HAZARDS OF TEMPERATURE ON FOOD AVAILABILITY IN CHANGING ENVIRONMENTS (HOT-FACE): GLOBAL WARMING COULD CAUSE FAILURE OF SEED YIELDS OF MAJOR FOOD CROPS

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ABSTRACT

Global temperatures are predicted to increase from rising levels of atmospheric carbon dioxide (CO_2) and other greenhouse gases. We conducted experiments in sunlit, controlled-environment chambers and temperature-gradient greenhouses to determine effects of elevated temperature and doubled CO_2 concentration on pollination and yield of rice, soybean, dry bean, peanut, and grain sorghum. Photosynthesis and vegetative growth were more tolerant of increasing temperatures than reproductive processes. Rice seed yields were optimum at 25°C mean daily temperature and decreased with increasing temperature (typically about 10% decline for each 1°C rise in temperature). Grain sorghum yield response to temperature was similar to rice, but dry bean was more sensitive, and soybean and peanut were more tolerant. Pollen viability followed a temperature response similar to seed yield. Comparisons of 43 rice cultivars in temperature-gradient greenhouses showed genetic variation in percent seed-set in response to a 4.5°C increase above ambient temperatures in Florida. Thus, there appears to be a range of adaptation of seed crops to temperature. Elevated CO_2 did not prevent high temperature decline in yield; in dry bean it made pollination more sensitive to high temperature. In summary, global warming will be a greater threat to crop seed yields than to photosynthesis and vegetative growth. However, crop genetic improvements might ameliorate part, but not all, of the high temperature hazards for seed yields and global food security.

INTRODUCTION

Global warming is anticipated from rising atmospheric carbon dioxide (CO_2) and other greenhouse gases. Depending on fossil fuel emission scenarios, CO_2 is projected to increase from 370 ppm up to a range of 540-970 ppm by 2100 [*Houghton et al.*, 2001]. With increases in greenhouse gases, global mean temperatures are predicted to increase 1.4 to 5.8^{o}C [*Houghton et al.*, 2001]. Such increases in global temperatures are expected to have adverse impacts on reproductive growth processes and seed yields of important crops in many regions of the world. Many studies have shown that increased CO_2 enhances productivity of grain crops by 30 to 35% [*Ainsworth et al.*, 2002; *Kimball et al*., 2002], but there have been few studies of effects of elevated temperature on seed production and effects measured so far were detrimental. The objectives are to report impacts of elevated temperature in combination with CO_2 on reproductive growth processes (pollen production & viability and seed-set & seed filling) and yield of several important food and feed seed-grain crops (rice, soybean, dry bean, peanut, and grain sorghum).

MATERIALS AND METHODS

Plants were grown in two types of facilities. The first was a set of eight Soil-Plant-Atmosphere Research (SPAR) units (sunlit, controlled-environment plant growth chambers) with continuous control of CO_2 concentration (ambient or elevated), air temperatures, and dewpoint temperatures. Air temperatures were typically controlled to daily sinusoidal cycles with 10°C maximum/minimum differences ranging from 28/18°C up to 44/34°C, depending on the study. Plant canopy photosynthetic and transpiration rates were computed every 5 min. The second facility was a set of temperature-gradient greenhouses (TGG) covering real field soil. Four zones in each TGG were maintained at baseline temperature, +1.5°C, +3.0°C, and +4.5°C compared to Gainesville, Florida USA ambient temperatures. We conducted many experiments in SPAR chambers and TGGs to determine effects of elevated temperature and doubled CO_2 on reproductive growth processes and yields of rice, soybean, dry bean, peanut, and grain sorghum.

RESULTS AND DISCUSSION

Photosynthesis and vegetative growth were generally much more tolerant of high temperatures than reproductive processes (data not shown). Table 1 summarizes the optimum temperature and the high temperature failure-point for seed yields of five crops. Typically seed yields declined about 10% for each 1°C rise in temperature above the optimum although there were differences among species and cultivars. Based on yield response curves, a temperature increase from 28°C (typical Florida July mean temperature) to 32°C was calculated to decrease yields from 10% for ‘Bragg’ soybean to 100% for ‘Montcalm’ dry bean (Table 1). Regions with higher mean temperatures might be at even greater risk from global warming [*Prasad et al*., 2003]. Seed yields of rice were optimum at 25°C mean daily temperature and decreased sharply with increasing temperature to a failure point at 36°C [*Baker and Allen*, 1993]. Grain sorghum yield response to temperature was similar to rice, but dry bean [*Prasad et al*., 2002] was more sensitive, and soybean [*Allen and Boote*, 2000] and peanut [*Prasad et al*., 2003] were more tolerant to high temperatures. Seed yield declines were due mainly to a decline in successful pollination. Pollen viability of dry bean and peanut followed a decline with temperature similar to seed yield declines [*Prasad et al*., 2002, 2003]. Increasing temperature caused a decrease in individual seed size in soybean, dry bean, and peanut, but not in rice and grain sorghum (data not shown). Elevated CO_2 did not prevent the high temperature decline in yield, and in dry bean, it made pollination more sensitive to increasing temperature. Screening of 43 rice cultivars in temperature-gradient greenhouses showed genetic variation in percent seed-set in response to a 4.5°C increase above ambient temperatures in Florida. Global warming will be more detrimental to food and feed production and global food security than to crop photosynthesis and vegetative growth because increasing temperatures cause reproductive failures (pollination failure, decreased percentage seed-set, and sometimes decreased seed size). However, there are potentials for crop genetic improvements to ameliorate part, but not all, of the hazards of high temperature on seed yields and food availability in changing environments, thereby improving the chances for global food security.

Table 1. Optimum mean daily temperature (T_{opt}) and failure-point high mean daily temperature (T_{max}) for seed-grain yields of cultivars of several crops, and yields calculated for T_{opt} , 28°C, and 32°C.

Crop	T_{opt} (°C)	T_{max} (°C)	Yield at T_{opt} (tonnes/ha)	Yield at 28°C (tonnes/ha)	Yield at 32°C (tonnes/ha)	% Decrease 28°C - 32°C
Rice (IR30)	25	36	7.55	6.31	2.93	54
Soybean (Bragg)	28	39	3.41	3.41	3.06	10
Dry bean (Montcalm)	22	32	2.87	1.39	0.00	100
Peanut (Georgia Green)	25	40	3.38	3.22	2.58	20
Grain sorghum (DK58E)	26	35	12.24	11.75	6.95	41

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