

Validation of flowering models for classifying maize into maturity groups in the different Agro-ecologies of West and Central Africa.

ABSTRACT

Aims: This study was conducted with a view to validate 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 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.

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: In 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.

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 important staple cereal produced in all agro-ecologies of WCA due to its popularity as 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 characterize the agro-ecological zones, including rainfall, temperature, length of the growing season, radiation and edaphic factors [3, 4, 5, 6]. The West and Central Africa 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].

Comment [s1]: This is too old research ??

Comment [s2]: In above write 2007/2008.... but here mention 2013,2013
This is need to clarify????

Comment [s3]: As a hunger

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

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

32 Maize is a short-day plant and the rate of progress towards flowering measured as $1/f$ declines in a linear
33 fashion with increasing daylength when that length exceeds a critical photoperiod of 12-13 hrs [14]. The
34 rate of progress can be quantified by linear responses to mean temperature and mean photoperiod [15,
35 16, 17, 18, 19]. Considerable genetic differences in responsiveness to photoperiod have been observed
36 especially in tropically adapted maize cultivars. These genotypic responses of maize to different climatic
37 conditions has led to the development of flowering models containing temperature, heat units,
38 photoperiod and their combinations to predict the time from planting to the expression of the flowering
39 traits of diverse maize cultivars in WCA [20]. However, these models have not been validated for their
40 accuracy in predicting days to flowering in maize in other trials which were outside the ones from which
41 the flowering models were developed in the rainforest Agro-ecology and other Agro-ecologies of WCA.
42 Therefore, the objective of the study was to validate the accuracy of the models in predicting the flowering
43 traits in maize.

Comment [s4]: have

44 45 46 2. MATERIAL AND METHODS

Comment [s5]: which statistic use for data analysis ? need clarification..

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48 Regression flowering models generated from a 2007 late planting season trial were used for this study
49 [20]. They were simple and multiple linear regressions of reciprocal of flowering ($1/f$) on mean values of

50 temperature, heat units and photoperiod which were performed separately on each flowering trait. They
51 were of these forms;

52 $1/f = a + bT$(1)

53 $1/f = a' + c'P$(2)

54 $1/f = a'' + d''H$ (3)

55 $1/f = a''' + b'''P + c'''T$ (4)

56 $1/f = a'''' + b''''P + d''''H$(5)

57 Where f is the number of days from sowing to flowering (Tasselling, Anthesis and Silikng), T is mean daily
58 temperature, P is the mean daily photoperiod, H is mean heat units also from planting to flowering. The
59 coefficients a, b, a', c', a'', d'', a''', b''', c''', a'''' and d'''' are genotypic constants (regression coefficients)
60 [21]. These five regression models were developed for individual varieties evaluated during the 2007 late
61 cropping season using all the flowering traits. Validation of the models was carried out using the data
62 obtained in 2008 early, 2008 late, 2009 early, 2012 late and 2013 early seasons as well as using data
63 obtained from other agroclimatic zones.

64 3. RESULTS 65

66 3.1 Summary Statistics of the Observed and predicted days to models 67

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

Comment [s6]: are

71 **Table 1:** Ranges, means±standard error (SE) and coefficients of variation (CV) for 2008 early cropping season of observed and predicted days to
72 tasseling, anthesis and silking using temperature, photoperiod, heat units, photothermal and photoheat units models.
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	TASSELING			ANTHESIS			SILKING		
<u>MODEL</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>
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
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

74
75 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
76 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
77 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
78 the CV (about 89%) was high. Predicted value for all the other models failed to approximate the observed values and their corresponding CVs
79 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
80 model closely approximated the observed values for anthesis and tasseling with CVs of about 16 and 73% respectively (Table 2).

Comment [s7]: the predicted

87 **Table 2:** Ranges, means±standard error (SE) and coefficients of variation (CV) for 2008 late cropping season of observed and
88 predicted days to tasseling, anthesis and silking using temperature, photoperiod, heat units, photothermal and photoheat units
89 models.
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	TASSELING			ANTHESIS			SILKING		
<u>MODEL</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>
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
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

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92 Here also, predicted values from other models and/or their CVs were not acceptable. For the 2009 early season, nearly all the predicted values
93 and their CVs were greatly different from the observed values (Table 3).

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106 **Table 3:** Ranges, means±standard error (SE) and coefficients of variation (CV) for 2009 early cropping season of observed and
107 predicted days to tasseling, anthesis and silking using temperature, photoperiod, heat units, photothermal and photoheat
108 units models.
109

	TASSELING			ANTHESIS			SILKING		
<u>MODEL</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>	<u>RANGE</u>	<u>MEAN±S.E</u>	<u>CV</u>
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
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)
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

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111 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),

112 but CV of 100% was too large to serve any useful purpose.

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114 **3.2 Validation of the Models**

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

120 **Table 4:** Validation of the flowering models developed with 2007 late cropping season trial data and predicted with 2008 early cropping season
121 trial data at the Obafemi Awolowo University Teaching and Research Farm.
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MODEL	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
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
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
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)

123 (C): Number of varieties common to both the observed and predicted number of days to flowering.

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

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

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

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

VAR	OBS ANTH	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
98SYNWECSRCo	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-W2000SRCo	51	-91	57	10	10	59

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

170 **Table 9:** Validation of days to anthesis models developed with 2007 late cropping season trial data and
171 predicted with 2013 early cropping season trial data at the Obafemi Awolowo University Teaching and
172 Research Farm.
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VAR	OBS ANTH	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

174
175 **Table 10:** Validation of days to silking models developed with 2007 late cropping season trial data and
176 predicted with 2013 early cropping season trial data at the Obafemi Awolowo University Teaching and
177 Research Farm.

VARIETY	OBSK	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

178

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.

Table 11: Validation of the days to anthesis models developed with 2007 late season trial data and predicted with Ikenne trial's data

VARIETY	OBSERVED ANTHESIS	TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
TZLCOMP4C3	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

VARIETY	OBSERVED SILKING	TEMP	PHOTO	HEAT	PHOTOHEAT	PHOTOTEMP
TZLCOMP4C3	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

200 **Table 13:** Validation of the days to anthesis models developed with 2007 late season trial data and
 201 predicted with Abuja trial's data

VARIETY	OBSERVED ANTHESIS	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

202

203 **Table 14:** Validation of the days to Silking models developed with 2007 late season trial data and
 204 predicted with Abuja trial's data

VARIETY	OBSERVED SILKING	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

205

206

207 **Table 15:** Validation of the days to anthesis models developed with 2007 late season trial data and
 208 predicted with Kano trial's data

209

VARIETY	OBSERVED ANTHESIS	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

210

211 **Table 16:** Validation of the days to silking models developed with 2007 late season trial data and
 212 predicted with Kano trial's data

VARIETY	OBSERVED SILKING	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- Y2000STRCoXPOOL18SRQPMxEV BC2F2	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
POOL18SRQPMxEVDTY2000STRC 1	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

213
 214 Validation of the models with flowering data obtained from Ikenne which is a rainforest agro-ecology. The
 215 prediction from thermal models for both days to anthesis and silking were closer to the observed values
 216 than those from other models (Tables 11 and 12). Predicted flowering data for Abuja and Kano were
 217 unrealistic, for all models being negative in most cases and when positive, were unreasonably large or
 218 too small (Tables 13 to 16).

219 DISCUSSION

220 Generally, simple linear regression model due to temperature predicted days to anthesis more closely to
 221 the observed anthesis when compared to the other models used to predict other flowering traits. In
 222 essence, thermal model due to days to anthesis predicted consistently and more closely to the observed
 223 days to anthesis from the early and late cropping seasons of 2008 and early cropping seasons of 2009.
 224 This is in agreement with the findings of [22] who discovered that thermal models accurately described
 225 the response of several developmental processes and has been widely used in predicting flowering time
 226 in rice.
 227 Validation of the models developed during the late season of 2007 with 2008 late season produced a
 228 more reliable validation when compared to the validation made with an early season trial. However, none
 229 of the predicted values of the flowering traits generated from the multiple linear regression models
 230 showed significant correlation with the observed flowering traits in each season.

Comment [s8]: it needs more extensively
discussion with recent references

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]. 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. CONCLUSION

In conclusion, the thermal and heat units models best predicted the time from sowing to the expression of these flowering traits. the thermal and heat units models closely predicted the flowering traits in environments within the same agro-ecology that fall outside the test location.

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