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Genotypic Differences in the Temperature Responses of Tropical Crops

I. GERMINATION CHARACTERISTICS OF GROUNDNUT (*ARACHIS HYPOGAEA* L.) AND PEARL MILLET (*PENNISETUM TYPHOIDES* S. & H.)

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ABSTRACT

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The germination at constant temperature of several genotypes of groundnut and pearl millet was investigated between 0 °C and 50 °C on a thermal gradient plate. Large differences in both germination rate and percentage germination were observed in both species.

Base temperatures vary from 8–11·5 °C and 8–13·5 °C in groundnut and millet, respectively and optimum temperatures from about 29–36·5 °C in both. Maximum temperatures for germination ranged from 41–47 °C. The results are discussed in terms of adaptation to high soil temperature and crop establishment in the semi-arid tropics.

Key words—Temperature, germination, millet, groundnut.

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INTRODUCTION

In many areas of the humid and semi-arid tropics high soil temperature is considered a major reason for poor crop establishment (Lal, 1974; Wilson, Raju, and Peacock, 1982). The occurrence of high soil temperature can be prevented by using various plant mulches, but such materials are costly and seldom available in adequate amounts for widespread use in the semi-arid tropics. The alternative is to use heat-tolerant genotypes. However, the vast majority of the published information on genotypic variation in the temperature responses of crops is concerned with the ability to grow at low temperatures in temperate regions, where crop establishment is delayed by low spring temperatures (Monteith and Elston, 1971).

Recent work at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, has shown that heat-tolerant genotypes of sorghum and pearl millet are available in the germplasm (Wilson *et al.*, 1982, ICRISAT Annual Report, 1982). In these studies, selection for seedling emergence was made at one or two soil temperatures only and it is not clear whether heat tolerance is associated with faster growth rate, which reduces

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exposure to damaging temperatures, or a higher upper temperature limit for germination. Information on which mechanism is most important is essential for a better understanding of heat tolerance and for the development of a reliable screening method for heat-tolerant genotypes.

In this paper we describe the germination rate, percentage germination and the cardinal temperatures of contrasting genotypes of two tropical crops, groundnut (*Arachis hypogaea* L.) and pearl millet (*Pennisetum typhoides* S. & H.). Both are major food crops of the semi-arid tropics, where soil temperatures regularly exceed 30–35 °C.

MATERIALS AND METHODS

Most seeds of pearl millet and groundnut, of various origins, were supplied by ICRISAT, but some groundnut seeds were obtained from the Agricultural Research Institute, Harare, Zimbabwe. They were stored at 20 °C during the experimental period. Their origins, dry weight and moisture content are shown in Table 1. Full details are given by Mohamed (1984).

Seeds were germinated on a large thermal gradient plate (1·5 × 0·6 m) which is an improved version of that described by Garcia-Huidobro, Monteith, and Squire (1982), but perspex boxes (11 × 4 × 2 cm) were used instead of Petri dishes. Germination media used were glass beads or sterilized sand covered by Whatman No. 1 filter paper, for millet and groundnut respectively. Between 20 to 30 seeds of millet and 12 to 18 seeds of groundnut were used per box, depending on the seed size of the genotype in use. Only sound seeds of uniform size were used in each case. Distilled water was added initially to saturate the sand, for groundnut in excess of 7·0 cm^3 and 3·0 cm^3 for millet and thereafter as required. A minimum of two replicates were used for each cultivar (across the plate) and boxes were placed at

TABLE 1. *Origins and seed data for (a) groundnut and (b) millet*

Cultivar	Origin	Crop growth duration (d)	Dry weight (mg/seed)	Moisture content (% of dry weight)
(a) Groundnut				
Robut 33-1	India	140	422	5·7
M-13	India	200	675	6·5
Egret	Zimbabwe	180	640	6·1
Flamingo	Zimbabwe	166	581	6·0
Swallow	Zimbabwe	131	567	5·8
Natal-common	Zimbabwe	130	317	6·0
Plover	Brazil	130	436	6·0
Valencia-R_1	Brazil	136	405	6·4
Makulu Red	Zimbabwe	150	507	6·0
Additional cultivars				
MH_2	Nigeria			
ICG-47	India			
ICG-30	India			
MK-374	India			
TMV-2	India			
ICG-21	India			
(b) Millet				
Oasis	Niger		3·42	10·9
Chadi	Rajastan (India)		2·81	10·7
Kala	India (Highlands)		2·76	10·6
Sanio	Senegal		1·87	11·0
IP8962	India (MH)		3·04	10·7
BK560	India (MH)		7·60	11·7
IP5248	India (MH)		1·80	10·5

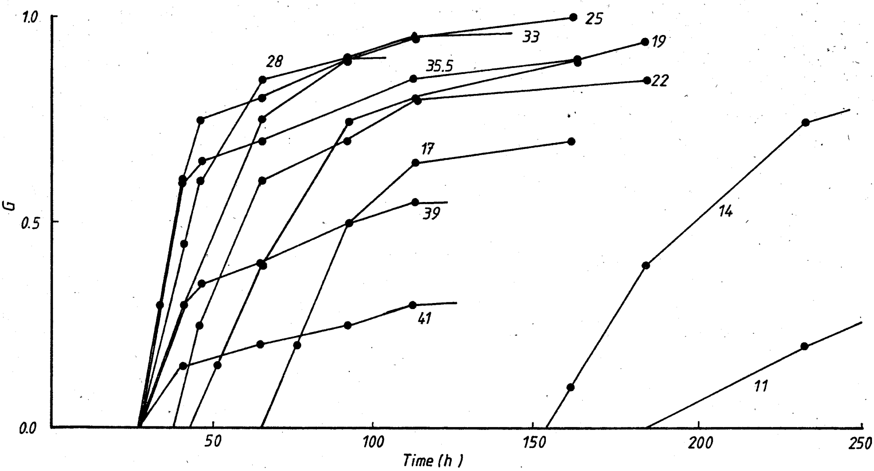


FIG. 1. The time-course of germination of groundnut cv. Flamingo at various constant temperatures (indicated on figure in °C).

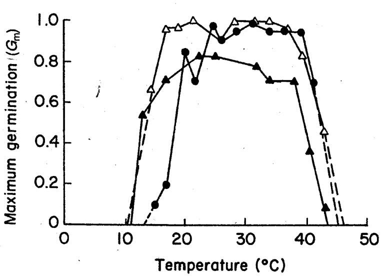
temperature intervals of 2 to 3 °C along the plate. The mean temperature of each box was measured at the centre, using copper–constantan thermocouples. Seeds were considered to have germinated when the radicle was 1·0 cm long and the rate of germination was taken as the reciprocal of time to 50% germination of the seed sample.

RESULTS

Fractional germination (G)

Figure 1 shows a typical set of graphs of temperature–time-course of germination of the groundnut cv. Flamingo. Germination commenced 27 h after sowing within the temperate range from 25 to 41 °C. The recorded times to the beginning of germination varied from 14 to 37 h for all cultivars. Similar graphs were obtained for the germination of pearl millet cultivars.

Figure 2 shows the final germination fraction, *G*, plotted against temperature, *T*, for the groundnut cvs ICG-21, Natal-common and M-13. The genotypes varied considerably in *G*, with ICG-21 having the highest values over most of the temperature range followed by N-common and M-13.



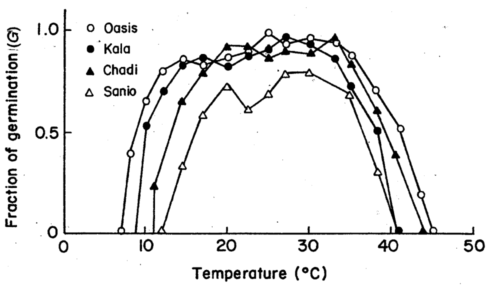
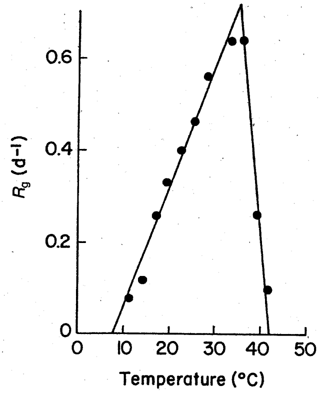


FIG. 2. (*left*) The final germination fraction (G_m) at various temperatures for three cultivars of groundnut M-13 (●), Natal-common (▲), and ICG-21 (△).

FIG. 3. (*right*) The final germination fraction of four cultivars of millet at various constant temperatures.



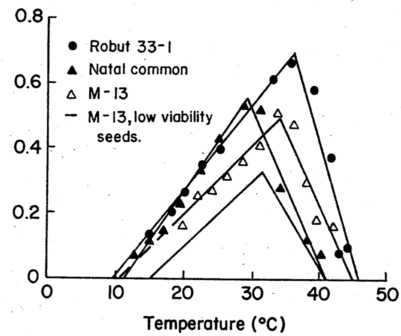


FIG. 4. (*left*) Rate of germination (R_g) of the groundnut cv. Flamingo at constant temperatures.
FIG. 5. (*right*) Rates of germination for three cultivars of groundnut at constant temperatures.

Figure 3 shows final G plotted against T for the millet cultivars Oasis, Chadi, Kala and Sanio. Genotypic differences in G were evident, with Oasis and Sanio representing the highest and lowest values, respectively. Below 18 °C the ranking of genotypes in terms of G is Oasis > Chadi > Kala > Sanio. The final G fraction is also associated with seed size (Table 1).

Rate of germination (R_g)

Figure 4 shows a plot of R_g against T for the cultivar Flamingo. Two straight lines described the response which can be expressed as

$$R_g = S_1(T - T_b) \tag{1a}$$

when $T_b < T < T_o$, and

$$R_g = S_2(T_m - T) \tag{1b}$$

when $T_o < T < T_m$, where S is the slope of the rate–temperature relation, equivalent to $1/\theta$. θ is the thermal time in degree-days (°Cd) required for germination and T_b, T_o and T_m are the base, optimal and maximum temperatures for germination, respectively (Garcia-Huidobro *et al.*, 1982). The rate, R_g, increases with T from T_b to T_o and decreases thereafter sharply to zero at T_m. Figures 5 and 6 show similar plots for four varieties each of groundnut and millet, respectively. In Fig. 5 cv. Robut has the highest R_g over most of the temperature range, particularly at $T > 30$ °C. The cultivar M-13 has the lowest R_g values at $T < 31$ °C, but higher R_g than those of N-common at higher temperatures. In Fig. 6, Oasis has the highest R_g over the whole range of temperatures, whereas Sanio has the lowest. The ranking of these millet cultivars at $T > 15$ °C was Oasis > Kala > Chadi > Sanio. At high temperatures Chadi germinated earlier than Kala but the ranking of Oasis and Sanio did not change. The differences were greatest at $T > 30$ °C. The mean standard error for the determination of the cardinal temperatures was about 0·5 °C and that for $\theta = 1$ °C.

Cardinal temperatures

Cardinal temperatures were determined from the $R_g - T$ relations for all genotypes and are presented in Table 2a and b. Correlations in all cases were significant and, because

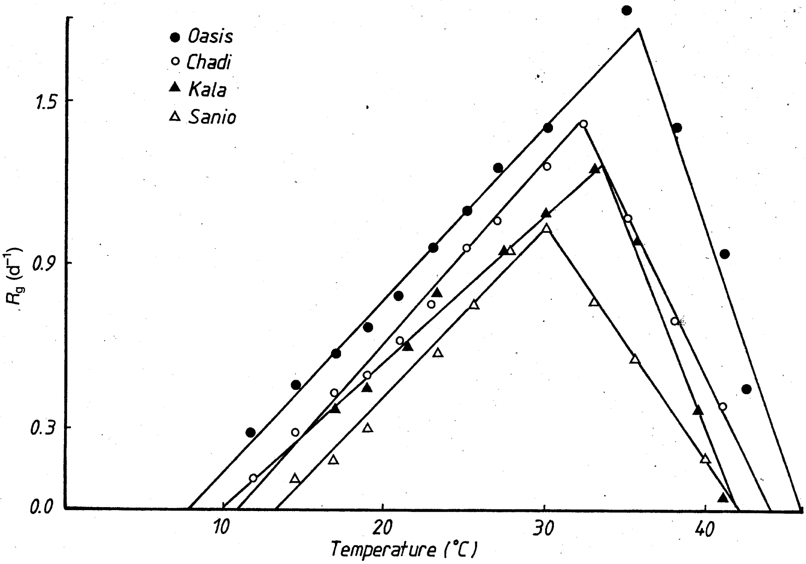


FIG. 6. Rates of germination (R_g) of four cultivars of millet at constant temperatures.

TABLE 2. *Cardinal temperatures and thermal time for germination for (a) groundnut and (b) millet*

Cultivars	T_b	T_o	T_m	θ_1	θ_2
(a) Groundnut					
Valencia R_2	8	35	43	35	9
Flamingo	8	34·5	42	36·5	10
Makulu Red	8·5	29	42	44	28·7
ICG-30	8	36	44	39·5	11
Egret	9	29	43	37	26
ICG-47	9	36·5	47	30	11·6
Robut 33-1	10	36·5	46	38·7	14
TMV	10	36	42	33	8
MK	10	36	44	38·5	13
Plover	10·5	34	42	29	9·5
ICG-21	11	35·5	45	38	15
M-13	11	34	45	50	21·7
Swallow	11	29	42	32·6	40
Natal-common	11·5	29	41	32	21
Ranges	8–11·5	29–36·5	41–47		
(b) Millet					
Oasis	8·0	35·7	45·6	15·7	5·2
Chadi	11·0	32·0	44·0	15·3	8·5
Kala	9·8	33·5	42·1	18·4	6·9
Sanio	13·5	30·0	42·3	15·6	12·1
Additional cultivars					
IP2788 (Chad)	10·5	35	44·0		
IP8962 (India)	11·0	34	42·6		
IP5248 (India)	12·0	34	42·0		

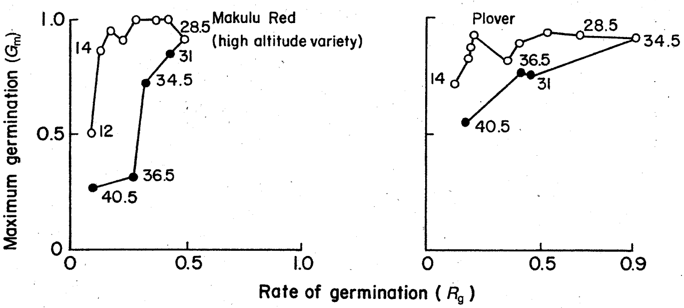


FIG. 7. The fractional germination (G)—rate of germination (R_g)—temperature relation for two groundnut cultivars.

of similarity in the general response, only the cardinal temperatures are shown for other genotypes. For groundnut T_b ranged from 8 to 11·5 °C; T_o from 29 to 36·5 °C and T_m from 41 to 47 °C. The African cultivars have a lower T_m, e.g. 41 to 43 °C and a generally lower T_o ($\simeq$ 29 °C) compared to the Indian cultivars. For pearl millet T_b ranged from 8 °C for Oasis to 13·5 °C for Sanio; T_o ranged from 30 °C for Sanio to 36 °C for Oasis and T_m ranged from 42 °C to 46 °C for Oasis.

Relations between R_g *and* G

The thermal time (θ) required for germination of the various cultivars differed considerably, both below and above T_o (Table 2). Temperatures close to T_b and T_m produce low rates of germination, but their influence is dependent on the genotype used. Plotting R_g against G demonstrates the differences between genotypes of groundnut (Fig. 7). For example, in groundnut G of cv. Makulu Red was much more sensitive to the reduction in R_g caused by high temperatures (> 28·5 °C) than by low ones (Fig. 7a). This high altitude genotype is, therefore, poorly adapted to high temperature. In contrast, cv. Plover, a Brazilian genotype, was less sensitive to high temperature. In millet, also, the germination fraction is reduced more by temperatures above the optimum than by those below it.

DISCUSSION

The rate–temperature responses of groundnut and pearl millet are similar to those described by Garcia-Huidobro *et al.* (1982) for two millet genotypes. Rates of germination increased linearly with temperature from T_b to T_o and decreased sharply above T_o. The highest rate of germination observed, 1·8 d^{-1} for Oasis, is similar to the rate for an indigenous Yemen variety reported by Garcia-Huidobro *et al.* (1982) where values of T_b and T_m were the same for both genotypes.

Significant differences in the cardinal temperatures of different cultivars were evident in both species. The values reported here were generally within the range reported by Stiles (1969) for pearl millet and also comparable to those reported by Garcia-Huidobro (1982), and for groundnut by Young, Cox, and Martin (1979). Leong and Ong (1983) concluded that T_b was conservative for many developmental processes and determined a T_b of 10 °C for cv. Robut. The optimal range of 28–36 °C reported here, with a mean of 32 °C, is similar to that reported by Mills (1964).

The final G differed between cultivars, being highest at most temperatures for Oasis and lowest for Sanio. In groundnut, G_m was highest for Robut and lowest for Natal-common.

This may reflect the potential of a genotype to emerge and to establish itself, particularly under adverse temperature conditions. Oasis, for example, can germinate at both temperature extremes, unlike either Kala or Sanio.

The germination and establishment of crops depends not only on the soil temperature but also on these cardinal temperatures, which indicate the temperature sensitivity or tolerance of a cultivar. The base temperature of Sanio, for example, is 5·5 °C higher than that of Oasis and that of N-common is 3·5 °C higher than that of Flamingo. In the semi-arid tropics the soil surface temperature can be as high as 60 °C (Dugdale, unpublished) and a high tolerance to high temperature could ensure adequate crop establishment. The differences between the cardinal temperatures observed in the cultivars investigated may be attributable to the original climates of adaptation: Sanio is from Senegal, a coastal area in West Africa (12–17° N). This region is exposed to the influence of the south-west monsoon with an overcast sky during part of the year and to the effect of the north-east Harmatan blowing from the Sahara during most of the remaining period. Such conditions have a moderating influence on soil temperature. On the other hand, Oasis originates from Niger, where extremes of heating and cooling occur and the soil surface temperature can reach 60 °C (Dugdale, unpublished). Kala is a highland cultivar from India with a low T_b and T_m.

The results demonstrate that heat tolerance does not necessarily accompany sensitivity to cold. A cultivar may be tolerant to both heat and cold, e.g. Oasis; sensitive to both heat and cold, e.g. Sanio; tolerant to heat but sensitive to cold, e.g. Chadi or vice versa, e.g. Kala. The results also demonstrate that the spread of cardinal temperatures within each of the two species is greater than the difference between species—the environment of adaptation is presumably more important than the species.

In addition to the ability of a genotype to germinate (or emerge) at various temperatures, variation in the rate of germination also has important implications for crop production in the semi-arid tropics. The rate of germination determines how long a seedling will take to emerge in a particular soil environment and, therefore, the duration of its exposure to high temperature and its risk of dehydration. At 38 °C, for example, Oasis germinated in less than a day whereas Sanio needed 3 d at the same temperature: R_g was 1·8 d^{-1} for Oasis compared to 0·6 d^{-1} for Sanio. At the maximum temperature for Sanio ($R_g = 0$) R_g was still 0·6 d^{-1} for Oasis. Similarly, at 35 °C the R_g of Robut is 1·5 times that of Natal-common. In addition to the direct heat stress, a prolonged germination period will weaken the seed, rendering it susceptible to attack by soil micro-organisms. Clearly, a rapid growth rate is advantageous in such environments. A combination of heat tolerance and rapid development will favour survival, as in Oasis and Robut.

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