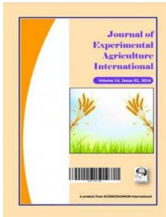

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Validation of Flowering Models for Classifying Maize into Maturity Groups in the Different Agro-ecologies of West and Central Africa

A. Oluwaranti[1*], M. A. B. Fakorede[1] and A. Menkir[2]

[1]Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife, Nigeria.
[2]IITA, P.M.B. 5320, Ibadan, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author AO managed the study and the literature searches, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MABF designed and supervised the study and author AM co-supervised the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study was conducted with a view to validate and compare flowering models (indices) containing temperature, heat units, photoperiod and their combinations developed to predict the number of days to flowering in maize in different agro-ecological zones of West and Central Africa.
Study Design: Simple and multiple linear regression models developed on 100 maize varieties as the inverse of the number of days from planting to flowering (1/f) on values of temperature, heat units and photoperiod were validated.
Place and Duration of Study: One hundred maize varieties of different maturity groups were evaluated for days to tasseling, anthesis and silking at the Teaching and Research Farm (TRF) of Obafemi Awolowo University Ile-Ife, Nigeria during late and early cropping seasons of 2007/2008 and 2008/2009 respectively. The 2007 developed models were validated with 2008 early, 2008 late, 2009 early, 2012 late, 2013 early seasons and flowering data of the other agro-ecologies.

**Corresponding author: E-mail: boluwaranti@yahoo.com;*

Methodology: The developed flowering models were validated with the flowering data of the 100 varieties obtained during the 2008 early, 2008 late, 2009 early, 2012 late and 2013 early seasons. Furthermore, flowering dates and the weather data from research stations in the Forest, Guinea savanna and Sudan savannah agro-ecologies were used to validate the flowering models.
Results: The thermal model best predicted the time from planting to the expression of anthesis. The thermal model accurately predicted the anthesis of about 30-40% of the varieties in the 2008 early and late seasons, trial in environment different from the one in which it was developed in the rainforest agro-ecology. Heat units models closely predicted 10 varieties from the hundred varieties evaluated in this study in 2012 late and 2013 early cropping seasons. In the Southern Guinea savannah and Sudan savannah, none of the models predicted the number of days to the flowering traits of some of the 100 varieties correctly.
Conclusion: Predicted days to anthesis due to thermal and heat units models are the best models to classify maize varieties into maturity groups in the rainforest agro-ecology The thermal model correctly classified over 40% of the 100 maize varieties into maturity groups, with the coefficient of determination (r^2) ranging from 0.94 to 0.97.

Keywords: Tasselling; anthesis; silking temperature; heat units; photoperiod.

1. INTRODUCTION

Maize is one of the most important cereal crops in countries of West and Central Africa (WCA). It is an essential staple cereal produced in all agro-ecologies of WCA due to its popularity as a hunger breaker in the drier savanna in addition to the forest and forest-savanna transition ecologies [1,2]. A broad range of climatic conditions have been used to characterise the agro-ecological zones, including rainfall, temperature, length of the growing season, radiation and edaphic factors [3-6]. The WCA region stretches between 4° and 25° N latitude 17° W and 18°E longitude. The agro-ecological zones of WCA are divided into six from South to North, Rain Forest, Derived Savanna, Southern Guinea Savanna, Northern Guinea Savanna, Sudan Savanna and Sahel Savanna [7].

There are several indices that have been used to classify maize into maturities for the agro-ecological zones. These could be grouped into three major classes namely thermal indices, time to flower in days and external appearances of the plant [8,9]. The thermal indices includes growing degree days (GDD) crop heat unit (CHU) and a general thermal index (GTI); time to flower in days include days to 50% tasseling, anthesis and silking while the external appearances of the plant include kernel respiration, kernel moisture, black layer rating and milk line rating [10]. Tropical maize exhibits delayed flowering time, increased plant height and a greater total leaf number when grown in temperate latitudes, where daily dark periods are shorter than 11 hours during the cropping season [11,12].

Classification of maize into maturity groups in WCA has been based primarily on days to silking. The use of number of days to silking as maturity index is unreliable due to the high influence of the environment on the expression of this and other flowering traits [13].

Maize is a short-day plant and the rate of progress towards flowering measured as 1/f (i.e. reciprocal of days to flowering) declines in a linear fashion with increasing temperature [14] and daylength when that length exceeds a critical photoperiod of 12-13 hrs [15]. The rate of progress can be quantified by linear responses to mean temperature and mean photoperiod [16, 17-20]. Considerable genetic differences in responsiveness to photoperiod have been observed especially in tropically adapted maize cultivar [21]. These genotypic responses of maize to different climatic conditions have led to the development of flowering models containing temperature, heat units, photoperiod, and their combinations to predict days to flowering (tasseling, anthesis and silking) of diverse maize cultivars in WCA [14]. However, these models have not been validated for their accuracy in predicting days to flowering in maize in other field trials which were outside the ones from which the flowering models were developed in the rainforest Agro-ecology and other Agro-ecologies of WCA. Therefore, the objectives of the study were to validate and compare the stability of these models in predicting the flowering traits in maize.

2. MATERIALS AND METHODS

2.1 Description of the Flowering Models

Regression flowering models generated from a 2007 late planting season trial were used for this study [14]. They were simple and multiple linear regressions of reciprocal of flowering (1/f) on mean values of temperature, heat units and photoperiod which were performed separately on each flowering trait. They were of these forms;

$1/f = a + bT$……………… ……………………(1)
(Thermal Model)
$1/f = a' + c'P$…………………………………… ..(2)
(Photoperiod Model)
$1/f = a'' + d''H$ ……………………………………(3)
(Heat Units Model)
$1/f = a''' + b'''P + c'''T$ …………………………(4)
(Photo-Thermal Model)
$1/f = a'''' + b''''P + d''''H$…………………………..(5)
(Photo-Heat units Model)

Where f is the number of days from sowing to flowering (Tasseling, Anthesis and Silikng) which resulted into three models for each equation, T is mean daily temperature, P is the mean daily photoperiod (day length) in hours, H is heat units calculated from the daily minimum and maximum temperature using this formula:

$$H = \sum_{i=1}^{n} ((X_i^{H''} + X_i^{L})/2) - 10$$

Where

X_i^L = Minimum temperature for the day
$X_i^{H''}$ = 30 – (X_i^H – 30) if X_i^H > 30 and
X_i^H = Maximum temperature for the day [22]

P and H are calculated from mean photoperiod and heat units from planting to flowering for each variety per replication. The coefficients a, b, a', c', a'', d'', a''', b''', c''', a'''', b'''' and d'''' are genotypic constants (regression coefficients) [23]. These five regression models were developed for individual varieties evaluated during the 2007 late cropping season using all the flowering traits [14]. Validation of the models was carried out using the data obtained from the 100 varieties used for the model development in 2008 early, 2008 late, 2009 early, 2012 late and 2013 early seasons at the Teaching and Research Farm (TRF) of Obafemi Awolowo University (7°28'N 4°33'E and 244 m above sea level), Ile-Ife which is a typical rainforest agro-ecology [14] as well as using data obtained from other agroclimatic zones in which some of the 100 maize varieties were evaluated.

2.2 Statistical Analyses

Summary statistics such as mean, standard error, range and coefficient of variation (CV) obtained for the observed and the predicted days to flowering were compared for all the trials to arrive at a decision on the best predictive model for flowering trait. Classification of the varieties into maturity groups using the flowering date predicted from modeling was compared with the classification based on observed flowering dates. Finally, regression of the observed days to flowering values on the Predicted values was carried out.

3. RESULTS

3.1 Summary Statistics of the Observed and Predicted Days to Models

A summary statistics of the ranges, means, standard errors (S.E) of the mean and coefficients of variation (CV) for the observed days to flowering in the 2008 early cropping season and their corresponding predicted values of the 2007 late season trial models is presented in Table 1.

Observed values ranged from 44 to 63 days after planting (DAP) for tasseling, 46-65 DAP for anthesis and 48-67 DAP for silking (Table 1). The predicted mean days to anthesis (58±0.87) using the thermal model closely approximated the observed (57.25±0.37). The CV for the model (about 15%) was also the least of all the models. Predicted days to tasseling (51.65±4.59) also closely approximated the observed value (55.04±0.36) but the CV (about 89%) was high. The predicted value for all the other models failed to approximate the observed values and their corresponding CVs were outrageous. The trends for the late season of 2008 were similar to those of the early season; that is, the predicted values from the thermal model closely approximated the observed values for anthesis and tasseling with CVs of about 16 and 73% respectively (Table 2).

Here also, predicted values from other models and/or their CVs were too large to be acceptable. For the 2009 early season, nearly all the predicted values and their CVs were greatly different from the observed values (Table 3).

The only exception was the predicted silking date from the thermal model (61.24±6.15) which compared favourably with the observed (60.9±0.33), but CV of 100% was too large to serve any useful purpose.

3.2 Validation of the Models

The b-values associated with the models developed using the data from 2007 late season trial were taken as genotypic constant for each variety. The models were used to predict the number of days after planting to each flowering event and the predicted values were compared with the observed values in the other three seasons not used for developing the models. Results of this approach are presented in Tables 4, 5 and 6 for the 2008 early season, 2008 late season and 2009 early season respectively.

The lowest observed value +2 S.E. was the range for the extra-early group. Other maturity groups were determined similarly. The ranges and number of varieties falling within them for the observed and predicted flowering dates are shown for each model in the tables. Across maturity groups the thermal model accurately validated 29, 41 and 47% of the varieties using tasseling, anthesis and silking respectively in the 2008 early season (Table 4). Other models predicted only 0 to 9% of the varieties. For the 2008 late season, the models were not too distinct from another in accurately predicting flowering dates except in a few cases (Table 5). All of the models poorly predicted flowering of the varieties in 2009 early season (Table 6). In terms of number of varieties common to both observed and predicted flowering dates within the group, the intermediate varieties had the greatest correspondence in all seasons and anthesis or silking as predicted by the thermal model was the best combination for this group in the early season of 2008 (Table 4). Both the early and intermediate groups had the largest number of varieties common to observed and predicted anthesis using thermal or heat units in the 2008 late season (Table 5). The extra-early and late maturity groups were the poorest in terms of correspondence between observed and predicted number of varieties. Contrary to this, validation of the models with flowering data obtained from 2012 late and 2013 early seasons' trials indicated that the Heat units predicted more closely to the observed days to flowering than the other flowering models. (Tables 7-10).

Validation of the flowering models developed from 2007 late cropping season with flowering data obtained from other locations and agro-ecologies (Rainforest, Southern Guinea savannah and Sudan Savannah) are presented in Tables 11 – 16.

Validation of the models with flowering data obtained from Ikenne which is a rainforest agro-ecology. The prediction from thermal models for both days to anthesis and silking were closer to the observed values than those from other models (Tables 11 and 12). Predicted flowering data for Abuja and Kano (Southern Guinea and Sudan Savannah Respectively) were unrealistic, for all models being negative in most cases and when positive, were unreasonably large or too small (Tables 13 to 16).

Regression of the observed values on the Predicted values showed high correspondence for a linear model with R^2 values of 0.97 and 0.94 for the early and late seasons, respectively (Figs. 1 and 2), an indication that the thermal model predicted anthesis fairly closely in these environments.

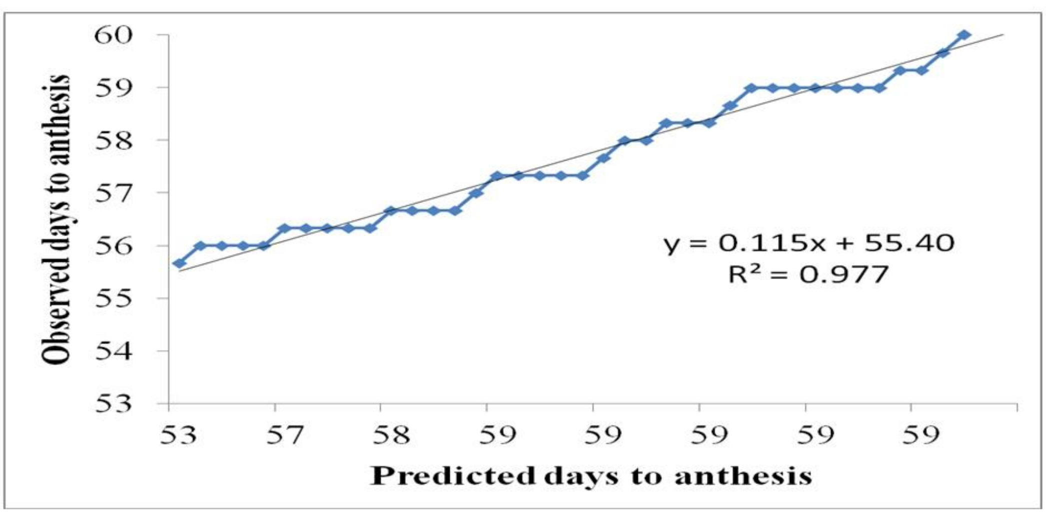

Fig. 1. Relation between the predicted and observed days to anthesis for the 2008 early season trial, using the thermal model

Table 1. Ranges, means±standard error (S.E) and coefficients of variation (CV) for 2008 early cropping season of observed and predicted days to tasseling, anthesis and silking using temperature, photoperiod, heat units, photothermal and photoheat units models

	TASSELING			ANTHESIS			SILKING		
	RANGE	MEAN±S.E	CV	RANGE	MEAN±S.E	CV	RANGE	MEAN±S.E	CV
OBSERVED	44-63	55.04±0.36	6.53	46-65	57.25±0.37	6.43	48-67	59.91±0.37	6.19
MODELS									
TEMP	(-375)-126	51.65±4.59	88.81	(-10)-102	58.47±0.87	14.95	(-207)-669	43.53±22.48	516.37
PHOTO	(-343)-1773	30.55±11.99	392.48	(-9494)-1773	(-832.41)±94.38	63.05	(-79)-134	72.26±24.43	66.15
HEAT	(-616)-559	100.10±24.96	249.38	(-85)-159	43.20±2.72	-113.31	(-163)-374	41.22±2.73	338.09
PHOTOTEMP	(-346)-1773	89.26±24.52	346.03	(-2189)-4694	144.10±73.86	512.57	(-125)-410	54.24±15.77	290.67
PHOTOHEAT	(-502)-297	29.87±10.34	274.69	(-5959)-585	(-1147)±84.43	-735.73	(-1935)-259	58.26±33.24	570.44

TEMP: Temperature, PHOTO: Photoperiod, HEAT: Heat Units, PHOTOTEMP: Photoperiod-Temperature, PHOTOHEAT: Photoperiod-Heat Units

Table 2. Ranges, means±standard error (SE) and coefficients of variation (CV) for 2008 late cropping season of observed and predicted days to tasseling, anthesis and silking using temperature, photoperiod, heat units, photothermal and photoheat units models.

	TASSELING			ANTHESIS			SILKING		
	RANGE	MEAN±S.E	CV	RANGE	MEAN±S.E	CV	RANGE	MEAN±S.E	CV
OBSERVED	42-64	51.82±0.31	5.92	44-66	53.72±0.03	5.60	45-68	55.73±0.29	5.22
MODELS									
TEMP	(-82)-319	47.46±3.46	72.90	(-10)-98	58.54±0.92	15.78	(-272)-218	48.17±4.14	85.94
PHOTO	19-583	70.58±9.51	134.72	(-21)-314	48.36±3.43	70.84	(-16)-583	46.65±5.77	123.63
HEAT	(-271)-216	40.39±6.35	157.20	(-37)-515	63.75±6.93	108.70	(-77)-10893	168.06±108.49	645.56
PHOTOTEMP	(-92)-583	60.91±9.44	155.01	(-21)-291	45.10±3.13	69.30	(-40)-5139	99.18±51.25	516.74
PHOTOHEAT	(-326)-185	28.08±6.61	235.53	(-12453)-151	82.24±124.9	159.74	(-79)-564	48.36±7.32	151.30

***TEMP:** Temperature, **PHOTO**: Photoperiod, **HEAT:** Heat Units, **PHOTOTEMP**: Photoperiod-Temperature, **PHOTOHEAT**: Photoperiod-Heat Units*

Table 3. Ranges, means±standard error (SE) and coefficients of variation (CV) for 2009 early cropping season of observed and predicted days to tasseling, anthesis and silking using temperature, photoperiod, heat units, photothermal and photoheat units models

	TASSELING			ANTHESIS			SILKING		
	RANGE	MEAN±S.E	CV	RANGE	MEAN±S.E	CV	RANGE	MEAN±S.E	CV
OBSERVED	47-63	55.82±0.31	5.52	49-65	58.27±0.32	5.44	52-68	60.90±0.33	5.42
MODELS									
TEMP	(-511)-551	75.62±10.78	142.5	(-511)-1908	79.32±19.56	246	(-470)-101	61.24±6.146	100
PHOTO	(-1796)-851	(-64.26)±181.56	(-2825)	(-2887)-1847	108.02±53.33	494	(-1782)-10974	100.71±124.25	1234
HEAT	(-5263)-763	(-65.49)±80.09	(-1223)	(-799)-2514	112.81±27.98	248	(-9904)-2831	(-77.62)-136.15	(-1754)

	TASSELING			ANTHESIS			SILKING		
	RANGE	**MEAN±S.E**	**CV**	**RANGE**	**MEAN±S.E**	**CV**	**RANGE**	**MEAN±S.E**	**CV**
PHOTOTEMP	(-581)-741	82.70±13.20	159.58	(-11078)-1097	52.91±20.56	388	(-732)-3867	98.42±51.12	519
PHOTOHEAT	(-4048)-1464	39.54±46.88	1185.3	(-3734)-4793	85.16±70.28	825	(-3341)-74555	787.73±748.98	951

***TEMP:** Temperature, **PHOTO:** Photoperiod, **HEAT:** Heat Units, **PHOTOTEMP:** Photoperiod-Temperature, **PHOTOHEAT:** Photoperiod-Heat Units*

Table 4. Validation of the flowering models developed with 2007 late cropping season trial data and predicted for flowering with 2008 early cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm.

Observed and predicted flowering models	Extra-Early		Early		Intermediate		Late		Total No of varieties
	DAP	No of varieties	DAP	No of varieties	DAP	No of varieties	DAP	No of varieties	
Tasseling									
Observed	44-48	2	49-53	32	54-58	49	59-63	17	100
Models									
Temp (C)	49-61	2(0)	(-27)-66	32(6)	02-126	49(10)	(-375)-60	17(13)	(29)
Photo (C)	64-67	2(0)	40-1773	32(0)	(-343)-155	49(1)	(-103)-1773	17(3)	(04)
Heat (C)	0-33	2(0)	(-49)-279	32(2)	(-473)-559	49(0)	(616)-60	17(1)	(03)
Phototemp(C)	64-73	2(0)	28-1696	32(0)	(-346)-144	49(4)	(-132)-1773	17(5)	(09)
Photoheat (C)	101-126	2(0)	(-11)-126	32(5)	(-223)-297	49(1)	(-502)-66	17(1)	(07)
Anthesis									
Observed	46-50	3	51-55	31	56-60	43	61-65	23	100
Models									
Temp (C)	57-66	3(0)	53-68	31(2)	(-10-60	43(39)	53-102	23(0)	(41)
Photo (C)	20-109	3(0)	(-343)-1773	31(0)	(-94194)-246	43(0)	(-333)-1677	23(0)	(00)
Heat (C)	(13)-41	3(0)	(-25)-159	31(1)	(-48)-136	43(0)	(-85)-113	23(0)	(01)
Phototemp(C)	59-81	3(0)	(-614)-1696	31(1)	(-405)-4694	43(17)	(-2189)-237	23(1)	(09)
Photoheat (C)	13-160	3(1)	(-97)-585	31(3)	(-59959)-179	43(3)	(-214)-247	23(0)	(07)
Silking									
Observed	48-52	2	53-57	21	58-62	48	63-67	29	100
Models									
Temp (C)	59	2(0)	36-60	21(2)	(-2097)-125	48(43)	39-669	29(2)	(47)
Photo (C)	71-95	2(0)	(-1354)-218	21(0)	(-1683)-360	48(0)	17-374	29(0)	(00)
Heat (C)	47-97	2(0)	22-127	21(0)	(-24)-134	48(0)	(-79)-111	29(0)	(00)
Phototemp(C)	62-93	2(0)	35-234	21(0)	(-1205)-237	48(5)	(-403)-410	29(2)	(07)
Photoheat (C)	39-46	2(0)	(-5)-139	21(0)	(-214)-2591	48(2)	(-1935)-239	29(1)	(03)

(C): Number of varieties common to both the observed and predicted number of days to flowering, DAP: days after planting

Table 5. Validation of the flowering models developed with 2007 late cropping season trial data and predicted with 2008 late cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm

Observed and predicted flowering models	Extra-Early		Early		Intermediate		Late		Total No of Varieties
	DAP	No of Varieties	DAP	No of Varieties	DAP	No of Varieties	DAP	No of Varieties	
Tasseling									
Observed	42-47	23	48-53	42	54-59	26	60-65	9	100
Models									
Temp (C)	(-47)-88	23(6)	(-82)-88	42(20)	23-319	26(2)	48-65	9(0)	(28)
Photo (C)	40-160	23(11)	27-583	42(17)	19-311	26(2)	38-522	9(0)	(30)
Heat (C)	0-185	23(7)	(-244)-216	42(12)	(-271)-208	26(8)	(-26)-56	9(0)	(27)
Phototemp(C)	0-113	23(11)	(-7)-583	42(16)	(-92)-70	26(2)	43-583	9(1)	(30)
Photoheat (C)	(-166)-185	23(6)	(-244)-77	42(11)	(-326)-89	26(3)	0-58	9(0)	(20)
Anthesis									
Observed	44-49	24	50-55	41	56-61	29	62-67	6	100
Models									
Temp (C)	49-65	24(2)	47-98	41(9)	(-10)-72	29(15)	61-67	6(4)	(30)
Photo (C)	20-49	24(16)	(-21)-158	41(3)	12-314	29(1)	13-46	6(0)	(20)
Heat (C)	(-10)-150	24(1)	(-37)-471	41(27)	44-515	29(2)	50-55	6(0)	(30)
Phototemp(C)	4-59	24(12)	(-21)-113	41(9)	(-20)-291	29(1)	62-67	6(1)	(23)
Photoheat (C)	5-151	24(8)	(-1245)-60	41(13)	1-88	29(2)	38-72	6(0)	(23)
Silking									
Observed	45-60	8	51-56	51	57-62	31	63-68	10	100
Models									
Temp (C)	45-106	8(5)	(-72)-166	51(16)	26-218	31(2)	(-272)-51	10(0)	(23)
Photo (C)	37-56	8(4)	2-583	51(2)	(-16)-98	31(0)	11-48	10(0)	(06)
Heat (C)	6-131	8(1)	(-7)-485	51(37)	7-1089	31(0)	(-77)-55	10(0)	(38)
Phototemp(C)	(-40)-49	8(0)	12-5139	51(6)	(-40)-89	31(0)	10-57	10(0)	(06)
Photoheat (C)	(-11)-54	8(1)	(-35)-564	51(15)	(-13)-97	31(1)	(-79)-59	10(0)	(07)

(C): Number of varieties common to both the observed and predicted number of days to flowering, DAP: days after planting

Table 6. Validation of the flowering models developed with 2007 late cropping season trial data and predicted with 2009 early cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm

Observed and predicted flowering models	Extra-Early		Early		Intermediate		Late		Total No of varieties
	DAP	No of Varieties	DAP	No of Varieties	DAP	No of Varieties	DAP	No of Varieties	
Tasseling									
Observed	48-52	12	53-57	28	58-62	48	63-67	12	100
Models									
Temp (C)	(-103)-150	12(0)	(-20)-551	28(0)	(-511)-209	48(1)	(-136)-75	12(6)	(07)
Photo (C)	27-553	12(0)	(-142)-460	28(1)	(-17936)-851	48(3)	(-229)-741	12(0)	(04)
Heat (C)	(-5219)-534	12(0)	(-5263)-663	28(0)	(-2233)-763	48(2)	15-144	12(0)	(02)
Phototemp(C)	(-62)-149	12(0)	(-151)-454	28(0)	(-177)-258	48(4)	(-581)-741	12(0)	(04)
Photoheat (C)	(-4048)-407	12(0)	(-297)-1464	28(0)	(-1216)-527	48(1)	(-53)-178	12(0)	(01)
Anthesis									
Observed	51-55	14	56-60	30	61-65	46	66-70	10	100
Models									
Temp (C)	(-511)-1908	14(0)	(-10)-81	30(1)	(-186)-91	46(1)	59-72	10(5)	(07)
Photo (C)	(-568)-1762	14(0)	(-2887)-879	30(0)	(-1078)-1847	46(0)	(-1782)-793	10(0)	(00)
Heat (C)	(-213)-222	14(0)	(-157)-330	30(0)	(-799)-581	46(1)	26-2514	10(0)	(01)
Phototemp(C)	(-80)-218	14(0)	(-323)-1097	30(0)	(-1108)-219	46(2)	(-122)-659	10(0)	(02)
Photoheat (C)	(-248)-277	14(1)	(-382)-700	30(1)	(-3734)-4793	46(0)	(-1311)-1044	10(0)	(02)
Silking									
Observed	55-59	23	60-64	30	65-69	42	70-74	5	100
Models									
Temp (C)	16-87	23(0)	(-220)-73	30(1)	(-470)-101	42(18)	69-75	5(3)	(22)
Photo (C)	(-1125)-754	23(0)	(-685)-3679	30(0)	(-1782)-10974	42(0)	(-525)-420	5(0)	(00)
Heat (C)	(-200)-2831	23(0)	(-1178)-309	30(0)	(-6624)-2514	42(0)	(-9904)-560	5(0)	(00)
Phototemp(C)	(-382)-2147	23(1)	(541)-3867	30(3)	(-732)-1550	42(0)	(-649)-120	5(1)	(05)
Photoheat (C)	(1936)-4793	23(0)	(-3341)-7455	30(0)	(-1437)-1989	42(0)	(-89)-690	5(0)	(00)

Table 7. Validation of days to anthesis models developed with 2007 late cropping season trial data and predicted with 2012 late cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm

VARIETY	OBS ANTH	MODEL				
		TEMP	HEAT-UNITS	PHOTO	PHOTOTEMP	PHOTOHEAT
TZECOMP3C2	49	-626	56	419	-956	56
TZECOMP.4C4	49	-65	56	10	-65	81
2004TZEE-WPOPSTRC4	50	-59	56	14	14	56
98SYNWECSTRCo	49	-176	56	19	89	61
TZE-WPOPDTSTRC4	49	-65	57	10	-65	81
TZEE-WSRBC5	48	-141	56	-313	-159	52
TZECOMP3C2	50	-1	56	14	14	54
TZEE-WPOPSTRC2	51	-99	54	45	-130	60
99SYNEE-W	50	-162	59	-249	-196	57
EVDT-W2000STRCo	51	-91	57	10	10	59

Table 8. Validation of days to silking models developed with 2007 late cropping season trial data and predicted with 2012 late cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm

Variety	OBSK	MODEL				
		TEMP	HEAT-UNITS	PHOTO	PHOTOTEMP	PHOTOHEAT
TZECOMP3C2	52	27	61	12	12	61
TZECOMP.4C4	52	-50	60	12	-19	51
2004TZEE-WPOPSTRC4	54	145	62	-91	-91	62
98SYNWECSTRCo	54	-17	63	-80	-21	55
TZE-WPOPDTSTRC4	52	-50	60	12	-19	51
TZEE-WSRBC5	53	98	61	-95	-4	48
TZECOMP3C2	53	98	61	-95	-4	48
TZEE-WPOPSTRC2	54	54	54	54	54	54
99SYNEE-W	54	-17	63	-80	-21	55
EVDT-W2000STRCo	54	145	62	-91	-91	62

Table 9. Validation of days to anthesis models developed with 2007 late cropping season trial data and predicted with 2013 early cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm

VARIETY	OBS ANTH	MODEL				
		TEMP	HEAT-UNITS	PHOTO	PHOTOTEMP	PHOTOHEAT
TZECOMP3C2	55	54	57	141	141	141
AK9331DMRSR	59	-4	62	36	-5	59
EV.8728-SR	55	-4	57	84	84	84
2004TZEE-WPOPSTRC4	54	-5	56	73	73	57
98SYNWECSTRCo	57	14	59	2	14	59
TZEE-YPOPSTRC4	54	52	57	47	47	47
TZE-YPOPDTSTRC4	54	-256	56	89	6	57
TZEE-WSRBC5	53	51	56	51	47	25
EVDT-W2000STRCo	57	51	61	51	45	98
TZECOMP3C2	55	54	57	141	141	141

Table 10. Validation of days to silking models developed with 2007 late cropping season trial data and predicted with 2013 early cropping season trial data at the Obafemi Awolowo University Teaching and Research Farm.

VARIETY	OBSK	MODEL				
		TEMP	HEAT-UNITS	PHOTO	PHOTOTEMP	PHOTOHEAT
TZECOMP3C2	57	6	59	39	39	39
AK9331DMRSR	59	-5	61	43	-40	63
EV.8728-SR	58	14	60	47	14	60
2004TZEE-WPOPSTRC4	55	7	57	47	47	47
98SYNWECSTRCo	59	62	62	62	62	62
TZEE-YPOPSTRC4	54	-15	56	43	43	43
TZE-YPOPDTSTRC4	56	-5	58	45	45	61
TZEE-WSRBC5	53	-30	55	50	50	50
EVDT-W2000STRCo	59	56	56	56	56	56
TZECOMP3C2	57	6	59	39	39	39

Table 11. Validation of the days to anthesis models developed with 2007 late season trial data and predicted with Ikenne trial's data (Rainforest Agro-ecology)

VARIETY	OBSERVED ANTHESIS	MODEL				
		TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
TZLCOMPC4C3	60	61	48	54	54	48
TZLCOMP3C3	59	57	47	54	60	50
TZB-SR	59	67	44	54	88	36
AMA.TZBR-WC2BF2	59	65	35	54	32	31
ACR.9449-SR	58	61	52	55	58	52
Oba Super I	61	60	72	54	53	56
SIN93TZUTSR-W	62	61	46	55	55	45
Oba Super II	54	65	20	55	44	20
IK.91TZLCOMP3-Y	61	61	44	54	88	36
ACR97TZLCOMPI-W	61	64	44	55	44	20

Table 12. Validation of the days to Silking models developed with 2007 late season trial data and predicted with Ikenne trial's data (Rainforest Agro-ecology)

VARIETY	OBSERVED SILKING	MODEL				
		TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
TZLCOMPC4C3	65	50	41	258	-13	47
TZLCOMP3C3	65	49	41	54	40	39
TZB-SR	63	50	41	49	46	51
AMA.TZBR-WC2BF2	64	48	47	48	10	49
ACR.9449-SR	62	53	3	55	48	55
Oba Super I	66	43	45	42	34	43
SIN93TZUTSR-W	67	50	12	53	11	11
Oba Super II	56	45	39	45	39	36
IK.91TZLCOMP3-Y	68	56	01	51	38	35
ACR97TZLCOMPI-W	66	49	35	54	62	79

Table 13. Validation of the days to anthesis models developed with 2007 late season trial data and predicted with Abuja trial's data (Southern Guinea Savannah Agro-ecology)

VARIETY	OBSERVED ANTHESIS	MODEL				
		TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
DTSR-WCI	58	-187	35	124	172	-315
ACR95DMRESRW	55	-88	-30	175	191	-34
TZLCOMP3C3	62	-134	155	254	198	-109
TZB-SR	66	-79	-261	-987	-395	-83
AMA.TZBR-WC2BF2	61	-108	-173	383	314	-301
Oba Super I	61	-401	50	156	03	-781
SIN93TZUTSR-W	51	-240	333	179	378	04
Oba Super II	54	-87	-24	174	181	-24
IK.91TZLCOMP3-Y	52	-207	256	174	113	52
ACR97TZLCOMP1-W	61	-158	282	223	301	88

Table 14. Validation of the days to Silking models developed with 2007 late season trial data and predicted with Abuja trial's data (Southern Guinea Savannah Agro-ecology)

VARIETY	OBSERVED SILKING	MODEL				
		TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
DTSR-WCI	62	119	-840	50	-73	03
ACR95DMRESRW	58	-145	03	276	-435	435
TZLCOMP3C3	64	-99	-263	245	-104	290
TZB-SR	69	-126	884	-120	-147	-117
AMA.TZBR-WC2BF2	64	-79	175	-151	14	-47
Oba Super I	63	-43	257	-70	-46	-21
SIN93TZUTSR-W	52	-164	-11	390	-09	-10
Oba Super II	56	-49	-550	-81	-142	113
IK.91TZLCOMP3-Y	53	-146	01	274	-432	430
ACR97TZLCOMP1-W	64	-98	-161	566	260	-78

Table 15. Validation of the days to anthesis models developed with 2007 late season trial data and predicted with Kano trial's data (Sudan Savannah Agro-ecology)

VARIETY	OBSERVED ANTHESIS	MODEL				
		TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
DTSR-WCI	57	-132	34	47	63	-191
TZECOMP.4C3	61	-200	-255	45	57	-839
TZLCOMP3C3	59	-101	165	42	52	-699
EVDT-Y2000STRCoxPOOL18SRQPMxEVBC2F2	67	-105	254	45	56	254
TZB-SR	64	-64	-216	40	118	-67
DTE –YSRBC3	55	-71	102	42	96	146
AMA.TZBR-WC2BF2	61	-84	-150	42	-68	-304
POOL18SRQPMxEVDTY2000STRC1	67	-78	134	44	79	-216
ACR88POOL16SD	67	-50	225	-10	10	-103
EVDT-W2000STRCo	65	-113	-41	45	57	-41
Oba Super I	61	-227	50	45	03	-515
ACR97TZLCOMPI-W	61	-116	328	43	-304	81

Table 16. Validation of the days to silking models developed with 2007 late season trial data and predicted with Kano trial's data (Sudan Savannah Agro-ecology)

VARIETY	OBSERVED SILKING	MODEL				
		TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
DTSR-WCI	59	130	-530	84	-196	03
TZECOMP.4C3	63	-61	-18	39	85	-254
TZLCOMP3C3	62	-78	-984	43	-311	-296
EVDT-Y2000STRCoxPOOL18SRQPMxEVBC2F2	68	-196	124	45	75	76
TZB-SR	66	-96	-196	34	61	99
DTE –YSRBC3	58	-107	161	46	49	115
AMA.TZBR-WC2BF2	64	-64	188	33	11	117
POOL18SRQPMxEVDTY2000STRC1	69	-216	332	45	55	98
ACR88POOL16SD	69	-63	217	40	61	119
EVDT-W2000STRCo	66	-70	-275	39	86	137
Oba Super I	63	-37	292	28	98	144
ACR97TZLCOMPI-W	64	-78	-141	42	43	47

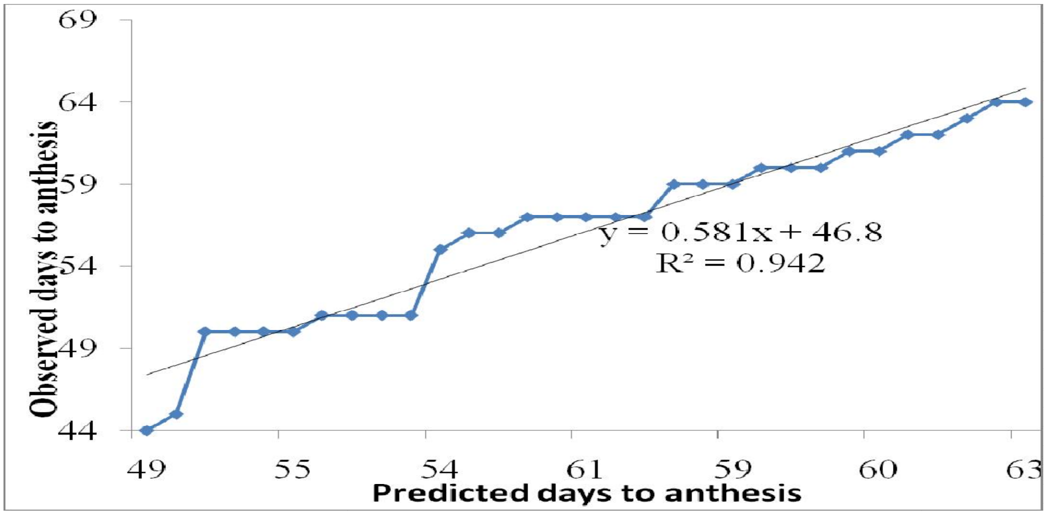

Fig. 2. Relation between the predicted and observed days to anthesis for the 2008 late season trial, using the thermal model

4. DISCUSSION

4.1 Identification of Flowering Traits of Maize for Maturity

The coefficient of variation (CVs) of the thermal predicted anthesis models are generally closer to the CVs of observed days to anthesis and lower in values when compared to the other predicting models. Hence days to anthesis was observed to be more stable and less influenced by the environments when compared to the other flowering traits. The CVs of thermal predicted days to anthesis model were more consistently lower in comparison to the other models in all the validations of the models carried out in this study. Hence, the reliability of this model (thermal predicted days to anthesis) in predicting flowering trait in maize. These findings are in agreement with the findings of Bonhomme et al. [15] that stated that anthesis predicted better than the other flowering traits due to higher influence of the environments on silk extrusion.

4.2 Validation of the Flowering Traits Models

Generally, simple linear regression model due to temperature predicted days to anthesis more closely to the observed anthesis when compared to the other models used to predict other flowering traits. In essence, thermal model due to days to anthesis predicted consistently and more closely to the observed days to anthesis from the early and late cropping seasons of 2008 and early cropping seasons of 2009. This is in agreement with the findings of [24] who discovered that thermal models accurately described the response of several developmental processes and has been widely used in predicting the flowering time in rice. Craufurd and Wheeler [25] also reported that temperature is the major determinant of the rate of plant development including flowering and maturity in maize and other annual crops. Validation of the models developed during the late season of 2007 with 2008 late season produced a more reliable validation when compared to the validation made with an early season trial. However, none of the predicted values of the flowering traits generated from the multiple linear regression models showed a significant correlation with the observed flowering traits in each season. However, Cober et al. [26] reported that flowering model containing Photoperiod alone improved prediction of days to flowering in Soybean while complete model containing photoperiod, temperature and irradiance predicted time to first flower in Soybean across the range of environmental conditions. The high R^2 values (0.94-0.97) obtained from the regression of the observed and predicted days to anthesis using the thermal model for the early and late cropping seasons also indicated the reliability of this model in predicting days to anthesis in maize.

Heat units as a measure of temperature was also observed to closely predict observed days to flowering in 2012 and 2013 than any other models as was previously observed in this location [8].

Crop Heat Unit (CHU) was also observed to be superior in prediction of maize phenology including observed days to flowering as reported by Kumudini et al. [27].

Result of validation of the flowering models developed with flowering data obtained from other agro-ecologies showed that models developed in one agro-ecology cannot be used in a different agro-ecology but locations within the same agro-ecologies can use the same flowering models to predict time to flowering. The predicted days to anthesis due to thermal models also indicated that the same set of varieties were picked or validated during the early seasons of the two rainforest locations (Ile-Ife and Ikenne) in this study. This is an indication of the robustness of the thermal model in predicting days to anthesis in the rainforest agro-ecology.

4.3 Maturity Classification of the Validated Varieties

The classification of the validated varieties with the thermal predicted anthesis model showed that this model is a strong classification model that predicted these maize varieties into different maturity groups accurately irrespective of evaluated location of the agro-ecology. This classification indicated that some of these varieties that were originally classified as early maturing varieties in the early season were observed and predicted as intermediate or late maturing varieties of the same location of evaluation while in the late season this model was able to classified most of the early maturing varieties as early.

5. CONCLUSION

In conclusion, anthesis was identified as the flowering trait of maize that best quantifies maturity. The thermal and heat units models best predicted the time from sowing to the expression of days to anthesis and silking in maize. the thermal and heat units models closely predicted the days to anthesis and silking in environments within the same agro-ecology that fall outside the test location. The thermal model correctly classified over 40% of the 100 maize varieties into maturity groups, with coefficient of determination (r^2) ranging from 0.94 to 0.97.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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