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Optimizing row spacing for dual-purpose wheat cultivation in Thailand

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ABSTRACT

Wheat production in Thailand is increasing due to rising domestic demand. Dual-purpose wheat cultivation, aimed at producing grain and stems for drinking straw manufacturing, has gained attention to enhance farmer income and promote sustainable practices. This study evaluated the effect of row spacing on yield potential (YP) yield components and stem qualities, including plant number (PN), spike number (SN), spike length (SL), thousand-grain weight (TGW), and stem qualities, specifically the diameter of the second internode (D2), length of the second internode (L2), stem hardness (Hs), and straw yield (SY) for drinking straw production. The experiment employed a randomized complete block design (RCBD) with three replications in 8 square meters plot sizes. Four-row spacings were tested: 15, 20 (conventional), 25, and 35 cm, with a seed rate of 125 kg/ha The findings indicated that row spacings of 20 cm and 25 cm yielded the highest values for YP (5,044,888 kg/ha), SN (309–308 spikes/m^2), TGW (37.42–37.64 g), D2 (3.57–3.66 mm), and SY (1,580,000–1,740,000 straws/rai). These spacings also received the highest ratings in a farmer satisfaction survey. The findings suggest that 20–25 cm row spacings are optimal for dual-purpose wheat cultivation in Thailand, balancing grain yield and stem quality for sustainable production.

Keywords: wheat, dual-purpose cropping, row spacing, sustainable agriculture, straw

INTRODUCTION

Despite being a temperate crop, wheat (*Triticum aestivum* L.) cultivation in Thailand has increased due to strong domestic demand from niche markets such as artisan bakeries, wheat grass juice producers, malt producers, and florists. These demands encourage using domestically produced high-quality seeds and dry spikes to avoid issues related to the importation process. Since 2019, several Thai organizations, including the Agricultural Research Development Agency (ARDA), Rajamangala University of Technology Lanna (RMUTL), the Rice Department, and Maejo University, have collaborated to enhance wheat research and its applications. As a result, wheat production in Thailand has significantly increased, particularly in the provinces of Chiang Mai, Mae Hong Son, and Chiang Rai in the upper northern region of the country (Panyatuy et al., 2021; Chaiwongsar et al., 2019; Rice Department, 2019; Rice Department, 2021). Dual-purpose wheat cropping is an agricultural method where wheat is grown for two main purposes: producing grain and providing fodder for livestock feed. This approach allows farmers to maximize the utility of their crops, particularly in regions where livestock is an integral part of the agricultural system (Sharma et al., 2019; Munsif et al., 2021). In tropical areas like Thailand, the climate can limit the effectiveness of this technique due to the short periods of low temperatures. Instead of focusing solely on grain and forage production, Thailand may be better suited for producing grain and stems specifically for processing into drinking straws. The high temperatures in this region can strengthen wheat stems by increasing lignin accumulation in their cell walls (Han et al., 2024; Lamba et al., 2023).

Wheat stems have several properties that make them ideal for drinking straw production, including a cylindrical shape and a hollow pith that resembles plastic straws. Additionally, they exhibit high tensile strength, low water absorption, resistance to sogginess, tolerance to boiling temperatures, suitability for both hot and cold beverages, and no tendency to stain colors. These characteristics are important for effective drinking straws (Jiang et al., 2020; Chaiwongsar et al., 2020; Munsif et al., 2021; Johnson et al., 2021; Zhang et al., 2022; Tarani and

Chrissafis, 2024). As a result, dual-purpose wheat farming for grain production and straw processing may present a sustainable alternative for wheat cultivation in Thailand. This method can optimize resource use by allowing farmers to yield grain and drinking straws, thus better-using land, water, and inputs while enhancing overall output. Moreover, it can diversify farmers' income streams, enabling them to earn revenue from stem and grain sales. This reduces dependency on a single source of income and improves financial stability. However, research on dual-purpose wheat farming in Thailand remains limited. As the diverse planting methods and tools used for wheat cultivation in Thailand, each type of equipment results in different row spacing, which may lead to variations in wheat quality, according to Hussain et al. (2012), Hussain et al. (2014), Mekonnen (2017) and Saini and Tiwana (2023). This study aims to evaluate the optimal row spacing for dual-purpose wheat cultivation in Thailand, focusing on grain yield and stem production for drinking straw processing.

MATERIALS AND METHODS

Site description and experimental design

Field experiments were conducted from October 2021 to March 2022 at the experimental field of Rajamangala University of Technology Lanna, Lampang campus, Mueang district, Lampang province, Thailand (latitude: 18° 21' 48" N, longitude: 99° 35' 40" E; elevation: MASL at 260 m). This region is characterized by a tropical wet-dry climate (Land Development Department, 2009). During the experiment, the average monthly temperatures in November, December, January, and February were below 25°C, while in October and March, they exceeded 25°C. Most rainfall occurred in October, totaling 2.4 mm (Figure 1). The soil at the experimental site was classified as silty clay loam (Land Development Department, 2009). Soil samples were collected and analyzed following the guidelines set by the Land Development Department (2017), and the soil properties are detailed in Table 1. The experimental plot utilized a randomized complete block design with three replications. Each replication comprised a plot size of 8 m^2, and this experiment used a sowing method for planting wheat with 125 kg/ha of seed rate and Fang 60 wheat variety. The experiment was conducted using four different inter-row spacings: 15, 20 (conventional), 25, and 35 cm. The fertilizer was applied two times; the first time was applied together with wheat planting and using fertilizer type 15-15-15 (N-P-K) with 250 kg/ha rates, and the second time using 46-0-0 (N-P-K) with 62.5 kg/ha rates, according to the recommendations of the Rice Department of Thailand. Irrigation was carried out using agriculture rain fall tape, with the first irrigation applied immediately after sowing and subsequent irrigations every 7–10 days until the ripening growth stage of wheat.

Yield potential and yield components

PN and SN were randomly counted from 1 square meter selected in each replication. SL was measured by assessing the length of ten randomly chosen spikes for each replication, excluding awns at the maturity stage. YP was recorded by measuring the weight of grains threshed from 1 square meter (sub-plot) and converting it to kilograms per hectare at 12% moisture content. TGW was determined by randomly selecting grains after threshing and weighing grains from each replication. These data were collected at the ripening stage of wheat.

Properties of wheat stem

The specific properties of wheat stems that are beneficial for the processing of drinking straws include several key measurements. PH was measured by taking the height of ten randomly selected plants from each replication, from the ground to the top of the spike, excluding the awns at the maturity stage. Wheat stems were collected randomly from the main stem of plants from the middle rows of each plot at the maturity stage. Only the second internode was analyzed (Figure 2) because this internode was the most suitable for drinking straw production. The first internode was damaged during harvesting, and the others were too small or too short for drinking straw processing (Chaiwongsar et al., 2020). The diameter of the D2 of ten random samples was measured by millimeters using a vernier caliper. The length of the L2 of the same ten samples was measured in centimeters using a ruler. The Hs of the same ten samples were assessed using a texture analyzer, with the results converted to N/mm^2 according to the method outlined by Shaw and Tabil (2005). Additionally, the SY was estimated by randomly counting the straws produced from a 1 m^2 subplot, which was converted to kg/ha. These data were collected at the ripening stage of wheat.

Survey and farmer satisfaction

Ten expert wheat growers from Chiang Mai and Mae Hong Son provinces were randomly selected to participate in an experiment to evaluate the outcomes of growing wheat with different row spacings. This evaluation was conducted at the experiment's beginning and end. A comprehensive assessment of farmer satisfaction regarding row spacings was performed using a 5-point hedonic scale. The average scores correspond to the following levels of satisfaction: 1.00–1.80 indicates minimal satisfaction, 1.81–2.60 denotes slight satisfaction, 2.61–3.40 reflects moderate satisfaction, 3.41–4.20 signifies high satisfaction, and 4.21–5.00 represents the highest satisfaction (Likert, 1967). The farmers' satisfaction was evaluated based on three key attributes: 1) Convenience: This refers to how easily farmers can apply the results in their practices. 2) Suitability: This assesses whether the row spacings are appropriate for their skills and available equipment. 3) Effectiveness: This measures the impact of row spacing on grain yield and the production of SY.

Data analysis

All experiments were conducted in triplicate. Differences between means were determined by one-way analysis of variance (ANOVA) and Duncan's multiple range test (using SPSS statistical software version 16) with a significant level of $P \leq 0.05$.

Table 1. Information on soil properties of the experimental sites

Soil composition analysis list	Value
pH	6.33
Electric conductivity (EC) (µS/cm)	540.29
Organic matter (OM) (%)	1.80
Total nitrogen (N) (%)	0.09
Available phosphorus (P) (mg/kg)	212.71
Exchangeable potassium (K) (mg/kg)	356.70

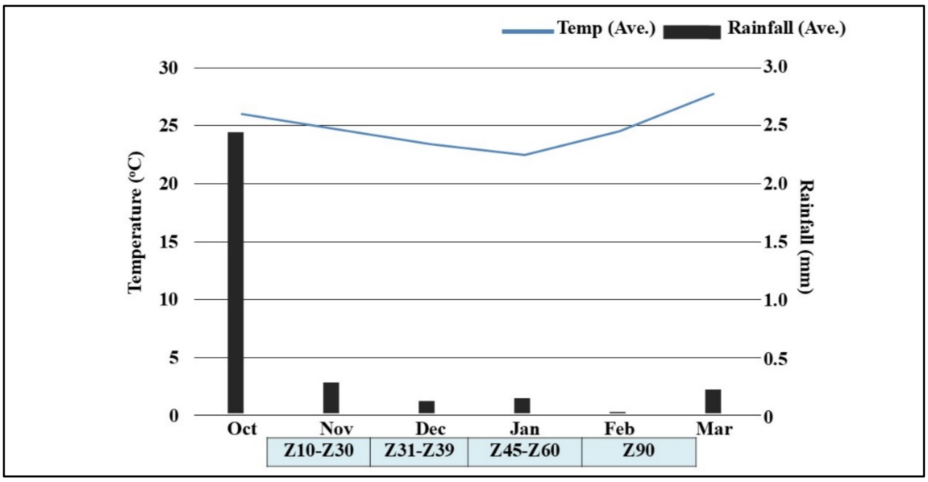

Figure 1. Average temperature and precipitation data collected at the experimental site by the weather station throughout the study, aligned with the major growth stages of wheat as indicated by Zadok's scale (Z).

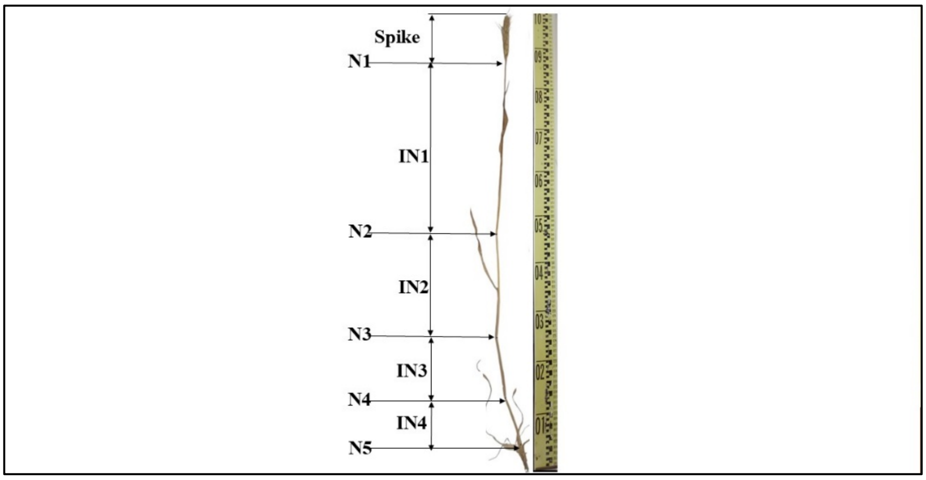

Figure 2. Schematic diagram of wheat straw with nodes (N) and internodes (IN). IN1 = the first internode; IN2 = the second internode; IN3 = the third internode; IN4 = the fourth internode; N1 = the first node; N2 = the second node; N3 = the third node; N4 = the fourth node; N5 = the fifth node.

RESULTS AND DISCUSSION

Effect of row spacing on yield and yield components

Row spacing regulates crop productivity by changing the plant architecture, photosynthetic efficiency of leaves, and source-sink relations of field crops (Samani et al. 1999). The investigation focused on two primary areas: productivity and the desirable characteristics of stems for drinking straw processing. Regarding productivity, row spacings of 15, 20, and 25 cm yielded the highest results per hectare (YP), measuring 4,956, 5,044, and 4,888 kg, respectively. These yields were consistent with other yield components, including TGW, where the highest values for TGW were observed at the 20 and 25-cm row spacings. Conversely, PN and SL did not show significant variation across different row spacings (Table 2). These findings align with previous research indicating that row spacing impacts wheat productivity. Studies by Abboye and Teto (2020), Chen et al. (2010), Hussain et al. (2014), and Mekonnen (2017) suggest that a row spacing of 20–30 cm tends to yield the best results. This is primarily attributed to the influence of row spacing on the photosynthetic capability of wheat plants. Narrow row spacing (15 cm) increases plant density within a given area, leading to heightened competition for light during photosynthesis. This competition can result in reduced yields and stunted plant growth. On the other hand, wider row spacing (35 cm) allows for more plants per row but can lead to greater competition for nutrients; due to the limited root length of wheat, the absorption of nutrients per plant is reduced. Additionally, wider row spacing may lead to an increased weed population, resulting in some nutrients being taken up by these weeds instead, negatively impacting grain yield. Further, Chen et al. (2010), Hussian et al. (2012), and Saini and Tiwana (2023) reported that high plant density in wheat cultivation can reduce grain yield by decreasing both spike number and thousand-grain weight.

Table 2. Analysis of mean values for yields and yield potential in different row spacing

Spacing (cm)	YP (kg/ha)	PN (plants/m^2)	SN (spikes/m^2)	SL (cm)	TGW(g)
15	4,956 ± 178.00^a	352.00 ± 45.03	316.33 ± 16.44^{ab}	9.73 ± 0.21	37.08 ± 0.43^b
20	5,044 ± 138.56^a	338.33 ± 40.72	309.00 ± 54.11^a	9.70 ± 0.53	37.42 ± 0.38^{ab}
25	4,888 ± 148.58^a	322.00 ± 18.33	308.00 ± 24.33^a	9.53 ± 0.32	37.64 ± 0.26^a
35	4,106 ± 156.95^b	339.67 ± 41.62	292.00 ± 13.86^b	9.53 ± 0.23	37.03 ± 0.10^b
F-test	**	ns	*	ns	*
CV (%)	13.85	13.02	12.48	1.80	5.52

^{ab}Means with the different lowercase superscripts in the same column indicate significant differences; *$P < 0.05$; **$P < 0.01$; ns = not significant; ± = standard deviation (S.D.); YP = yield potential; PN = plant number per square meter; SN = spike number per square meter; SL = spikes length; TGW = thousand-grain weight.

Effect of row spacing on desirable characteristics of stems for drinking straw processing

According to Table 3, row spacing did not influence PH, the length of the L2, or Hs. This finding aligns with the report by Woldekitros (2020), which stated that row spacing had a nonsignificant effect on plant height. Additionally, studies by Deressa et al. (2013) and Otteson et al. (2007) indicated that seeding rate, rather than row spacing, had a more significant impact on plant height and internode length. Since the same seeding rate was applied in this experiment, no differences in PH and L2 were observed. The D2 and SY were significantly affected by row spacing. Specifically, row spacings of 20 and 25 cm achieved the highest values for both D2 and SY because these distances allowed for optimal plant density. In contrast, other spacings resulted in higher plant density either per unit area or within the rows. As plant density escalates, leaf overlap occurs, diminishing photosynthetic efficiency and glucose translocation to the stem. This subsequently results in the basal internodes of the stalks being thinner (Xue et al., 2021). Research has indicated that higher planting densities can significantly reduce stem diameter and wall thickness, which in turn diminishes stem strength (Zheng et al., 2017; Kuai et al., 2016). However, we did not observe any differences in Hs or stem strength with variations in row spacing. It's important to note that data on wall thickness were not collected in this experiment, and this aspect should be investigated further. Additionally, SY is correlated with the SN, as shown in Table 2, since straws are generated from the stems with spikes (Chaiwongsar et al., 2020).

Table 3. Analysis of mean values for desirable characteristics of stems for drinking straw processing in different row spacing

Spacing (cm)	**PH (cm)**	**D2 (mm)**	**L2 (cm)**	**Hs (N/mm^{2})**	**SY (straws/ha)**
15	71.53 ± 2.49	3.17 ± 0.17^{b}	18.52 ± 0.69	2.26 ± 0.20	1,450,000 ± 17,457^{b}
20	71.23 ± 3.23	3.57 ± 0.16^{a}	18.08 ± 0.69	2.15 ± 0.14	1,580,000 ± 12,840^{ab}
25	70.10 ± 0.63	3.66 ± 0.01^{a}	16.42 ± 2.60	2.13 ± 0.28	1,740,000 ± 21,023^{a}
35	71.25 ± 2.51	3.25 ± 0.18^{b}	16.88 ± 1.21	2.31 ± 0.35	1,460,000 ± 14,578^{b}
F-test	ns	*	ns	ns	*
CV (%)	1.87	4.35	6.40	6.08	11.53

^{ab}Means with the different superscripts in the same column indicate significant differences; ns = not significant; *P < 0.05; ± = standard deviation (S.D.); PH = plant height; D2 = diameter of second internode; L2 = length of second internode; L2 = length of second internode; Hs = hardness of stalks; SY = straw yield.

Correlation analysis between productivity and the desirable characteristics of stems for drinking straw processing

The correlation analysis in Table 4 indicates that wheat productivity (YP) has a significant positive relationship with SN and SL, with correlation coefficients of 0.84. This suggests that SN and SL are critical components influencing productivity. Research by Jaenisch et al. (2022), Koppensteiner et al. (2022), Rachana et al. (2021), and Mohammadi et al. (2012) has shown that increases in SN and SL contribute to enhanced YP, as a higher spike number and grain number per spike support greater yields. Interestingly, the analysis also reveals a strong negative correlation between PN and TGW, with a coefficient of –0.96. This negative relationship may be attributed to the fact that a higher number of plants per area leads to increased competition for nutrients, resulting in deficiencies that can diminish TGW. This finding is supported by the works of Chen et al. (2010), Hussian et al. (2012), and Saini and Tiwana (2023).

For the desired characteristics of stems used in drinking straw processing, the correlation analysis presented in Table 4 indicates that PH has a positive and significant relationship with L2 (0.71). This may be because greater height positively influences stem elongation, increasing L2 (Panday et al., 2020; Yang et al., 2015). Conversely, PH shows a significant negative relationship with Hs (–0.68), which aligns with previous studies that report that increased stem elongation results in less lignin formation, thereby reducing stalk hardness (Milan et al., 2022; Farhad et al., 2023; Padam and Mukti, 2020; Han et al., 2024; Lamba et al., 2023). Additionally, Hs has significant negative correlations with PH (–0.68), D2 (–0.73), and L2 (–0.87). Since PH, D2, and L2 are crucial traits for wheat growth and development and are highly influenced by environmental factors, high temperatures during cultivation can induce plant stress. As reported by Milan et al. (2022) and Padam et al. (2020), such stress can hinder plant growth and development, adversely increasing stem strength due to elevated lignin synthesis and accumulation in the stem (Han et al., 2024; Lamba et al., 2023). The relationship between productivity and the desirable characteristics of stems for drinking straw processing showed that YP had a significant positive correlation with D2 measurements (0.70) and SY (0.85). This indicates a promising opportunity to develop and expand dual-purpose wheat cultivation in Thailand, aiming to produce grain and stems for drinking straw manufacturing. Particularly, when optimal conditions, such as appropriate row spacing, are implemented for dual-purpose wheat cropping, farmers can benefit from increased income through both grain and stem production

Table 4. The coefficient correlation between productivity and the desirable characteristics of stems for drinking straw processing in different row spacing

Traits	YP	PN	SN	SL	TGW	PH	D2	L2	Hs
YP									
PN	0.28								
SN	0.84^{*}	0.69^{**}							
SL	0.84^{*}	0.71	0.52						
TGW	0.59	-0.96^{*}	0.61	−0.65					
PH	0.04	−0.05	−0.24	0.57	−0.78				
D2	0.70^{*}	0.83	0.78	−0.28	0.91	−0.69			
L2	0.73	0.84	−0.28	0.98^{*}	−0.78	0.71^{*}	−0.46		
Hs	−0.56	−0.67	−0.66	−0.69	−0.76	-0.68^{*}	-0.73^{*}	-0.87^{*}	
SY	0.85^{*}	0.73^{*}	0.85^{*}	0.72	0.51	0.13	0.23	0.11	−0.44

*P < 0.05; **P < 0.01.

Farmer acceptance

A survey on satisfaction and interviews conducted with ten expert wheat growers from the Chiang Mai and Mae Hong Son provinces determined that row spacings of 20 and 25 cm received the highest satisfaction scores of 4.8 and 4.5, respectively (Table 5). These row spacings were rated highest based on crucial criteria: convenience, suitability, and effectiveness. The growers noted that row spacings of 15 and 35 cm were neither convenient nor suitable for their needs due to the lack of available equipment. Consequently, these options would lead to increased labor and production costs while also struggling to compete with other row spacings in terms of productivity. Additionally, the growers expressed concerns that wider row spacings might attract pest problems. This feedback strongly supports the adoption of 20 cm and 25 cm row spacings for dual-purpose wheat cultivation, as these spacings align with other findings indicating that they yield good productivity and desirable stem characteristics for straw processing.

Table 5. Farmer satisfaction with wheat cultivation on 4 different row spacings

Items	Row spacing (cm)				F-test	CV(%)
	15	20	25	35		
Convenience	2.4 ± 0.8^{b}	4.5 ± 0.5^{a}	4.5 ± 0.4^{a}	2.3 ± 0.7^{b}	**	19.29
Suitability	2.2 ± 0.9^{b}	4.8 ± 0.5^{a}	4.5 ± 0.5^{a}	2.1 ± 0.9^{b}	**	14.58
Effectiveness	2.6 ± 0.7^{b}	4.4 ± 0.4^{a}	4.6 ± 0.6^{a}	2.3 ± 0.6^{b}	**	19.67
Overall	2.4 ± 0.8^{b}	4.8 ± 0.4^{a}	4.5 ± 0.5^{a}	2.1 ± 0.7^{b}		

^{ab}Means with the different superscripts in the same row represented significant differences; ** P < 0.01.

CONCLUSIONS

Row spacing impacts the yield potential and components of wheat, as well as specific stem properties that are desirable for drinking straw production. In Thailand, a row spacing of 20 cm and 25 cm has proven suitable for dual-purpose wheat cultivation to produce grain and stems for drinking straw manufacturing. These row spacings yielded the highest potential outputs of 5,044 and 4,888 kg/ha and straw yields of 1,580,000 and 1,740,000 straws kg/ha, respectively. A farmer satisfaction survey also supports the adoption of these spacings, as they received the highest satisfaction ratings.

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