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Effects of Hypoxic Duration at Different Growth Stages on Yield Potential of Waxy Corn (*Zea mays* L.)

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***Abstract*—**Hypoxia has negative effects on growth and crop yield, its severity is so varied depending on crop growth stages, duration of hypoxia and crop species. The objective was to evaluate the sensitive growth stage and the duration of hypoxia negatively affecting growth and yield of waxy corn. Pot experiment was conducted using a split plot in randomized complete block with 3 growth stages: V3 (3-4 true leaves), V7 (7-8 true leaves) and R1 (silking stage), and 3 hypoxic durations: 6, 9 and 12 days, in an open –ended outdoor greenhouse during January to March 2013. The results revealed that different growth stages had significantly ($p < 0.5$) different responses to hypoxia, seeing that the sensitive growth stage affecting plant height, yield and yield components was mostly detected in V7 growth stage whereas leaf greenness and days to silking were sensitive to hypoxia at R1 growth stage. Different hypoxic durations significantly affected yield and yield components, hypoxic duration of 12 days showed the most negative effect greater than the others. In this present study, it can be concluded that waxy corn plants were waterlogged at V7 growth stage for 12 days had the most negative effect on yield and yield components.

***Keywords*—**Hypoxia duration, waxy corn, growth stage.

I. Introduction

WAXY corn is one of local economic crops in Thailand. It can be grown through the year due to short harvesting time of 60-65 days. Furthermore, it can be grown as cash crop for increasing farmer incomes. One problem in waxy corn production is however heavy soil texture (clay soil) which exhibits poor drainage resulted in waterlogged condition after heavy rain. This problem seriously affects growth and yield potential of waxy corn. The main effect induced by waterlogging condition is oxygen deficiency in plant root caused to be anaerobic respiration which cannot supply enough energy to move nutrients from soil solution into plant shoot; consequently growth is quite inhibited culminated in yield reduction respectively. Oxygen deficiency periods triggered functional and developmental responses that promote acclimation to hypoxic or anoxic conditions [1]. Besides waterlogging also influenced biochemical processes in plants, i.e. photosynthesis and respiration, relating to growth and yield potential. The severity of waterlogging depended on growth stage, duration of waterlogging [2] and crop species [3]. Therefore, the objective of this present study was to evaluate the sensitive growth stage and hypoxic duration negatively affecting yield potential of waxy corn.

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II. Materials and Method

A. Experimental Design

Split plot in Randomized complete block design with three main plots and three subplots and replicated four times was performed. The treatment details are as follows:

Main plot was three different growth stages as follows:

1. V3 growth stage (3-4 true leaves)
2. V7 growth stage (7-8 true leaves)
3. R1 growth stage (silking stage)

Subplot was three different hypoxic durations as follows:

1. 6 days of hypoxic duration
2. 9 days of hypoxic duration
3. 12 days of hypoxic duration

B. Experimental Method

Four seeds of waxy corn cv. Big white 852 were grown in 60–cm diameter cement tank having an opened-closed valve for water drainage and containing soil having chemical properties as follows: pH= 4.05, % OM = 1.55 (quite low), ECe 1.08 dS/m (saltless), aval. P = 15.92 mg/kg (quite high), exch. K = 157.27 mg/kg (very high). Cultural practices such as weed control and fertilizer application was performed as waxy corn growing recommendation until the treated period, waterlogging (hypoxia) condition was initially imposed in each growth stage according to the treatment details. When the duration of waterlogging in each growth stage was completely performed. Irrigation was immediately drained and then normal irrigation practice was again performed until harvesting time. At harvesting time, data as plant height, leaf greenness, days to silking, yield and yield components were recorded. All data were subjected to analysis of variance according to utilized experimental design by MSTAT program and treatment means were compared by least significant difference (LSD).

III. Results and Discussion

A. Leaf Greenness at Harvest

Different growth stages were differently affected by hypoxic condition. Leaf greenness subjected to hypoxia at R1growth stage was the most sensitive and significantly differed ($p < 0.5$) from that in V3 and V7 growth stages. This finding was similar to the report of [4] who found that the total chlorophyll content as well as chlorophyll *a* and *b* of quinoa (*Chenopodium quinoa* Wild.) were reduced under waterlogging stress. Leaf greenness of waxy corn among different hypoxic durations did not show any significance which was contrary to the work of [5] who revealed that the lowest spad value (leaf greenness) of cotton was detected under 7 days of waterlogging. No interaction between growth stage and hypoxic duration was observed (Table I).

TABLE I
EFFECTS OF DIFFERENT GROWTH STAGES AND HYPOXIC DURATIONS ON LEAF GREENNESS, PLANT HEIGHT AND DAYS TO SILKING OF WAXY CORN

Treatment	Leaf greenness (spad unit)	Plant height (cm)	Days to silking (days)
Growth stage (C)			
V3 (3-4 true leaves)	49.85 [a]	127.68 [b]	44.08[a]
V 7 (7-8 true leaves)	46.02 [a]	91.40 [c]	44.17[a]
R1 (silking stage)	37.02 [b]	152.61[a]	42.58[b]
Hypoxic duration (H)			
6 days	45.99	130.06	44.00
9 days	43.35	123.71	43.42
12 days	43.56	117.91	43.42
(C) * (H)			
V3 *6 days	49.97	138.12	43.50[bcde]
V3 *9 days	49.72	126.10	44.50[ab]
V3 *12 days	49.87	118.82	44.25[abc]
V7 *6 days	49.57	97.50	45.50[a]
V7 *9 days	45.00	93.57	43.25[bcde]
V7 *12 days	43.50	83.12	43.75[bcd]
R1 *6 days	38.42	154.57	43.00[cde]
R1 *9 days	35.32	151.47	42.50[de]
R1 *12 days	37.32	151.80	42.25[e]
$LSD_{.05}$ (C)	5.31	12.55	1.02
$LSD_{.05}$ (H)	ns	ns	Ns
$LSD_{.05}$ (C) * (H)	ns	ns	1.32
CV (%)	10.30	11.54	2.03

B. Leaf Greenness at Harvest

Plant height of corn plants under hypoxia showed significantly different ($p < 0.5$) among different growth stages. V7 growth stage had the most sensitive on plant height followed by V3 whereas the least effect on plant height was observed at R1 growth stage. Regarding hypoxic duration and interaction between growth stage and hypoxic duration, no significant differences ($p > 0.5$) were found (Table I). Contrary result reported by [1] found that plant height of fiber crops subjected to waterlogging for 105 days was most reduced (38.9% of the control) when it was compared with 45,60, 75 and 90 days of waterlogging which showed height reduction of 1.4, 7.2, 11.3 and 24.7% of the control respectively.

C. Leaf Greenness at Harvest

Different growth stages subjected to hypoxia had significant ($p < 0.5$) effects on silking day. Days to silking of waxy corn were slightly prolonged when it was subjected to hypoxia at V7 and V3 growth stages respectively and significantly exhibited from those at R1 growth stage which silking was normally generated like those in normal condition (no hypoxia). The same result by [6] reported that ear emergence of winter wheat (*Triticum aestivum* L.) was delayed under water logging, two thirds ofear was still inside the boot. Different hypoxic durations were not significantly different on silking day. In contrary to the work of [7] who reported that 120 days of waterlogging in mid winter delayed ear emergence by 2 days compared to drained control. Interaction between growth stage and hypoxic duration was significantly ($p < 0.5$) observed. Waxy corn subjected to hypoxia at V7 growth stage for 6 days remarkably prolonged silking day but did not significantly differ from those subjected to hypoxia at V3 growth stage for 9 and 12 days (Table I).

D. Dehusk Yield

Different growth stages, hypoxic durations and interaction between growth stage and hypoxic duration had significant differences ($p < 0.5$) on dehusk yield. Dehusk yield of waxy corn under hypoxia at R1 growth stage was least decreased but it was most decreased under hypoxia at V7 and V3 growth stages respectively. Hypoxic duration of 12 days showed more negative effect than the others. Grain yield of winter wheat was decreased by 20% under water logging at 93 days after sowing for 44 days [6]. The interaction effect revealed that hypoxic duration of 12 days at V7 growth stage had the lowest dehusk yield while the slightly negative effect was observed at V7 growth stage with 12 days of hypoxic duration (Table II).

E. Husk Yield

Husk yield of waxy corn under hypoxia at V7 growth stages was seriously decreased and the decreases significantly ($p < 0.5$) differed from those at V3 and R1 growth stages. The hypoxic duration effect indicated significant difference ($p < 0.5$) among different hypoxic durations. Husk yield under hypoxic duration of 6 days was slightly decreased when it was compared to those of 9 and 12 days which seriously affected husk yield. Reference [8] studied in different chickpea cultivars found that transient waterlogging reduced seed yield of kaburi cultivar Almaz by 54% and desi cultivar Rupali by 44%. Interaction between growth stage and hypoxic duration was significantly ($p < 0.5$) shown. Hypoxic duration of 12 days at V7 growth stage negatively affected husk yield greater than the other interactions whereas 6 days of hypoxic duration at V3 growth stage had the least negative effect and did not differ from those in all hypoxic durations at R1 growth stage (Table II).

TABLE II
EFFECTS OF DIFFERENT GROWTH STAGES AND HYPOXIC DURATIONS ON ROW NUMBERS PER EAR, HUSK YIELD AND DEHUSK YIELD OF WAXY CORN

Treatment	Row numbers /ear (row)	Husk yield (g/trt)	Dehusk yield (g/trt)	Ear width (mm)	Ear length (cm)
Growth stage (C)					
V3 (3-4 true leaves)	10.7^{b}	483.5^{b}	308.8^{b}	37.8	14.9^{a}
V 7 (7-8 true leaves)	11.1^{b}	354.9^{c}	212.7^{c}	38.4	12.3^{b}
R1 (silking stage)	12.3^{a}	637.8^{a}	487.8^{a}	39.6	14.5^{a}
Hypoxic duration (H)					
6 days	11.7^{a}	622.6^{a}	440.6^{a}	39.2	14.3
9 days	11.3^{ab}	441.5^{b}	311.3^{b}	38.9	13.8
12 days	11.0^{b}	412.0^{b}	256.7^{c}	37.6	13.6
(C) * (H)					
V3 *6 days	11.3	681.1^{a}	476.7^{a}	38.9	15.6
V3 *9 days	10.5	409.7^{c}	274.7^{b}	37.4	14.6
V3 *12 days	10.3	359.5^{c}	172.7^{c}	37.1	14.6
V7 *6 days	11.0	546.1^{b}	348.5^{b}	38.7	12.7
V7 *9 days	11.5	264.0^{d}	170.3^{c}	38.8	11.9
V7 *12 days	10.8	254.5^{d}	119.3^{c}	37.7	12.3
R1 *6 days	12.8	640.5^{a}	496.6^{a}	40.1	14.7
R1 *9 days	12.0	650.8^{a}	488.9^{a}	40.6	14.9
R1 *12 days	12.0	622.1^{ab}	478.0^{a}	38.2	13.8
LSD$_{.05}$ (C)	0.86	70.0	75.9	ns	1.7
LSD$_{.05}$ (H)	0.49	50.3	46.2	ns	ns
LSD$_{.05}$ (C) * (H)	ns	87.1	80.0	ns	ns
CV (%)	5.02	11.91	16.02	4.92	10.3

F. Row Numbers per Ear

Waxy corn plants occurred hypoxia at R1 growth stage still had potential to maintain row numbers per ear greater than did at the other growth stages. Row numbers per ear encountered hypoxia at V3and V7 growth stages were seriously decreased. For the hypoxic duration effect, there was significance among different hypoxic durations, the most serious and slight effects were observed in 12 and 6 days of hypoxic duration respectively. Interaction between growth stage and hypoxic duration was not found (Table II). Pods per plant and seeds per pod of winter rape (*Brassica napus* L.) were reduced by 28.2 and 22.3 % and 8.2 and 13.9% under waterlogging at seedling and floral bud appearance stages respectively [9]. Pod numbers per plant and seed numbers per pod of chickpea were decreased under subsurface waterlogged [8].

G. Ear Width and Length

Different growth stages, hypoxic durations as well as interaction between growth stage and hypoxic duration did not significantly ($p>0.5$) affect ear width (Table II). With regard to ear length, a significant difference ($p< 0.5$) was shown among different corn growth stages subjected to hypoxia. V7 growth stage was the most sensitivity to hypoxia resulted in decreased ear length. V3 growth stage showed the best performance to maintain ear length under hypoxia and did not significantly differ from R1 growth stage. Waterlogging decreased spike length of MH-97 wheat genotype [10]. There was not a significant difference on growth stage and hypoxic duration interaction (Table II).

IV. CONCLUSION

From this present study, it can be concluded that the hypoxic (waterlogging) condition occurred at V7 (7-8 true leaves) growth stage with 12 days of duration showed the highest negative effect on growth and yield potential of waxy corn whereas the lowest negative effect was detected at R1growth stage (silking stage) with 6 days of duration.

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