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Communication

Soybean Seed Growth in Response to Long-Term Exposures to Differing Oxygen Partial Pressures

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ABSTRACT

Short-term studies have indicated that alterations in the oxygen partial pressure (pO_2) around developing soybean (*Glycine max* [L.] Merr.) seeds may alter seed growth characteristics. A 2-year field study was undertaken to determine the effects on seed development of long-term exposures of individual pods to either sub-ambient or supra-ambient pO_2. Pod chambers were used through which fixed pO_2 were continuously flowed throughout seed development. No effects on maturity date were observed from exposures to either sub-ambient or supra-ambient pO_2. On the other hand, seed weight was reduced by 0.10 pO_2 in both years of the study implicating an O_2 limitation on seed growth rate at this fairly high pO_2. In 1 of the 2 years, supra-ambient pO_2 resulted in increased seed weight.

Several studies have demonstrated that soybean (*Glycine max* [L.] Merr.) seed growth traits are affected by short-term exposures of developing seeds to atmospheres differing in pO_2[1] from ambient. Decreases in pO_2 have been found to decrease seed respiration rates (3) and sucrose uptake rates (12). Conversely, increases in pO_2 above ambient were found to increase seed respiration rates (4) and sucrose uptake rates (12). These results from short-term studies implicate O_2 as an important factor regulating seed growth.

Only one set of long-term experiments of altered pO_2 has been reported from which effects on soybean seed growth can be inferred. Quebedeaux and Hardy (5, 6) sealed the entire shoots of soybean into chambers in which pO_2 was maintained at 0.05, 0.21, or 0.40 for extended periods. Plants exposed to 0.05 pO_2 during the period of seed development produced little or no seed. Plants exposed to 0.40 pO_2 during seed development produced less seed mass than those in 0.21 pO_2. However, exposure of the entire shoot to 0.40 pO_2 confounded the influence of O_2 on seed growth because photorespiration in the leaves was probably stimulated at this high pO_2, resulting in less net carbon fixation by the plant.

This study was undertaken to examine the effects of altering pO_2 in the atmosphere around individual pods during seed growth. Small chambers were placed around developing pods to allow them to be exposed to pO_2 below, at, or above ambient levels. The results from this 2-year field study demonstrated that altered pO_2 had no effect on pod maturity date, but significantly influenced final seed weight.

[1] Abbreviation: pO_2, oxygen partial pressure.

MATERIALS AND METHODS

A 2-year study was conducted on the University of Florida Agronomy Farm where the soil type was Arredondo fine sand (loamy, siliceous, hyperthermic Grossarenic Palendalf). Before sowing, the field was broadcast with 56 g m^{-2} of 0-10-20 (N-P_2O_5-K_2O) fertilizer. In each year the soybean cultivar Williams was sown in rows spaced 0.76 m apart with a spacing of 26 to 33 plants per m within the row. The sowing date in 1983 was 8 April and in 1984 it was 2 April. The crop was irrigated to avoid any drought stress.

Young pods 10 to 30 mm long on primary racemes between the 5th and 8th nodes were enclosed in chambers on 31 May in 1983 and on 29 May in 1984. These chambers, similar to those used by Spaeth and Sinclair (8) in the measurements of pod respiration rates, were 10 cm^3 plastic syringe bodies from which the plungers had been removed. Only one pod per plant was placed in a syringe and the syringe was attached to the plant with rubber bands around the plant stem. Air was flowed continuously at 1.7 cm^3 s^{-1} into the chamber from an air line attached to the needle end of the syringe at the distal end of the pod. The gas in the chamber was allowed to escape freely from the chamber around the plant stem at the proximal end of the pod.

In 1983 pods were exposed to one of four pO_2: 0.10, 0.21 (ambient), 0.42, and 0.62. The three pO_2 differing from atmospheric partial pressure were obtained by adding either N_2 or O_2 gas to ambient air. No attempt was made to reestablish ambient CO_2 levels in the treatments derived by dilution with either N_2 or O_2. Ambient CO_2 dilution (50%) was equal in the 0.10 and 0.62 pO_2 treatments and it was less in the 0.42 pO_2 treatment. The pO_2 was confirmed daily at the pod chambers with a paramagnetic O_2 analyzer (model 570A, Sybron Instruments[2]) and the pO_2 was confirmed to be within 0.02 atm of the prescribed treatment. Forty chambers received each gas mixture, for a total of 160 chambers used in this experiment. Pods were harvested at physiological maturity, the date noted and the dry weight of individual seeds obtained. Physiological maturity was judged to have occurred when pod walls changed to a yellowish color (1, 9, 11).

In 1984, the 0.62 pO_2 treatment was eliminated but a set of control pods was included on which no chambers were used. Eighty pods were identified for each treatment. Two intermediate harvests of 20 pods each were made on 12 and 26 June. Forty pods were harvested from each treatment on the final date, which was 6 July when most pods were yellow or brown. Pod color and individual seed dry weights were recorded.

[2] Mention of company names or commercial products does not imply recommendation or endorsement by the United States Department of Agriculture over others not mentioned.

RESULTS AND DISCUSSION

Pod development in the chambers was visually observed to be no different than those pods outside of chambers. Similar to the natural situation some of the pods in the chambers were aborted and abscised. No differences in pod abortion rate among the pO_2 treatments was observed with all treatments having about 5% pod abscision.

No significant difference was found in maturity date among the four pO_2 treatments in the 1983 experiment (Table I). On the other hand, significant differences were found in mean seed dry weight. When compared to the seed weights produced by pods exposed to ambient pO_2, the 0.10 pO_2 produced significantly lower seed weights and the 0.42 and 0.62 pO_2 produced significantly greater seed weights. The derived seed growth rate at 0.21 pO_2 was approaching 90% of the maximum achieved at 0.42 pO_2.

The results from 1984 essentially confirmed those from the previous year. The distribution in pod color at the final harvest was similar among the four treatments with over 95% of the pods in each treatment having attained a yellow or brown color. These results indicated no difference in maturity among the treatments. However, significantly lower seed dry weights were obtained from the pods subjected to 0.10 pO_2 as compared to those treatments receiving greater pO_2 (Table II). The data from this second year confirmed that the main effect of altered pO_2 was to alter seed growth rate rather than maturity date.

These results, then, indicate that seed growth rate is regulated at the individual pod level. Alteration of pO_2 around an individual pod resulted directly in a change of the seed growth rates in that pod. Yet, changes in individual seed growth rate did not result in a change in the date of physiological maturity for the pod. Consequently, it is inferred that pod maturity is regulated at the whole-plant level rather than at the individual pod. Spaeth and Sinclair (9) similarly concluded in studies of seed maturation of an indeterminate soybean cultivar that maturation occurred uniformly on plants regardless of individual seed growth rate or seed weight. The failure of individual seed growth rate and mass to correlate well with yield (2, 7, 10) further confirms the importance of the regulation of the overall seed development and maturation at the whole-plant level.

Nevertheless, the more than 20% decrease in seed dry weight in each of the 2 years for the 0.10 pO_2 treatment as compared to the other treatments is somewhat surprising. The K_m of mitochondria for dissolved O_2 is approximately 100 nM, or about 1×10^{-4} atm gaseous O_2. Respiration should have been easily O_2 saturated in the 0.10 pO_2 treatment unless a substantial drop in pO_2 occurred somewhere in the seeds. Since the seed growth rate was in fact decreased at 0.10 pO_2, it can be inferred that a physical barrier to O_2 diffusion exists in soybean seeds that results in major decreases in pO_2 at the respiratory sites of the rate-limiting steps for seed growth rate. The magnitude of the barrier is apparently such that under ambient pO_2 the decrease in O_2 within the seed results in very little respiratory inhibition, but at lowered pO_2 the restriction becomes important. Interestingly, Thorne (12) found sucrose uptake rates by isolated soybean embryos subjected to anaerobic conditions were still 68 to 77% of those under ambient pO_2. Consequently, it is suggested that the diffusion barrier and much of the sensitivity to pO_2 resides in the seed coat rather than the embryo. However, additional work is required to verify the existence of a diffusion barrier and to identify the specific site of the O_2 sensitivity in growing soybean seeds.

Table I. *Mean Harvest Dates and Seed Weights of 1983 Experiment*

Treatment	Mean Harvest Date	Mean Seed Dry Weight
pO₂		*mg*
0.10	15 July (a)[a]	129 (a)
0.21	15 July (a)	167 (b)
0.42	14 July (a)	199 (c)
0.62	13 July (a)	194 (c)

[a] Means followed with the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table II. *Seed Weights at Three Harvest Dates in 1984 Experiment*

Treatment	Seed Weight		
	12 June	26 June	6 July
pO₂		*mg*	
0.10	46 (a)[a]	142 (a)	167 (a)
0.21 (chamber)	65 (bc)	174 (b)	213 (b)
0.21 (natural)	60 (b)	187 (c)	224 (c)
0.42	67 (c)	191 (c)	214 (b)

[a] Means followed with the same letter are not significantly different at the 5% level according to Duncan's multiple range test within each harvest date.

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