Effects of soybean foliage grown under elevated CO_2 on the Japanese beetle, *Popillia japonica* (Newman)

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Abstract

At the soybean free-air carbon-dioxide-enriched (SoyFACE) site, Japanese beetles (*Popillia japonica* Newman) were twice as abundant on plants grown at projected future levels of elevated CO_2. Increased abundance could reflect the fact that elevated CO_2 increases foliar sugar content; sugars are feeding stimulants for *P. japonica*. To determine effects of consuming elevated CO_2 plants on lifespan and fecundity, Japanese beetles in the laboratory were fed soybean leaves either grown in an elevated carbon dioxide atmosphere (550 ppm), grown in a control atmosphere (370 ppm), or supplemented with sugars (sucrose, glucose, and fructose) administered through their petioles, for the duration of their adult lives. Cages were checked daily for adult beetle mortality, and laying substrate was sifted weekly to allow counting of eggs and larvae. Adult lifespans of both male and female beetles were significantly prolonged on elevated-CO_2 foliage; in addition, these females laid significantly greater numbers of eggs ($p < 0.001$). Increased egg production was at least in part attributable to increased longevity, as there was a significant correlation between eggs laid and total beetle days. There was no significant difference in egg production between females fed elevated levels of sugars and females fed either elevated CO_2 or ambient leaves. Increased sugars had no effect on beetle longevity but may contribute to increased fecundity. Increased lifespan may be due to elevated levels of longevity-enhancing phytochemicals in foliage resulting from exposure to elevated carbon dioxide.

Figure 1a

Figure 1b

Figure 1c

Figure 1 – a, pair of *Popillia japonica* on a *Glycine max leaf*. b, the SoyFACE site in central Illinois. c, Experimental cages.

Introduction

Atmospheric carbon dioxide levels have risen since the start of the industrial revolution, from 280 ul l^{-1} to 370 ul l^{-1} today. This rise is expected to double within the next 100 years. Effects on plants have been widely studied, with the general pattern that elevated carbon dioxide stimulates photosynthesis and productivity (Curtis and Wang, 1998). Such changes would seem to favor future crop production except for the fact that effects on other species in the ecosystem, such as insect herbivores, have not been extensively investigated. We examined the effects of feeding on foliage of soybean (*Glycine max*) exposed to elevated carbon dioxide atmospheres on *Popillia japonica*, the Japanese beetle (Figure 1a), an invasive species that in central Illinois is an important defoliator of soybeans. The effects we were most interested in looking at were those on fecundity and longevity. These two life history attributes contribute significantly to pest population growth and are important to determine in order to predict future impacts of global atmospheric change on agriculture.

Methods

Virgin Japanese beetles were collected from a local park (Meadowbrook Park, Urbana, IL) at emergence in the last week of June 2004. Beetles were divided into groups, with five males and five females per cage containing a layer of fine sand for oviposition (Fig. 1c). Treatments were replicated four times. Beetles in each of the three treatments were fed soybean leaves either grown in an elevated carbon dioxide atmosphere (550 ppm), a control atmosphere (370 ppm), or grown in a control atmosphere but supplemented with a sugar treatment before being fed to the beetles. Leaves in the sugar treatment were given sugar solution, consisting of 8.9 mg g^{-1} glucose, 1.0 mg g^{-1} fructose, and 4.3 mg g^{-1} sucrose (based on concentrations in foliage grown under CO_2, A. Rogers 2004, personal communication), fed through their petioles. Leaves were collected from the SoyFACE site in Savoy, IL (Fig. 1b), and changed every other day as long as beetles were alive. Cages were checked daily for adult beetle mortality, and laying substrate was monitored by sifting substrate weekly to allow counting of eggs and larvae. Differences in survivorship among treatments were subjected to Kaplan-Meier analysis (SPSS 9.0) and egg production was analyzed by analysis of covariance (SPSS 9.0) with total number of beetle days alive as a covariate (egg production is correlated with longevity, $r = 0.490$, $P = 0.009$)

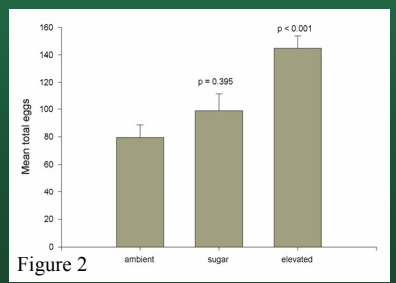

Figure 2

Results

Female beetles fed foliage from plants grown under elevated carbon dioxide laid significantly more eggs than control females (Figure 2). While there was a significant increase in egg production by females fed foliage grown at elevated CO_2, there was no significant difference in egg production between females fed elevated levels of sugars and females fed elevated carbon dioxide leaves or ambient leaves. Both male and female beetles fed foliage from plants grown under elevated carbon dioxide lived significantly longer than control insects (Figure 3). Increased sugars had no effect on beetle longevity.

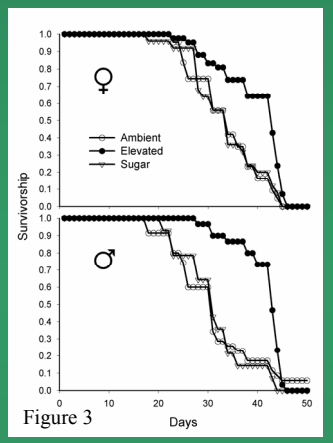

Figure 3

Discussion

The indirect effects of elevated CO_2 on Japanese beetle fecundity are manifested in two ways. First, because both male and female beetles live longer, there is more opportunity to mate and more time to lay eggs. Second, there is an additional positive effect that is not related to longevity, as the analysis of covariance yielded a significant treatment effect after removal of variation in longevity. This latter effect might be nutritional; the sugar treatment yielded egg production levels intermediate between, and not significantly different from, the control and elevated CO_2 treatments. Increased lifespan may be due to elevated levels of as-yet unidentified longevity-enhancing phytochemicals in foliage resulting from exposure to elevated carbon dioxide This enhancement of Japanese beetle fecundity, coupled with a marked preference for soybeans grown at elevated CO_2 (Hamilton et al., 2004), suggest that defoliation of soybeans by Japanese beetles may in the future become more extensive as a consequence of global change.

Acknowledgements

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