

Yield and yield components of purple waxy corn grown under different locations in Thailand

Gossai Mohamed¹, Kamol Lertrat^{1,2} and Bhalang Suriarn^{1,2*}

ABSTRACT: The information on yield and yield components is very important for breeding of purple waxy corn (*Zea mays* L.var.*ceratina*) before the new varieties are released to the farmers. The objective of this investigation was to determine the effects of location, variety and their interactions on yield, yield components and agronomic characters of five varieties of purple waxy corn at milky and maturity stages. Field experiment was carried out in a randomized complete block design with three replications at two locations in Uthai Thani and Khon Kaen, Thailand in the dry season 2014/2015. Location, variety and location by variety interactions were significant for yield at both milky and maturity stages except the interaction between location and variety for yield at maturity stage. Most interactions between location and variety had low contributions to total variations in yield at maturity stage, ranging from 2.9% to 9.8% except the interactions for seed yield (23.4%) and corn husk (17.3%). The results suggested that stable variety may be selected across locations. Khon Kaen had higher yield than Uthai Thani but the crop had longer maturity due to lower temperature at vegetative period. FC111 had the highest yield of 4,060 kg Rai⁻¹ followed by KGW5 (2,824 kg Rai⁻¹). FC111 also had longer days to maturity (65 days) than did KGW5 (54 days). KND had low yield of 2,364 kg Rai⁻¹ but it had the shortest days to flowering (52 days). The information on yield is very important for anthocyanin production from purple waxy corn.

Keywords: anthocyanin, GxE interaction, *Zea mays* L.var.*ceratina*

Introduction

Waxy or glutinous corn is an important food crop in Asia including Cambodia, China, Japan, Korea, Myanmar, Laos, Taiwan, Thailand and Vietnam. It is popular among local people in this region because of its stickiness. Similar to sticky rice, the stickiness in sticky corn is due to the amylopectin containing in its endosperm. The farmers in Asian countries have planted waxy corn for vegetable as a cash crop after rice harvest for decades (Lertrat and Thongnarin, 2008; Kesornkeaw et al., 2009). Moreover, starch of waxy corn has high amylopectin content

compared with that of normal corn, and it has high possibilities in industrial use (Klimeket et al., 2012). However, waxy corn has lower yield and more susceptible to pests than normal corn and super sweet corn due to the fact that waxy corn has received little interest for genetic improvement through breeding.

Recently, the new elite lines of waxy corn were developed from the Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University, Thailand (Hussanun et al., 2014). These waxy corn genotypes contain purple color in many plant parts including stem, husk, seed, silk and cob. In normal purple corn,

¹ Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand 40002

² Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University, Khon Kaen, Thailand 40002

* Corresponding author: bsuriarn@gmail.com

anthocyanin levels varied significantly among different purple corn parts, and it is particularly high in the husk and cob (Li et al., 2008). Kernels of purple waxy corn had high anthocyanin and antioxidant activity in both milky and maturity stages compared with those of white waxy corn, super sweet corn and field corn (Khampas et al., 2013). Purple waxy corn is an important source of anthocyanin with beneficial effect in diabetic cataract condition which leads to suppress aldose reductase inhibitory activity and delay the cataractogenesis and has a protective property against diabetic (Thiraphatthanavong et al., 2014).

Anthocyanin with antioxidant activities has beneficial effect on human health that leads to reduce the risk of diseases such as cardiovascular diseases (de Pascual-Teresa and Sanchez-Ballesta, 2008; Wang and Stoner, 2008). In addition to their applications in food coloring, anthocyanin pigments possess various physiological activities such as hydroxyl and superoxide radical scavenging and growth inhibition of colon cancer cells (Li et al., 2008). Anthocyanin in normal purple corn has antioxidant and anticarcinogenic properties, and purple waxy corn is more attractive for the nutraceutical and functional food market (Cevallos-Casals et al., 2003; 2004). However, little information is available on yield and yield components (stem, husk, seed, silk and cob) of purple corn genotypes. Therefore, the objective of present study was to evaluate the effects of location, genotype and interaction between location and genotype on yield and yield components at milky and maturity stages. The information will be used to choose the best locations and to identify the

suitable genotypes and suitable harvesting stage for food factories.

Materials and Methods

Plant materials

Five genotypes of purple waxy corn (KGW3, KGW4, KGW5, Fancy 111 and KND) and one normal waxy corn (Big white 852) were selected in this study (Table 1). Most genotypes are F_1 hybrids except for KND, which is an open-pollinated variety. Three hybrids (KGW3, KGW4 and KGW5) and also KND were obtained from Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture Khon Kean University, and Fancy 111 and Big White 852 were obtained from Pacific Seeds (Thai) Ltd. and East-West Seed Company, respectively.

Field experiment

Field experiment was conducted in a randomized complete block design with three replications in the dry season 2014/2015 at two locations in Uthai Thani and the Vegetable Experimental Farm of Khon Kaen University in Khon Kaen, Thailand. This dry season is most popular for waxy corn production in Thailand because of low pest and disease problem.

The soil in Uthai Thani was loamy and the soil in Khon Kaen was sandy. Soil pH at the location in Khon Kaen was 6.4, whereas soil pH at the location in Uthai Thani was 5.5. The location in Uthai Thani had organic matter of 1.4%, whereas organic matter at the location in Khon Kaen was lower (0.7%). The location in Khon Kaen also had higher available P (234 ppm) and exchangeable K (158 ppm) than did the location in Uthai

Thani (44 ppm and 59 ppm, respectively), but the location in Khon Kaen had lower exchangeable Ca (54 ppm) than did the location in Uthai Thani (1,337 ppm). Both locations had similar solar radiation and rainfall at vegetative period (0-60 days), but the location in Khon Kaen had lower maximum and minimum than did Uthai Thani (Table 2).

Cultural practices

The plot had six rows with 5.0 m long and spacing of 0.80 m between rows and 0.25 m between plants (24 m²). The cultural practices used in the experiment were according to the Thailand agricultural recommendations including fertilization, irrigation and weed control. Fertilizer formula 15-15-15 of NPK was applied at the rate 50 kg per Rai before planting (1 Rai = 0.16 ha), and fertilizers formula 15-15-15 plus formula 46-0-0 at the rate 25kg per Rai were applied four weeks after planting. Irrigation system was available at the location in Uthai Thani and sprinkler system was used at the location in Khon Kaen. Weeds were control manually at both two experimental sites.

Data collection

The data for days to silking and days to tasseling were recorded at pollination stage when 50% of all plants in each plot produced silk and tassels, respectively. Ear height and plant height were recorded from 10 randomly-chosen plants in each plot at five days after pollination.

Plants were harvested at R4 growth stage (milking stage with 70% kernel moisture) and R6 growth stage (physiological maturity) in the area of 7.5 m² for each plot, and the plants were

separated into stem, husk, seed, silk and cob. The data were converted to per Rai. At R4 growth stage, fresh weights of the samples were determined, whereas, at R6 growth stage, the samples were oven-dried at 60 °C for 48 hours and dry weight of the samples were determined.

Statistical analysis

Analysis of variance was performed for each parameter according to a randomized complete block design, and least significant difference (LSD) with pair-wise comparisons was used to compare means at $P < 0.05$ (Gomez and Gomez, 1984). The combined analysis of variance was performed across the locations for the characters with homogeneous error variance, which was lower than three-time difference.

Results and Discussion

Sources of variation

At milky stage, locations were significantly different ($P \leq 0.05$ or 0.01) for un-husked ear weight, husked ear weight, cob weight, silk weight and husk weight, but locations were not statistically different for seed yield (Table 3). Varieties, however, were statistically different ($P \leq 0.05$ or 0.01) for all characters, and the interactions between location and variety were also significant for all characters.

The contributions of location to total variations were low (9.3% for seed yield) to high (35% for husk weight). Variety contributed to large portions of total variations for all characters ranking from 29.5% for husk weight to 52.77% for husked ear weight, the interactions between variety and location were also contributed to large portions

of total variations for all characters, ranging from 19.2% for cob weight to 28.8% for un-husked ear weight.

At physiological maturity stage, locations were significantly different ($P \leq 0.05$ or 0.01) for un-husked ear weight, husked ear weight, seed yield, cob weight and husk weight, but they were not significantly different for silk weight. The differences among varieties were significant ($P \leq 0.01$) for all characters, and the interactions between location and variety were significant ($P \leq 0.01$) for seed yield and husk weight, but they were not significant for un-husked ear weight, husked ear weight, cob weight, and silk weight.

Location contributed to large portions of total variations in un-husked ear weight, husked ear weight, seed yield, cob weight and husk weight, ranging from 26.6% for seed yield to 66.6% for cob weight, but it gave a small contribution to silk weight (0.8%). Variety contributed to large portions of total variations for all characters, ranging from 19.1% for cob weight to 69.6% for silk weight. Most interactions between variety and location were not significant and gave small portions to total variations except for seed yield (23.4%) and husk weight (17.3%).

Locations were not significantly different for days to silking and days to tasseling, but they were significantly different ($P \leq 0.01$) for ear height and plant height (**Table 4**). Varieties were significantly different ($P \leq 0.01$) for all characters. The interactions between variety and location were not significant for days to silking and days to tasseling, but they were significant ($P \leq 0.01$) for ear height and plant height.

Location contributed to very small portions of total variations in days to silking and days to

tasseling (0.1 and 0.5%, respectively), but the contributions were large for ear height (44.2%) and plant height (33.3%). The contributions of variety were large for all characters, ranging from 21.5% for ear height to 69.4% for days to silking. The contributions of the interactions between variety and location were rather small, ranging from 3.6% for days to silking to 18.0% for ear height.

In this study, the aim was to identify the best varieties. The results agreed with previous study that variety was the large source of variance for yield in the waxy corn (Suriharn and Lertrrat, 2013). Therefore, the identification of the best varieties should be not difficult. In this study, variety contributed to variation in yield at milky stage larger than that reported previously (Suriharn and Lertrrat, 2013). The differences in the results of different studies might be due to difference in genetic materials used and locations effect in these two studies.

However, in this study, the interactions gave low contributions to variations in most traits at physiological maturity stage except for seed yield and husk weight. The results showed that purple waxy corn genotypes in milky stage responded differently to the environments, indicating that varieties performance was inconsistency between two locations. Therefore, the best varieties should be selected in optimum locations at milky stage for fresh market.

In previous study, purple waxy corn seed had higher anthocyanin at the maturity stage than milky stage (Khampas et al., 2013). Purple waxy corn should be harvested at physiological maturity stage to produce high anthocyanin for health food products and pharmaceutical

industries. In this study, varieties responded almost the same to the locations at maturity stage due to low variety and location interactions, indicating that stable variety could be selected across locations.

Yields and yield components

The location in Khon Kaen had higher un-husked ear weight and husk weight at milky stage and seed yield at maturity stage than did the location in Uthai Thani (**Table 5**). Moreover, the location in Khon Kaen had also higher cob weight, silk weight and husk weight than did the location in Uthai Thani, and the location in Uthai Thani had taller ear height and plant height than did the location in Khon Kaen.

The results can be explained by low temperature in KK at vegetative stage (**Table 2**). Thus, purple waxy corn varieties had higher yield and yield components longer days to maturity at the location in Khon Kaen than the location in Uthai Thani. This was possibly due to the extension of crop duration due to lower temperature (Suriharn and Lertrat, 2013). In this study, soil and rainfall were not limiting factors because corn management was done under good recommended practices without other stresses.

At milky stage, FC111 had the highest un-husked ear weight at the location in Khon Kaen (4,060 kg/Rai) followed by Big white 852 at the location in Khon Kaen (3,010 kg/Rai) and KGW5 at the location in Khon Kaen (2,824 kg/Rai) (**Table 5**). FC111 (2,167 kg/Rai) and KGW5 (2,212 kg/Rai) had the highest un-husked ear weight at maturity stage. In general, KND had low yield at both stages. This could be explained by hybrid vigor or type of variety (Crow, 1998). KND is only

one open-pollinated variety used in this study, and other variety are hybrid. However, KND is a very good sources of anthocyanin and performed well under unfavorable environments (Khampas et al., 2015).

At milky stage, FC111 had the highest husk weight at the location in Khon Kaen (2,439 kg/Rai) followed by Big white 852 at the location in Khon Kaen and KGW5 at the location in Uthai Thani (1,794 and 1,783 kg/Rai, respectively). FC111 and Big white 852 are waxy corn varieties from private company. FC111 performed well at both locations but Big white 852 had high yield only at the location in Khon Kaen, indicating general and specific adaptation for these two varieties. At maturity stage, FC111, KGW5 and KGW3 had the highest husk weight across locations (1,874, 1,835 and 1,735 kg/ Rai, respectively). FC111 had the highest seed yield (1,273 kg/Rai) at milky stage. FC111 (1,002 kg/Rai), KGW5 (953 kg/Rai), KGW3 (916 kg/Rai) and KND (901 kg/Rai) had the highest seed yield at milky stage.

FC111 had the highest cob weight at milky stage (1,002 kg/Rai) followed by Big white 852 (768 kg/Rai) (**Table 6**). FC111, KGW5, KGW4 and KGW3 had the highest cob weight at maturity stage (181, 174, 170 and 164 kg/Rai, respectively).

FC111 had the highest silk weight at the locations in Khon Kaen (35.5 kg/Rai) and Uthai Thani (44.4 kg/Rai) followed by FC111 (35.5 kg/Rai), KGW5 (30.9 kg/Rai), KGW3 (30.9 kg/Rai), KGW4 (30.7 kg/Rai) and KND (30.4 kg/Rai) at the location in Uthai Thani. FC111 had also the highest silk weight at maturity stage (9.2 kg/Rai) followed by KND (6.9 kg/Rai) and KGW5 (6.5 kg/Rai). FC111 had the highest husk weight (1,041

kg/Rai) followed by Big white 852 (768 kg/Rai) at milky stage. KGW5 and FC111 had the highest husk weight at maturity stage (324 and 300 kg/Rai) followed by Big white 852 (272 kg/Rai).

Cob, silk and husk are waste products from corn production. However, these components of purple waxy corn are purple or rich in phytochemical including anthocyanin and anti-oxidant activity. These corn parts showed potential for use in food, pharmaceutical and cosmetic industries. In general, FC111 or high yield variety had also high cob, silk and husk compared with other varieties in this study.

Agronomic characters

KND had the earliest days to silking (52) and tasseling (51), whereas FC111 had the latest (65 and 63, respectively) (**Table 7**). From previous results, FC111 had also higher yield than did KND because FC111 had longer vegetative growth period, more time for nutrition and uptake and in consequence late variety had higher yield than early variety (Suriham and Lertrrat, 2013). FC111 had the tallest ear height (106.7 cm) at the location in Uthai Thani. FC111, KGW3 and KGW5 had the highest plant height at the location in Uthai Thani (208.3, 201.7 and 196.0 cm).

Table 1 Waxy corn varieties used in this study

Genotypes	Seed color	Cob color	Types
1. KGW3	Purple	Purple	Hybrid
2. KGW4	Purple	Purple	Hybrid
3. KGW4	Purple	Purple	Hybrid
4. KND	Purple	Purple	Opened pollinated
5. FANCY 111	Purple	Purple	Hybrid commercial variety
6. Big white 852	White	White	Hybrid commercial variety

Table 2 Solar radiation, rainfall, maximum and minimum temperature at two locations in the dry season 2014/15

Days after planting	Solar radiation (MJ m ⁻² d ⁻¹)		Rainfall (mm)		Max. Temp. (°C)		Min. Temp. (°C)	
	UT	KK	UT	KK	UT	KK	UT	KK
0-15	16.5	14.8	0.0	0.0	36.9	32.5	25.5	23.2
16-30	16.7	15.6	0.0	0.0	36.7	30.5	21.4	18.2
31-45	16.3	16.0	0.0	0.0	35.8	29.0	20.9	16.3
41-60	15.6	15.1	0.0	18.6	32.6	28.6	19.8	15.2
61-75	11.5	17.7	10.6	10.6	26.0	31.8	19.8	15.7

UT is Uthai Thani and KK is Khon Kaen.

Table 3 Mean squares for un-husked ear weight, Husked ear weight, seed yield, cob weigh, silk weigh and husk weight of six varieties of purple waxy corn evaluated at two locations at milky and maturity stages

SOV	d.f.	Un-husked ear weight	Husked ear weight	Seed yield	Cob weight	Silk weigh	Husk weight
Milky stage							
Location (L)	1	3,580,169 ** (32.8)	549,377 ** (16.4)	96,856 ns (9.3)	212,091 ** (22.2)	369 ** (13.0)	526,495 ** (35.0)
Replication (R)/L (a)	4	24,954	6,957	15,201	5,506	18	4,951
Variety (V)	5	687,579 ** (31.5)	352,917 ** (52.7)	96,513 ** (46.3)	85,910 ** (45.0)	240 ** (42.0)	88,545 ** (29.5)
L x V	5	627,833 ** (28.8)	165,502 ** (24.7)	44,006 ** (21.1)	36,620 ** (19.2)	153 ** (27.0)	77,485 ** (25.8)
Error (b)	20	32,936	9,015	9,118	5,376	22	6,306
CV (%) (a)		6.0	5.1	11.6	12.5	15.6	12.7
CV (%) (b)		6.9	5.8	9.0	12.4	17.3	14.4
Maturity stage							
Location (L)	1	2,075,905 ** (42.0)	1,166,688 ** (43.3)	140,975 * (26.6)	39,468 ** (66.6)	1.1 ns (0.8)	55,885 ** (52.0)
Replication (R)/L (a)	4	65,002	18,312	11,074	590	0.7	381
Variety (V)	5	317,292 ** (32.1)	191,257 ** (35.5)	24,537 ** (23.2)	2,258 ** (19.1)	20.1 ** (69.6)	4,414 ** (20.5)
L x V	5	80,640 ns (8.2)	17,657 ns (3.3)	24,766 ** (23.4)	339 ns (2.9)	2.8 ns (9.8)	3,717 ** (17.3)
Error (b)	20	30,720	20,393	4,889	219	1.3	472
CV (%) (a)		13.4	8.1	12.6	15.1	13.4	8.8
CV (%) (b)		9.2	8.6	8.4	9.2	18.5	9.8

ns = non significant

* and ** = significant different at the $P<0.05$ and $P<0.01$ probability levels, respectively

Values in parenthesis are percentages of sum squares that contribute to total variation for the trait.

Table 4 Mean squares for days to silking, days to tasseling, ear height and plant height of six varieties of purple waxy corn evaluated at two locations

SOV	d.f.	Days to silking	Days to tasseling	Ear height	Plant height
Location (L)	1	0.1 ns (0.1)	4.0 ns (0.5)	2,209 ** (44.2)	3,660 ** (33.3)
Replication (R)/L (a)	4	16.4	10.9	32	18
Variety (V)	5	122.4 ** (69.4)	104.8 ** (67.8)	214 ** (21.5)	987 ** (44.5)
L×V	5	6.6 ns (3.8)	13.2 ns (8.5)	180 ** (18.0)	261 ** (11.8)
Error (b)	20	8.5	6.8	34	56
CV (%) (a)		7.2	6.1	6.9	2.4
CV (%) (b)		5.2	4.8	7.1	4.2

ns = non significant

** = significant different at the $P<0.01$ probability levels

Values in parenthesis are percentages of sum squares that contribute to total variation for the trait.

Table 5 Means for un-husked ear weight, husked ear weight and seed yield of six waxy corn varieties evaluated at two locations at milky and maturity stages

Varieties	Un-husked ear weight (kg Rai ⁻¹)			Husked ear weight (kg Rai ⁻¹)			Seed yield (kg Rai ⁻¹)		
	Milky stage		Maturity stage	Milky stage		Maturity stage	Milky stage		Maturity stage
	UT	KK		UT	KK		UT	KK	
KND	2,144g	2,364efg	1,730bc	1,152f	1,423e	1,519c	880c	739ef	901abcd
KGW3	2,541cdef	2,679cd	1,909b	1,505de	1,640bcd	1,735ab	1,082b	795cde	916abc
KGW4	2,324fg	2,651cde	1,770bc	1,499de	1,577de	1,572bc	1,060b	933ab	817bcde
KGW5	2,605cdef	2,824bc	2,212a	1,783bc	1,614d	1,835a	1,077b	794cde	953a
FC111	2,389defg	4,060a	2,167a	1,622cd	2,439a	1,874a	1,273a	732ef	1,002a
Big white 852	1,800h	3,010b	1,674c	1,443e	1,794b	1,437c	1,013b	633f	787de
Mean	2,301B	2,931A	1,910	1,501B	1,748A	1,662	1,046	771B	896A

Means in the same column with the same letter(s) are not significantly different (*p*<0.05) by LSD

Means in the same row with the same capital letter are not significantly different (*p*<0.05) by LSD

UT is Uthai Thani and KK is Khon Kaen.

Table 6 Cob weight, silk weight and husk weight of six varieties of purple waxy corn evaluated at two locations at milky and maturity stages

Varieties	Cob weight (kg Rai ⁻¹)				Silk weight (kg Rai ⁻¹)				Husk weight (kg Rai ⁻¹)			
	Milky stage		Maturity stage		Milky stage		Maturity stage		Milky stage		Maturity stage	
	UT	KK	UT	KK	UT	KK	UT	KK	UT	KK	UT	KK
KND	427f	559cdef	143b	30.4bc	18.9ef	6.9b	384e	547cd	179de	256c		
KGW3	495def	577cde	164a	30.9bc	20.3def	5.1c	466cde	574c	178de	215d		
KGW4	473ef	538cdef	170a	30.7bc	17.6ef	4.9c	429de	512cde	192d	201d		
KGW5	603cd	564cde	174a	30.9bc	15.2f	6.5b	557cd	594c	184d	324a		
FC111	632c	1,002a	181a	35.5b	44.4a	9.2a	530cd	1,041a	214d	300ab		
Big white 852	457ef	768b	131b	24.0cde	27.6bcd	4.1c	218f	768b	150e	272bc		
Mean	515B	66A	161	30.4A	24.0B	6.1	431B	673A	183B	261A		

Means in the same column with the same letter(s) are not significantly different ($p<0.05$) by LSD

Means in the same row with the same capital letter are not significantly different ($p<0.05$) by LSD

UT is Uthai Thani and KK is Khon Kaen.

Table 7 Days to silking, days to tasseling, days to harvest, ear height and plant height of six waxy corn varieties

Varieties	Days to silking	Days to tasseling	Ear height (cm)		Plant height (cm)	
			UT	KK	UT	KK
KND	52c	51c	77.7cd	75.7cde	168.3fg	173.3ef
KGW3	53bc	52bc	90.7b	81.7bc	201.7ab	178.0ef
KGW4	55bc	55b	90.3b	69.3de	185.0cde	159.0gh
KGW5	54bc	53bc	90.7b	79.0cd	196.0abc	167.0fg
FC111	65a	63a	106.7a	73.0cde	208.3a	191.3bcd
Big white 852	56b	53bc	82.7bc	66.0e	181.7de	151.3h
Mean	56	54	89.8A	74.1B	190.2A	170.0B

Means in the same column with the same letter(s) are not significantly different ($p < 0.05$) by LSD

Means in the same row with the same capital letter are not significantly different ($p < 0.05$) by LSD

UT is Uthai Thani and KK is Khon Kaen.

Conclusion

In conclusion, the location in Khon Kaen were more suitable for purple corn production than the location in Uthai Thani due to higher yield and better yield components. At milky stage, FC111 had the highest yield followed by KGW5 at KK. FC111 and KGW5 had the highest yield at maturity stage. KND had low yield but it had the shortest days to pollination, indicating early maturity. The information obtained in this study is important for development of purple waxy corn for used as raw material for functional food products, and useful in corn breeding programs at different environments. More studies about anthocyanin contents from these variety and their components are still needed.

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