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Impacts of climate change on plant food allergens: a previously unrecognized threat to human health

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Abstract Global climate change has had, and will continue to have, many significant impacts on biological and human systems. There are now many studies of climate change impacts on aeroallergens, particularly pollen, including a study demonstrating significant increases in the major allergen content of ragweed pollen as a function of rising atmospheric carbon dioxide concentration ([CO_2]). Recent research has also demonstrated more allergenic poison ivy in response to elevated [CO_2]. Here, we suggest, for the first time, the potential for global climate change, and, in particular, increased [CO_2] and temperature, to have an impact on the allergenicity of plant food allergens such as peanut. Such impacts could have significant impacts on associated allergic diseases, and pose a previously unrecognized threat to human health. There is an urgent need for research on the impacts of climate change on plant food allergens.

Keywords Carbon dioxide CO_2 · Temperature · Climate change · Peanut · *Arachis hypogaea* · Allergen

Introduction

Global climate change has had, and will continue to have, many significant impacts on biological and human systems. There are now many studies of climate change impacts on aeroallergens, particularly pollen. This research includes a study demonstrating significant increases in the major allergen content of ragweed pollen as a function of rising atmospheric carbon dioxide concentration ([CO_2]) (Singer et al. 2005). Recent research has also demonstrated more allergenic poison ivy in response to elevated [CO_2] (Mohan et al. 2006). Such impacts of climate change on aeroallergens and contact allergens could have significant impacts on associated allergic diseases such as asthma, allergic rhinitis, and allergic dermatitis. Here, we suggest, for the first time, the potential for global climate change, and, in particular, increased [CO_2] and temperature, to have an impact on the allergenicity of plant food allergens such as peanut.

In the following sections, we describe the changes in atmospheric composition and climate that are of greatest relevance to impacts of climate change on plant allergens, briefly review existing work on these impacts, including recent work on pollen and contact allergenicity, and discuss the potential for climate change to impact on plant food allergens.

Climate change

Global atmospheric concentrations of carbon dioxide and other greenhouse gases have increased markedly as a result of human activities since 1750 (Alley et al. 2007). The global [CO_2] has increased from a pre-industrial value of about 280 parts per million (ppm) to 379 ppm in 2005 (Alley et al. 2007). This current concentration exceeds, by far, the natural range over the last 650,000 years (180 to 300 ppm) (Alley et al. 2007). The increase in global [CO_2] since 1750 has not been linear. Mean annual [CO_2] data from the Mauna Loa Observatory in Hawaii show a 19% increase since the start of the records in 1959, when it was

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316 ppm (Keeling and Whorf 2005), suggesting that approximately two thirds of the increase in [CO_2] since 1750 has occurred over the last 50 years or so.

These increases in greenhouse gas concentrations have enhanced the greenhouse effect, resulting in global warming and related changes in climate. Global average surface temperature has risen by 0.74°C±0.18°C over the last 100 years (1906–2005) (Trenberth et al. 2007). However, 'the rate of warming over the last 50 years is almost double that over the last 100 years', and 'land regions have warmed at a faster rate than the oceans' (Trenberth et al. 2007).

In addition to these already observed changes, human influences will continue to change atmospheric composition and climate throughout the twenty-first century and beyond (Albritton et al. 2001). [CO_2] is projected to increase to 540 to 970 ppm by 2100 for the Intergovernmental Panel on Climate Change's, Special Report on Emission Scenarios illustrative scenarios (Albritton et al. 2001). The best estimate of projected global average surface warming at the end of the twenty-first century (relative to 1980–1999) is 1.8 to 4.0°C, with a likely range of 1.1 to 6.4°C (Alley et al. 2007). Like the observed warming, projected warming is expected to be greatest over the land (Alley et al. 2007).

Impacts on plant allergens

Aeroallergens

Increases in [CO_2] and temperature (and other changes in climate) have many significant impacts on plants. These include the impacts of climate change on aeroallergens such as pollen (Beggs 2004; Confalonieri et al. 2007; Rosenzweig et al. 2007), such as impacts on pollen amount, pollen allergenicity, pollen season, plant and pollen distribution, and other plant attributes.

Experimental studies have found pollen production of common ragweed (*Ambrosia artemisiifolia* L.) increases significantly both from pre-industrial to current [CO_2] (Ziska and Caulfield 2000) and current to potential future [CO_2]s (Wayne et al. 2002; Ziska and Caulfield 2000). Pollen production of common ragweed is also significantly greater when grown at the higher [CO_2] and temperature of urban areas compared to adjacent rural areas (Ziska et al. 2003). Experimental warming has also been found to significantly increase total pollen production and pollen diameter of western ragweed (*Ambrosia psilostachya*) (Wan et al. 2002).

A number of environmental aeroallergen monitoring studies (e.g., Clot 2003; Rasmussen 2002; Teranishi et al. 2000) have also found changes in the atmospheric concentration of pollen from allergenic species over the latter decades of the twentieth century. For example, Clot (2003) found a significant increase of pollen quantities for *Alnus*, *Ambrosia*, *Artemisia* and Taxus/Cupressaceae over 21 years from 1979 to 1999 in Neuchâtel, Switzerland, which was related to temperature increases.

Pollen allergenicity

In addition to the research on pollen amount, and other impacts of climate change on aeroallergens, there is now a study on the impact of rising [CO_2] on actual allergen content of pollen. Singer et al. (2005) quantified ragweed's major allergen, Amb a 1, in protein extracted from pollen of *A. artemisiifolia* grown at pre-industrial (280 ppm), current (370 ppm), and a projected future (600 ppm) [CO_2]. Amb a 1 content increased significantly between pre-industrial and projected future [CO_2] (1.8 times) and between current and projected future [CO_2] (1.6 times) (Singer et al. 2005). Earlier research on birch (*Betula*) pollen allergens by Hjelmroos et al. (1995) and Ahlholm et al. (1998) suggests higher temperatures may also result in increased pollen allergenicity.

Contact allergens

Only a single study has contemplated the impacts of climate change on allergic disease other than asthma and allergic rhinitis. Recent research by Mohan et al. (2006) examined the responses of poison ivy (*Toxicodendron radicans*) to elevated [CO_2]. They found poison ivy grown at elevated [CO_2] (570 ppm) was more allergenic, or toxic, than plants grown at ambient [CO_2], containing a significantly increased concentration of the unsaturated triene congener of urushiol (the relative amount of which is related to the human contact dermatitis response).

Food allergens

Sensitization to food allergens can occur in the gastrointestinal tract or as a consequence of an allergic sensitization to inhalant allergens (Sampson 2004). The major plant food allergens associated with sensitization in the gastrointestinal tract are water-soluble glycoproteins that are stable to heat, acid and proteases, including, for example, proteins in peanut and nonspecific lipid transfer proteins found in apple or corn (Sicherer and Sampson 2006). Plant food allergens associated with sensitization to inhalant allergens (such as birch pollen) are largely profilins, which show cross-reactivity with such pollens, and occur in raw fruits and vegetables such as apple and carrot (Sampson 2004; Sicherer and Sampson 2006). Plant allergens are found predominantly in the Cupin (seed storage proteins) and Prolamin (albumin seed storage proteins and nonspecific

Table 1 Summary of studies on impacts of elevated [CO_2] and/or temperature on attributes of peanut (*Arachis hypogaea* L.)

Attributes studied[a]	[CO_2](s) (ppm)	Temperature(s) (°C)	Results[b]	Reference
(a) Leaf area (b) Specific leaf area (c) Leaf dry weight (d) Total leaf area (e) Leaf number (f) Fibrous root and plant dry weights (g) Numbers of pods per plant (h) Pod fresh and dry weights (i) Immature pods and seeds	400 700	28/22 (12 h d^{-1} each)	(a, f–i) higher at 700 than at 400	Mortley et al. (1997)
(a) Foliage fresh and dry weights (b) Number of pods (c) Fresh and dry weights of pods (d) Total seed yield (e) Harvest index (f) Branch length (g) Specific leaf area (h) Net photosynthetic rate (i) Stomatal conductance (j) Carboxylation efficiency (k) Yield of immature pods	400 800 1200	28/22 (12 h d^{-1} each)	(b–f) increased with increasing [CO_2] (a, h) increased from 400 to 800 but declined from 800 to 1200 (j) similar at 400 and 800 but decreased at 1200 (g, i) decreased with increasing [CO_2]	Stanciel et al. (2000)
(a) Number of pegs and pods per plant (b) Flower production (c) Proportion of flowers forming fruits (fruit-set)	360	28, 34, 42, or 48 day temperature for 2, 4, or 6 d, or 34, 42, or 48 for 6 d for 6 or 12 h d^{-1}	(a) reduced by high temperature (b) reduced by high temperature over the range 28–43 (c) reduced by temperatures >36 during whole day and morning	Prasad et al. (2000)
(a) Leaf photosynthesis (b) Seed yield (c) Seed-set (d) Pollen viability (e) Seed number per pod (f) Seed size (g) Seed harvest index (h) Shelling percentage (i) Seed growth rates	350 700	32/22 (day/night) 36/26 (day/night) 40/30 (day/night) 44/34 (day/night)	(a, b) increased from 350 to 700 (b, g) decreased with increasing temperature Lower (c), poor (d), smaller (f), and decreased (h, i) at high temperatures	Prasad et al. (2003)
(a) Photosynthetic CO_2 exchange rate (b) Transpiration (c) Stomatal conductance (d) Water-use efficiency (e) Activity and protein content of Rubisco (f) Rubisco photosynthetic efficiency (g) Leaf soluble sugars and starch (h) Activity of sucrose-P synthase (i) Activity of adenosine 5′-diphosphoglucose pyrophosphorylase	360 720	1.5 and 6.0 above ambient	Higher (a, d, f, h) and lower (b, c, e) at elevated [CO_2] (g) reduced at high temperature at 360	Vu (2005)

[a] There are no studies on impacts of elevated [CO_2] and/or temperature on peanut allergens.
[b] Attributes that did not change due to [CO_2] and/or temperature are not mentioned in the Results column.

lipid transfer proteins) superfamilies and the protein families of the plant defense system (Breiteneder and Radauer 2004).

There are a number of ways in which climate change may affect plant food allergenicity. For example, some of the allergenic proteins generated by the plant defense system are generated in response to, amongst other things, environmental stresses and, as noted by Sampson (2004), 'consequently can be present in variable quantities within the same fruit or vegetable species'. Alternatively, CO_2 and temperature directly affect plant metabolism, through, for example, photosynthesis, and under elevated [CO_2]s, many plants show often a better plant performance and are able to invest into a higher reproductive capacity or storage.

To date, there have been no studies of the impacts of global climate change on plant food allergens. Amongst the most important plant food allergens are peanut (*Arachis hypogaea*), tree nuts, soy, wheat, and mustard (Arbes et al. 2005; Grundy et al. 2002; Hoffmann-Sommergruber 2005; Lee and Burks 2006; Mills et al. 2007; Rancé 2003). Although there is an urgent need for research on the impacts of elevated [CO_2] and temperature on these and other plant food allergens, there is some research showing impacts on other attributes of these plant species. For example, a number of studies have investigated the impacts of elevated [CO_2] and/or temperature on peanut (Table 1). These studies demonstrate that allergenic food plants, like many other plants, are responsive to increases in [CO_2] and temperature, and add weight to the suggestion that such atmospheric changes could influence their allergenic characteristics. In particular, for peanut, impacts on the peanut seeds themselves, shown in Table 1, make changes in allergen content and composition in the peanut seed more plausible.

A number of methods could be employed to investigate impacts on plant food allergens. These include the growth of plants in elevated [CO_2] and/or temperature in controlled environments or enclosures (such as glasshouses and growth chambers), or free-air CO_2 enrichment (FACE) experiments (Ainsworth and Long 2005). Allergen quantification can then be determined using, for example, radioallergosorbent test (RAST), enzyme allergosorbent test (EAST), or enzyme-linked immunosorbent assay (ELISA) (Poms et al. 2004).

Implications for human health

Impacts of climate change on allergens could have serious implications for human health. Impacts on aeroallergens such as pollens could result in changes in associated allergic diseases such as asthma and allergic rhinitis (Beggs and Bambrick 2005). Similarly, it has been suggested that elevated [CO_2] impacts on poison ivy will make it a greater health problem in the future (Mohan et al. 2006).

A significant proportion of the population is either affected by or concerned about food allergy (Lee and Burks 2006; Mills et al. 2007). Recently, Arbes et al. (2005) found the prevalence of positive skin test response to peanut allergen in the US population to be 8.6%. There is also some evidence that the prevalence of food allergies has increased over the past decades (Hoffmann-Sommergruber 2005). For example, Grundy et al. (2002) found peanut sensitization increased three-fold, from 1.1% for children born in 1989, to 3.3% for children born in 1994 to 1996, on the Isle of Wight, UK. Similarly, the self-reported prevalence of peanut allergy among children in the US doubled (from 0.4% to 0.8%) over the 5 years from 1997 to 2002 (Sicherer et al. 2003). Impacts of climate change on plant food allergens are likely to have, and may have already had, impacts on human health. Further, impacts of climate change on pollen may lead to increased sensitization to food allergens as a consequence of an allergic sensitization to inhalant allergens.

Impacts of climate change on plant food allergens would add to the previously recognized impacts on food and human health, such as human nutrition, food security, and food safety (Confalonieri et al. 2007). Although beyond the scope of the current study, another area in need of further investigation, and one related to both allergens and food safety, is the impact of climate change on fungi. For example, aflatoxin contamination, a serious health hazard, occurs when specific fungi in the genus *Aspergillus* infect crops such as peanut. There is some research to suggest that such fungi could also be sensitive to changes in climate (Bernard et al. 2001; Corden et al. 2003; Cotty and Jaime-Garcia 2007; Harvell et al. 2002).

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