EVALUATING SPLIT TIMING FERTILIZER APPLICATIONS FOR IMPROVING BREAD BAKING QUALITY OF SOFT RED WINTER WHEAT IN KENTUCKY

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ABSTRACT

There is growing interest among farmers to locally produce high protein and strong gluten wheat that is suitable for bread making and meet the demand of local artisanal bakers in Kentucky. The warm and humid weather in southeast region is ideal for soft red winter wheat (SRW) production which characterized by low protein content. The technique of splitting nitrogen (N) fertilization according to the growth stages has been suggested to improve protein content and its composition. This study evaluated the effect of split N application on yield and baking quality traits of two SRW wheat cultivars grown in the eastern U.S. region in conventional and organic cropping systems. One landrace (Purple Straw) and one modern cultivar (Pembroke 2014) were grown under three split N application treatments (ST1, ST2 and ST3). Late N applications (ST3) significantly increased protein content for both years by 5.45% and 6.11% respectively compared to a single application; however, this treatment decreased yield. Cropping system had consistent effects in that conventional system exceeded organic system except for thousand kernel weight. Conventional system had greater yield by 16.11% and 20.17% respectively for both years than organic system. Similarly, sedimentation value (a baking quality trait) was greater by 14.27% and 11.12% respectively in conventional than organic system. This study has generally found improvement in protein content by N application on soft red winter wheat. In addition, more studies should be done in organic system to examine other baking quality traits.

Key words: late nitrogen application; cultivars; feekes scale; production system

تقييم فعالية تجزئة ووقت اضافة السماد في تحسين الحاصل والصفات النوعية للحنطة الشتوية الناعمة الحمراء في كنتاكي

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المستخلص

يزداد الاهتمام بين الفلاحين في كنتاكي لإنتاج حنطة محلياً تمتاز بمحتواها من البروتين والكلوتين لغرض الخبز بما يتلائم واحتياج متطلبات سوق المخابز. أن المناخ الرطب والحار السائد في جنوب شرق الولايات المتحدة ملائم لزراعة وانتاج الحنطة الحمراء الناعمة والتي تمتاز بقلة محتواها من البروتين. من التقنيات المقترحة لتحسين خواص البروتين وزيادة محتواه هو تجزئة اضافة السماد النايتروجيني بناءا على مراحل نمو المحصول. تهدف هذه الدراسة لتقييم فعالية تجزئة مواعيد اضافة السماد النايتروجيني بالطريقة التقليدية والعضوية واثرها في نمو الحاصل والصفات النوعية للخبز لصنفين من الحنطة الحمراء الناعمة المزروعة في المنطقة الشرقية من الولايات المتحدة الامريكية. شملت عوامل الدراسة صنفين من الحنطة الناعمة الاول (Purple Straw) والصنف الاخر(Pembroke 2014) تضمن العامل ثلاث مستويات من وقت تجزئة اضافة النايتروجين. اظهرت النتائج ان الاضافة المتأخرة ادت الى زيادة نسبة البروتين معنوياً بنسبة 5.45% و 6.11% للموسمين بالتتابع مقارنة بالاضافة على دفعة واحدة بالرغم من انها ادت الى انخفاض الحاصل. تفوق نظام الزراعة التقليدي على نظام الزراعة العضوي في جميع الصفات المدروسة عدا وزن ١٠٠٠ حبة. تفوق حاصل الزراعة التقليدي عن نظام الزراعة العضوي بنسبة 16.11% و 20.17% للموسمين بالتتابع. كما اظهرت النتائج تفوق النظام التقليدي لصفة ترسب طحين الحنطة والتي هي احد الصفات المدروسة لتقييم جودة الخبز بنسبة 14.27% و 11.12% خلال موسمي الدراسة. خلصت هذه الدراسة الى ان هناك تحسين في نسبة محتوى البروتين وبعض الصفات النوعية للحنطة الناعمة الحمراء عن طريق تجزئة ووقت اضافة السماد النيتروجيني.

الكلمات المفتاحية: اضافة النايتروجين المتأخرة، الاصناف، مراحل نمو محصول الحنطة، نظُم الزراعة

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is a major part of the world's diet and is a major source of energy, protein, vitamins and other beneficial compounds (13, 21). Soft red winter wheat (SRW) is characterized by high grain yield with relatively low protein content, which makes it an important source of grain used in baking products such as cookies, pastries, and cakes, but typically not bread. Environmental conditions exert a large effect on end-use baking quality traits. SRW is commonly grown in the southeastern region of the United States, which is known for its warm, humid weather during the summer months (14). This kind of weather is not suitable for producing high protein bread wheat. Adoption of effective nitrogen (N) fertilizer management practices such as split fertilizer N applications is a strategy of dividing total N application into two or more treatments. It is one of the methods that can help growers enhance N use, promote optimum yields and mitigate the loss of nutrients through leaching, denitrification, runoff and volatilization (11). Timing of N applications has also been shown to influence protein concentration when applied at late growth stage (heading or anthesis) (4, 27). Limited research has been conducted in many parts of the world on the effect of split N application for wheat and its relationship with grain yield and quality traits (17). Furthermore, this practice has not been examined in the southeastern US as a strategy for positively influencing desired end-use traits. At the same time, there is a growing demand in the region to produce wheat grain with increased protein content and/or strength for local, artisan bread baking markets (15). As protein content in wheats grown for bread have been shown to be significantly related to N management and availability (12), additional work to identify how N management in various production systems to achieve desired end-use trait goals is needed. Specifically, split N application also affects the quality of wheat flour because delayed N applications mainly benefit protein build-up over starch in grain and extend the duration of grain filling (22). However, the impact of split N on wheat quality has varied between studies (9,10,20). The positive effects of N splitting can be mainly attributed to the alteration in grain protein content, which results in an improvement of the baking quality of wheat flour gliadins and glutenin as well as certain high molecular weights of glutenin subunits (HMW-GS), which lead to an improved baking quality of wheat flour. Therefore, N splitting is more efficient than late N application in improving wheat quality, and it has the potential to reduce N fertilization rates in wheat production systems (29).

Further, it has been previously shown that conventional and organic cropping system have varying effects on yield and end-use quality traits (3, 7). Specifically, previous studies have shown that wheat grown in conventional production systems may result in higher yields, higher gluten content, and greater loaf volume than wheat grown in organic systems. Conversely, wheat grown in organic systems may have lower gluten content, but higher gluten strength (8). The objectives of this study were: (1) to investigate the effect of cropping systems (conventional) and (organic) on growth, yield, and baking quality traits of soft red winter wheat and (2) the response of selected landrace and modern cultivars to different N splitting and timing treatments in these two cropping systems.

MATERIALS AND METHODS

This study was conducted at the University of Kentucky Horticulture Research Field, (37^o 9'74.6.34"N, 84^o 53.45.52’’W) in Lexington, KY, USA) during two growing seasons 2018-2019 (Y1) and 2019-2020 (Y2). The soil type is a Bluegrass-Maury silt loam (Fine, mixed, active, mesic oxyaquic paleudalfs). Winter wheat (*Triticum aestivum* L.) was planted on 24 October 2018 and 25 October 2019. The experiment was conducted using randomized complete block design with cropping system, wheat cultivar and split timing N application as treatment factors. Treatments were arranged within fields of each cropping system (one field conventional, one field organic) with four replications. Fields were rotated each year to reduce carry-over of treatment factors between years. Six row plots measuring 5.5m^2 (4.6m x 1.2m) were used for the study. Two SRW cultivars were evaluated: one modern cultivar selected for high yield potential and lodging resistance and good test weight (Pembroke

2014) and one landrace selected for regional and historical adaptation to Kentucky (Purple Straw). Purple Straw was one of the earliest SRW varieties grown in the United States and was used regionally in southeastern states due to winter hardiness and wide adaptability (23). In addition, it is known for being low-gluten, high-protein and with a flavor that includes floral overtones. Nitrogen sources were selected based on conventional and organic management specifications. Urea (46% N) was used for all applications in the conventional system (CONV) and a granular organic fertilizer (10% N, NatureSafe 10-2-8, Darling Ingredients, Inc. Irving, TX) was used in the organic system (ORG). In each system, N applications consisted of three timing treatments, where N was added in one, two or three applications (ST1, ST2, ST3, respectively). Total N application for all treatments was 112.08 kg/ha, divided evenly between any split N treatments. Treatments were applied according to growth stage and common application timing for each production system (CONV or ORG) (Figure 1). The first application for the ORG system was prior to planting, which is customary for ORG production in the region, due to the relatively slow-release of nutrients from the manure-based fertilizer. The first application of fertilizer in the CONV was at Feekes stage 3 in the spring, due to the readily available nature of the CONV mineral fertilizer (also customary practice in the study region).

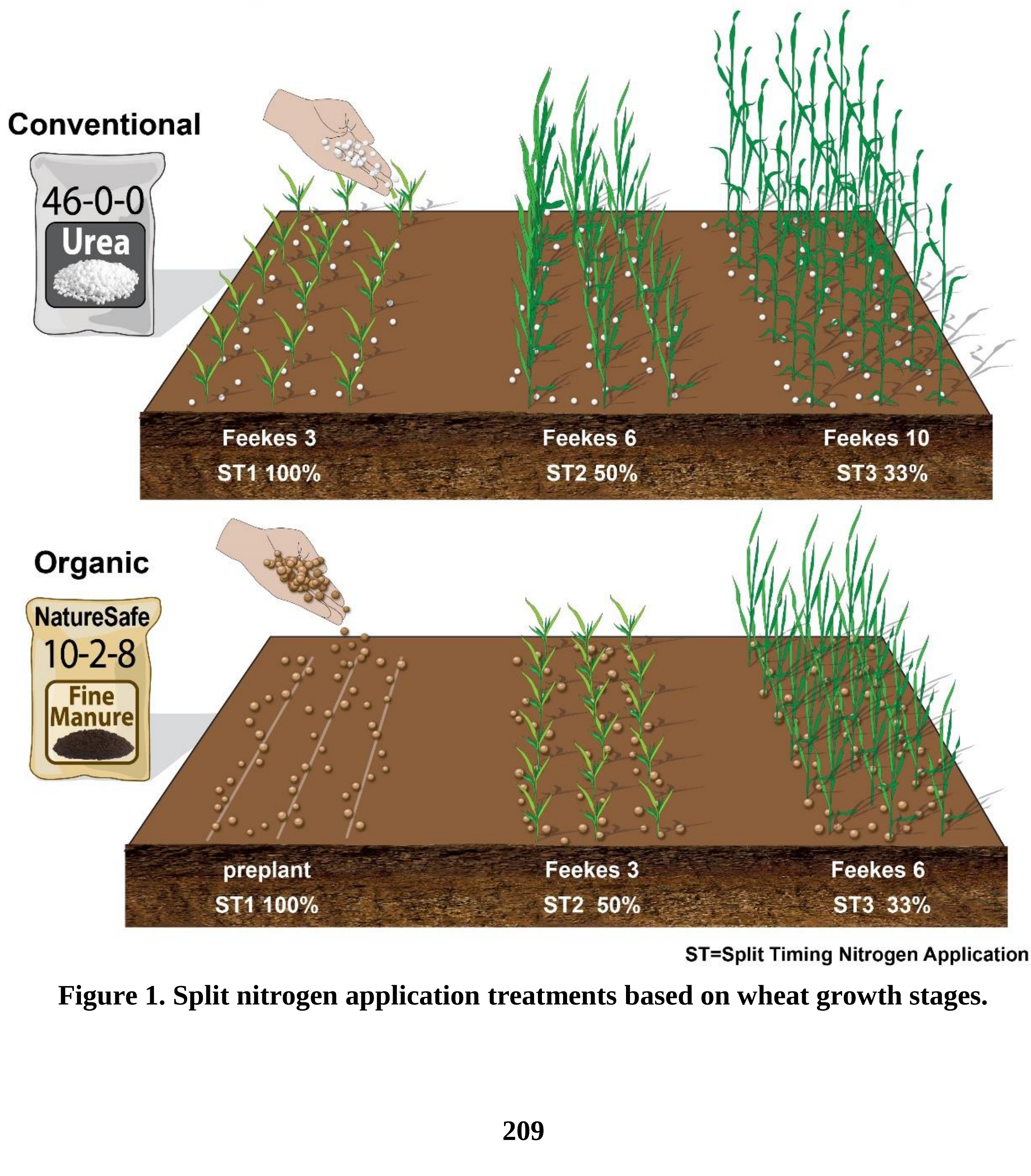

Figure 1. Split nitrogen application treatments based on wheat growth stages.

Weeds were monitored by weekly scouting and managed according to standard practice for each system. Weeds were not above the economic threshold in the CONV plots in either year, so no herbicide was applied. In the ORG plots, however, weeds were controlled using hand cultivation at Feekes growth stage 6, in early April of each year. The ORG field was managed following the USDA National Organic Program rules (24) but was not certified organic.

Agronomic traits and statistical analysis

All growth performance and grain quality data were collected from the center four rows of each plot. Growth traits recorded included growth stage (Feekes scale), heading date (HD; Julian), and plant height (PH; cm). The HD was determined for each plot when more than 50% of the spikes within a plot had emerged from the flag leaf sheath. Plant height was measured from the soil surface to the spike's top, excluding awns. Yield components included thousand kernel weight (TKW). The yield was calculated from post-harvest plot yields after adjusting for moisture and test weight using a GAC 2100b grain analysis computer (Dickey-John, Auburn, IL). The thousand kernel weights were measured using an ESC-1 seed counter (Agriculex Inc., Ontario, Canada). Grain quality traits included sedimentation value (SV, mL), protein content (%), and predicted lactic acid (%). Sedimentation value was measured after the method of Dick and Quick (1983). Protein content and the predicated lactic acid were measured from a 50g subsample of grain from each plot using near-infrared reflectance (NIR) (DA 7250, Perten Instrument, Hagersten, Sweden). Analysis of variance (ANOVA) was performed using a linear mixed model (PROC GLIMMIX, SAS 9.4, SAS Institute, Cary, NC, USA). Data were analyzed as a split plot, with cropping system by split N application as the main plot factor and cultivars as the split-plot factor. Split N application, cultivars, system, and all possible interactions were fixed effects and the interaction between system, split N application and replicate was a random effect. Mean comparison analysis for main effects and interactions were calculated using Tukey's test (HSD) at the 0.05 level.

RESULTS AND DISCUSSION

Agronomic traits

Plant height

Averaged across cultivar and split N timing treatments, plants were taller in the CONV compared to ORG cropping system in both years (3.5% in Y1 and 3.7% Y2) (Table 1). Purple Straw was significantly taller than Pembroke 2014 by 54.2% and 59.1% in Y1 and Y2, respectively (Table 1). Plant height was not affected by the split timing of N treatments (Table 1). Plant height varied in the modern cultivar (Pembroke 2014), depending upon the system it was grown in, and was consistently shorter when grown in the ORG system (Table 2).

Table 1. Main effect for plant height (cm), thousand kernel weight (TKW, g), yield (kg ha^{-1}), protein content (%), lactic acid (SRC, %) and sedimentation value (SV, mL). Means with the same letters within each column and main effect are not significantly different based on Tukey's Honest Significant Difference (HSD) test performed at α≤0.05.

Main effect		Plant height		TKW		Yield		Protein content		SRC		SV	
		Mean		Mean		Mean		Mean		Mean		Mean	
Year		Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
System	CONV	115.15a	107.39a	36.98b	40.44	3457.64a	3055.22a	11.0a	12.76a	98.15	110.11a	7.05a	9.30a
	ORG	111.20b	103.58b	38.90a	39.83	2941.96b	2495.35b	10.64b	11.24b	98.77	105.83b	6.11b	8.32b
Cultivar	Purple Straw	137.30a	129.54a	37.69	40.38	2118.36b	2693.32	11.64a	12.13a	96.83b	108.06	6.68	9.86a
	Pembroke 2014	89.04b	81.42b	38.18	39.88	4281.24a	2857.24	9.99b	11.87b	100.46a	107.89	6.48	7.76b
Timing	ST1	113.24	105.62	37.63	39.83	3295.39	2679.45	10.53b	11.57b	98.51	107.08	6.33	8.66
	ST2	113.45	105.62	37.74	40.66	3176.95	2845.23	10.80ab	12.13ab	98.73	108.00	6.56	8.93
	ST3	112.82	105.2	38.45	39.91	3127.06	2801.17	11.12a	12.30a	98.69	108.83	6.85	8.83

Table 2. Mean values for plant height (cm), thousand kernel weight (TKW, g), solvent retention capacity (SRC, %), and sedimentation value (SV, mL) for the system by cultivar interaction. Means with the same letters within each column are not significantly different based on Tukey's Honest Significant Difference (HSD) test performed at α ≤ 0.05.

System	Cultivar	Mean plant height		TKW	SRC	SV
		Y1	Y2	Y2	Y2	Y2
CONV	Purple Straw	138.01a	130.10a	40.33ab	111.67a	10.08a
CONV	Pembroke 2014	92.29b	84.67b	40.55a	108.56b	8.53b
ORG	Purple Straw	136.60a	128.98a	40.44ab	104.44c	9.64a
ORG	Pembroke 2014	85.79c	78.17c	39.22b	107.22b	7.00c

Grain yield

Grain yield was consistently greater in the CONV cropping system compared to the ORG system (Table 1). In Y1, yield in the CONV system was greater by 17.5%, and by 22.4% in Y2. In Y1, the cultivar main effect was significant, with Pembroke demonstrating 67.59% greater yields than Purple Straw. In the same year, yield in the CONV system was more sensitive to timing of N applications (Table 3). Yields in the CONV ST1 treatments were greater than the CONV ST3 treatments, though neither differed from the CONV ST2 treatment. In the ORG system, yield did not differ between timing treatments, and were numerically lower in all ORG treatments compared to the CONV treatments, though ORG timing treatments did not differ statistically from the CONV ST2 and ST3 treatments (Table 3).

Table 3. Mean value for yield (kg ha^{-1}) and sedimentation value (SV, mL) for the system by split N timing interaction in Y1. Means with the same letters within each column are not significantly different based on Tukey's Honest Significant Difference (HSD) test performed at α ≤ 0.05.

System	Timing	Yield	SV
CONV	ST1	3782.86a	7.37a
CONV	ST2	3402.34ab	6.79a
CONV	ST3	3187.71bc	7.00a
ORG	ST1	2807.92c	5.29b
ORG	ST2	2951.56bc	6.33ab
ORG	ST3	3066.40bc	6.71a

Thousand kernel weight

In Y1, TKW was 5.06% lower in the CONV system than in the ORG system (Table 1) when averaged across cultivar and N rates. However, in Y2, no significant differences were observed between systems, nor between cultivars or split N application treatments in either year (Table 1). In Y2, Pembroke 2014 grown in the CONV system had significantly greater TKW than same cultivar grown in ORG system but did not differ significantly from Purple Straw in either system (Table 2).

Quality traits

Protein content

Protein content was consistently higher in the CONV system than in the ORG system. In Y1, plants in the CONV treatments produced more protein content than in the ORG when averaged across cultivar and split N timing treatments (Table 1). This trend was also repeated in Y2. Purple Straw had greater protein content than Pembroke 2014 by 15.25% and 2.16% in Y1 and Y2, respectively (Table 1). Treatments with three split N applications (ST3) had greater protein content than those with only one N application (ST1). However, protein content in ST1 and ST2 did not differ. This was also true for ST2 and ST3 regardless of cropping system and cultivar (Table 1). Cultivars responded differently to the timing treatments in Y2 (Figure 2). Purple Straw grown with three split applications (ST3) had greater protein content than the same cultivar with only one N application (ST1), though protein content in the Purple Straw ST3 did not differ from the same cultivar with two N applications, nor Pembroke 2014 with two applications. Protein content did not vary by N treatments in Pembroke 2014.

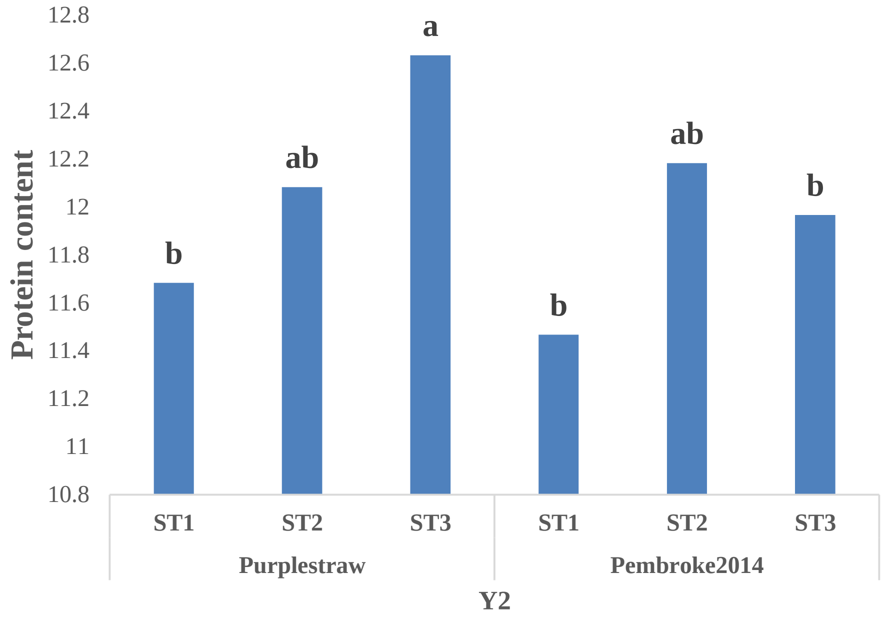

Figure 2. Protein content (%) as affected by cultivar and split N timing interaction in Y2 (means with same letters are not significantly different).

Lactic acid

In the CONV system, gluten strength predicted by lactic acid solvent retention (SRC%) was significantly greater than the ORG system in Y2, while, in Y1, data presented no significant differences between systems (Table 1). Among cultivars, in Y1, the SRC% value of Pembroke 2014 was significantly higher than Purple Straw when averaged across cultivar and split N timing treatments. This trend differed in Y2, as there were no significant differences between cultivars. split N timing treatments did not significantly affect the predicted SRC% regardless of cropping system and cultivar (Table 1). In Y2, SRC% was affected by the system interaction with cultivar (Table 2). Purple Straw grown in the CONV system had the highest SRC% value within and across systems, while Pembroke 2014 did not differ across systems. In Y1, the cultivars used in the study demonstrated variable responses to the N application treatments, depending on which system they were grown in (Figure 3). Greater SRC% content was observed in Pembroke 2014 grown in the ORG system with a single N application (ST1) than Purple Straw grown in ORG system with one or two N applications (ST1 and ST2, respectively). However, Pembroke 2014 ST1 ORG treatments did not differ statistically than all other treatments grown in CONV or/and ORG systems. Solvent retention capacity did not vary among the treatments in the CONV system. There was a more variable response to N timing treatments by cultivar in the ORG system. Purple Straw had significantly lower SRC% than Pembroke 2014 in the ST1 and ST2 treatments but did not differ in the ST3 treatment.

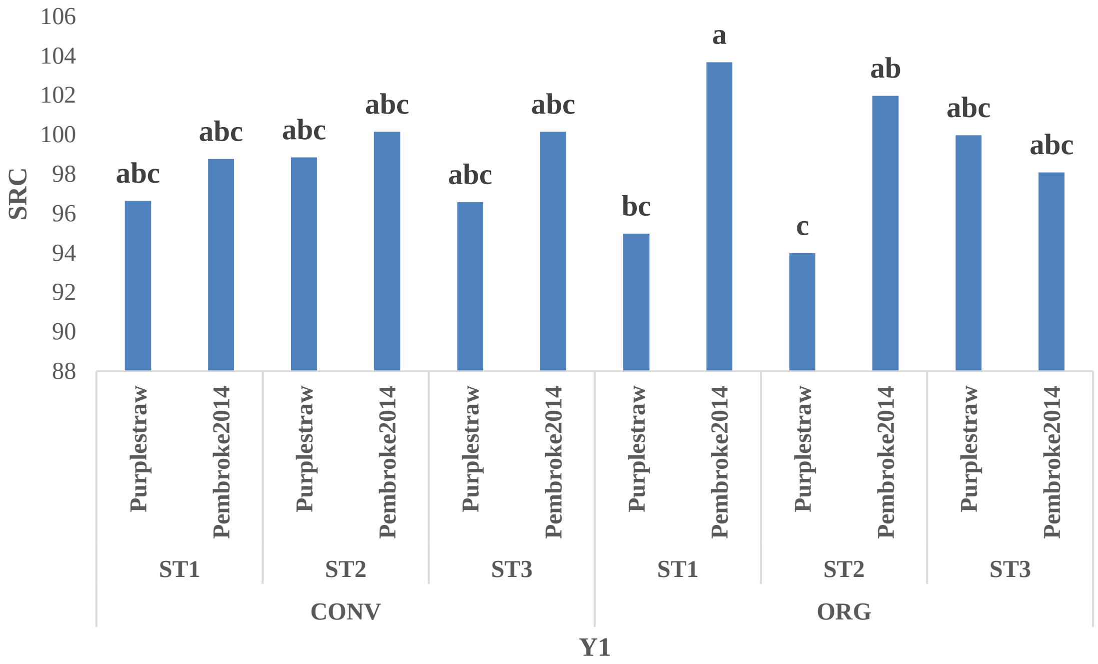

Figure 3. Lactic acid (SRC%) affected by cultivar, system, and split N timing interactions in Y1 (means with same letters are not significantly different).

Sedimentation value

Sedimentation values (SV, mL) were significantly higher in the CONV system than the ORG system, averaged across cultivar and N timing treatments (Table 1). The same pattern was shown in both years with SV differences by 15.4% and 11.8%, respectively. In Y2, significant differences between cultivar were observed. Purple Straw had a significantly higher SV value by 27.06 % than Pembroke 2014, irrespective of split N timing treatment or cropping system. Split N application had no significant effect on SV% value regardless of cropping system and cultivar (Table 1). There was a significant interaction between systems and timing in Y1 and systems and cultivar in Y2 (Tables 2 and 3). In Y1, there was no significant differences in split N timing treatments within or across systems except for ORG ST1 treatment, which gave the lowest value (Table 3). As for Y2, within each system, SV differed significantly between the cultivars (Table 2). Purple Straw showed greater SV than Pembroke 2014 in both systems (Table 2).

Agronomic traits

Plant height

Conventional cropping systems are often distinguished by the use of high-yielding, dwarf (HYD) cultivars and the application of plant-available fertilizers. The landrace cultivar (Purple Straw) is among the oldest wheat cultivars currently grown in the southeastern US (23). Like many land race wheats, it is known for greater plant height than modern cultivars, as well as higher protein content. These findings are consistent with other studies comparing N fertilizer response in organic and conventional systems, which show that mineral fertilizers increase plant height more than organic or biological fertilizers (e.g., manures) and that increasing N rate increases plant height (19). When averaged across systems, the plant height of Pembroke 2014 differed significantly but this was not the case with Purple Straw (Table 2). It may suggest for Purple Straw that innate traits like plant height may be more dependent upon genetic factors than management when N is not seriously limited (26).

Grain yield

The greatest yield was achieved in the CONV system in the ST1, though it did not differ from the CONV ST2 treatment (Table 3). The CONV ST3 treatments had the lowest yield within the CONV system. We assume that since there is a negative correlation between yield and grain N (5), wheat plant under the later N application tends to utilize N to produce high grain protein content rather than high yield. On the other hand, N application in the season indicated similar and significantly lower yield in the ST3 than ST1 and ST2, respectively. Therefore, the plants benefitted from the applied N at the growth stages Feekes 3 and 6 to increase yield. On the other hand, late N application at Feekes 10 induced the plants to produce grain with higher protein content rather than yield (Tables 1 and 3). As for the ORG system, the consistency in the lower yield probably related to the limited N availability in accordance with the unfavorable weather condition (Table 3). The greatest yields were consistently observed in the potential high-yield cultivar, Pembroke 2014 (Table 1), which has demonstrated consistently high yield potential, test weight, and lodging resistance in previous cultivar trials in the region (25). Given that weed pressure was virtually equal in both systems, yield variation between cultivars grown in CONV and ORG systems are most likely due to lower soil N supply in the organically managed field. These results are consistent with those of Campiglia et al. (6), who found that grain yields were 15% lower in organic cropping systems compared to conventional cropping system when comparing winter wheat production, although the yield gap between the cropping systems varied from 5 to 32% across six consecutive growing seasons.

Thousand kernel weight

Although yield was lower in the ORG system, TKW was significantly greater in the CONV system in Y1 (Table 1). Thousand kernel weight in the ORG system was 5.2% higher than in the CONV in Y1 (Table 1). The limited N availability in the ORG system may have reduced yields and increased TKW. In Y2, no differences were observed between production systems as a main effect. Although, it is modified by cultivar × system interaction whereas the results showed a different trend as Pembroke 2014 grown in CONV system had highest TKW (Table 2). The availability of N in CONV system may have allowed for greater TKW than ORG system. This is consistent with previous work by Cox et al. (7), who found that wheat produced in a conventional system had relatively higher TKW than wheat grown in an organic system during the early years of organic production in the northeast USA.

Quality traits

Protein content

Protein content varied between the CONV and ORG systems. The conventional cropping system demonstrated higher protein content for both years of study (Table 1). The results agreed with the finding of Le Campion et al. (16), who reported cultivar grown in an organically managed system had a reduction in protein content about 10 to 22%. When averaged across production systems and N timing, Purple Straw resulted significantly in greater protein content by 15.25% and 2.16% in Y1 and Y2, respectively, than Pembroke 2014. This result may be attributed to the genetic background as well as timing and site N availability. Protein content was greater in the ST3 treatment than in the ST1 treatment during both study years, though it did not differ from protein content in the ST2 treatment (Table 1). However, in Y2, Purple Straw interacted with ST3 and gave higher protein content than Pembroke 2014 with the same treatments (Figure 2). The grain protein content is shown to be dependent on the amount of soil mineral N available during plant growth and favorable growing conditions (1, 2). This result indicates that soil N availability at critical periods of seed fulling has sufficient available N to express cultivar variability in N content and, as a result, protein content as seen in ST3 indicating that applying N in Feekes 10 may increase protein content.

Lactic acid

Lactic acid SRC is a measure to predict gluten strength (28). The conventional cropping system resulted in higher SCR% than ORG cropping system in Y2 (Table 1). Pembroke 2014 had significantly greater SRC% than Purple Straw in Y1. It is probably attributed to the genetic background of this cultivar. Van Sanford et al. (25) reported that Pembroke2014 had greater lactic acid SRC% than the average values of 13 studied cultivar and breeding lines. This result was modified by interaction in Y2, as Purple Straw grown in CONV system gave higher SRC% than all treatments (Table 2). Several factors could be involved and attested to SRC, such as response to N level availability during production season and the favorable environmental conditions. In addition, it may be affected by the freeze damage that occurred during gain filling that gave advantage to Purple Straw as it is known to have greater winter hardiness than some modern cultivars (23). The interaction between cultivar, system, and split N timing in lactic acid SRC in Y1 (Figure 3) indicated significant differences among cultivars. whereas Pembroke 2014 ST1 ORG treatment gave highest SRC% than Purple Straw ST1 and ST2 ORG treatments which demonstrated that cultivar played a crucial role in this interaction rather than systems and split N application.

Sedimentation value

Sedimentation values (SV) varied between the CONV and ORG systems since the same cultivar produced significantly greater SV in CONV than ORG systems (Table 1). This attributed to the richness of N availability in CONV system. Ottman et al. (29) reported that SV value increased with the using of high nitrogen application. In Y2, the interaction between systems and cultivar, Purple Straw showed comparatively higher SV than Pembroke 2014 regardless to system (Table 2). This result may be related to the fact that this quality trait is correlated with protein content as Purple Straw is known to be a genetically high protein cultivar (23). In Y1 (Table 3), the interaction between system and timing indicate that late N application can improve the end-use baking quality trait (29). The variation in SV appeared more prominently in ORG system than CONV. This may be due to the slow release of organic fertilizer during the grown season in accordance with split N timing treatments at Feekes 6 (stem elongation). No difference was noticed in the CONV system for split N treatments.

CONCLUSIONS

The purpose of the current study was to evaluate the split timing fertilizer application effect on traits associated with baking quality in different production systems. The findings of this study showed that late N application at Feekes 10 resulted in increased protein content. However, there was no obvious effect of split N timing application on the other studied traits. The two cultivars in this study responded differently in the traits that were evaluated. Purple Straw had a greater plant height and protein content due to its genetic characteristic as a landrace cultivar in southeastern states. Pembroke 2014 resulted in a greater lactic acid SRC %, and yield in Y1 only. Thus, we suggest that late split N application would be beneficial to improve the end-use baking quality traits of SRW wheat. On the other hand, more research should be done regarding the effect of N late application on organic farming system.

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