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AN ITERATIVE REGRESSION APPROACH FOR PREDICTION OF SORGHUM (sorghum bicolor) PHENOLOGY IN THE SEMI-ARID TROPICS

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ABSTRACT

Reddy, S. Jeevananda, Maiti, R.K. and Seetharama, N., 1984. An iterative regression approach for prediction of sorghum (sorghum bicolor) phenology in the semi-arid tropics. Agric. For. Meteorol., 32: 323—338.

Equations are derived to predict the duration of three growth stages of sorghum under adequate moisture and nutrient availability, on the basis of temperature and relative humidity, following an iterative regression approach. The predictions are very good. The response of temperature on phenophase duration was curvilinear. The common base temperature of 10°C and the point of inflection temperature of 19.6°C are shared by all the 4 genotypes studied, but the degree of response in development by each of them varied considerably. The response for each growth stage was different. This study also presents a simple iterative regression approach to solve non-linear functions. This procedure is very valuable where facilities such as sophisticated computers or programmable calculators are lacking.

INTRODUCTION

During recent years increasing appreciation has been shown for dividing sorghum development into well-defined stages (Vanderlip, 1972; Eastin, 1973) and ir[illegible] of environmental factors for predicting crop development under [illegible]rson et al., 1978; Angus et al. [illegible]se determines the accumulatior[illegible] organs, the size of source (leav[illegible]sponse to environmental and [illegible]ss and grain yield (Dalton, 19[illegible]

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The inf[illegible] temperature and photoperic[illegible]ied extensively in several cro[illegible]6), but predictions of field ph[illegible]n less satisfactory.

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Thomas (1980) has reviewed phenological studies on sorghum and modeling of the duration of the three growth stages described by Eastin (1973). Most authors have made use of a classical heat unit approach which is also followed in the dynamic sorghum growth model, SORGF (Arkin et al., 1976). However, in recent years it has been quite apparent that substantial modifications have to be made in the model including phenology subroutines if it is to be widely applicable (Huda et al., 1980). It has also been shown in the literature that the classical heat unit or degree day concept is not accurate enough to be able to predict phenological events. (Quinby et al., 1973). Therefore an attempt has been made to develop improved prediction equations based on environmental factors (temperature and relative humidity) for each of the three major growth stages (vegetative, panicle development and grain filling stages) of sorghum. Finally the genotypic differences were also elucidated for the temperature response.

MATERIAL AND METHODS

Phenological data collected in several trials at ICRISAT Center, Patancheru (Lat. 17.5°N; Long. 78.5°E; Elev. 545 m) during rainy, post rainy and summer seasons between 1974 and 1980 are used. The data represent those trials which are free from moisture stress with 120 000 pl ha^{-1} population and nitrogen of 60—80 kg ha^{-1} applied at two intervals. The meteorological data are from the agrometeorological observatory situated at the center of the ICRISAT Research Farm equipped with both recording and non-recording instruments. In the case of the non-recording type, the observations are taken twice daily, i.e., at 0717 and 1417 h local time. They represent, respectively, approximately the lowest and the highest temperature occurrence times of the day and approximately the highest and lowest relative humidities. The temperatures used in this study refer to the maximum average and minimum average temperatures, recorded daily using mercury-in-glass and alcohol thermometers, respectively. The relative humidity corresponds to the average of morning and afternoon observations at the above-mentioned times estimated daily using dry- and wet-bulb mercury-in-glass thermometers. The 4 thermometers were housed in a standard single Stevenson screen. These thermometers are the most reliable temperature recording instruments up to 0.1°C (most of the recording instruments of temperature and relative humidity are standardised daily with these thermometers only). This set-up is less costly, easily operated and is available for a wide network of stations in the semi-arid tropics. Global solar radiation represents the integrated daily values recorded by the Pyronometer while sunshine hours represents the integrated daily values from the Campbell sunshine recorder. The range of environmental factors during the growth of the crops are: temperature 18—33°C; relative humidity 30—80%; global solar radiation 300—600 cal cm^{-2} day^{-1}; sunshine 0—11 h day^{-1}; and photoperiod 10.8—13.1 h day^{-1}.

The three growth stages described by Eastin (1973) were studied namely

Growth stage 1 (GS1) seedling emergence to panicle initiation — vegetative stage

Growth stage 2 (GS2) panicle initiation to half bloom — panicle development stage

Growth stage 3 (GS3) half bloom to physiological maturity — grain filling stage

For panicle initiation, the plants are monitored on alternate days from the 20th day after emergence Six plants were dissected, if three or more of them had a dome-shaped meristem with constricted base, visible under binocular stereomicroscope (Carl Zeiss), it was assumed that panicle initiation was complete A growth stage is assumed to have occurred when 50% or more of the plants in the plot reached that stage

For each phenophase duration the average of each meteorological parameter is computed In order to develop equations for predicting length of the phenophase using climatic variables, 20 data sets on sorghum cv - CSH1 are pooled from different trials sown between 1974 and 1980 Ten—twelve data sets are available for three more sorghum cvs — V302, M35-1 and Patancheru Local (hereafter referred to as Local) collected during 1974—1980

An iterative regression approach (see next section for details) is followed to derive the relationships between duration of phenophases and environmental parameters

RESULTS

A probabilistic model to predict the duration of different growth stages

Preliminary analysis of data showed that temperature is the most important factor determining the duration of any growth stage of sorghum cv-CSH1 This was also reported by several others in sorghums (Fryer et al , 1966, Eastin et al , 1975, Angus et al., 1980). Hence an attempt is made to investigate whether the conventional heat units (Table I) are useful in predicting the length of any of the growth phases or combinations of them (GS1 + GS2 = days to flowering GS1 + GS2 + GS3 = days to maturity) As seen from the size of coefficients of variation (Table I), the heat units approach (based on 10°C as base) is poorer in predicting length of phenophase than the use of calender days themselves. For example, the coefficient of variation for days to GS1, GS1 + GS2 and GS1 + GS2 + GS3 are, respectively, 13.1, 9.5 and 6.8%, while the coefficients of variation in heat units are correspondingly 21.9, 13.0 and 11.4%. This is also evident from Huda et al. (1980). The same conclusion is valid even when changing the various base temperatures or when using 30°C as the upper limit for computation of heat units.

The degree day or heat units concept, assumes that constant heat units are required to reach a particular growth stage. Under this condition, the coefficient of variation of heat units must be far below the number of days

TABLE I

Phenology of sorghum cv CSH1, in days and heat units with 10°C as base temperature

	Days				Heat units			
Phenophase	Mean[a]	CV (%)	Max − Min	(Range)	Mean[a]	CV (%)	Max − Min	(Range)
GS1	23 6	13 1	29 − 20	(9)	665 9	21 9	1065 6 − 506 0	(559 6)
GS2	34 0	12 4	41 − 25	(16)	944 8	12 7	1224 0 − 787 4	(436 6)
GS3	33 4	10 7	40 − 25	(15)	956 7	14 7	1265 4 − 765 6	(499 8)
GS1 + GS2	58 3	9 5	69 − 50	(19)	1595 8	13 0	2289 6 − 1343 6	(946 0)
GS1 + GS2 + GS3	91 8	6 8	102 − 79	(23)	2552 5	11 4	3425 2 − 2233 0	(1192 2)

[a] Total number of observations = 20

to a particular growth stage The results given above would appear contrary to this This may be because of the non-linear behaviour of these two parameters It is evident from the study of De Wit et al (1970) that plant growth is a non-linear function of climatic parameters A similar pattern was also shown for the case of development (Arkin et al , 1976) Hence it may be inferred that the heat unit approach is less suitable under the varying climatic conditions that exist in the tropics Using the calendar days approach, the differential response can be integrated mathematically and also the number of days is a more direct expression of phenophase duration, which is easier to remember for a particular genotype Hence, this approach is followed in this study

As a second step the following two non-linear equations are used to predict various developmental stages based on prevailing average (of daily maximum and minimum) temperature

$$Y = a/\exp\,[b/(T-d1)] \tag{1}$$

$$Y = a \pm b\,[|d2 - T|]^{1/3} \tag{2}$$

where Y is the duration of any one of the phases or combination of growth phases (measured in days), T is average daily temperature for the duration of growth phases (°C), $|d2 - T|$ is the absolute value of $d2 - T$ ($-$b if $T > d2$, $+$b if $T < d2$) and a, b, $d1$ and $d2$ are constants to be derived $d1$ and $d2$ represent the critical temperature limits

Maximum likelihood approach is generally followed in solving the non-linear functions of the above form However, on many occasions, this approach requires a computer facility or programmable calculator (the latter still requires statistical knowledge) The computer facility is rarely available to scientists working in developing countries Therefore, to overcome this constraint, a simple least-square procedure or iterative regression is outlined here This procedure is in no way inferior to the maximum likelihood approach This approach is followed in solving a, b and $d1$, and $d2$ in (1) and (2) This is done as follows

Step 1. First it is assumed that $d = A1$ ($d = d1$ for (1) and $d = d2$ for (2)), a and b are then derived by a simple regression (least squares) approach. The corresponding correlation coefficient(r) is then calculated

Step 2 This is repeated with values of $d = A2, A3, \ldots$, values of a and b are then computed with their respective correlation coefficients

In this example, d may vary between 0 and 50°C Hence, $A1$, $A2$, . . , can first be assumed to be 0, 10, . . . , 50. If the correlation coefficient gives the highest value at $A3$ (20°C) for example, then at the second stage $A1$, $A2$, . . . , may represent 15, 16, . . , 25, respectively. If the correlation coefficient is greatest at $A5$ (19°C), then at the final stage $A1, A2, \ldots$, may represent 18.5, 18.6, . . . , 19.5, respectively. If the correlation coefficient is the highest at 19.1°C then this value represents the value of $d1$ or $d2$ as the case may be.

TABLE II

Regression coefficients of predictive equations for sorghum cv CSH1

Phenophase	Equation	Regression parameters			
		a	*b*	*c*	*R*
GS1	2a	29 5	− 3 6[a]		0 51
	3	34 0	− 3 6[a]	−0 07	0 55
GS2	2a	49 6	−10 1[b]		0 71
	3	58 7	− 6 8[b]	−0 23[b]	0 87
GS3	2a	44 2	− 5 8[b]		0 60
	3	43 9	− 5 7[b]	−0 02	0 62
Days to anthesis	2a	79 3	−13 7[b]		0 75
(GS1 + GS2)	3	92 9	−11 2[b]	−0 27[b]	0 86
Days to physiological	2a	120 5	−18 2[b]		0 70
maturity (GS1 + GS2 + GS3)	3	133 2	−12 6[b]	−0 35[b]	0 83

[a]Significant at 5% level [b]Significant at 1% level

Step 3 Steps 1 and 2 are repeated for the three phenophases

Step 4 The values of d for the three phenophases are identified as those values for which the respective correlation coefficients are the greatest However, there is only a small difference between the values of d for the 3 phases Therefore it was assumed that the average of these 3 values represented the values of d, and these were calculated as $d1 = 10$ and $d2 = 19\ 6$ The procedure above is not only simple, but also gives better insight into the problem compared to maximum likelihood estimates Equations 1 and 2 are rewritten

$$Y = a/\exp\,[b/(T-10)] \tag{1a}$$

$$Y = a \pm b\,[|19\ 6 - T|]^{1\ 3} \tag{2a}$$

Step 5 Using a simple regression approach a and b in (1a) and (2a) can be solved for each phenophase

Predictions based on (2a) were found to agree slightly better with observed data, therefore (2a) was used in this study The results from (2a) are presented in Table II However, (1a) does provide a simple functional way of deriving the minimum temperature at which plant-growth is inhibited

One important point that emerged from the above two equations is that 10°C is the lower limit (base temperature) for phenological development of the sorghum cultivars studied, and a daily temperature of 19 6°C forms the point of inflection around which maximum reponse in determining phenophase to temperature occurs Simulation using (1a) and (2a) at higher average temperature, indicates that for temperatures > 30°C the change in rate of development of phenophase duration is very small

To improve the accuracy of prediction further, various other environ-

TABLE III

Observed, calculated and deviations from observed number of days in different growth stages

Data[a] points	GS1			GS2			GS3			Days to anthesis			Days to maturity		
	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D
1	23	23	0	30	32	2	34	32	−2	54	56	2	88	87	−1
2	25	22	−3	25	28	3	29	32	3	50	51	1	79	83	4
3	20	22	2	31	29	−2	34	33	−1	51	51	0	85	84	−1
4	23	22	−1	31	29	−2	32	32	0	54	51	−3	86	84	−2
5	22	22	0	29	28	−1	30	32	2	51	51	0	81	83	2
6	25	22	−3	32	29	−3	34	33	−1	57	51	−6	91	84	−7
7	21	22	1	32	29	−3	33	32	−1	53	52	−1	86	83	−3
8	23	22	−1	26	30	4	32	32	0	49	52	3	81	84	3
9	23	22	−1	31	31	0	31	34	3	54	54	0	85	88	3
10	20	23	3	31	34	3	40	37	−3	51	57	6	91	93	2
11	23	24	1	35	36	1	35	37	2	58	60	2	93	95	2
12	20	24	4	36	36	0	38	35	−3	59	61	2	97	97	0
13	20	24	4	39	37	−2	33	35	2	59	61	2	92	94	2
14	27	24	−3	34	36	2	36	34	−2	61	60	−1	97	94	−3
15	22	25	3	36	36	0	34	34	0	58	62	4	92	94	2
16	28	25	−3	41	39	−2	33	36	3	69	64	−5	102	98	−4
17	29	26	−3	33	34	1	33	33	0	62	61	−1	95	94	−1
18	25	25	0	36	34	−2	32	32	0	61	60	−1	93	93	0
19	22	24	2	37	35	−2	30	31	1	59	59	0	89	93	4
20	29	28	−1	39	38	−1	30	31	1	68	65	−3	98	97	−1

Range (days)	Percent deviations in given range				
0–2	55	75	75	65	60
3–4	45	25	25	20	35
⩾5	—	—	—	15	05

[a]Odd data points were used to derive the regression coefficients and even data points were used to test the equations O, observed, C, calculated, D = C − O

mental parameters, such as photoperiod, radiation and relative humidity are used as independent variables. In addition to temperature, relative humidity appears to be a significant factor influencing different growth stages. This is given as

$$Y = a + b(|19.6 - T|)^{1/3} + ch \tag{3}$$

where h = relative humidity (%), and c is a constant to be estimated.

Results of regression analysis with average temperature (2a), and average temperature and relative humidity (3), as independent variables are presented in Table II. The influence of humidity can be seen most clearly in GS2 (correlation coefficient, R, increases from 0.71 to 0.87). However, the effect of humidity is significant in the case of days to anthesis and days to

physiological maturity (correlation coefficient increases from 0 75 to 0 86 and 0 70 to 0 83 respectively)

The observed and predicted durations, along with the deviations from the observed duration of each growth phase (using eq 3) are presented in Table III The 20 data points are arranged according to calender dates and months (see also Table III footnotes) Figure 1 also shows the observed vs predicted durations of each of these growth stages According to the chi square test, most of these predictions are significant at the $<5\%$ level, either considering all the 20 data points or the ten data points (even rows) that are used to test the validity of these models The range in observed duration varies from 9 days in GS1 to 23 days during the whole life cycle (GS1 + GS2 + GS3) In more than half of the examples, deviations of computed values from observed values are 2—4 days in each of the phases Generally, the agreement between observed and estimated duration in different phases is good Note that there are about 2—4 days of difference between replications themselves within a single experiment

It is a common practice to give too many statistics like standard errors or residuals or R^2 (square of correlation or variance) to validate the predictive ability of the equations

However, in a recent study by Reddy et al (1984) recorded an anomalous situation in the prediction of global solar radiation where the R^2 values are significantly different for two months but the percent deviations in different ranges ($\leq 5\%$, 5—10%, $>10\%$) indicate similar patterns It would appear that the statistical parameters derived also depend more on the range and magnitude of the data set used in the analysis Therefore, these types of statistics are more useful in the comparison of two or more equations with a similar data set, and are less realistic in expressing the validity of the predictive equation Therefore, the suggested procedure for validation of the predictive equations is to first identify the level of observational errors (2 days in this paper) and then to arrange the predicted deviations from observed values under different ranges expressed as multiples of the minimum observational error limit This procedure was adopted in this study

It may be seen from Table III that in only 25—45% of occasions are the deviations more than 2 days (error limit) Occurrence of twice this limit is zero in GS1, GS2 and GS3, while it is 15% in the case of days to anthesis and 5% in the case of days to maturity, suggesting this equation could be used reasonably

To test the usefulness of the above equations in predicting phenological events of CSH1 in other locations, limited data from Bijapur (Lat 16 7°N, Long 75 6°E, Elev 594 m) and Bhavanisagar (Lat 11 4°N, Long 77 1°E) were used As seen from Table IV, the estimated values are systematically lower than the observed data, particularly in the GS3 phase For the data from Bijapur, this could be due partly to the fact that the crop grew solely on stored soil-moisture

Similar equations to (3) are developed for 3 more cvs V302, M35—1 and Local (Table V) Note that the size of coefficients i.e , the relative effects)

TABLE IV

Observed, calculated and deviations from observed (in days) of different growth stages of sorghum cv CSH1 at Bijapur and Bhavanisagar[a]

	GS1 + GS2			GS3			GS1 + GS2 + GS3		
Date of sowing	O	C	D	O	C	D	O	C	D
Bijapur									
26 9 1977	60	56	−4	40	37	−3	100	92	−8
15 9 1978	56	54	−2	39	35	−4	95	89	−6
Bhavanisagar									
14 10 1979	50	50	0	37	33	−4	87	84	−3

[a]O, Observed C Calculated and D = C−O

TABLE V

Regression coefficients of predictive equations[a] for sorghum cvs V302, Local and M35 1

Phenophase	Genotype	Regression parameters			
		a	*b*	*c*	*R*
GS1	V302	70 7	−13 2[c]	−0 37[b]	0 85
	Local	49 3	−2 3	−0 18	0 30
	M35 1	70 8	−7 0[b]	−0 57[c]	0 82
GS2	V302	49 5	−10 7[c]	0 03	0 62
	Local	57 3	−10 8[c]	−0 06	0 78
	M35 1	63 8	−16 2[c]	−0 06	0 92
GS3	V302	30 7	−0 7	0 09	0 47
	Local	49 8	−5 4[b]	−0 12	0 50
	M35 1	39 5	−1 9	−0 03	0 31
Days to anthesis (GS1 + GS2)	V302	105 8	−17 1[c]	−0 29[c]	0 82
	Local	100 1	−9 5[b]	−0 20	0 69
	M35 1	107 3	−18 4[c]	0 32[c]	0 86
Days to physiological maturity (GS1 + GS2 + GS3)	V302	149 5	−16 5[c]	−0 48[c]	0 79
	Local	152 5	−13 9[b]	−0 39[c]	0 67
	M35 1	143 5	−16 9[c]	−0 31[c]	0 74

[a]See eq 3 in text [b]Significant at 5% level [c]Significant at 1% level

for temperature and humidity not only vary with the phenophase of a single genotype, but also with genotypes themselves Many of the regression coefficients are significant ($P < 5\%$) In the case of V302, the effect of temperature and relative humidity is maximum in GS1 and minimum in the GS3 phase. However, for Local, little effect of temperature on GS1 phase is seen The temperature effect on GS2 is greatest in M35-1 and smallest in CSH1. This may explain the high sensitivity of M35-1 to smaller changes in

TABLE VI

Deviations[a] of calculated growth stages from observed values for sorghum cvs. V302, Local and M35-1

Data points	V302[b]					Local[b]					M35-1[b]				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	1	0	−1	1	1	1	1	1	3	4	−2	1	2	1	2
2	−5	7	−1	3	2	−8	6	3	−2	1	1	1	3	3	4
3	−3	4	0	1	−1	−6	3	0	−1	−1	−2	−3	1	−3	0
4	0	5	0	5	2	−7	1	5	−5	0	0	2	0	0	0
5	0	1	−3	2	3	−3	5	−3	3	0	0	0	1	−2	−2
6	4	−10	3	−5	0	−2	−4	1	−5	−5	−3	0	4	−4	1
7	4	−6	−2	−1	2	−1	−1	−2	−2	−5	−2	−2	−4	0	0
8	1	3	1	1	2	7	−5	4	1	6	0	−1	1	0	2
9	3	−1	−1	3	1	6	−1	1	5	6	1	0	−1	−4	1
10	0	−4	2	−3	2	9	−5	1	3	5	0	0	1	0	0
11						−6	4	2	−4	−5	0	0	−1	1	0
12						−1	−3	−1	2	3	5	−5	−2	1	1
Range (days)	Percentage of deviations in a given range														
0 − 2	50	30	80	50	90	33	33	67	42	33	84	84	75	67	92
3 − 4	40	40	20	30	10	8	33	25	33	17	8	8	25	33	8
⩾ 5	10	30	—	20	—	59	33	8	25	50	8	8	—	—	—

[a] Deviations = Calculated − observed. Odd data points were used in deriving the regression coefficients and even data points to test the equations.

[b] 1 = GS1; 2 = GS2; 3 = GS3; 4 = GS1 + GS2; 5 = GS1 + GS2 + GS3.

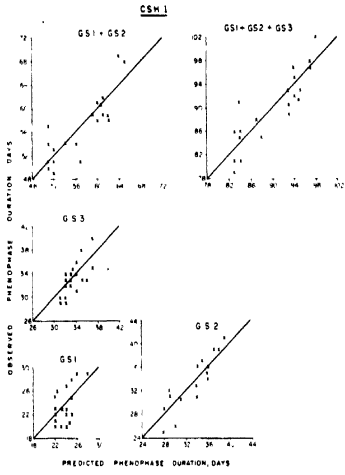

Fig. 1. Observed and predicted phenophase duration of different phenological phases of sorghum cultivar, CSH1.

temperature but not to relative humidity during the flowering phase. M35-1 appears to be insensitive to the temperature change in the GS3 phase, and relative humidity plays a significant role in the GS1 phase. In the example of CSH1, the effect of relative humidity is significant in GS2 (which is not seen in the case of other genotypes) and vice-versa is the case in GS1 phase. These differences may be because CSH1 is highly adapted to the rainy season and at least 2 other (M35-1 and Local) genotypes are adapted to the post-rainy season. However, in the example of days to anthesis and days to physiological maturity, the effect of relative humidity is significant in all 4 genotypes.

The deviations of predicted durations of each phenophase (Table V) for V302, Local and M35-1 from observations are presented in Table VI. In Table VI, the data points are arranged according to calender dates and months.

Figure 2 shows observed vs. predicted duration for days to anthesis and days to maturity for V302 and Local. According to the chi-square test the majority of these predictions are significant at the $< 5\%$ level, either considering all of the data points, or the (5 or 6) even points that are used to

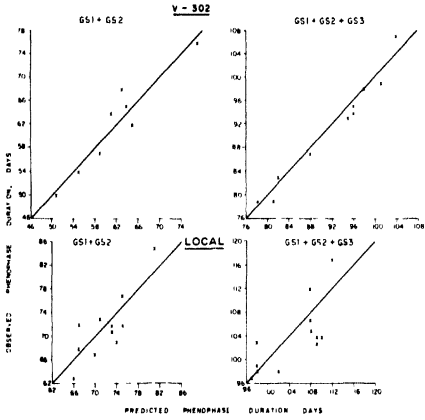

Fig. 2. Observed and predicted phenophase durations of days to anthesis and days to maturity of sorghum cultivars, Local and V302.

test the validity of these models. It may be seen from Table VI, that in the case of M35-1, the deviations exceeding the observational error limit (2 days) are 8—33%, while a greater number of deviations exceeds the limit in the case of V302 (10—70%) and Local (33—67%). In the case of Local and V302 the deviations occur more often during GS1 and GS2. This may be due to the error in identifying the actual time of panicle initiation. This fact emerges from the observation that in most cases where the deviations are relatively large, the signs of the deviations in GS1 and GS2 are opposite (Table VI). However, in the case of days to anthesis or days to physiological maturity the deviations are smaller.

DISCUSSION

The effect of temperature on duration of different phases is curvilinear. Brown (1960) working with soybeans grown under controlled conditions established curvilinear relationships between phenological rate of development and temperature (above 10°C and below 30°C). Similar curvilinear relationships are also reported in groundnut by Cox and Martin (1974) and in maize by Tollenaar et al. (1979). A negative exponential relationship between temperature and boll maturation period is reported in cotton (Mutsaers, 1976).

From the equations derived in this paper, it is also evident that the effect of temperature could be linear for a narrow range of temperature around the point of inflection This varies with growth stages and genotypes Because of this, heat units are poorly correlated with the length of the phenophases Thus, the present approach has an advantage in deciding suitability of a particular genotype in a given location or season in terms of phenological development

The effect of temperature varied between different growth stages and between genotypes, with GS2 being most sensitive Gipson et al (1979) have also found that the greatest temperature response occurred in GS2 This growth-stage is dependent upon production and expansion of 6—8 upper leaves (Sahaffer et al , 1979) which support the grain filling Also, during this phase, the most important component of yield (i e , seed number) is determined Hence, planting date has to be adjusted such that environmental effects, especially temperature, during GS2 are most favourable for yield

Though many studies have emphasized the role of the photoperiod, in addition to temperature, (and the interaction between the two) in deciding length of GS1 and GS2, photoperiod in the current study was not found to contribute significantly, since the cultivars CSH1, V302, M35-1 and Local did not show any photoperiod sensitivity within the range of photoperiod under the field conditions at ICRISAT Center Also, a part of the photoperiod effect is integrated in temperature

Relative humidity significantly influenced the phenology Though less commonly reported, it is not surprising since lower humidity may cause severe atmospheric drought O'Leary (1975) and Tromp (1977) concluded that although relative humidity played a significant role in plant growth and development, there is scant literature on the effect of humidity During recent years, the effect of humidity on crop growth and yield has been reported in wheat (Hoffman and Jobes, 1978) and in cotton (Bartsch, 1977), but there is little related to the effect on phenology Iwata (1975) observed that more heat units are required during the total growing periods of the same variety sown in the dry season than during the rainy season, even when temperatures are the same between seasons For sorghum Appathurai (1957) observed that under high humidity (> 80%) the duration of the total life-cycle is shortened, while low humidity (< 50%) tends to lengthen the total life-cycle Decrease in humidity caused a delay in days to anthesis and in days to physiological maturity The effect of relative humidity is significant on the GS2 phase in CSH1 (mainly adapted to rainy season) while it is significant in the GS1 phase in the case of M35-1, V302 and Local (mainly adapted to post-rainy season) Most values of c in Tables II and V are negative, which is in agreement with the above observations (and when they are positive the size of the coefficient is very small)

This may be explained as follows It is commonly known that genotypic differences exist in terms of their adaptability to dry and humid climates Recent micrometeorological investigations also indicate that under similar

treatments and climatic conditions, the leaf temperature and conductance differ (which appears to be more related to its inherent physiological property) particularly during afternoon hours, during which period the temperature is generally highest and the relative humidity is lowest for the day During this period, partial stomatal closure is also observed This may have a retarding effect on both development and growth, as this may affect the net photosynthetic activity in the plant Finally, it comes down to meeting the optimum transpirational requirements of the plant It may be that partial closing of stomata may be for a longer period under dry conditions compared to humid conditions This is an important area that needs to be investigated

Anderson, et al (1978) found that soil moisture was a significant factor in deciding phenological events in sunflower Seetharama and Bidinger (1979) observed substantial genotypic differences in sorghum phenology due to water stress In the present study, only data from trials receiving sufficient water from rains or irrigation are used, and hence a discussion of soil moisture in this study was not applicable

The extent of the influence of temperature and relative humidity on different genotypes in the present study at different phases, appears to be related to the adaptability of a genotype to a particular season (i e , rainy or post rainy seasons) The higher the regression coefficients (b and c in Table V) the lower the adaptability to wider climates and seasons For example, CSH1 with lower regression coefficients is adapted in both rainy and early-sown post-rainy seasons over a wide latitude belt in India (Table V) M35 1, with higher regression coefficients, is adapted only to the post-rainy season and a smaller latitude belt in India

CONCLUSIONS

It is evident from this study that the development rate is not a linear function of the wide range of temperatures encountered in the tropics, it is linear only over a small range of temperature and this varies for different phenophases and genotypes, change in rate of phenological development, in response to temperature, differs with the stage of growth and with genotypes, and other environmental variables, such as relative humidity, in the absence of water and nutrient stress, have a major effect on some phenophases

The predictive equations developed can be used to understand the adaptability of a genotype to an environment better

It is necessary to verify the method of determining the phenophase durations (in the field) in the case of V302 and Local

The iterative regression approach can be adapted reasonably well to solving non-linear functions where there are no facilities such as a computer or a programmable calculator

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Chemical Changes at Different Stages of Seed Development in Vegetable Pigeonpeas (*Cajanus cajan*)*

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ABSTRACT

Developing green seeds of two vegetable pigeonpea (Cajanus cajan *L Millsp*) *cultivars that differ in their morphological characteristics were sampled at 24, 26, 28, 30 and 32 days after flowering (dates that are relevant to vegetable harvest). An increase in seed size was noticed between 24 and 26 days after flowering, although it continued up to 32 days after flowering. The dry matter accumulation as the seed matured was greater in ICP 7035 than in T 15-15. Analysis of freeze-dried samples showed that soluble sugars, and proteins, decreased and starch content increased between 24 and 32 days after flowering. Calcium and magnesium contents were considerably higher in T 15-15 than in ICP 7035, but there was little difference in zinc, iron and copper contents. ICP 7035 contained significantly higher amounts of soluble sugars than T 15-15 at all stages of seed development; this indicates that it had sweet seeds, a requisite of vegetable pigeonpea cultivars.*

Key words: Vegetable pigeonpea, chemical changes, seed development.

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INTRODUCTION

Pigeonpea (*Cajanus cajan* L. Millsp) is an important pulse crop in India, and it is grown in tropical and subtropical regions of the world. The edible seeds of the leguminous plants are harvested, processed and consumed in many different ways. The developing pods of pigeonpea are harvested and shelled, and the green seeds are used as a vegetable in India and in some south-east Asian and African countries (Singh *et al* 1977, Faris *et al* 1987). Canned or frozen green pigeonpeas are used in Latin American and Caribbean countries and are also exported to North America and Europe (Mansfield 1981). Pigeonpea seeds are more nutritious when green than dry because they contain more protein, sugar and fat, but less flatulence-causing sugars and trypsin and amylase inhibitors before they are mature and dried (Singh *et al* 1984a).

To find out the right stage to harvest green pods, seeds are visually examined. Fully developed bright green seeds are preferred, but pods should be harvested just before they start losing their green colour (Faris *et al* 1987). It is also important to remember that the appearance of pods used as vegetables varies with each cultivar (Saxena *et al* 1983). Hand-picking or mechanical harvesting of green pods have become common practice for vegetable pigeonpea, and for large-scale processing for canning and freezing (Mansfield 1981). Because of the non-synchronised and continuous flowering behaviour of pigeonpea, it is difficult to pick developing pods at the same stage of physiological maturity. At ICRISAT Center, efforts have been made to identify and develop cultivars suitable for use as vegetables and to study their nutritional quality (Singh *et al* 1984a, Faris *et al* 1987). Pigeonpea pods sold as vegetables are generally picked 25–30 days after flowering (Singh *et al* 1984a). This study was planned to examine the changes in the levels of principal dietary constituents, and mineral and trace elements of pigeonpea at different stages of seed development in cultivars suitable for use as vegetables. One objective was to compare the two vegetable types (varieties) and to examine the changes with a view to suggesting a harvesting stage.

MATERIALS AND METHODS

Materials

Two genotypes (T 15-15 and ICP 7035) that differ in morphological and chemical characteristics were grown during the 1988 rainy season in deep vertisols at ICRISAT Center. For each cultivar a 100 m^2 plot was used. Two cultivars were allocated to the two plots randomly. Both plots had similar soil and field conditions and the cultivars were grown under normal cultural practices. Cultivar T 15-15 has green developing pods with medium sized seeds; it is widely grown in Gujarat State both as a vegetable and for its dry seeds. ICP 7035 has dark brown developing pods with large seeds that have a high soluble sugar content. Nearly 3000 flowers of each genotype were randomly chosen and tagged at the pollination stage on the same day. We could not undertake an experiment on bigger plots because of the high cost of operation and the non-availability of land. At the same time, since

it is difficult to get about 3000 flowers on a single day in smaller plots, it was not feasible to work on more, but smaller, plots. About 20% of the tagged flowers set as pods. On each of 5 days (24, 26, 28, 30 and 32 days after tagging) the developing pods set by about 600 randomly assigned flowers were collected. Freshly harvested pods were shelled and the green seeds were separated. For each variety and on each day all seeds were collected into a single sample from which a 3-g and a c 40-g sample were taken. A 3-g green seed sample was used for moisture estimation, and the remaining sample (about 40 g) was freeze dried for chemical analysis. Moisture determinations were made by drying the samples in an oven at 55 C for 16 h. Prior to chemical analysis freeze dried samples (about 10 g) were finely ground in a Udy cyclone mill and passed through a 0·4-mm screen.

METHODS

Chemical constituents

The nitrogen content of the samples was determined using a Technicon auto analyser (Singh and Jambunathan 1981), and nitrogen values were converted to protein contents by multiplying by a factor of 6·25. Methods described previously were used to determine soluble sugars and starch (Singh *et al* 1980) and fibre contents (AOAC 1975).

Minerals and trace elements

A triacid mixture containing nitric, perchloric and sulphuric acids in the ratio of 20:4:1 was used for digestion. Freeze-dried defatted samples (0·5 g) were weighed and transferred to a block digester glass tube. After adding 6 ml of the triacid mixture, the sample was first digested at 70 C for 30 min, then at 180 C for 30 min, and finally at 220 C for 30 min. After digestion the mixture was cooled and dissolved in distilled water, and the volume was increased to 50 ml. The sample was then analysed for calcium, magnesium, zinc, iron and copper using an atomic absorption spectrophotometer (Varian Tectran Model 1200; Piper 1966).

Statistical analysis

For all chemical analyses, two replicates were used for the determination of each constituent. Standard errors (SE) were determined by one-way analysis of variance (Snedecor and Cochran 1967).

RESULTS AND DISCUSSION

Dry matter accumulation

In both genotypes, dry seed weight continued to increase until 32 days after flowering (Fig 1), but the increase was noticeably greater in ICP 7035 than in T 15-15 as the seeds matured. No noticeable differences in dry seed weight of these genotypes were observed at 24 and 26 days after flowering. The rate of dry matter accumulation appeared to be remarkably higher in ICP 7035 than in T 15-15

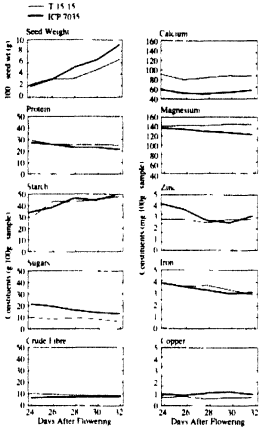

Fig 1. Levels of dry seed weight, protein, sugars, starch, crude fibre, calcium, magnesium, zinc, iron and copper at different stages of seed development in T 15-15 and ICP 7035

between 26 and 28 days after flowering. This possibly happened because ICP 7035 has larger seeds than T 15-15. This is apparent from the differences in genotype dry seed weights at 24 and 32 days after flowering (Fig 1). As expected, seed moisture content decreased with maturation in both genotypes.

Singh *et al* (1980) reported that the weight of the developing seeds increased up to 28 days after flowering in ST-1 and HY 3C cultivars of pigeonpea. The results of this study indicate an increase in fresh weight up to 32 days, although the rate of increase was slightly slower at the later stages of development. However, it is to be expected that there will be differences between experiments carried out on different occasions in variable environmental conditions. Provided the seeds stay green, and with reference to these results on dry matter accumulation, developing seeds could be harvested at nearly 30 days after flowering and still be suitable for use as a vegetable.

Chemical changes

As shown in Fig 1, the percentage of soluble sugars and of protein decreased continuously in both genotypes. Starch content increased with maturation in ICP 7035 as well as in T 15-15 but the increase was more pronounced between 24 and 28 days after flowering in both genotypes. Protein content and soluble sugars showed a gradual decrease with maturation in both genotypes (Fig 1). However, when results were expressed as mg seed^{-1}, an increasing trend in the amounts of

soluble sugars, protein and starch was observed as the seeds increased in size and matured in both genotypes. Crude fibre, expressed as a percentage of the sample weight, decreased continuously very slightly in T 15-15 (Fig 1) and increased slightly in ICP 7035 (Fig 1) as the seeds matured. When the results were expressed as mg seed^{-1}, the amount of crude fibre increased with maturation in both cultivars but the increase was greater in ICP 7035 than in T 15-15.

It has been reported that in pigeonpea seed rapid starch accumulation occurs during the period between 14 and 28 days after flowering, and is accompanied by reduction in the levels of soluble sugars during the same period (Singh *et al* 1980). Further, ICP 7035 has been reported as a cultivar that has a high seed soluble sugar content (Faris *et al* 1987). As shown in Fig 1, ICP 7035 contained remarkably higher amounts of soluble sugars than T 15-15 (Fig 1) at all stages of seed development studied. These cultivars did not differ appreciably with respect to starch content during maturation. This indicates that the developing green seeds of ICP 7035 are more biochemically active in accumulating soluble sugars. Therefore this cultivar has sweet seeds that make it desirable as a vegetable.

Mineral and trace elements

Mineral and trace elements, particularly calcium, iron and zinc, are important nutrients that are usually missing from the diets of low-income people in developing countries. There were noticeable differences in the levels of calcium, magnesium, zinc, iron and copper in developing green seeds of T 15-15 and ICP 7035 (Fig 1). Calcium and magnesium were considerably higher in T 15-15 than in ICP 7035, but the reverse was true for copper at all stages of seed development. The calcium content of T 15-15 was remarkably higher than ICP 7035 at all stages of seed development. The iron contents were not appreciably different in these genotypes but decreased in both genotypes as the seeds matured. However, zinc content of ICP 7035 was considerably higher than in T 15-15 during 24 to 26 days after flowering and showed no large difference during 28 to 32 days after flowering. When consumed, developing green seeds are a richer source of iron, copper and zinc than mature seeds (Singh *et al* 1984b). The results of the present study show that green seeds of T 15-15 are a richer source of calcium and magnesium than ICP 7035. The results also suggest that, when picked between 26 and 32 days after flowering for use as a vegetable, the green seed of these genotypes does not show wide variation in its calcium, magnesium, zinc, iron or copper contents.

CONCLUSIONS

Although it is not clear what quality factors are important in selecting genotypes for use as vegetables, breeders at ICRISAT started work some years ago on developing sweet large-seeded cultivars that also give stable production. The results of this study indicate that, depending on the stage of harvesting, the levels of protein, sugars and starch vary but minerals and trace elements do not change appreciably in green pigeonpea seeds of these two genotypes used as vegetables. There are also noticeable differences in these parameters among genotypes.

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