that a 1:2 mixture of a low yielding high quality wheat cultivar and a high yielding lower quality wheat cultivar had a protein content as high as the low yielding cultivar. Newton et al. (1998) showed that the malting quality of barley cultivar mixtures was equal to that of the pure varieties in 14 out of the 15 cultivar mixtures tested and was better than the pure varieties in one three-way cultivar mixture. However, few studies have focused on flour quality. The current study found that all dough rheological and chemical properties in the variety LM26 in pure variety were superior to other treatments while the 3-variety mixture significantly improved dough rheological properties and some chemical properties particularly water absorption, flour yield and Zeleny sedimentation value over the variety LFM9. Highest correlations with bread volume were found for water absorption and Zeleny sedimentation value (Konopka et al., 2004;

Bockstaele et al., 2008). The varieties used in current study differed in yield and quality. The variety LM26 had a lower grain yield but excellent protein quality (strong gluten), LFM9 had a higher yield, with good quality but was susceptible to lodging, while LFM16 reputed to be a widely adapted cultivar with high grain yield potential and medium-gluten strength variety. Both were evident in this study. The results of the 3-wheat variety mixture in Northeast China are encouraging for improving end-product quality. This is because the milling and baking quality of a medium-quality variety could be masked by mixing with an excellent quality spring wheat variety. Manthey and Fehrmann (1993) reported no loss in wheat quality from growing blends. Therefore, use of variety mixtures is an economical alternative when designed to exploit competitiveness and complementarity of component varieties in achieving the desired level of trait expression while attaining a higher yield.

Grain yield is the ultimate result of genotype-environment interactions and the overall performance of a mixture cannot be derived from the simple accumulation of performances of the component cultivars, nor can individual contributions to the performance of the mixture be deduced accurately from measurements in pure varieties (Finckh and Mundt, 1992). Hence, a mixing effect could be the result of many small effects. Complementarity among varieties can occur for harvested product quality, as demonstrated with the protein content of wheat (Saradon and Saradon, 1995). Varieties that perform well in a given environment may compensate the sub-optimal growth of others (Stützel and Aufhammer, 1990). Whether the current result comes from inter-plant competition, compensation or complementarity needs further investigation. In addition, more research should be performed to get a better understanding of the mixture effect on direct baking tests. As suggested by Liu et al. (1995) that the direct baking testing is the most cogent method to evaluate cultivar’s inherent baking quality.

Conclusions

Variety mixtures tend to increase and stabilize wheat yields and have potential application for improvement of flour quality. Deliberate combination of more general variety characteristics such as high yield levels, different quality and environmental responsiveness is more attractive from an agronomic perspective. The 1:1:1 mixture of a highly strong gluten, shorter height but lower yield variety, mixed with a good quality, taller height and high yield variety and with a medium-gluten, average height and higher yield variety may be the most stable variety mixture in northeast China. If variety mixtures are to be adopted more widely by farmers, future research should address such mixtures more deliberately.

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