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Weather factors influencing phenology and yield of pigeonpea (*Cajanus cajan* (L.) Millsp.)

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ABSTRACT

A split plot design was used to investigate the influence of weather variables on phenology and yield of two diverse pigeonpea (*Cajanus cajan* (L.) genotypes. Cumulative degree days (CDD) expressed in (°Cd) described the phenological potential in pigeonpea. Shortening of growing season in pigeonpea generally related to reduced CDD. Correlation analyses between seed yield and weather variables demonstrated that the high maximum temperatures prevailed at flower bud initiation stage and consistently low minimum temperatures throughout entire growing season caused reduction in seed yield. High vapor pressure deficit during the late vegetative and early reproductive phase showed negative influence on the seed yield. High photosynthetically active radiation during late vegetative and pod filling phase is correlated with increased seed yield. The best fit regression models were developed for predicting the seed yield using these weather variables.

Key words : Pigeonpea, Phenology, Weather, HTU, PAR.

Pigeonpea, a major pulse crop, is grown usually under rainfed environments across Semi Arid Tropics (SAT). In such areas of uncertainty, intra and inter annual variability in weather causes substantial fluctuations in pigeonpea productivity. Therefore, any possible understanding of weather-yield relationship may help to determine the best time to apply specific agronomic practices in order to maximize yield. Production potential for a given crop is often strongly related to crop phenology which is largely sensitive to temperature variations (McPherson *et al.* 1985). The term most often used to quantify temperature effects on phenological development has been the degree day or heat unit (Rajput *et al.* 1987; Balakrishnan and Natarajaratnam, 1986). In this paper, we report a statistical analysis of weather factors affecting the phenology and yield response of pigeonpea genotypes to sowing dates at the same location.

MATERIALS AND METHODS

The study was conducted at Gujarat Agricultural University farm, Anand, Gujarat (22° 35' N latitude) on loamy sand soil in the years 1993 and 1994. Data on maximum and minimum temperatures were recorded at agrometeorological observatory located 50 m from the experimental site (Fig.1).

One seed was dibbled at an inter and intra row spacing of 60 and 30 cm.

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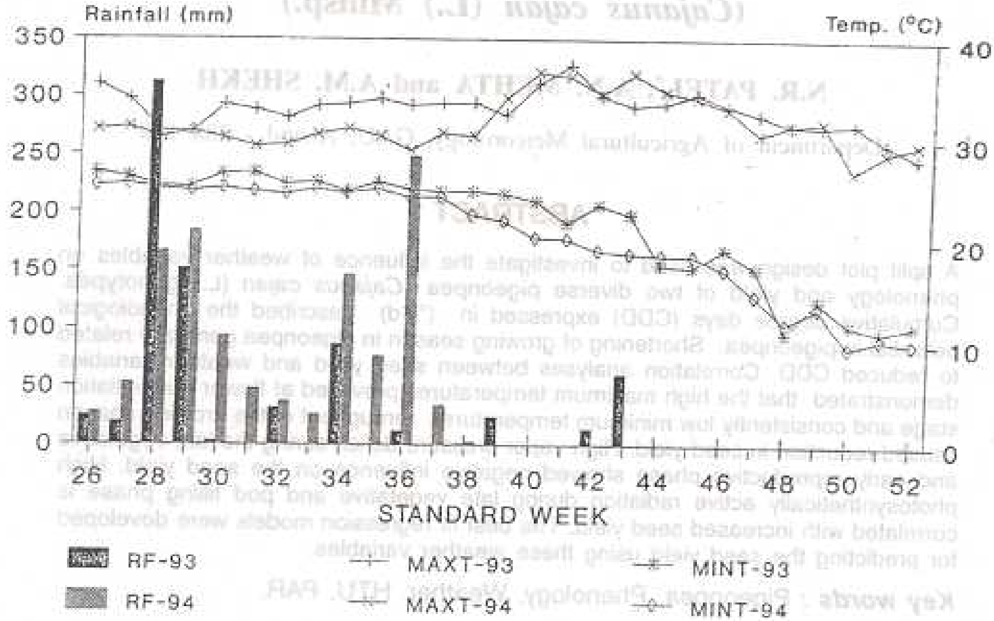

Fig. 1 : Weekly rainfall and temperature during growing season

respectively to achieve density of 55555 plants ha^{-1}. Two pigeonpea genotypes namely, GT-100 and BDN-2 were sown on three dates viz., 30th June (D1), 20th July (D2) and 9th August (D3) during both seasons 1993 and 1994. Split plot design having sowing dates as main plot and genotypes as sub plot treatments were used and treatments were replicated four times. Plot size was 9 m x 6 m comprising 300 plants per plot. Nitrogen and Phosphorous fertilizers were broadcasted at 25 and 50 kg ha^{-1}, respectively of N and P and incorporated into the seedbed before planting. Pesticides were applied as per recommended schedule to prevent pest and disease attack. Weeds were controlled manually.

The number of days taken to reach emergence, primary branch initiation, flower bud initiation, 50 % flowering, 50% podding and physiological maturity were recorded when 50% of plants in each plot reached these phenological phases. These phenophases were denoted as P1 : Emergence to initiation of primary branch, P2 : Initiation of primary branch to flower bud initiation, P3 : Flower bud initiation to 50 per cent flowering, P4 : 50 per cent flowering to 50 per cent podding, P5 : 50 per cent podding to physiological maturity, P6 : Emergence to flower bud initiation (Vegetative phase), P7 : Flower bud initiation to physiological maturity (Reproductive phase), P8 : Emergence to physiological maturity

The cumulative degree days, helio thermal unit (Accu. HTU) and accumulated photosynthetically active radiation (Accu. PAR) were calculated as

$$CDD = \sum_{i=1}^{n} (Tmi - 10^0C)$$

$$Accu.\ HTU = \sum_{i=1}^{n} (Tmi - 10^0C) * BSS_i$$

$$Accu.\ PAR = \sum_{i=1}^{n} PAR_i$$

Tmi = Mean temperature
BSS_i = Bright sunshine
PAR_i = Incident PAR
i = 1,2,3,.....n days
n = Number of days in phenophase of interest

Daily PAR values were derived as 41 % of short wave radiation which was obtained from agrometeorological observatory (Khushu, 1994)

Seed yield data were analyzed using split plot design. Subsequently, correlation and stepwise regression analysis were performed using grain yield as dependent and agrometeorological data as independent variable. Phenological prediction models were developed to predict various phenophases using actual days and cumulative degree days through linear regression analysis.

RESULTS AND DISCUSSION

Phenological development

The duration of various phenophases with respect to season, varieties and sowing dates (Fig. 2) show wide variations. The number of days taken for attainment of different phenological stages were largely in the order D1 > D2 > D3 . During 1994, especially low air temperatures (Fig.1) have lengthened vegetative phase, which in turn has extended growing period in GT-100. More days were taken by GT-100 to reach maturity in 1994 than the 1993. While, reverse trend has been exhibited by BDN-2 genotype. The most early sowing D1 took longest time (134 & 167 days) in 1993 and (150 & 163 days) in 1994 for attainment of maturity in GT-100 and BDN-2 genotypes, respectively.

Degree-days based phenology

The CDD required to attain different phenological stages in pigeonpea genotypes (Table 1) revealed that sowing date could have marked influence on degree days accumulated. For different sowing dates and seasons, CDD for emergence to maturity ranged between 2036 to 2530 °Cd and 2046 to 2830 °Cd for GT-100 and BDN-2, respectively. For both flower bud initiation and maturity, crop sown on 30th June required the highest CDD and the lowest was in case of 9th August sown crop for both the genotypes and seasons. It was also inferred that both genotypes sown at different dates have used more CDD to attain primary phenophses (P_2 to P_5) during 1993 compared to 1994 season except for a slight difference in magnitude of CDD. Exceptionally, CDD required from emergence to primary branch initiation were higher in 1994 season. These results are in agreement with reported in past (Turnbull, 1986).

Regression models were developed for predicting timing of various phenophases with R^2 values of 0.97 for each genotype. These models were

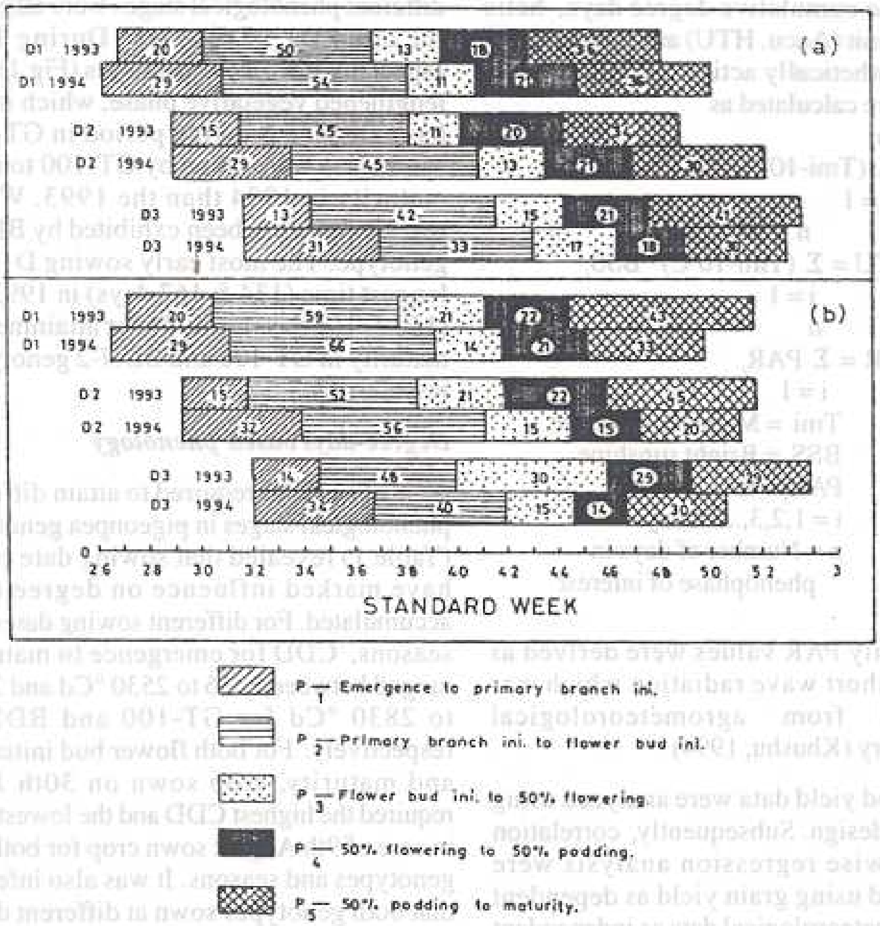

Fig. 2: Phenological calender of pigeonpea cv. (a) GT-100 & (b) BDN-2

$Y = 1.093 + 0.0575x$ and

$Y = 2.224 + 0.0587x$

where, Y is predicted days to reach particular phenophase and x is CDD for particular phase of interest for GT-100 and BDN-2, respectively.

Using these linearly fitted line, the days taken to various phenophases could be predicted depending upon the minimum values CDD required to reach that phase. The models for both genotypes were tested by calculating the predicted values and were found normally fit for all primary phenophases (P_2 to P_4) except P_5 phase (Table 2). This could be attributed to terminal water deficit that develops during pod filling stage which disturbs quantitative phenological response to temperature via

Table 1 : Cumulative degree days (CDD) required to attain various phenophases of pigeonpea

Growth phase	D1		D2		D3		Mean
	1993	1994	1993	1994	1993	1994	
Cultivar GT-100							
P1	375	505	287	530	245	548	412
P2	949	906	847	779	791	585	812
P3	236	200	205	223	285	299	241
P4	343	369	367	350	330	275	339
P5	596	530	504	448	494	326	484
P6	1324	1430	1134	1288	1036	1133	1224
P7	1175	1100	1076	1021	1110	903	1064
P8	2499	2530	2209	2309	2146	2036	2288
Cultivar BDN-2							
P1	370	511	290	567	260	594	432
P2	1120	1153	982	978	910	708	975
P3	387	248	391	249	499	244	336
P4	378	359	360	223	385	189	316
P5	575	406	536	316	310	311	409
P6	1490	1664	1272	1545	1170	1302	1407
P7	1340	1013	1287	788	1194	744	1061
P8	2830	2677	2559	2333	2364	2046	2468

degree-days (Undersander and Christiansen, 1986). The mean differences between actual and predicted days for different phenophases (P_1 to P_5) ranged from 1.7 to 6.5 days and from 0.0 to 9.0 days in GT-100 and BDN-2 genotypes, respectively.

Yield-weather relationship

Perusal of data (Table3) showed that differences in seed yield was greatly explained by sowing date for different genotypes and seasons. It could be inferred, therefore, that, weather factors e.g. temperature, sunshine, humidity, radiation) played a great role, either directly or indirectly, in the expression of yield than any other source of variation in the yield.

Data in Table 4 demonstrated that bright sunshine (BSS) showed significantly negative correlation during almost all critical phases. During early growth phase (P_2), maximum temperature (MaxT) exhibited negative association with seed yield in both genotypes. It was therefore, deduced that high day time temperatures in the early phases affected seed yield by causing loss of early phenological potential for biomass accumulation. Minimum temperature (MinT) has demonstrated strong and consistent positive association with seed yield in GT-100 and BDN-2. It was also reported that pigeonpea flowered under low

Table 2: Predicted calendar days required to attain various phenophases in pigeonpea

Growth phase		D1 1993	D1 1994	D2 1993	D2 1994	D3 1993	D3 1994	Mean
Cultivar GT-100								
P1	P	23	30	18	30	15	33	24.8
	D	3	1	3	1	2	2	2
P2	P	56	54	50	46	47	35	48.0
	D	6	0	5	1	5	2	3
P3	P	15	13	13	14	17	18	15.0
	D	1	2	2	1	2	1	2
P4	P	21	22	22	21	20	17	20.5
	D	3	1	2	0	-1	1	2
P5	P	35	32	30	27	30	20	29.0
	D	-1	-4	-4	-9	-11	-10	7
P6	P	77	83	66	75	61	66	71.0
	D	7	1	7	1	7	2	4
P7	P	68	64	63	60	65	53	62.1
	D	4	-4	0	-10	-12	-13	6
P8	P	145	147	128	134	125	118	133.0
	D	11	-3	6	-8	-6	-12	2
Cultivar BDN-2								
P1	P	24	32	19	36	18	37	27.0
	D	4	3	4	4	4	3	4
P2	P	68	70	60	60	56	44	59.0
	D	9	4	8	4	12	4	6
P3	P	25	17	25	17	32	17	22.1
	D	4	3	4	2	2	2	3
P4	P	24	23	23	15	25	13	20.5
	D	2	2	1	0	4	1	0
P5	P	36	26	34	21	20	20	26.1
	D	-9	-7	-11	-8	-9	-10	9
P6	P	90	100	77	93	71	79	85.0
	D	12	5	10	5	9	5	8
P7	P	81	62	78	49	73	46	65.0
	D	-7	-6	-10	-10	-15	-14	10
P8	P	168	160	152	139	141	122	147.0
	D	5	-3	1	-6	-7	-10	6

P - Predicted days D - Deviation from actual days

Table 3 : Seed yield (kg ha^{-1}) as influenced by sowing date and genotypes

Sowing date	1993 GT-100	1993 BDN-2	1993 Mean	1994 GT-100	1994 BDN-2	1994 Mean
D1	1781	1303	1542	1895	1290	1593
D2	1703	1291	1497	1313	945	1129
D3	1175	976	1075	1000	608	804
Mean	1553	1190		1403	948	
Treatments		C.D. at 5%			C. D. at 5%	
Sowing date		194.6			155.86	
Genotypes		90.9			112.0	
Interaction		ns			128.6	

temperatures reduced pod setting (Akinola and Whiteman, 1975). Balakrishnan and Natarajaratnam (1988) have stated that pod setting in pigeonpea decreases with a decrease in extreme minimum and maximum temperatures during the growing period. Both morning (VPD1) and afternoon vapour pressure deficit (VPD2) during P_2 and P_3 phases have significantly negative association with seed yield in GT-100 and BDN-2, but exerted favorable influence during late phenophase P_5 (pod filling phase).

Correlation analysis further illustrated that Accu. PAR had significant positive association with seed yield during late vegetative (P_2) and late reproductive phase (P_5). while, CDD was found strongly and positively related to seed yield during important phenophases except the most early vegetative growth stage (P_1). This was the probable reason for the highest seed yield recorded by 30th June sown crop. It can also be deduced that higher Accu. HTU during early vegetative phase adversely affect the seed yield in pigeonpea. Stepwise multiple regression analyses was performed on different sets of agrometeorological parameters in various phenophases as causal variable and seed yield as response variable. Two different regression models were developed for prediction of seed yield in GT-100 and BDN-2 about 30 days prior to harvest.

$$Y = -513.1 - 188.6BSS(P_2) - 278.5MaxT(P_2) + 413.2TR(P_2) + 148MinT(P_4) + 289.5 MinT(P_6) - 224.4TR(P_6) \quad ......(1)$$

$$(R^2 = 0.96)$$

$$Y = -7051.1 + 121.2MaxT(P_4) + 166.7Mint(P_6) \quad ....(2)$$

$$(R^2 = 0.78)$$

These models (1) and (2) can be practiced for predicting yield in GT-100 and BDN-2, respectively.

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Table 4: Correlation coefficients between seed yield and different agrometeorological parameters during different phenophases of pigeonpea

Pheno phases	agrometeorological parameters									
	BSS	EP	Max T	Min T	TR	VPD1	VPD2	CDD	Accu. HTU	Accu. PAR
Cultivar GT-100.										
P1	-0.348	-0.183	-0.036	0.514*	-0.269	0.113	0.398	-0.117	-0.563**	-0.173
P2	-0.799**	-0.534**	-0.611**	0.667**	-0.822**	-0.256	-0.793**	0.848**	-0.457*	0.657**
P3	-0.135	-0.166	-0.373	0.479*	-0.491*	-0.623**	-0.314	0.650**	-0.542**	0.306
P4	-0.221	0.371	0.854**	0.671**	-0.309*	-0.402**	0.438*	0.632**	0.581**	0.561*
P5	-0.529**	0.844**	0.878**	0.803**	-0.663**	0.798**	0.650**	0.733**	0.740**	0.229
P6	-0.599**	-0.192	-0.262	0.721**	-0.796**	0.065	-0.606**	0.704**	-0.454*	0.438*
P7	-0.387	0.521**	0.963**	0.787**	-0.624**	0.023	0.36	0.599**	0.327	0.391
P8	-0.783**	0.180	0.269	0.555**	-0.927**	0.023	-0.883**	0.844**	-0.418*	0.287
Cultivar BDN-2.										
P1	-0.571**	0.057	-0.177	0.625**	0.084	0.361	0.113	-0.327	-0.694**	-0.399
P2	-0.556**	-0.558**	-0.562**	0.719**	-0.794**	-0.318	-0.781**	0.803**	0.096	0.709**
P3	-0.428*	-0.033	-0.233	0.663**	-0.565**	-0.640**	-0.364	0.238	-0.092	0.226
P4	-0.419*	-0.03	0.740* *	0.740**	-0.375	-0.114	0.248	0.683**	0.670**	0.490**
P5	-0.187	0.621**	0.725**	0.795**	-0.52 **	0.785**	0.531**	0.723**	0.726**	0.629**
P6	-0.372	0.047	0.024	0.735**	-0.577**	0.273	-0.367	0.411*	-0.301	0.146
P7	-0.295	-0.218	0.774**	0.778**	-0.614**	-0.150	-0.103	0.673**	0.707**	0.589**
P8	-0.440*	-0.096	0.353	0.785**	-0.649**	0.041	-0.614**	0.863**	0.481*	0.756**

* Significant at 5% level ** Significant at 1% level

P1 : Emergence to initiation of primary branch
P2 : Initiation of primary branch to flower bud initiation
P3 : Flower bud initiation to 50 per cent flowering
P4 : 50 per cent flowering to 50 per cent podding
P5 : 50 per cent podding to physiological maturity
P6 : Emergence to flower bud initiation (Vegetative phase)
P7 : Flower bud initiation to physiological maturity (Reproductive phase)
P8 : Emergence to physiological maturity

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