MINI REVIEW

Xenohormesis: health benefits from an eon of plant stress response evolution

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Abstract Xenohormesis is a biological principle that explains how environmentally stressed plants produce bioactive compounds that can confer stress resistance and survival benefits to animals that consume them. Animals can piggyback off products of plants' sophisticated stress response which has evolved as a result of their stationary lifestyle. Factors eliciting the plant stress response can judiciously be employed to maximize yield of health-promoting plant compounds. The xenohormetic plant compounds can, when ingested, improve longevity and fitness by activating the animal's cellular stress response and can be applied in drug discovery, drug production, and nutritional enhancement of diet.

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In the last half century, two powerful yet simple concepts have gained increasing prominence in scientific thought. The first is the concept of the adaptive stress response. Research in the science of stress has established that the ability of organisms to respond to physical, chemical, and social stressors is a fundamental process of life (Feder and Hofmann 1999; Selye 1978; Tytell and Hooper 2001; Welch 1993). A particularly key realization in this area is the idea that low levels of stress can improve an organism's health, well-being, adaptability, and fitness through stimulation of the cellular stress response, a phenomenon known as hormesis (Calabrese and Baldwin 2003; Gerber et al. 1999; Rattan 2008). The second concept is the notion of the basic interconnectedness of living organisms on this planet. The field of ecology in particular has established the remarkable degree to which the success or failure of one species depends not only on its inert physical environment but also on the success or failure of the other species sharing that environment (Boucher 1985; Bronstein et al. 2006; Jones et al. 1994; Odling-Smee et al. 2003). The concept of xenohormesis—the process by which one organism benefits from the stress response of another (Howitz et al. 2003; Howitz and Sinclair 2008)—lies at the confluence of these two streams of scientific thought.

The phenomenon of xenohormesis was first named by Howitz and Sinclair (2008; Lamming et al. 2004). As the prefix *xeno* comes from the Greek word meaning stranger or foreigner, xenohormesis describes the phenomenon of a "foreign" organism's stress response producing chemicals

that yield benefits to another organism. The word most often refers to the ability of stressed plants to confer stress tolerance to animals that consume them.

In this paper, we review and synthesize recent research bearing on the phenomenon of xenohormesis and point to a number of practical implications of the concept for medicine and agronomy. The following sections introduce the stress response of plants, outline the types of xenohormetic relationships that can exist between plants and herbivores, and discuss the variety of xenohormetic substances that can positively impact animal survival and longevity. The paper aims to build on the existing published literature on xenohormesis by aggregating the growing number of examples of stressed plants producing added nutrient value for the animal that consumes them. Additionally, while several mechanisms for xenohormetic action have been proposed (Howitz and Sinclair 2008), we hypothesize a novel pathway by which products of the plant stress response confer stress tolerance and extend longevity in animals. Finally, we discuss the implications of the principle of xenohormesis for maximizing the nutritional and medicinal properties of plants and for addressing the challenges of adaptation and survival in an ever-changing environment.

Plant stress response

While the cellular stress response and stress chaperones are thought to be at least two and a half billion years old (Feder and Hofmann 1999), plants and their stress response have been evolving for almost one billion years. Because the sessile plant cannot physically move away from stressors, environmental extremes of temperature variation, water or nutrient availability, or predation must be endured in place. As a result, the complexity of the plant stress response humbles that of animals (Kotak et al. 2007). Yet, when an animal eats a plant that has activated its stress response, the animal may readily benefit from the plant's travail.

It is not intuitive that stressed plants may offer more beneficial nutrient products than plants grown under seemingly ideal conditions that maximize the crop yield in terms of mass alone. A prime example of such an unexpected outcome is observed in the production of wine, where the best grapes in terms of taste and health benefit often result from relatively dry, sun-exposed, infertile soil (de Andrés-de Prado et al. 2007; Gambuti et al. 2007). Indeed, the synthesis of resveratrol—a polyphenol that activates the mammalian stress response system and extends longevity (Baur and Sinclair 2006; Putics et al. 2008)—is stimulated by UV light, ozone, or pathogen stress (Brehm et al. 1999; Preisig-Müller et al. 1999; Versari et al. 2001; Wang et al. 2008). Resveratrol protects the plant itself by reducing UV damage and eliminating pathogenic molds (Adrian et al. 1997; Tang et al. 2010). Similarly, drought-stressed strawberries have better taste, antioxidant capacity, and phenol content (Terry et al. 2007), an observation supported by the rich flavor of strawberries found in the wild in contrast to those that are cultivated under more controlled conditions.

Table 1 provides examples of plants that produce higher concentration of health-promoting substances when enriched by stressful conditions. The table includes hormetic "elicitors" that have been used to increase production of pharmacologically active substances—a practice that could, and perhaps should, be widely applied to future ethno-pharmaceutical production and food agronomy. Indeed, commonly consumed food products like lettuce and fruits can be nutritionally enhanced by cold stress, light stress, water deficit, or nutrient deficit stress (Atkinson et al. 2005; Oh et al. 2009). Heavy metals, salicylic acid, and other compounds can function as hormetic elicitors without compromising crop yield (Kuzel et al. 2009; Zhang et al. 2006). Finally, viral, fungal, and bacterial infection can, in some cases, paradoxically improve the plant's nutritional content via hormesis (Banchio et al. 2010; De Vos et al. 2005; Métraux et al. 1990).

The class of compounds classified as phenols and polyphenols deserve special comment, as they are important categories of secondary metabolites in higher plants that have diverse therapeutic applications. They are divided into flavonoids—which include rutin, quercetin, epigallocatechin gallate (EGCG), isoflavones, and anthrocyanidins—and non-flavonoids—including hydroxybenzoic acid and stilbene derivatives such as resveratrol, cinnamic acid, caffeic acid, curcumin, rosmarinic acid, and ferulic acid. Key enzymes for synthesis of phenolic compounds are phenylalanine ammonia-lyase and stilbene synthase, both of which respond to plant stressors as part of the plant defense against infection and environmental challenge (Benoît et al. 2000; Brehm et al. 1999). Phenolic compounds activate the mammalian stress response when ingested, have antioxidant and anti-inflammatory effects, and have therapeutic effects against aging, cancer, type 2 diabetes, neurodegenerative diseases, and renal disease (Bengmark et al. 2009; Kidd 2009; Knutson and Leeuwenburgh 2008; Leonarduzzi et al. 2009). Finally, dietary polyphenol intake in both humans and wild primates (about 14 mg/kg/day) is within the range of having real biological effects (Milton 2003).

Plant–animal xenohormetic relationships

There are multiple potential forms of xenohormetic relationships between plants and animals, including our own species. In some cases, xenohormesis is embedded within an active mutualistic relationship between plant and animal

Table 1 Examples of stressed plants producing higher yields of potentially therapeutic bioactive compounds

Plant	Stressor	Bioactive product	Benefit
American Mayapple (*Podophyllum peltatum*)	Light stress (Cushman et al. 2004)	Podophyllom	Cancer, warts, arthritis, psoriasis
Artemisia annua	Light and cold stress (Zeng et al. 2008)	Artemisinin	Anti-malarial (Graham et al. 2010)
Black chokeberry (*Aronia melanocarpa*)	Catabolites of polyamine biosynthesis, ornithine decarboxylase inhibitor (Hudec et al. 2006)	Phenolic compounds	Phenolic effects: antioxidant, anti-inflammatory, cancer, aging, diabetes, neurodegenerative diseases, renal disease (Bengmark et al. 2009; Kidd 2009; Knutson and Leeuwenburgh 2008; Leonarduzzi et al. 2009)
Black Current (*Ribes nigrum*)	Ornithine decarboxylase inhibitor, *O*-phosphoethanolamine, carboxymethyl chitin (Hudec et al. 2009)	Phenolic compounds	Phenolic effects
Cistus clusii	Water deficit stress (Hernandez et al. 2004)	Ascorbic acid, phenolic compounds	Common cold (Heimer et al. 2009), phenolic effects
Cucumber (*Cucumis sativus*)	Fungal and viral infection (Métraux et al. 1990)	Salicylate	Arthritis, fever, cardiovascular disease (Rainsford 2007)
Curcuma (*Curcuma longa*)	Nutrient deprivation, heat stress (Li and Zhang 1999; Xia et al. 2005)	Curcumin	Cancer, liver cirrhosis, chronic renal disease, chronic obstructive lung disease, diabetes and Alzheimer's disease, intensive care patients, Crohn's disease (Bengmark et al. 2009)
Dandelion (*Taxaxacum officinale*)	Ornithine decarboxylase inhibitor, *O*-phosphoethanolamine, carboxymethyl chitin (Hudec et al. 2007)	Phenolic compounds	Phenolic effects
Grape (*Vitis vinifera*)	Heat (Wang et al. 2008), fungal infection (Roldán et al. 2003)	Phenolic compounds	Phenolic effects
Gray poplar (*Populus x canescens*)	Osmotic stress high salinity (Luo et al. 2009)	Abscisic acid	Diabetes (Guri et al. 2007)
Green algae (*Haematococcus pluvialis*)	Light and nutrient stress (Vidhyavathi et al. 2008)	Carotenoids (astaxanthin)	Alzheimers disease, skin and eye diseases (Shudo et al. 2009), cardiovascular disease (Fassett and Coombes 2009)
Hypericum brasiliense	Heat and water deficit stress (Nacif de Abreu and Mazzafera 2005)	Phenolic compounds	Phenolic effects
Lavender (*Lavandula vera*)	Vanadyl sulfate (Georgiev et al. 2006)	Rosmarinic acid	Atopic dermatitis (Lee et al. 2008), antiviral (Swarup et al. 2007), sun screen, cancer (Sánchez-Campillo et al. 2009)
Lettuce (*Lactuca sativa*)	Heat, cold, light stress (Oh et al. 2009)	Ascorbic acid, alpha-tocopherol, phenolic compounds	Common cold (Heimer et al. 2009), leg cramps (Oh et al. 2009), phenolic effects
Mustard (*Arabidopsis*)	Bacterial and fungal infection, aphid attack (De Vos et al. 2005)	Jasmonate	Cancer (Cohen and Flescher 2009)
Oregano (*Origanum x majoricum*)	Bacterial infection (Banchio et al. 2010)	Carvacrol	Antibiotic, antiparasitic, diabetes, analgesic, cancer, anti-inflammatory (Baser 2008)
Prickly pear cactus (*Opuntia ficus indica*)	Heat stress and pH stress (Chaidee and Pfeiffer 2006)	Betalains	Diabetes, dyslipidemia, gastritis, prostate hypertrophy (Ennouri et al. 2006)
Purple coneflower (*Echinacea purpurea*)	Acetylsalicylic acid, salicylic acid, methylsalicylate, titanium (IV) ascorbate (Kuzel et al. 2009), ornithine decarboxylase inhibitor, *O*-phosphoethanolamine, carboxymethyl chitin (Hudec et al. 2007)	Caffeic acid and other phenolic compounds	Cardiovascular disease (Kumaran and Prince 2010), phenolic effects

Table 1 (continued)

Plant	Stressor	Bioactive product	Benefit
Soy beans (*Glycine max*)	Salicylic acid, methyl salicylate, ethyl acetate (Zhang et al. 2006)	Phenolic compounds	Phenolic effects
St. John's wort *Hypericum perforatum*	Water deficit stress (Gray et al. 2003)	Hyperforin	Antidepressant (Linde 2009)
Strawberry (*Fragaria chiloensis*)	Water deficit stress (Terry et al. 2007)	Phenolic compounds	Phenolic effects, improved taste
Taxus yunnanensis cell suspension cultures	Fungal elicitors, yeast elicitors, methyl jasmonate, chitosan, heavy metals, and heat (Zhang and Fevereiro 2007)	Paclitaxel	Cancer
Wheat-rye hybrid (triticale)	Water deficit stress (Hura et al. 2009a, b)	Ferulic acid, phenolic compounds	Neurodegenerative disorders, cardiovascular disease, diabetes, cancer (Barone et al. 2009), phenolic effects
Willow seedlings (*Salix sericea*)	Beetle herbivory (Fields and Orians 2006)	Salicylate	Improved stress response, longevity, antipyretic, anti-inflammatory (Batulan et al. 2005; Strong et al. 2008)

species, and the substances produced by the stressed plant are specifically targeted to produce benefits for the helper animal species. For example, trees like *Cecropia*, *Acacia*, and *Macaranda* have evolved indirect defense to herbivores by attracting and nourishing other organisms that reduce plant herbivore damage (Heil 2008). Over a century ago, Francis Darwin described a "standing army of ants" that consume *Acacia* food bodies and protect the plant from the ravages of herbivores (Darwin 1877). The damage from herbivore feeding elicits an octadecanoid cascade, which leads to jasmonic acid synthesis and the production of extrafloral nectar and food bodies. These food bodies provide carbohydrates, lipids, amino acids, and micronutrients that attract ants and parasitic wasps that protect against the offending herbivores (Heil 2008; Linsenmair et al. 2001). Plant–animal mutualisms also occur to facilitate the dispersal of seeds and pollination of flowers by animals (Bronstein et al. 2006); consumption of xenohormetic substances in stressed plants may enable animals to more successfully distribute the plant's genes when conditions are difficult.

While mutualism between plants and animals can support a co-evolutionary impetus for xenohormesis, xenohormesis can also occur with no apparent benefit to the plant. In these cases, the animal is able to piggyback on the self-directed adaptive response of the plant. In fact, most of the bioactive compounds listed in Table 1 are simply products of the plant's stress response that protect it from further environmental damage.

Xenohormetic plant compounds can yield benefits to the animal directly, or by activating the animal's own stress defense pathways. The xenohormetic benefit of the *Cecropia*–ant relationship, for example, comes mainly in the form of calories (Heil 2008). Ascorbic acid, flavonoids, and alpha-tocopherol produced by lettuce and soy act primarily as antioxidants (Leonarduzzi et al. 2009; Oh et al. 2009; Zhang et al. 2006). Other hormetic compounds like podophyllum and paclitaxel have a low dose therapeutic effect, but are quite toxic at higher doses (Biganzoli et al. 2009; Kao et al. 1992). Polyphenols such as resveratrol, curcumin, and carvacrol, on the other hand, are able to stimulate the animal's stress response with minimal systemic toxicity (Allard et al. 2009; Baur and Sinclair 2006; Kato et al. 1998; Scapagnini et al. 2001).

There are several possible explanations for why the animal's stress response should be activated by products of a plant's stress response (Howitz and Sinclair 2008). First, it may occur as a fortunate coincidence, especially in the case of marginally toxic products that produce hormetic benefits via the animal's generalized stress response. Second, it may be due to shared evolutionary history and physiology. Animals and plants, for instance, share a high degree of sequence homology between their stress response signaling pathways, particularly for highly conserved kinases and heat shock proteins (Jiménez et al. 2007). Finally, selection may have favored animal physiology that responds to products of the plant's stress response in order to gauge changing environmental conditions, a hypothesis that has been particularly emphasized in the work of Howitz and colleagues (Howitz et al. 2003; Howitz and Sinclair 2008; Lamming et al. 2004).

Xenohormetic compounds and longevity pathways

Many bioactive plant compounds that are associated with improved animal longevity confer their benefits by activat-

ing or priming cellular survival pathways. The caloric restriction model of inducing robustness and longevity has been used to explain much of hormetic action (Rattan 2008). In fact, the term "caloric restriction mimetics" is often used to describe bioactive compounds with hormetic effects (Ingram et al. 2006; Redman et al. 2008). Recent studies associate caloric deprivation signaling with both activation of the stress response and restoration of energy supply (Canto et al. 2009; Saunders and Verdin 2009).

The key alarm that initiates the response to caloric restriction is lack of available energy in the form of ATP deficit and/or oxidative stress. Figure 1 illustrates a direct pathway that responds to a low energy state and results in a robust stress response and energy recovery. A high AMP/ATP ratio, as occurs with caloric restriction and exercise, activates AMPK (AMP-activated protein kinase), which then, via the NAD+/NADH redox state, stimulates sirtuin 1 (SIRT-1) deacetylation of key transcription factors including heat shock factor-1 (HSF-1; Canto et al. 2009). HSF-1 activates most heat shock proteins (Hsps) and is associated with stress survival and longevity extension across diverse species (Saunders and Verdin 2009).

HSF-1 specifically orchestrates cellular viability by limiting replicative senescence, apoptosis, inflammation, and stress vulnerability (Logan et al. 2009; Meldrum et al. 2003; Pandita et al. 2004; Saunders and Verdin 2009). AMPK activation also limits protein and fat synthesis while stimulating fatty acid oxidation and glycolysis in order to restore the availability of ATP. The net effect on the organism is to meet demands for immediate energy availability and cellular organelle protection. We suggest that an activated stress response plays a fundamental role in conferring fitness and survival benefits to animals consuming stressed plants. In support of this notion, overexpression of HSF-1 extends longevity, while under-

Fig. 1 Longevity pathway demonstrating how caloric restriction, exercise, and stress-derived plant products activate the mammalian stress response

expression reduces it in transgenic animal models (Calderwood et al. 2009; Hsu et al. 2003; Morley and Morimoto 2004). Importantly, plant caloric restriction mimetics can have effects at several steps of the pathway illustrated in Fig. 1. In some cases, it is difficult to identify the predominate level that any particular xenohormetic compound activates; for instance, resveratrol activates both AMPK (Fullerton and Steinberg 2010) and SIRT1 (Westerheide et al. 2009), but it is not yet definitively clear which activation dominates its effect.

To date, the primary bioactive plant compounds known to raise Hsps and to be associated with extension of animal life span are resveratrol (Putics et al. 2008; Westerheide et al. 2009), curcumin (Chen et al. 2001; Kitani et al. 2007; Scapagnini et al. 2001), salicylate (Batulan et al. 2005; Strong et al. 2008), and EGCG (Abbas and Wink 2009; Zhang et al. 2009). Plant compounds that raise Hsps but currently have no proven longevity effects are rosmarinic acid (Rattan et al. 2009), ferulic acid (Calabrese et al. 2008), jasmonic acid (Oh et al. 2005), and carvacrol (Wieten et al. 2010). As a class, these compounds are associated with pleiotropic medicinal benefits that include improved stress tolerance, anti-carcinogenesis, improved glycemic control in diabetes, and reduced cardiovascular disease (see Table 1). The therapeutic promise of these Hsp-augmenting substances and their derivatives are substantial. We should note, however, that because most studies to date have been carried out in cell culture and at super-physiological concentrations, there remain high returns to research focusing on the magnitude of these benefits under more natural conditions.

Another pathway associated with longevity extension that is activated by xenohormetic compounds involves transcription factor nuclear factor-E2-related factor 2 (Nrf2; Godman et al. 2009; Onken and Driscoll 2010). Nrf2 binds antioxidant response elements upstream of cytoprotective stress response proteins such as heme oxygenase and Hsp 22/40/90. The xenohormetic compound curcumin, for example, activates heme oxygenase by regulating Nrf2 (Balogun et al. 2003), while other plant compounds that are not necessarily xenohormetic like sulforaphane (in broccoli) and allicin (in garlic) also activate Nrf2 (Chen et al. 2004; Dinkova-Kostova et al. 2002).

Remarkably, antioxidants like ascorbate, alpha-tocopherol, and some flavonoids have not been associated with improved longevity (Muller et al. 2007). The lack of long-term therapeutic benefit of antioxidants may be partially explained by their suppression of the endogenous stress response. Oxidation products are potent stimulants of HSF-1 activity, and decreasing oxidation in the cell can reduce the HSF-1 stress response (Hooper and Hooper 2004).
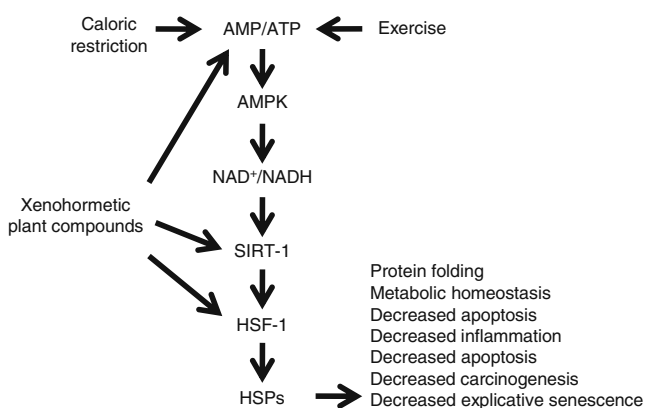
Implications of xenohormesis

How can humans leverage the lessons of xenohormesis? As mentioned above, elicitors can improve production of ethno-pharmaceutical products and the nutrient quality of commonly consumed agricultural products. For instance, the global spread of drug-resistant malaria has created a major demand for the anti-malarial artemisinin, a sesquiterpenoid compound that is synthesized in glandular trichomes of *Artemisia annua* (Graham et al. 2010). The fact that *A. annua*'s glandular trichomes are similar to the food bodies described by Darwin, in that they increase in density and size in response to stress, is probably not a random coincidence; however, unlike the food bodies, they release oils that directly protect the plant from herbivore attack and/or attract pollinators (Schilmiller et al. 2008). Indeed, the hormetic elicitors of cold and light stress increase artemisinin yield in *A. annua* (Zeng et al. 2008) and may be employed to address pharmaceutical production shortages.

While the original concept of xenohormesis focused on micronutrients (Howitz et al. 2003), the concept can also be extended at the macronutrient level. Vígh and colleagues observed that plants exposed to cold shock increase synthesis of unsaturated fatty acids, increasing membrane fluidity and stabilizing the stressed membrane (Quinn et al. 1989; Vígh et al. 1985). Pertinently, animal consumption of these less saturated fats lowers the animal's threshold for triggering the stress response and is associated with a hearty, less disease-prone state. The hyperfluidization of mammalian cell membranes acts as a signal to initiate the heat shock protein response (Balogh et al. 2005; Nagy et al. 2007). In fact, evidence supporting the positive impact of "healthy" plant and animal oils (e.g., olive oil and omega-3 fatty acids) on our well-being is rapidly expanding (Sofi 2009; Zevenbergen et al. 2009). This xenohormetic process also provides a natural model for the action of the Hsp co-inducing hydroxylamines: like unsaturated plant lipids, these membrane-intercalating compounds are capable of simultaneously reducing the molecular order of specific membrane domains and correcting dysregulated expression of Hsps (Török et al. 2003).

Continued focused research on plants' adaptive stress response will likely lead to the discovery of new health-promoting compounds with significant pharmaceutical promise. Close examination of bioactive products found in plants that survive and thrive in environmentally harsh conditions may reveal potent therapeutic substances. For example, extracts from the prickly pear cactus (*Opuntia ficus indica*) can be effective in reducing the symptoms of excessive alcohol consumption. When ingested, the cactus extract increases Hsp levels and is promoted for use by endurance athletes (Wiesse et al. 2004). The active ingredient may be a betalain, which is associated with potentially broad medicinal benefits, including treatment of diabetes, dyslipidemia, gastritis, and prostate hypertrophy (Ennouri et al. 2006).

Another insight from an understanding of xenohormesis is that it may partially explain the conundrum currently surrounding many ethno-pharmaceutical studies that too often cannot stand up to standards of scientific reproducibility. From study to study, researchers may not take into consideration variability in the concentration of bioactive compounds elicited by the conditions under which the medicinal plant was grown. For instance, while a number of studies suggest that cinnamon consumption should improve glycemic control in patients with type 2 diabetes milletus, the result has failed to be confirmed by meta-analysis (Baker et al. 2008). In other words, cinnamon used in one study may not have the same biological effect as cinnamon in another study because it does not have the same concentration of environment-dependent bioactive compounds.

The use of herbs and spices in traditional ethnic cuisines may harness both hormetic and xenohormetic principles. In particular, the use of curcumin, lavender, oregano, mustard (see Table 1), thyme (a source of carvacrol: Baser 2008), and red wine may not only enhance taste but also yield health benefits by priming the consumer's stress response pathways. More generally, while adaptive explanations for the use of spices have focused on their potential effectiveness against pathogens (Billing and Sherman 1998), the theory and data presented here suggest that spices—especially those grown under stressed conditions—may also improve human health via hormetic and xenohormetic pathways (Gerber et al. 1999).

A more global question in this context is whether we are losing important health and nutritional benefits by consuming agricultural products grown in soils and conditions that maximize crop yield but that minimize the stress that would have existed in more natural environments. Has the popularity of controlled mono-cropping in the last few decades affected other species as well? The epidemic of the colony collapse syndrome, for example, has devastated honeybee populations. Is the honeybee no longer ingesting stress-derived and stress-protective bioactive nutrients from a variety of plant species, and therefore becoming more vulnerable itself to life's stresses (Alaux et al. 2010)? Does humanity share a similar risk? As our climate and environment change, it will be more essential than ever for humanity to engage in mutualistic interplay with species at all trophic levels. Perhaps our species can harness the sophisticated stress response of plants to better survive and thrive in a stressful and ever-changing world.

References

Abbas S, Wink M (2009) Epigallocatechin gallate from green tea (*Camellia sinensis*) increases lifespan and stress resistance in *Caenorhabditis elegans*. Planta Med 75:216–221

Adrian M, Jeandet P, Veneau J, Weston LA, Bessis R (1997) Biological activity of resveratrol, a stilbenic compound from grapevines, against *Botrytis cinerea*, the causal agent for gray mold. J Chem Ecol 23:1689–1702

Alaux C, Ducloz F, Crauser D, Le Conte Y (2010) Diet effects on honeybee immunocompetence. Biol Lett (in press)

Allard JS, Perez E, Zou S, de Cabo R (2009) Dietary activators of Sirt1. Mol Cell Endocrinol 299:58–63

Atkinson CJ, Nestby R, Ford YY, Dodds PA (2005) Enhancing beneficial antioxidants in fruits: a plant physiological perspective. Biofactors 23:229–234

Baker WL, Gutierrez-Williams G, White CM, Kluger J, Coleman CI (2008) Effect of cinnamon on glucose control and lipid parameters. Diab Care 31:41–43

Balogh G, Horvàth I, Nagy E, Hoyk Z, Benkõ S, Bensaude O, Vígh L (2005) The hyperfluidization of mammalian cell membranes acts as a signal to initiate the heat shock protein response. FEBS J 272:6077–6086

Balogun E, Hoque M, Gong P, Killeen E, Green CJ, Foresti R, Alam J, Motterlini R (2003) Curcumin activates the haem oxygenase-1 gene via regulation of Nrf2 and the antioxidant-responsive element. Biochem J 371:887–895

Banchio E, Bogino PC, Santoro M, Torres L, Zygadlo J, Giordano W (2010) Systemic induction of monoterpene biosynthesis in Origanumxmajoricum by soil bacteria. J Agric Food Chem 58:650–654

Barone E, Calabrese V, Mancuso C (2009) Ferulic acid and its therapeutic potential as a hormetin for age-related diseases. Biogerontology 10:97–108

Baser KH (2008) Biological and pharmacological activies of carvacrol and carvacrol bearing essential oils. Curr Pharm Des 14(29):3106–3119

Batulan Z, Nalbantoglu J, Durham HD (2005) Nonsteroidal anti-inflammatory drugs differentially affect the heat shock response in cultured spinal cord cells. Cell Stress Chaperones 10:185–196

Baur JA, Sinclair DA (2006) Therapeutic potential of resveratrol: the in vivo evidence. Nat Rev Drug Discov 5:493–506

Bengmark S, Mesa MD, Gil A (2009) Plant-derived health - the effects of tumeric and curcuminoids. Nutr Hosp 24:273–281

Benoît MA, D'Aprano G, Lacroix M (2000) Effect of γ-irradiation on phenylalanine ammonia-lyase activity, total phenolic content, and respiration of mushrooms (*Agaricus bisporus*). J Agric Food Chem 48:6312–6316

Biganzoli L, Licitra S, Moretti E, Pestrin M, Zafarana E, Di Leio A (2009) Taxanes in the elderly: can we gain as much and be less toxic? Crit Rev Oncol Hematol 70:262–271

Billing J, Sherman PW (1998) Antimicrobial functions of spices: why some like it hot. Q Rev Biol 73:3–49

Boucher DH (ed) (1985) The biology of mutualism: ecology and evolution. Oxford University Press, New York

Brehm I, Preisig-Müller R, Kindl H (1999) Grapevine protoplasts as a transient expression system for comparison of stilbene synthase genes containing cGMP-responsive promotor elements. Z Naturforsch 54:220–229

Bronstein JL, Alarcón R, Geber M (2006) The evolution of plant-insect mutualisms. New Phytol 172:412–428

Calabrese EJ, Baldwin LA (2003) Toxicology rethinks its central belief. Nature 421:691–692

Calabrese V, Calafato S, Puleo E, Cornelius C, Sapienza M, Morganti P, Mancuso C (2008) Redox regulation of cellular stress response by ferulic acid ethyl ester in human dermal fibroblasts: role of vitagenes. Clin Dermatol 26:358–363

Calderwood SK, Murshid A, Prince T (2009) The shock of aging: molecular chaperones and the heat shock response in longevity and aging. Gerontology 55:550–558

Canto C, Gerhart-Hines Z, Feige JN, Lagouge M, Noriega L, Milne JC, Elliott PJ, Puigserver P, Auwerx J (2009) AMPK regulates energy expenditure by modulating NAD+metabolism and SIRT1 activity. Nature 458:1056–1060

Chaidee A, Pfeiffer W (2006) Parameters for cellular viability and membrane function in *chenopodium* cells show a specific response of extracellular pH to heat shock with extreme Q_{10}. Plant Biol 8:42–51

Chen YC, Tsai SH, Shen SC, Lin JK, Lee WR (2001) Alternative activation of extracellular signal-regulated protein kinases in curcumin and arsenite-induced HSP70 gene expression in human colorectal carcinoma cells. Eur J Cell Biol 80:213–221

Chen C, Pung D, Leong V, Hebbar V, Shen G, Nair S, Li W, Kong AN (2004) Induction of detoxifying enzymes by garlic organosulfur compounds through transcription factor Nrf2: effect of chemical structure and stress signals. Free Radic Biol Med 37:1578–1590

Cohen S, Flescher E (2009) Methyl jasmonate: a plant stress hormone as an anti-cancer drug. Phytochemistry 70:1600–1609

Cushman KE, Maqbool M, Lata H, Bedir E, Khan IA, Moraes RM (2004) Podophyllotoxin content and yield of American mayapple leaves in sun and shade. Hort Science 40(1):60–63

Darwin F (1877) On the glandular bodies on *Acacia sphærocephala* and *Cecropia peltata* serving as food for ants. With an appendix on the nectar-glands of the common brake fern. J Linn Soc Lond Bot 15:298–409

de Andrés-de Prado R, Yuste-Rojas M, Sort X, Andrés-Lacueva C, Torres M, Lamuela-Raventós RM (2007) Effect of soil type on wines produced from *Vitis vinefera* L. Cv. grenache in commercial vineyards. J Agric Food Chem 55:779–786

De Vos M, Van Oosten VR, Van Poecke RM, Van Pelt JA, Pozo MJ, Mueller MJ, Buchala AJ, Métraux JP, Van Loon LC, Dicke M et al (2005) Signal signature and transcriptome changes of *Arabidopsis* during pathogen and insect attack. Mol Plant Microb Interact 18:923–937

Dinkova-Kostova AT, Holtzclaw WD, Cole RN, Itoh K, Wakabayashi N, Katoh Y, Yamamoto M, Talalay P (2002) Direct evidence that sulfhydryl groups of Keap1 are the sensors regulating induction of phase 2 enzymes that protect against carcinogens and oxidants. Proc Natl Acad Sci U S A 99:11908–11913

Ennouri M, Fetoui H, Bourret E, Zeghal N, Guermazi F, Attia H (2006) Evaluation of some biological parameters of *Opuntia ficus indica*. 2. Influence of seed supplemented diet on rats. Bioresour Technol 97:2136–2140

Fassett RG, Coombes JS (2009) Astaxanthin, oxidative stress, inflammation and cardiovascular disease. Future Cardiol 5:333–342

Feder ME, Hofmann GE (1999) Heat-shock proteins, molecular chaperones and the stress response: evolutionary and ecological physiology. Annu Rev Physiol 61:243–282

Fields MJ, Orians CM (2006) Specificity of phenolic glycoside induction in willow seedlings (*Salix sericea*) in response to herbivory. J Chem Ecol 32:2647–2656

Fullerton MD, Steinberg GR (2010) SIRT1 takes a backseat to AMPK in the regulation of insulin sensitivity by resveratrol. Diabetes 59:551–553

Gambuti A, Strollo D, Erbaggio A, Lecce L, Moio L (2007) Effect of winemaking practices on color indexes and selected bioactive phenolics of Aglianico wine. J Food Sci 72:S623–S628

Georgiev M, Kuzeva S, Pavlov A, Kovacheva E, Ilieva M (2006) Enhanced rosmarinic acid production by *Lavandula vera* MM

cell suspension culture through elicitation with vanadyl sulfate. Z Naturforsch C 61:241–244

Gerber LM, Williams GC, Gray SJ (1999) The nutrient-toxin dosage continuum in human evolution and modern health. Q Rev Biol 74:273–289

Godman CA, Chheda KP, Hightower LE, Perdrizet G, Shin DG, Giardina C (2009) Hyperbaric oxygen induces a cytoprotective and angiogenic response in human microvascular endothelial cells. Cell Stress Chaperones (in press)

Graham IA, Besser K, Blumer S, Branigan CA, Czechowski T, Elias L, Guterman I, Harvey D, Isaac PG, Khan AM et al (2010) The genetic map of *Artemisia annua* L. identifies loci affecting yield of the antimalarial drug artemisinin. Science 327:328–331

Gray DE, Pallardy SG, Garrett HE, Rottinghaus GE (2003) Effect of acute drought stress and time of harvest on phytochemistry and dry weight of St. John's wort leaves and flowers. Planta Med 69:1024–1030

Guri AJ, Hontecillas R, Si H, Liu D, Bassaganya-Riera J (2007) Dietary abscisic acid ameliorates glucose tolerance and obesity-related inflammation in db/db mice fed high-fat diets. Clin Nutr 26:107–116

Heil M (2008) Indirect defence via tritophic interactions. New Phytol 178:41–61

Heimer KA, Hart AM, Martin LG, Rubio-Wallace S (2009) Examining the evidence for the use of vitamin C in the prophylaxis and treatment of the common cold. J Am Acad Nurse Pract 21:295–300

Hernandez I, Alegre L, Munne-Bosch S (2004) Drought-induced changes in flavonoids and other low molecular weight antioxidants in *Cistus clusii* grown under Mediterranean field conditions. Tree Physiol 24:1303–1311

Hooper PL, Hooper JJ (2004) Vitamin E and atherosclerosis. Prev Cardiol 7:144

Howitz KT, Sinclair DA (2008) Xenohormesis: sensing the chemical cues of other species. Cell 133:387–391

Howitz KT, Bitterman KJ, Cohen HY, Lamming DW, Lavu S, Wood JG, Zipkin RE, Chung P, Kisielewski A, Zhang LL et al (2003) Small molecule activators of sirtuins extend *Saccharomyces cerevisiae* lifespan. Nature 425:191–196

Hsu AL, Murphy CT, Kenyon C (2003) Regulation of aging and age-related disease by DAF-16 and heat-shock factor. Science 300:1142–1145

Hudec J, Bakos D, Mravec D, Kobida L, Burdova M, Turianica I, Hlusek J (2006) Content of phenolic compounds and free polyamines in black chokeberry (*Aronia melanocarpa*) after application of polyamine biosynthesis regulators. J Agric Food Chem 54:3625–3628

Hudec J, Burdova M, Kobida L, Komora L, Macho V, Kogan G, Turianica I, Kochanova R, Lozek O, Haban M et al (2007) Antioxidant capacity changes and phenolic profile of *Echinacea purpurea*, nettle (*Urtica dioica* L.), and dandelion (*Taraxacum officinale*) after application of polyamine and phenolic biosynthesis regulators. J Agric Food Chem 55:5689–5696

Hudec J, Kochanova R, Burdova M, Kobida L, Kogan G, Turianica I, Chlebo P, Hanackova E, Slamka P (2009) Regulation of the phenolic profile of berries can increase their antioxidant activity. J Agric Food Chem (in press)

Hura T, Hura K, Grzesiak S (2009a) Leaf dehydration induces different content of phenolics and ferulic acid in drought-resistant and -sensitive genotypes of spring triticale. Z Naturforsch C 64:85–95

Hura T, Hura K, Grzesiak S (2009b) Possible contribution of cell-wall-bound ferulic acid in drought resistance and recovery in triticale seedlings. J Plant Physiol 166:1720–1733

Ingram DK, Zhu M, Mamczarz J, Zou S, Lane MA, Roth GS, deCabo R (2006) Calorie restriction mimetics: an emerging research field. Aging Cell 5:97–108

Jiménez C, Cossío BR, Rivard CJ, Berl T, Capasso JM (2007) Cell division in the unicellular microalga *Dunaliella viridis* depends on phosphorylation of extracellular signal-regulated kinases (ERKs). J Exp Bot 58:1001–1011

Jones CG, Lawton JH, Shachak M (1994) Organisms as ecosystem engineers. Oikos 69:373–386

Kao WF, Hung DZ, Tsai WJ, Lin KP, Deng JF (1992) Podophyllo-toxin intoxication: toxic effect of bajiaolian in herbal therapeutics. Hum Exp Toxicol 11:480–487

Kato K, Ito H, Kamei K, Iwamoto I (1998) Stimulation of the stress-induced expression of stress proteins by curcumin in cultured cells and in rat tissues in vivo. Cell Stress Chaperones 3:152–160

Kidd PM (2009) Bioavailability and activity of phytosome complexes from botanical polyphenols: the silymarin, curcumin, green tea, and grape seed extracts. Altern Med Rev 14:226–246

Kitani K, Osawa T, Yokozawa T (2007) The effects of tetrahydro-curcumin and green tea polyphenol on the survival of male C57BL/6 mice. Biogerontology 8:567–573

Knutson MD, Leeuwenburgh C (2008) Resveratrol and novel potent activators of SIRT1: effects on aging and age-related diseases. Nutr Rev 66:591–596

Kotak S, Larkindale J, Lee U, von Koskull-Döring P, Vierling E, Scharf KD (2007) Complexity of the heat stress response in plants. Curr Opin Plant Biol 10:310–316

Kumaran KS, Prince PS (2010) Caffeic acid protects rat heart mitochondria against isoproterenol-induced oxidative damage. Cell Stress Chaperones (in press)

Kuzel S, Vydra J, Triska J, Vrchotova N, Hruby M, Cigler P (2009) Elicitation of pharmacologically active substances in an intact medical plant. J Agric Food Chem 57:7907–7911

Lamming DW, Wood JG, Sinclair DA (2004) Small molecules that regulate lifespan: evidence for xenohormesis. Mol Microbiol 53:1003–1009

Lee J, Jung E, Koh J, Kim YS, Park D (2008) Effect of rosmarinic acid on atopic dermatitis. J Dermatol 35:768–771

Leonarduzzi G, Testa G, Sottero B, Gamba P, Poli G (2010) Design and development of nanovehicle-based delivery systems for preventive or therapeutic supplementation with flavonoids. Curr Med Chem 17(1):74–95

Li L, Zhang Y (1999) Effects of cultivating measures on rhizome yield and some main active constituents of *Curcuma longa* L. Zhongguo Zhong Yao Za Zhi 24(531–533):574

Linde K (2009) St. John's wort—an overview. Forsch Komplement Med 16:146–155

Linsenmair KE, Heil M, Kaiser WM, Fiala B, Koch T, Boland W (2001) Adaptations to biotic and abiotic stress: *Macaranda*-ant plants optimize investment in biotice defence. J Exp Bot 52:2057–2065

Logan IR, McNeill HV, Cook S, Lu X, Meek DW, Fuller-Pace FV, Lunec J, Robson CN (2009) Heat shock factor-1 modulates p53 activity in the transcriptional response to DNA damage. Nucleic Acids Res 37:2962–2973

Luo ZB, Janz D, Jiang X, Gobel C, Wildhagen H, Tan Y, Rennenberg H, Feussner I, Polle A (2009) Upgrading root physiology for stress tolerance by ectomycorrhizas: insights from metabolite and transcriptional profiling into reprogramming for stress anticipation. Plant Physiol 151:1902–1917

Meldrum KK, Burnett AL, Meng X, Misseri R, Shaw MB, Gearhart JP, Meldrum DR (2003) Liposomal delivery of heat shock protein 72 into renal tubular cells blocks nuclear factor-kappaB activation, tumor necrosis factor-alpha production, and subsequent ischemia-induced apoptosis. Circ Res 92:293–299

Métraux JP, Signer H, Ryals J, Ward E, Wyss-Benz M, Gaudin J, Raschdorf K, Schmid E, Blum W, Inverardi B (1990) Increase in salicylic acid at the onset of systemic acquired resistance in cucumber. Science 250:1004–1006

Milton K (2003) Micronutrient intakes of wild primates: are humans different? Comp Biochem Physiol A Mol Integr Physiol 136:47–59

Morley JF, Morimoto RI (2004) Regulation of longevity in *Caenorhabditis elegans* by heat shock factor and molecular chaperones. Mol Biol Cell 15:657–664

Muller FL, Lustgarten MS, Jang Y, Richardson A, Van Remmen H (2007) Trends in oxidative aging theories. Free Radic Biol Med 43:477–503

Nacif de Abreu I, Mazzafera P (2005) Effect of water and temperature stress on the content of active constituents of *Hypericum brasiliense* Choisy. Plant Physiol Biochem 43:241–248

Nagy E, Balogi Z, Gombos I, Åkerfelt M, Björkbom A, Balogh G, Török G, Maslyanko A, Fiszer-Kierzkowska A, Lisowska K et al (2007) Hyperfluidization-coupled membrane microdomain reorganization is linked to activation of the heat shock response in a murine melanoma cell line. PNAS 104:7945–7950

Odling-Smee FJ, Laland KN, Feldman MW (2003) Niche construction: the neglected process in evolution. Princeton University Press, Princeton

Oh SY, Kim JH, Park MJ, Kim SM, Yoon CS, Joo YM, Park JS, Han SI, Park HG, Kang HS (2005) Induction of heat shock protein 72 in C6 glioma cells by methyl jasmonate through ROS-dependent heat shock factor 1 activation. Int J Mol Med 16:833–839

Oh MM, Carey EE, Rajashekar CB (2009) Environmental stresses induce health-promoting phytochemicals in lettuce. Plant Physiol Biochem 47:578–583

Onken B, Driscoll M (2010) Metformin induces a dietary restriction-like state and the oxidative stress response to extend *C. elegans* Healthspan via AMPK, LKB1, and SKN-1. PLoS ONE 5:e8758

Pandita TK, Higashikubo R, Hunt CR (2004) HSP70 and genomic stability. Cell Cycle 3:591–592

Preisig-Müller R, Schwekendiek A, Brehm I, Reif HJ, Kindl H (1999) Characterization of a pine multigene family containing elicitor-responsive stilbene synthase genes. Plant Mol Biol 39:221–229

Putics A, Végh EM, Csermely P, Soti C (2008) Resveratrol induces the heat-shock response and protects human cells from severe heat stress. Antioxid Redox Signal 10:65–75

Quinn PJ, Joo F, Vígh L (1989) The role of unsaturated lipids on membrane structure and stability. Prog Biophys Mol Biol 53:71–103

Rainsford KD (2007) Anti-inflammatory drugs in the 21st century. Subcell Biochem 42:3–27

Rattan SI (2008) Hormesis in aging. Ageing Res Rev 7:63–78

Rattan SI, Fernandes RA, Demirovic D, Dymek B, Lima CF (2009) Heat stress and hormetin-induced hormesis in human cells: effects on aging, wound healing, angiogenesis, and differentiation. Dose Response 7:90–103

Redman LM, Martin CK, Williamson DA, Ravussin E (2008) Effect of caloric restriction in non-obese humans on physiological, psychological and behavioral outcomes. Physiol Behav 94:643–648

Roldán A, Palacios V, Caro I, Pérez L (2003) Resveratrol content of *Palomino fino* grapes: influence of vintage and fungal infection. J Agric Food Chem 51:1464–1468

Sánchez-Campillo M, Gabaldon JA, Castillo J, Benavente-García O, Del Baño MJ, Alcaraz M, Vicente V, Alvarez N, Lozano JA (2009) Rosmarinic acid, a photo-protective agent against UV and other ionizing radiations. Food Chem Toxicol 47:386–392

Saunders LR, Verdin E (2009) Stress response and aging. Science 323:1021–1022

Scapagnini G, Foresti R, Calabrese V, Guiffrida Stell AM, Green CJ, Motterlini R (2001) Caffeic acid phenethyl ester and curcumin: a novel class of heme oxygenase-1 inducers. J Cell Biol 80:213–221

Schilmiller AL, Last RL, Pichersky E (2008) Harnessing plant trichome biochemisty for the production of useful compounds. Plant J 54:702–711

Selye H (1978) The stress of life, 2nd edn. McGraw-Hill, New York

Shudo K, Fukasawa H, Nakagomi M, Yamagata N (2009) Towards retinoid therapy for Alzheimer's disease. Curr Alzheimer Res 6:302–311

Sofi F (2009) The Medditerranean diet revisited: evidence of its effectiveness grows. Curr Opin Cardiol 24:442–446

Strong R, Miller RA, Astle CM, Floyd RA, Flurkey K, Hensley KL, Javors MA, Leeuwenburgh C, Nelson JF, Ongini E et al (2008) Nordihydroguaiaretic acid and aspirin increase lifespan of genetically heterogeneous male mice. Aging Cell 7:641–650

Swarup V, Ghosh J, Ghosh S, Saxena A, Basu A (2007) Antiviral and anti-inflammatory effects of rosmarinic acid in an experimental murine model of Japanese encephalitis. Antimicrob Agents Chemother 51:3367–3370

Tang K, Zhan JC, Yang HR, Huang WD (2010) Changes of resveratrol and antioxidant enzymes during UV-induced plant defense response in peanut seedlings. J Plant Physiol 167:95–102

Terry LA, Chope GA, Bordonaba JG (2007) Effect of water deficit irrigation and inoculation with *Botrytis cinerea* on strawberry (*Fragaria* x *ananassa*) fruit quality. J Agric Food Chem 55:10812–10819

Török Z, Tsvetkova NM, Balogh G, Horváth I, Nagy E, Pénzes Z, Hargitai J, Bensaude O, Csermely P, Crowe JH et al (2003) Heat shock protein coinducers with no effect on protein denaturation specifically modulate the membrane lipid phase. PNAS 100:3131–3136

Tytell M, Hooper PL (2001) Heat shock proteins: new keys to the development of cytoprotective therapies. Emerg Ther Targets 5:267–287

Versari A, Parpinello GP, Tornielli GB, Ferrarini R, Guilivo C (2001) Stilbene compounds and stilbene synthase expression during ripening, wilting, and UV treatment in grape cv. *Corvina*. J Agric Food Chem 49:5531–5536

Vidhyavathi R, Venkatachalam L, Sarada R, Ravishankar GA (2008) Regulation of carotenoid biosynthetic genes expression and carotenoid accumulation in the green alga *Haematococcus pluvialis* under nutrient stress conditions. J Exp Bot 59:1409–1418

Vígh L, Horvàth I, van Hasselt PR, Kuiper PJC (1985) Effect of frost hardening on lipid and fatty acid composition of chloroplast thylakoid membranes in two wheat varieties of contrasting hardiness. Plant Physiol 79:756–759

Wang W, Wan SB, Zhang P, Wang HL, Zhan JC, Huang WD (2008) Prokaryotic expression, polyclonal antibody preparation of the stilbene synthase gene from grape berry and its different expression in fruit development and under heat acclimation. Plant Physiol Biochem 46:1085–1092

Welch WJ (1993) How cells respond to stress. Sci Am 268:56–64

Westerheide SD, Anckar J, Stevens SM, Sistonen L, Morimoto RI (2009) Stress-inducible regulation of heat shock factor 1 by the deacetylase SIRT1. Science 232:1063–1066

Wiesse J, McPherson S, Odden MC, Shlipak MG (2004) Effect of *Opuntia ficus indica* on symptoms of the alcohol hangover. Arch Intern Med 164:1334–1340

Wieten L, van der Zee R, Goedemans R, Sijtsma J, Serafini M, Lubsen NH, van Eden W, Boroere F (2010) Hsp70 expression and induction as a readout for detection of immune modulatory components in foods. Cell Stress Chaperones 15:25–37

Xia Q, Zhao KJ, Huang ZG, Zhang P, Dong TT, Li SP, Tsim KW (2005) Molecular genetic and chemical assessment of Rhizoma Curcumae in China. J Agric Food Chem 53:6019–6026

Zeng Q, Zhao C, Yin L, Yang R, Zeng X, Huang Y, Feng L, Yang X (2008) Cloning of artemisinin biosynthetic cDNAs and novel ESTs and quantification of low temperature-induced gene over-expression. Sci China C Life Sci 51:232–244

Zevenbergen H, de Bree A, Zeelenberg M, Laitinen K, van Duijn G, Flöter E (2009) Foods with a high fat quality are essential for healthy diets. Ann Nutr Metab 59(Suppl 1):15–24

Zhang C, Fevereiro PS (2007) The effect of heat shock on paclitaxel production in *Taxus yunnanensis* cell suspension cultures: role of abscisic acid pretreatment. Biotechnol Bioeng 96:506–514

Zhang B, Hettiarachchy N, Chen P, Horax R, Cornelious B, Zhu D (2006) Influence of the application of three different elicitors on soybean plants on the concentrations of several isoflavones in soybean seeds. J Agric Food Chem 54:5548–5554

Zhang L, Jie G, Zhang J, Zhao B (2009) Significant longevity-extending effects of EGCG on *Caenorhabditis elegans* under stress. Free Radic Biol Med 46:414–421