

Full Length Research Paper

Phenological and grain yield response of hybrid maize varieties, released for differing agro-ecologies, to growing temperatures and planting dates in Ethiopia

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Received 30 July, 2020; Accepted 3 November, 2020

Growing temperatures and planting dates affect phenology and grain yields of maize varieties and farmers have to choose suitable varieties that fit into different planting dates and growing temperatures. A field experiment was conducted to investigate the response of different hybrid maize varieties to different growing temperatures through growing the varieties at different locations varying in altitudes (low land, mid altitude and highlands) under three planting dates. Results revealed that days to seed emergence were influenced by growing temperatures, with days to emergence difference of two weeks observed between Didesa/Uke (high temperature locations) and Holeta (low temperature location). Almost for all varieties except for BH546, days to tasseling and maturity were longer under low temperature at Holeta while they were shorter under high temperature at Didesa and Uke. Early planting resulted in higher grain yields especially at Uke, Bako and Ambo. Grain yield was influenced by the interaction effect of variety and temperature, with BH546 being more yielder than AMH851 under high temperature at Uke. Thus, for most of the tested varieties early planting is recommended, as this will enable the varieties to escape moisture stress that occasionally occurs at grain filling and maturation period, which can seriously affect grain yield.

Key words: Growing temperature, grain yield, maize phenology, maize varieties, planting date.

INTRODUCTION

Maize is one of the major and strategic cereal crops that play an important role in food security and farmers' livelihoods in Ethiopia. Being one of the most important cereals cultivated in Ethiopia both the area and production of maize has shown a sharp increase in the past few decades. Production for instance has increased

from 23.9 million quintals in 2004 to 94.9 million quintals in 2018/2019 (CSA, 2004/205; CSA, 2018/2019). Area under improved maize varieties tremendously increased from 14% in 2004 to 59% in 201 (CSA, 2004/2005; CSA, 2018/2019). Maize ranks second after teff (*Eragrostis tef*) in area coverage but ranks first in terms of total

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production and can be grown on a different soil types and temperature regimes in the country. The current national average yield of maize is 4.0 t ha^{-1} (CSA, 2018/2019), which is still low compared to its yield potential. Productivity of maize in Ethiopia ranks second in Sub-Saharan Africa next to South Africa.

In Ethiopia, maize is produced under diverse agro-ecologies ranging from an elevation of 1000 to 2400 masl and from high moisture to moisture stress areas due to the availability of different maize cultivars developed being tailored for each condition (ESA, 2014). Although, maize varieties are released for specific agro-ecology, it was observed that some farmers sometimes grow maize varieties that are not recommended for their area for various reasons including lack of timely supply of the desired suitable varieties (Tesfaye et al., 2019). Temperature and light are the major factors regulating the phenological response of crops including maize (Hatfield and Prueger, 2015). Crop development is usually accelerated under higher temperature (Harrison et al., 2011). This, however, may reduce grain yield through limiting the amount of total solar radiation received by the plant during each developmental stage and in particular at the grain filling stage (White and Reynolds, 2003; Harrison et al., 2011). Thus, temperature regimes seriously affect phenology as well as grain yield (Harrison et al., 2011). However, it may not affect total leaf area as well as total biomass yield (Hatfield, 2016). The influence of temperature on grain yield is related to its effect on number of kernels per ear (Hatfield, 2016).

Planting date also affects maize phenology such as days to tasseling, silking, maturity as well as crop yield (Dahmardeh and Dahmardeh, 2010; Shrestha et al., 2016, 2018; Lizaso et al., 2018; Baum et al., 2019). Delay in planting time and low soil temperatures reduced days to seed emergence (Dos Santos et al., 2019) as well as maize grain yields (Baum et al., 2019). Owing to the difference in maturity and length of growing seasons, the ideal planting dates for hybrid maize vary among locations that highly contrast in growing temperatures and even seasonally with locations due to varying weather (Tsimba et al., 2013). More appropriate planting date was also reported to be dependent on type of maize varieties grown (Beiragi et al., 2011). Thus, it is very important to generate information on the phenological and grain yield responses of maize varieties released in Ethiopia, under different temperatures and planting dates to adjust planting date that best fits each variety at each location. This is because moisture could be limiting if the phenology takes longer period especially in the high altitude areas, where temperatures are lower and each growth phase may take longer time. Therefore, this study was aimed at investigating (i.) the effect of growing temperature on phenology and yields of maize varieties and (ii.) the effect of planting dates on phenology and yields of maize varieties as well as (iii.) to see if there is

an interaction effect of varieties, growing temperature and planting date on phenology and yields of maize.

METHODOLOGY

Description of the study areas

The experiments were purposively executed at five test locations that represent low altitude, mid-altitude and high altitude agro-ecology to test the phenological and yield response of different maize varieties under varying temperature regimes. Soils of the four locations (Dedessa, Uke-Kersa, Bako and Holeta) were Nitisols while Ambo site is dominated by pellic vertisols. Figure 1 shows the locations of the study sites in the context of the country map; Table 1 shows coordinates of the study locations and their altitudes; while Table 2 shows characteristics of the tested maize varieties in terms of their altitude requirement, maturity category and disease reaction.

Treatments and design

During 2016 cropping season 5 hybrid maize varieties (all hybrids) namely (BH546, BH661, Limu, Jibat (AMH851) and Kolba (AMH853), each released for differing agro-ecologies were grown at five locations namely Holeta, Ambo, Bako, Didessa and Uke. These locations had different temperature regimes from very low to very high (see min., max. and average temperatures in Table 1). The varieties were planted at three different sowing times and during each sowing time the treatments were replicated three times, with the varieties arranged in randomized complete block design. Rainfall is assumed as not growth limiting in all the study sites since the rainfall recorded at all the sites was more than the rainfall requirement of maize crop (Tables 1 and 2). All the necessary phenological parameters (Days to emergence, tasseling, maturity) as well as grain yield were recorded.

Crop establishment and management

Land preparation was carried out by ploughing three times and leveled using tractor. Row making (0.75 m) and planting were manually done at all location on May 23, May 30 and 6 June, 2016 cropping season. Maize seeds were planted with 0.75 m inter row and 0.30 m intra row spacing (with plant population of $44,444 \text{ plants ha}^{-1}$). A total of 110 kg N ha^{-1} (92 from Urea and 18 N from DAP) and 20 P ($46 \text{ P}_2\text{O}_5$) from DAP fertilizer were applied uniformly to all plots as a blanket recommendation. Full dose of DAP fertilizer was applied at planting while urea fertilizer was applied in three equal split at planting, 35 day after planting and flag leaf stage.

The experiments were uniformly managed at all locations to control weeds through repeated hand weeding. The first weeding was done with the aid of traditional hoes at 25-30 days after planting/before first urea application. The second and third weeding was done using the same hand-held hoe during the second top dressing of urea application to also incorporate the applied fertilizers. The fourth weeding was done using locally available sickles. Air temperature was recorded by keeping digital thermometer in the field, at the respective locations.

Data collection

Phenology data: Data on days to emergence, days to tasseling and days to maturity were collected, when 90% of the plant

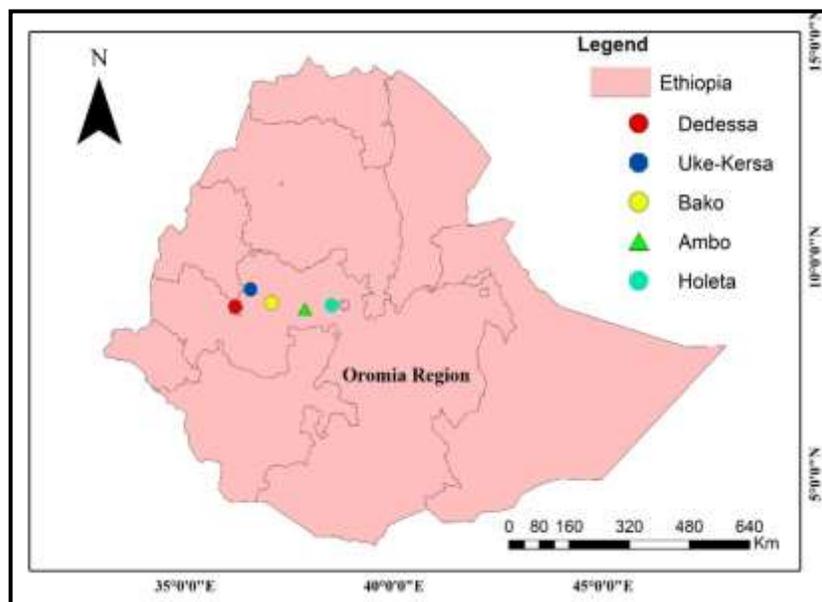


Figure 1. Map showing the five test locations.

Table 1. Temperature, total rainfall, latitude, longitude and altitude of the test locations.

Site	Geographic locations			Air temperature (2016 growing season)			Total rainfall
	Latitude	Longitude	Altitude (masl)	Min (°C)	Max (°C)	Av. (°C)	(mm)
Didessa	9.01008314	36.1704821	1231	20.0	33.0	26.5	2090
Uke-Kersa	9.41832385	36.5398268	1318	18.0	31.0	24.5	2090
Bako	9.10033506	37.0432229	1648	14.0	27.0	20.7	1300
Ambo	8.96768521	37.8597355	2159	10.0	25.0	17.5	1100
Holeta	9.05639602	38.5039351	2352	7.0	21.0	14.0	1040

Table 2. General characteristics of maize varieties tested.

Variety Name	Maturity	Altitude requirement masl	Rainfall requirement (mm)	Reaction to major leaf diseases	Seed colour
BH 661	Late	1600-2200	1000-1500	Tolerant	White
BH 546	Medium	1000-2000	1000-1500	Tolerant	White
AMH 851	Late	1800-2600	1000-1200	Resistant	White
AMH 853	Late	1800-2600	1000-1200	Tolerant	White
Limu	Medium	1200-2000	1000-1500	Tolerant	White

Early 105-120; Medium 120-150 and late 160-180 days.

population has emerged, tasseled and matured respectively.

Grain yield: Harvesting was done at physiological maturity from a net plot area of 4 m × 4.5 m (18 m²). The total cob weight per plot was determined using hand-held hanging type sensitive balance. The cob weight was converted to field grain weight after determining the shelling percentage of three sample cobs. The field

grain weight was then converted to actual grain weight per plot after it was adjusted to the standard moisture content of 12.5% as described in the following formula,

$$\text{Grain yield (kg ha}^{-1}\text{)} = \text{Cob weight} * \frac{(100 - M)}{(100 - 12.5)} * 0.81$$

Where, M is the measured moisture content in grain.

Data analysis

Data were analyzed using analysis of variance (ANOVA) procedures using a Statistical Analysis System (SAS), version 9.3 Software, (SAS institute INC., Cary, USA). The ANOVA was computed based on PROC GLM procedure and when ANOVA showed the presence of significant treatment effects, mean separation was carried out using Tukey's test at $\alpha=5\%$ level of significance.

RESULTS AND DISCUSSION

Days to emergence

The analysis of variance showed that days to emergence was not influenced by the main effect of variety. However, it was highly influenced by the main effect of growing temperature ($P<0.01$; Table 3) as well as by the main effect of planting date ($P<0.05$; Table 3). The interaction effect of variety by temperature and variety by planting date on days to emergence was not significant. However, interaction effects of temperature by planting date and variety by temperature by planting date on days to emergence was significant ($P<0.01$; Table 3).

Main effects of temperature

Days to emergence was significantly affected by the main effect of temperature. However, temperature and variety did not have interaction effects on days to emergence (Table 3). Significantly longer days to emergence was observed at Holeta where the temperature was lower ($7/21^{\circ}\text{C}$), followed by Ambo ($10/25^{\circ}\text{C}$). Days to emergence was synonymously shorter for Bako, Uke and Didesa (Figure 2) due to the relatively higher growing temperatures. At these locations, although not measured, the soil temperatures are also higher thus playing significant role in enhancing seed germination and emergence. In line with our observation, Dos Santos et al. (2019) also reported delayed seed emergence of up to two weeks under lower temperature compared to high temperature. They also reported that under extreme low or high soil temperatures percentage seed emergence may even highly decline. Unlike our observation, where we could not see difference in days to emergence between varieties, Kharazmshahi et al. (2015) reported significant effect of maize varieties on days to emergence.

Interaction effect of temperature and planting date:

Days to emergence was significantly influenced both by the main effect of planting date and the interaction effect

of growing temperature and planting date. Results indicated that days to emergence did not differ between planting dates for locations such as Uke and Didesa, but differed between planting dates for locations such as Bako, Ambo and Holeta (Table 5). Days to emergence were particularly longer for early planting (May 23) at Ambo and for late planting (June 6) at Holeta under cool temperatures (Table 5). Overall, days to emergence took only seven days at the test locations, which were characterized by warm temperature (Didesa and Uke), while it took between 18 to 22 days at Holeta under cool temperature (Table 5). Stone et al. (1998) also reported maize seedling emergence to have occurred after 14 days in cool temperature compared to warm temperature. Likewise, Alessi and Power (1971) reported that seed germination and seedling emergence were delayed if soil temperatures are low and these findings substantiate our observation in the current study.

Days to tasseling

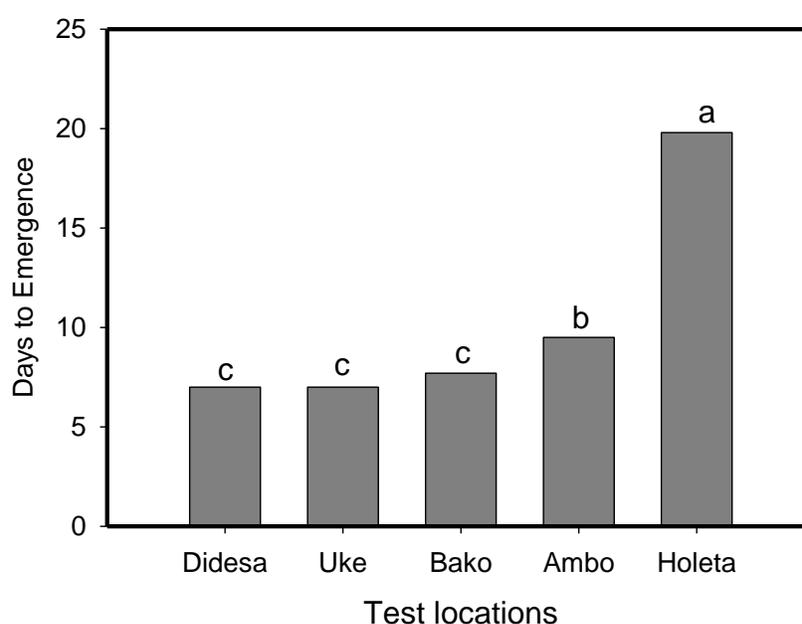
The analysis of variance showed that days to tasseling was significantly influenced by the main effects of both variety and growing temperature. However, it was not affected by the main effect of planting date (Table 3). Days to tasseling was also influenced by the interaction effects of growing temperature and planting date ($P<0.05$; Table 3) as well as by the interaction effect of growing temperature and variety ($P<0.01$; Table 3).

Interaction effects of temperature, variety and planting date

Days to tasseling was significantly influenced by the interaction effect of growing temperature and variety as well as growing temperature and planting date (Table 3). At Didesa, Uke and Bako under warm growing temperature, days to tasseling was longer for BH661, while at Ambo and Holeta under cool temperatures there was no difference among varieties in terms of days to tasseling (Table 4). For varieties AMH851, AMH853, BH661 and Limu, days to tasseling was significantly the longest at Holeta, where temperature was very low, followed by Ambo and Bako in that order. However, it was synonymously the shortest at Uke and Didesa (Figure 3). Unlike other varieties, for variety BH546, however, days to tasseling did not differ between Uke, Didesa and Bako as days to tasseling was synonymously the shortest at all the three locations (Figure 3). Days to tasseling was also significantly influenced by the interaction effect of growing temperature and planting date. Under cool growing temperature at Holeta, days to tasseling was longer for late planting (June 6), whereas at other locations the length of days to tasseling did not significantly differ

Table 3. P values as generated from Analysis of Variance table.

Source	P values			
	Days to emergence	Days to Tasseling	Days to maturity	Grain yield
Variety (V)	0.5 (ns)	<0.01	<0.01	0.24 ^{ns}
Growing temperature (T)	<0.01	<0.01	<0.01	<0.01
Planting dates (PD)	<0.05	0.08 ^{ns}	0.07 ^{ns}	<0.05
V*T	0.58 ^{ns}	<0.01	<0.05	<0.01
V*PD	0.136 ^{ns}	0.96 ^{ns}	0.08 ^{ns}	0.11 ^{ns}
T*PD	<0.01	0.05	<0.05	<0.01
V*T*PD	<0.01	0.84 ^{ns}	0.31 ^{ns}	0.08 ^{ns}

**Figure 2.** Main effect of location (growing temperature) on days to emergence.

(Table 5). However, contrary to our observation, Shrestha et al. (2016) and Maresma et al. (2019) reported shorter days to silking, for late than for early planting.

Days to maturity

The analysis of variance showed that days to maturity was significantly influenced by the main effects of variety and growing temperature ($P < 0.01$; Table 3) and by the interaction effect of variety and growing temperature as well as by the interaction effect of growing temperature and planting time ($P < 0.05$ both cases). However, days to maturity was not affected by the main effect of planting time and the interaction of variety and planting time as well as by the interaction effect of variety, growing temperature and planting time (Table 3).

Interaction effect of growing temperature, variety and planting date

Days to maturity was also significantly influenced by the interaction effect of growing temperature and variety. Under warm temperatures, days to maturity was longer for Bako hybrids (BH661 and BH546); whereas under cool temperatures at Holeta, days to maturity was longer for a pioneer hybrid Limu. Overall, days to maturity steadily increased with the decline in the growing temperature as one moved from Didesa, a low altitude location to Holeta, a high-altitude location. For varieties, AMH851, AMH853 and BH661, days to maturity significantly varied among locations, the longest being at Holeta followed by Ambo and Bako in that order. For the same varieties, days to maturity were the shortest at Didesa. For varieties BH546 and Limu, days to maturity

Table 4. Interaction effects of growing temperature and maize variety on days to tasseling, maturity and grain yields of maize (Effect of varieties at each location).

Growing temperature	Variety	Days to tasseling	Days to maturity	Grain yield (kg ha ⁻¹)
20/33°C (Didessa)	AMH851	66.0 ^b	125.8 ^b	5383 ^a
	AMH853	66.4 ^b	126.1 ^b	5243 ^a
	BH661	75.4 ^a	139.3 ^{ab}	6896 ^a
	BH546	75.7 ^a	141.1 ^a	4736 ^a
	Limu	69.2 ^b	129.5 ^{ab}	5960 ^a
LSD (5%)		6.0	14.0	4155
18/31°C (Uke)	AMH851	67.4 ^c	146.4 ^{ab}	7258 ^b
	AMH853	66.6 ^c	139.9 ^c	7748 ^{ab}
	BH661	73.8 ^a	150.2 ^a	8153 ^{ab}
	BH546	71.1 ^b	146.4 ^{ab}	9465 ^a
	Limu	70.3 ^b	143.2 ^{bc}	8515 ^{ab}
LSD (5%)		2.0	5.3	1844
14/27°C (Bako)	AMH851	74.2 ^b	154.0 ^a	6033 ^a
	AMH853	70.3 ^b	143.1 ^b	7111 ^a
	BH661	82.7 ^a	155.5 ^a	6362 ^a
	BH546	76.2 ^{ab}	154.6 ^a	8674 ^a
	Limu	76.3 ^{ab}	154.0 ^a	8271 ^a
LSD (5%)		7.1	5.5	3833
10/25°C (Ambo)	AMH851	91.2 ^a	194.1 ^a	9884 ^a
	AMH853	89.3 ^a	187.3 ^a	9713 ^a
	BH661	99.2 ^a	196.7 ^a	8947 ^a
	BH546	95.8 ^a	192.4 ^a	9007 ^a
	Limu	95.8 ^a	183.4 ^a	8365 ^a
LSD (5%)		2.35	18.4	3493
7/21°C (Holeta)	AMH851	124.1a	185.7ab	ND
	AMH853	122.3a	182.7b	ND
	BH661	123.0a	185.7ab	ND
	BH546	122.7a	185.0ab	ND
	Limu	124.9a	187.3a	ND
LSD (5%)		8.3	3.3	-

ND: Not determined.

did not vary between Holeta and Ambo, where it was significantly the longest and between Didesa and Uke where it was the shortest (Figure 4).

Days to maturity was also significantly influenced by the interaction effect of growing temperature and planting time (Table 3). Under warm temperature, at Uke, late planting (June 6) resulted in longer days to maturity while under cool weather at Holeta, early planting (May 23) resulted in longer days to maturity. Thus, there is no clear trend of planting date effect on days to maturity since the influence of planting date on days to maturity varied with growing temperatures of the locations. At the other three locations, however, days to maturity did not significantly differ between planting dates. According to reports of Shrestha et al. (2016), days to attain different

phenological stages decreased with late sowing, which agrees with our observation under lower temperature (7/21°C) at Holeta, where days to maturity decreased with the progress of planting time. Such crop strategy will enable the crop to escape the expected moisture limitation at the end of the season, which usually happens with late planting. However, at a growing temperature of 18/31°C (min/max at Uke) which is warm, days to maturity was longer for late planting (June 6), while under cool temperature at Holeta, early planting (May 23) resulted in longer days to maturity.

Grain yield

The analysis of variance indicated that there was main

Table 5. Interaction effects of growing temperature and planting date on days to emergence, tasseling and maturity (effect of planting dates at each location).

Growing temperature	Planting time	Days to emergence	Days to tasseling	Days to Maturity	Grain yield (kg ha ⁻¹)
20/33°C (Didessa)	May 23	7 ^a	70.6 ^a	134.2 ^a	4319 ^b
	May 30	7 ^a	71.6 ^a	136.2 ^a	4140 ^b
	June 6	7 ^a	69.5 ^a	126.7 ^a	9035 ^a
LSD (5%)		-	5.4	10.2	1759
18/31°C (Uke)	May 23	7 ^a	69.5 ^a	142.8 ^b	8922 ^a
	May 30	7 ^a	70.4 ^a	145.3 ^{ab}	7542 ^b
	June 6	7 ^a	69.7 ^a	147.7 ^a	8220 ^{ab}
LSD (5%)		-	2.7	4.3	1268
14/27°C (Bako)	May 23	8 ^a	73.4 ^a	154.3 ^a	7914 ^a
	May 30	7 ^b	76.7 ^a	154.5 ^a	9251 ^a
	June 6	8 ^a	77.9 ^a	147.9 ^a	4875 ^b
LSD (5%)		0.8	5.6	4.76	1990
10/25°C (Ambo)	May 23	12 ^a	94.3 ^a	188.5 ^a	11439 ^a
	May 30	8 ^b	93.9 ^a	192.7 ^a	9112 ^b
	June 6	8 ^b	93.4 ^a	191.2 ^a	6998 ^c
LSD (5%)		0.72	4.1	12.5	1590
7/21°C (Holeta)	May 23	18 ^b	121.9 ^b	186.8 ^a	ND
	May 30	18 ^b	121.3 ^b	184.0 ^b	ND
	June 6	22 ^a	126.9 ^a	184.8 ^{ab}	ND
LSD (5%)		2.4	4.9	2.27	

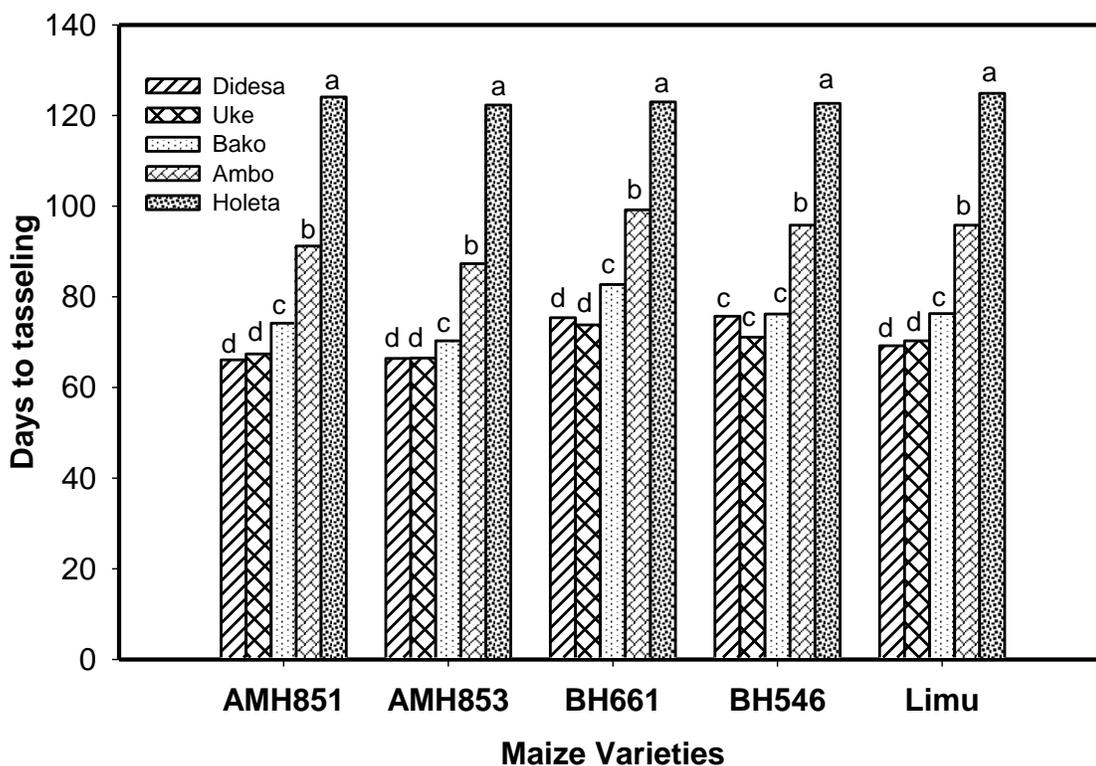


Figure 3. Interaction effect of growing temperatures (locations) and maize varieties on days to tasseling (Effect of growing temperatures/locations on each variety).

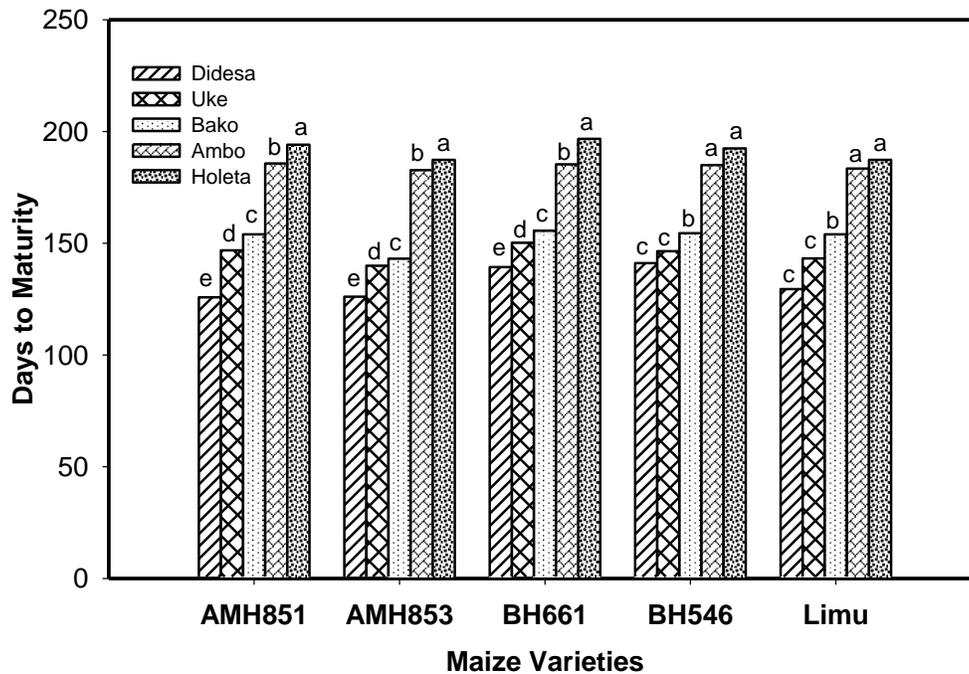


Figure 4. Interaction effect of growing temperatures (locations) and maize varieties on days to maturity (Effect of growing temperatures/locations on each variety)

factor effects of growing temperature ($P < 0.01$) and planting date ($P < 0.05$) on grain yield. There was also an interaction effects of variety and temperature ($P < 0.01$) as well as planting time and temperature ($P < 0.01$) on grain yield (Table 3).

Interaction effects of temperature, variety and planting date

Although grain yield was significantly affected by the main effect of growing temperature and planting date, this aspect is not discussed in this section since their interaction effect was also significant. Grain yield was influenced by the interaction effect of growing temperature and planting date ($P < 0.01$; Table 3). Under warm temperatures at Didesa, grain yield was significantly higher for late planting (June 6). However, at Uke, where the temperature is still warm, early planting (May 23) gave higher grain yield. At the other two locations (Bako and Ambo) early planting resulted in better grain yield compared to late planting. In line with our findings, Tsimba et al. (2013) also reported high grain yield for early planting of maize compared to late planting, as delayed planting may expose the plant to terminal drought at grain filling stage. Similarly, Varma et al. (2014) also recommended early or at least mid planting for better maize seed yields and quality, which confirms our finding. Many other literatures also witnessed

that grain yield is highly influenced by planting date, although the effect is context specific as early planting increases grain yield in some regions (Shrestha et al., 2018; Lizaso et al., 2018; Baum et al., 2019) or reduces grain yield in other regions (Dahmardeh, 2012). There could be yield penalty or complete crop failure if optimum planting window could not be met, especially under the current unpredictable weather changes such as early rain stops as observed in some regions of the country during some years. Lizaso et al. (2018) ascribed the grain yield difference between planting dates to difference in kernel weight since he observed higher kernel weight for the first sowing date which resulted in higher grain yields. Early sowing which resulted in higher yields, however, might be associated to sufficient moisture during grain filling, in our context, not with temperature unlike his speculation.

Grain yield was also affected by the interaction effect of variety and temperature. At Uke, under warm temperature, BH546 gave significantly higher yield compared to AMH851 (Table 4) whereas grain yield did not vary among varieties at the other locations. For varieties, AMH851 and AMH853, grain yield was significantly higher at Ambo than the other three locations (Table 4) and this is acceptable as these varieties were released for similar highland agro-ecologies. For all varieties, the lowest grain yield was recorded under higher temperature at Didesa (Figure 5). Grain yield at Uke and Bako did not show much difference. The reason for the yield reduction at Didesa, where temperature was

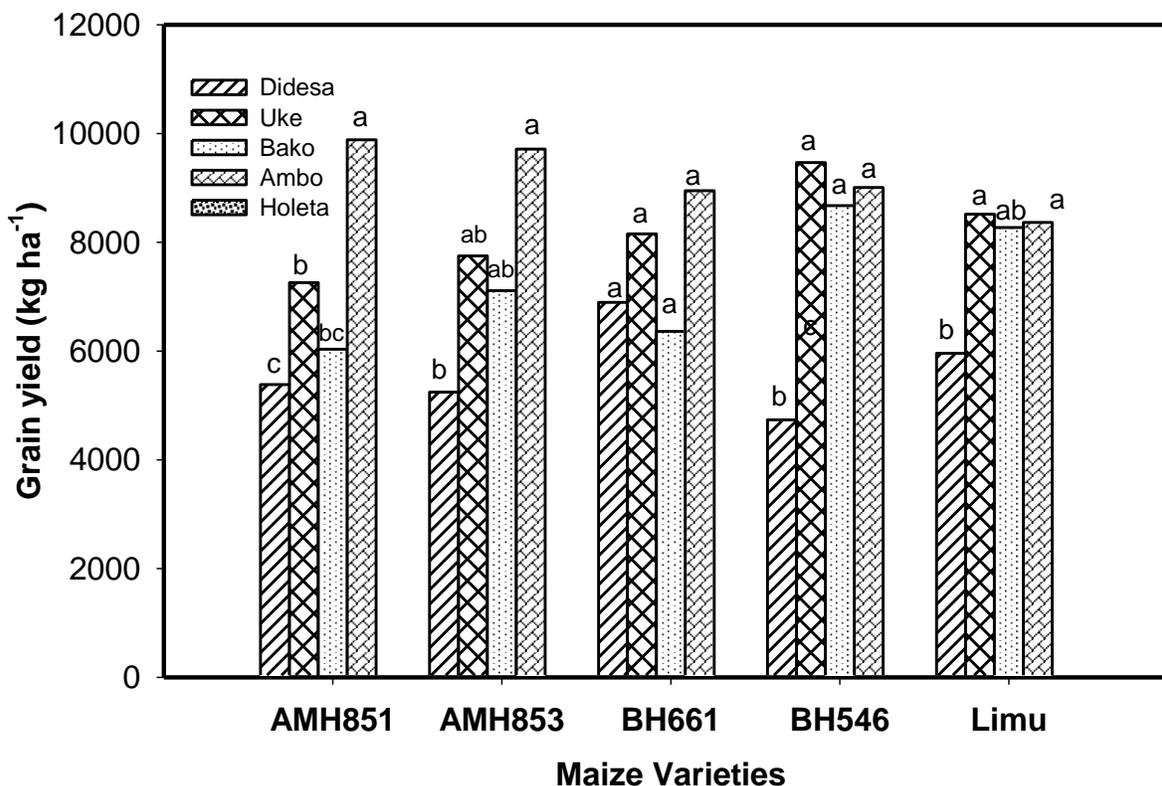


Figure 5. Interaction effect of growing temperatures/locations and varieties on grain yields (Effect of growing temperatures/locations on each variety)

very warm compared to the other locations could be related to higher dark respiration, which negatively affects the crops ability of conserving the carbon fixed through photosynthesis (poor carbon budgeting) as suggested by Hatfield (2016). The reduction in grain yield thus could be related to poor assimilate partitioning to the grain resulting in less kernel weight and kernel number per cob as reported by Lizaso et al. (2018). In our study we did not see the interaction effect of maize variety and planting dates, although this was possible in other studies (Beiragi et al., 2011).

Conclusion

Days to seed emergence was influenced by the growing temperature, with days to emergence difference of two weeks observed between Didesa/Uke (high temperature locations) and Holeta (low temperature location). Almost for all varieties except for BH546, days to tasseling and maturity were longer under low temperature at Holeta while they were shorter under high temperature at Didesa and Uke. Early planting resulted in higher grain yields especially at Uke, Bako and Ambo. Yield performance was influenced by the interaction effect of variety and temperature, with BH546 being more yielder than AMH851

under high temperature at Uke. Based on the result of the current study, early planting is recommended, as this will enable the varieties to escape moisture stress that occasionally occurs at grain filling and maturation period, which can seriously affect grain yield. However, such experiments should be repeated to confirm consistence of the results across years to reach reliable conclusion.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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