Constant temperatures and the rate of seed germination in maize (*Zea mays* L.) of contrasting endosperm

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SUMMARY

The germination of quality protein maize (QPM) cultivar, Obatanpa, was compared to normal endosperm (NEM) cultivar, Okomasa, on a temperature gradient plate at constant temperatures ranging from 15-45 °C. Germination occurred at all temperatures except at 42.5 °C for the QPM cultivar and 45 °C for the NEM cultivar. The rate of germination of the NEM cultivar was faster than that of the QPM cultivar at all temperatures. The thermal times for median germination were 46 for QPM and 40.7 °Cd for the NEM cultivar. The cardinal temperatures (base, T_b, optimum, T_o and ceiling, T_c) for the NEM cultivar were T_b: 7, T_o: 30 and T_c: 48.2 °C. The corresponding values for the QPM cultivar were T_b: 7.6, T_o: 27.5 and T_c: 43.4 °C. The base and optimal temperatures were not significantly different but the ceiling temperature for the QPM was significantly lower ($P<0.05$). For each cultivar, a positive linear relationship was established between temperature and rate of germination from the base temperature, T_b, at which germination rate was zero to the optimum temperature, T_o, at which germination rate was maximal. Above T_o, negative linear relationships were established between temperature and rate of germination to the respective ceiling temperatures, T_c, at which germination rate was again zero.

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RÉSUMÉ

AFLAKPUI, G. K. S. : *Les températures constantes et la proportion de germination de graine dans le maïs (*Zea mays *L.) d'endorsperme contrasté.* La germination d'Obatanpa, une variété de maïs protéine de qualité (QPM) était comparée à Okomasa, une variété de maïs d'endorsperme normal (NEM) sur une plaque de gradient de température aux températures constantes s'étendant de 15-45 °C. La germination a eu lieu à toutes les températures excepté à 42.5 °C pour la variété NEM. La proportion de la germinatiomn de la variété NEM était plus vite que celle de la variété QPM à toutes les températures. Les temps thermique pour la germination médiane étaient 46 pour QPM et 40.7 °Cd pour la variété NEM. Les températures cardinales (base T_b, Optimum T_o et plafond T_c) pour la variété NEM étaient T_b:7, T_o:30 et T_c:48.2 °C. Les températures de base et optimale n' étaient pas considérablement différentes mais la température de plafond pour QPM était considérablement plus basse ($P<0.05$). Pour chaque variété cultivée, une relation linéaire positive était établie entre la température et la proportion de germination de la température de base T_b à laquelle la proportion de germination était zéro à la température optimum T_o à laquelle la proportion de germination était maximal. Au-dessus de T_o les relations linéaires négatives étaient établies entre la température et la proportion de germination aux températures de plafond respective T_c à laquelle la proportion de germination était encore zéro.

Introduction

Seed germination and emergence are influenced by a complex of factors among which temperature plays a vital role. Temperature affects germination rate by increasing or decreasing the period of time needed for initial radicle elongation to occur in any given seed lot (Milthorpe & Moorby, 1979). Bierhuizen & Wagenvoort (1974) applied the thermal time concept to germination and observed that when optimal soil conditions are met, seed germination depends mainly on temperature. The thermal

time concept (q,°Cd) assumes that daily differences between actual and base temperatures must accumulate until a set value to start off a particular developmental event in a plant (crop). This approach assumes that there is a linear relationship between developmental rate ($1/t_d$, d^{-1}, where t_d is the duration of a given developmental phase) and temperature (T, °C) between the base and optimum temperatures (Ellis & Barrett, 1994).

Crop yields are influenced by the number of plants established per unit area. A targeted plant population can only be achieved if the seed exhibits a high per cent germination and subsequent good emergence (Itabari, Gregory & Jones, 1993). This is particularly true for maize since the crop does not have the capacity to adjust to poor stands by tillering. Under field conditions, rapid germination and emergence greatly reduce the exposure of the seeds to adverse conditions in the soil. Early emergence, particularly in relation to weed emergence can also enhance crop growth by improving its ability to compete with weeds (Wicks *et al.*, 1986). Variability in emergence of seedlings in the field may result in variation in the growth and maturity of a crop and may even reduce crop yield and quality (Gray, 1978).

The Ghana Grains Development Project (GGDP) has released a number of maize cultivars for cultivation throughout the country. One of the latest releases is quality protein maize (QPM) cultivar, Obatanpa (Twumasi-Afriyie *et al.*, 1992). The major difference between the QPM and the normal endosperm (NEM) is the presence of the opaque-2 gene which confers a softer endosperm to QPM, and contains lysine and tryptophan. Because of its superior quality protein (contains lysine and tryptophan), it has attracted a lot of interest. The Ministry of Health in collaboration with the Sasakawa Global 2000 and the Ghana Grains Development Project have been promoting the use of Obatanpa by nursing mothers in Ghana (GGDP, 1994). There is the need to generate and update information on all aspects of the variety to take advantage of its superior protein characteristics. Information on the germination of other established maize varieties released by the Ghana Grains Development Project has not been critically assessed. Carberry, Muchow & McCown (1989) indicated that cardinal temperatures (base, optimum and ceiling) and other phenotypic characters differ between maize cultivars. None of the earlier work investigated the germination characteristics of soft endosperm quality protein maize cultivars.

The objectives of this study were: to compare the germination of Okomasa, the leading normal endosperm maize (NEM) cultivar in Ghana to Obatanpa, the soft endosperm quality protein maize (QPM) cultivar, at constant temperatures; to calculate and compare the cardinal temperatures and the thermal times for the germination of the two cultivars, and to determine the relationships between temperature and rate of germination for the NEM and QPM cultivars both above and below the optimum temperature.

Materials and methods

The experiment was conducted between late April to mid May 1995 using the temperature gradient plate in the Department of Agriculture, University of Reading.

The temperature gradient plate

The details of the design, operation and characteristics of the temperature gradient plate used have been described by Murdoch, Roberts & Goedert (1989). The surface of the temperature gradient plate was covered with a 940 mm × 940 mm sheet of Whatman 3*M* chromatography paper. This was moistened with distilled water and the edges of the paper tucked into troughs along all four sides of the plate. A 13 × 13 grid, with 51.4 mm × 51.4 mm cells were placed onto the paper into which seeds were placed. The temperatures on the plate were allowed to stabilize after moistening the chromatography paper before any seeds were placed on the plate. The troughs were regularly replenished with distilled water during the course of the experiment. After seeds were placed on the plate, the grid was covered with polythene sheets to prevent evapo-

ration of moisture from cell to cell.

Seed

Seeds of Okomasa and Obatanpa were obtained from the Plant Breeding Maize Division, GGDP/CRI in September 1994 and stored in a cold room at Reading. They were surface sterilized by soaking in 1 per cent sodium hypochlorite solution for 5 min to prevent fungal growth during germination. The seeds were washed with distilled water until the chlorine smell disappeared. The seeds were put into square plastic boxes lined with moistened Whatman filter paper and germinated at a constant range of temperatures of 15-45 °C at 2.5 °C intervals on a temperature gradient plate. A total of 50 seeds per temperature divided over 5 replicates were used for each cultivar. The seeds were regularly kept moist by adding distilled water. Cells were examined every 6-8 h for the first 72 h, then every 10-12 h thereafter and germinated seeds counted. The criterion for germination was protrusion of radicle of 1-2 mm.

Analysis of results

The progress of germination over the five replicates at each temperature regime was bulked and used to construct germination curves. Estimates of the time taken to cumulative median germination at each temperature were obtained by interpolation. The reciprocals of the time (rate) to median germination were plotted against temperature to estimate the optimum temperature at which the rate of germination was maximal, T_o. The rate of germination for each cultivar was regressed separately against temperature according to equations introduced by Garcia-Huidobro, Monteith & Squire (1982). The reciprocal of each regression slope provided the value of thermal time, θ, required for germination. Equation (1) was used to describe the rates of germination below and up to the optimum temperature.

$$1/t = [T-T_b]/\theta_1 \qquad (1)$$

where t = time taken in days to median germination; T = temperature (°C); T_b = base temperature for the given sub-set of the seed population at which temperature 1/t is zero (intercept on the temperature axis); θ_1 = thermal time (number of degree-days above T_b required by the seed to germinate). To describe responses above T_o but below the ceiling temperature, T_c, equation (2) was used:

$$1/t = [T_c-T]/\theta_2 \qquad (2)$$

At T_c, 1/t is again zero and θ_2 is the second value of thermal time.

Results

Effect of temperature on maximum germination

Germination occurred at all temperatures except at 42.5 °C for the QPM cultivar and 45 °C for the NEM cultivar within 240 h. Maximum per cent germination was generally higher for the NEM cultivar than the QPM cultivar (Fig. 1). The maximum germination possible (100 %) was recorded at 25, 27.5 and 30 °C for the NEM cultivar. At temperatures above 34 °C, the maximum percentage germination fell below 80 per cent for both cultivars.

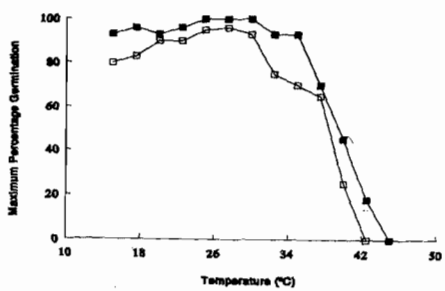

Fig. 1. Effect of temperature on maximum per cent germination of a normal endosperm (NEM) cultivar (■) and a quality protein maize (QPM) cultivar(□) within 240 h

Effect of temperature on the rate of germination

The rate of germination (reciprocal of the time to 50 % germination) of the NEM cultivar was faster than that of the QPM cultivar at all temperatures. Germination occurred most rapidly at 27.5 °C for the QPM cultivar and was progressively delayed as temperatures diverged from this estimated optimum. For the NEM cultivar, germination was

most rapid at 30 °C. Consequently, 27.5 °C and below were considered sub-optimal for the QPM cultivar compared with 30 °C for the NEM cultivar.

Cardinal temperatures and thermal time

The response of rate of germination to temperature was regressed separately for each cultivar in both the sub- and supra-optimal temperature ranges. The intercepts of the fitted regression lines on the temperature axes gave the base, T_b, and ceiling, T_c, temperatures. The estimated base temperatures were 7.6 and 7 °C, respectively for the QPM and NEM cultivars (Fig. 2), with ceiling temperatures of 43.4 and 48.2 °C, respectively (Fig. 3). The thermal times, 01, (reciprocal of the slope of the regression line) for median germination in the sub-optimal temperature range were 46 and 40.7 °Cd, respectively for the QPM and NEM cultivars. In the supra-optimal temperature range, the estimated thermal times, θ_2, were 30.4 and 32 °Cd for the QPM and NEM cultivars. The optimum temperatures, T_o, were taken as temperatures with the highest rates of germination.

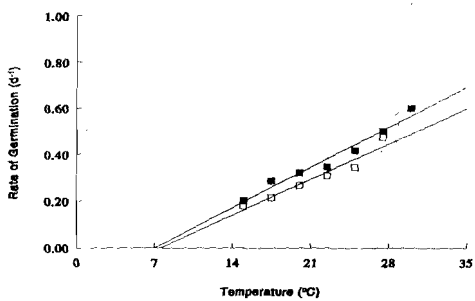

Fig. 2. Effect of temperature on the rate of germination of a quality protein maize (QPM) cultivar (□) and a normal endosperm (NEM) cultivar (■) at sub-optimal temperatures. The fitted lines give R^2=0.9311 and 0.9644, base temperatures of 7 °C and thermal times of 40.7 and 46 °Cd, respectively for the QPM and NEM cultivars

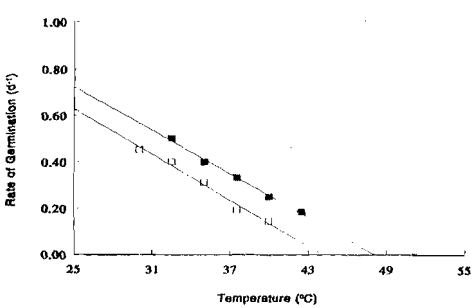

Fig. 3. Effect of temperature on the rate of germination of a quality protein maize (QPM) cultivar (□) and a normal endosperm (NEM) cultivar (■) at supra-optimal temperatures. The fitted lines give R^2 = 0.9814 and 0.9947, and ceiling temperatures of 43.4 and 48.2 °C and thermal times of 30.4 and 32 °Cd, respectively for the QPM and NEM cultivars

Discussion

Carberry, Muchow & McCown (1989) indicated that cardinal temperatures and other phenotypic characters differ between maize cultivars. For the QPM cultivar, Obatanpa, the fastest rate of germination occurred at 27.5 °C compared to 30 °C for the NEM cultivar, Okomasa. The rate of germination was linearly related to temperature for both cultivars, up to the respective optimal temperatures. The optimum temperature for the QPM cultivar was slightly lower than the 30 °C reported elsewhere for two other cultivars of maize (Blacklow, 1972; Warrington & Kanemasu, 1983). Though there were no indications of the endosperm types of these cultivars, and since there has been limited commercial success with QPM cultivars worldwide (Mertz, Bates & Nelson, 1964; Brown, 1975; Twumasi-Afriyie *et al.*, 1992), it is assumed that these cultivars were of the normal endosperm type. The optimum temperature of the NEM cultivar, therefore, concurs with the results of Blacklow (1972) and Warrington & Kanemasu (1983). Itabari, Gregory & Jones (1993), however, reported an optimum temperature of 33.6 °C, for another maize cultivar, Katumani composite B. The optimal temperatures obtained in this study for both the QPM and NEM cultivars were lower than reported by Itabari, Gregory & Jones (1993).

The base temperature for the QPM cultivar, 7.6 °C, was similar to that of the NEM cultivar, 7 °C. The base temperatures of both the QPM and NEM cultivars were slightly higher than the 6.1°C re-

ported by Itabari, Gregory & Jones (1993) but lower than the 9.8 °C reported by Angus *et al.* (1981) and 9 °C reported for two other cultivars of maize (Blacklow, 1972; Warrington & Kanemasu, 1983). Estimates of base temperatures are influenced by the method of determination and the temperature range from which the calculations are made (Arnold, 1959; Augus *et al.*, 1981). The use of data which are influenced by water deficits and the averaging of daily mean temperatures which are outside the range of the linear rate/temperature relationship also influence the accuracy of estimates of base temperature (Leong & Ong, 1983).

There were negative linear relationships between rate of germination and temperature above the optimal temperatures, giving ceiling temperatures of 43.4 and 48.2 °C, respectively for the QPM and NEM cultivars. The ceiling temperature for the QPM cultivar was similar to the 42.9 °C reported by Itabari, Gregory & Jones (1993) but higher than the 40 °C reported by Blacklow (1972). The ceiling temperature for the NEM cultivar was higher than reported by Blacklow (1972) and Itabari, Gregory & Jones (1993).

The optimal range of soil temperature of maize was found to be from 25 to 34 °C (Walker, 1970). In many tropical soils, temperatures in the 5 cm depth vary from 24 to 42 °C depending on the time of the day and whether the surface is bare or mulched (Lal, 1974). Soman & Peacock (1985) also reported that in many parts of West Africa, soil surface temperatures in farmers' fields commonly exceed 45 °C and temperatures as high as 60 °C have occasionally been measured. These reported values of soil temperatures have implications for making a choice between the NEM and QPM cultivars *vis-a-vis* the cardinal temperatures estimated from this study.

The rate of germination of the NEM cultivar was faster than the QPM cultivar at all temperatures as shown in Fig. 2 and Fig. 3. The slower rate of germination coupled with the significantly lower ceiling temperature ($P<0.05$) of the QPM cultivar indicates that the QPM cultivar, with the opaque-2 gene conferring softer endosperm characters on it, may require slightly cooler temperatures to attain maximum germination. It is conceivable that higher temperatures will cause faster protein denaturation, resulting in faster seed death rate of the QPM compared to the NEM cultivar. Similarly, lower temperatures may predispose the softer endosperm QPM cultivar to rotting at a faster rate than the NEM cultivar. The slower rate of germination of the QPM cultivar may have consequences in the field where rapid germination reduces the risk of mortality before emergence.

The cardinal temperatures and rate of germination obtained in this study can be used in selection programmes for different objectives. Where the soil temperature of a location is known, it is possible to estimate the likelihood of obtaining satisfactory germination of the two cultivars since high soil temperature is a major cause of poor crop establishment in many tropical regions (Soman & Peacock, 1985). The results can also be used as a tool in germplasm screening programmes for seed germination to distinguish between genotypic and environmental effects as reported by Ellis *et al.* (1986), and as indicated by Carberry, Muchow & McCown (1989), knowledge of the cardinal temperatures is a prerequisite of the application of any predictive model of crop response to the environment.

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