AAAAI Work Group Report

Landscape Plant Selection Criteria for the Allergic Patient

Brett J. Green, PhD[a], Estelle Levetin, PhD[b], W. Elliott Horner, PhD[c], Rosa Codina, PhD[d], Charles S. Barnes, PhD[e], and Warren V. Filley, MD[f] *Morgantown, WVa; Tulsa and Oklahoma City, Okla; Marietta, Ga; Lenoir, NC; and Kansas City, Mo*

Patients with pollen-related allergies are concerned about the species within their landscape that provoke their symptoms. Allergists are often asked for guidance but few information sources are available to aid patients in the recognition of allergenic plants and strategies to avoid personal exposure to them. Landscaping and horticultural workers also have few reliable guidance references, and what is available usually extols the virtues of the plants rather than their negative features. The aim of this article was to provide the results of the Landscape Allergen Working Group that was formed by the AAAAI Aerobiology Committee, which aimed to fill these existing knowledge gaps and develop guidance on producing a low-allergenic landscape. Within the context that complete pollen avoidance is unrealistic, the workgroup introduces selection criteria, avoidance strategies, and guidance on low-allergenic plants that could be selected by patients to reduce the overall pollen burden in their landscape environment. Specific focus is placed on entomophilous plants, which require insects as dispersal vectors and generally produce lower quantities of pollen, compared with anemophilous (wind-pollinated) species. Other biological hazards that can be encountered while performing landscaping activities are additionally reviewed and avoidance methods presented with the aim of protecting gardeners, and workers in the landscape and horticulture industries. The guidance presented in this article will ultimately be a helpful resource for the allergist and assist in engaging patients who are seeking to reduce the burden of allergen in their landscape environment. Published by Elsevier Inc. on behalf of the American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2018;■:■-■)

Key words: Allergy; Plants; Pollen; Landscape; Biological hazards

[a]Allergy and Clinical Immunology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Morgantown, WVa
[b]Department of Biological Science, University of Tulsa, Tulsa, Okla
[c]UL Environment, Marietta, Ga
[d]Allergen Science and Consulting, Lenoir, NC
[e]Division of Allergy/Immunology, Children's Mercy Hospital, Kansas City, Mo
[f]Oklahoma Allergy & Asthma Clinic, University of Oklahoma Health Science Center, Oklahoma City, Okla
Conflicts of interest: The authors declare that they have no relevant conflicts of interest.
Received for publication May 15, 2018; accepted for publication May 15, 2018.
Available online ■■
Corresponding author: Brett J. Green, PhD, FAAAAI, Allergy and Clinical Immunology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, 1095 Willowdale Rd, Morgantown, WV 26505. E-mail: dox6@cdc.gov.
2213-2198
Published by Elsevier Inc. on behalf of the American Academy of Allergy, Asthma & Immunology
https://doi.org/10.1016/j.jaip.2018.05.020

BACKGROUND

Plants produce reproductive propagules termed pollen that are aerosolized into local air masses. Although pollen deposition generally occurs in proximity to the source,[1] there are examples of pollen transportation across regions, states, and even entire countries.[2-8] Personal pollen exposure occurs in both urban and rural settings, and airborne levels vary among species, with highest concentrations usually reported during the spring (trees), summer (weeds and grass), and fall (weeds). The lowest concentrations occur during winter. Personal exposure to pollen grains, their associated fragments, and allergen released into the air can result in allergic sensitization, which can cause allergic rhinoconjunctivitis, and allergic asthma.

Many allergic patients often seek guidance from allergists to assist in plant identification or enquire about avoidance strategies to minimize personal exposure. In response to questions and concerns that were voiced to the AAAAI Aerobiology Committee, the Landscape Allergen Working Group was formed and consisted of clinicians and researchers with expertise in allergy, occupational health, aerobiology, and botany. The aim of the workgroup was to address the existing knowledge gaps and provide guidance on strategies that patients and workers could use to reduce the burden of pollen exposure within their personal landscape or workplace. This approach focused on design strategies that would result in the selection of candidate plants with a low pollen yield. These design characteristics will ultimately assist the patient and the worker but also provide a new resource that clinicians could use to assist patients during the design phases of a low-allergenic landscape.

Although eliminating personal pollen exposure is not completely feasible given regional and background sources, the guidelines and avoidance strategies developed by the workgroup that are outlined in this article could assist in the local reduction of pollen exposure and associated plant hazards. It is important to note that the design and production phases of a low-allergenic landscape require a basic understanding of plant biology concepts and botany. Understanding these concepts will further enhance the patient's ability to participate in the selection of plant species that produce the least amount of pollen but are able to grow and persist in their landscape environment. An algorithm and selection guidelines that are intended to assist the patient in the selection of a nonallergenic plant landscape are also included in this article. Methods to reduce exposure to other plant-related hazards are additionally discussed.

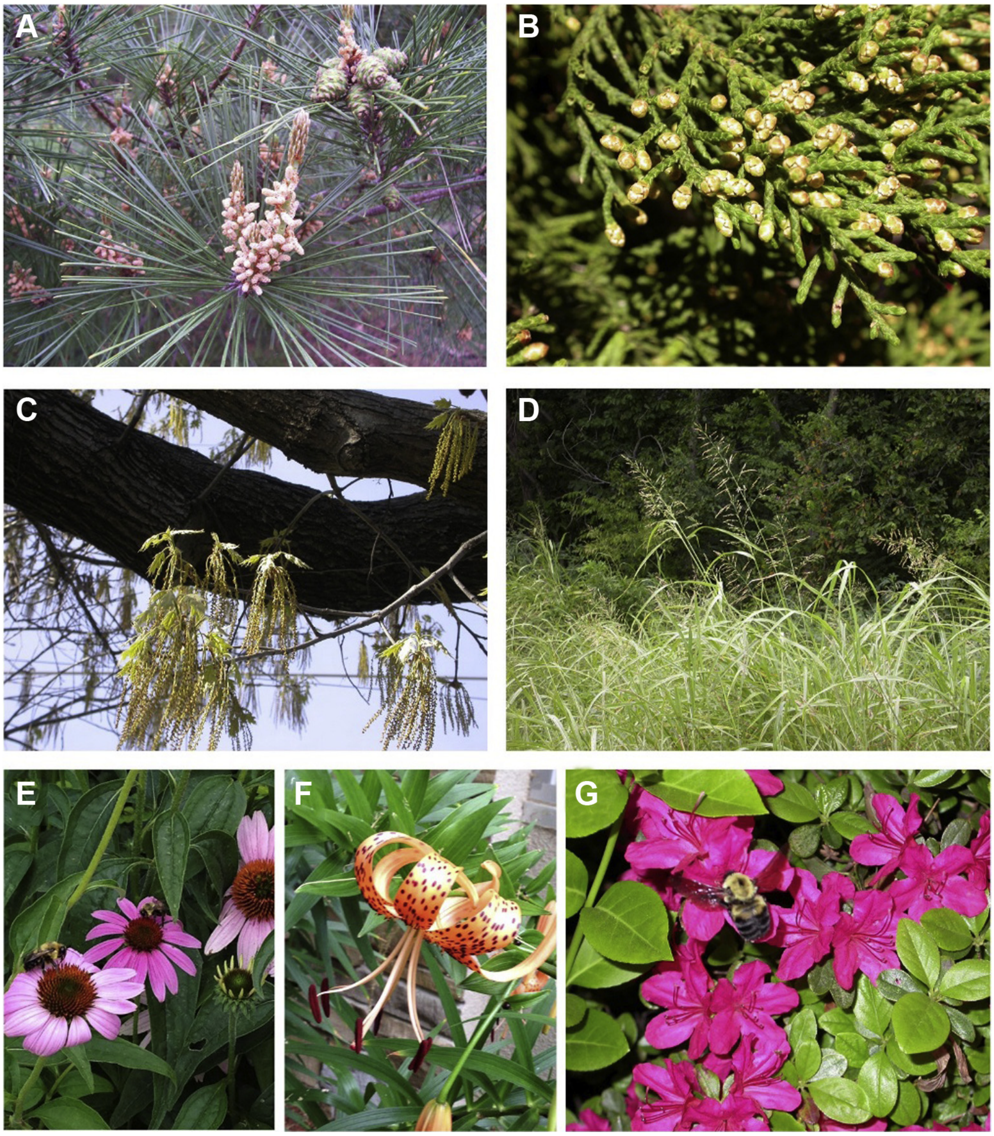

FIGURE 1. Pollen-bearing structures of representative gymnosperm and angiosperm plant species that disperse pollen via an anemophilous or wind mechanisms (**A-D**) and angiosperms that disseminate pollen via an entomophilous or insect-mediated strategy **(E-G)**. ***A***, Megasporangial and pollen-bearing microsporangial cones derived from Loblolly pine (*Pinus taeda*). ***B***, Pollen-bearing microsporangial cones of mountain cedar (*Juniperus ashei*). ***C***, Red oak (*Quercus rubra*) male catkins that consist of long, slender inflorescences of staminate flowers. ***D***, Insconspicuous flowers of Johnson grass (*Sorghum halepense*). Insect-pollinated showy or perfect flowers derived from (**E**) Coneflower (*Echinacea purpurea*), (**F**) Tiger lily (*Lilium lancifolium*), and (**G**) Azaleas (*Rhododendron* species).

POLLEN BIOLOGY

Many land plants disperse reproductive propagules through the air. Mosses and ferns produce spores that are spread by air currents, although in small amounts and usually over limited areas. In contrast, conifers and some flowering plants can produce large quantities of pollen that can reach high local concentrations[1,9] and can travel in air masses over regional and continental distances.[2-8] Pollen from both conifers and flowering plants may be of allergenic clinical relevance at the community level.

Conifers are gymnosperms, or plants that produce naked seeds that are not enclosed in a fruit. The pine, spruce, and fir cones are seed-bearing (female or megasporangial) strobili. These cones are aggregates of scales, with each scale, or bract, bearing 2 naked seeds on the axial surface. The smaller, more ephemeral-male (microsporangial) cones of pine, juniper, spruce, and fir are also aggregates of scales but bear pollen sacs on the axial surface of each scale. The male cones drop as soon as the pollen sheds, whereas the female cones are retained for the season to allow maturation of the seeds. Figure 1 shows the megasporangial and microsporangial arrangements of Loblolly pine (Figure 1, *A*) and microsporangial cones of mountain cedar (Figure 1, *B*), respectively.

Flowering plants, or angiosperms, produce seeds from ovules encased in an ovary (fruit) rather than naked on a scale. Flowering plants include those with the ancestral “magnolia-type” flowers, inconspicuous flowers such as those produced by grasses,

TABLE I. Recognized allergenic plants according to US floristic zone

Zone name	Trees/shrubs	Grasses	Weeds
Northern Forest	Alder, aspen, birch, cedar, fir, juniper, maple, pine, willow	Low levels of pasture grasses	Chenopods, mugwort, nettle, pigweeds
Eastern Agricultural	Alder, ash, beech, birch, box elder, elm, hawthorn, hickory, locust, maple, oak, pines, red cedar, sycamore, walnut	Northeast states: brome, fescue, orchard, ryegrass, sweet vernal, timothy Southern states: Bermuda, Johnson	Dock, lamb's quarter, mugwort, nettle, pigweed, plantain, sheep sorrel; Short, giant, southern, and western ragweed
Central Plains	As in Eastern Agricultural; box elder, cottonwood, locust, willow	As in Eastern Agricultural	As in Eastern Agricultural; chenopods, pigweed, waterhemp
Rocky Mountains	Ash, aspen, box elder, cottonwood, maple, mountain cedar, oak, pines, willow	Brome, fescue, ryegrass, orchard, timothy	Amaranths, chenopods, dock, giant and western ragweed, sagebrush, sage
Northwest Coastal	Alder, birch, cedar, fir, hazel, pine	Brome, fescue, orchard, sweet vernal, timothy, ryegrass, velvet	Amaranths, chenopods, dock, plantain, short ragweed, sheep sorrel
California Lowland	Alder, elm, eucalyptus, olive, sycamore, walnut, willow	Bermuda, Johnson, velvet	Amaranth, baccharis, nettle, scales, tumbleweeds,
Arid Southwest	Ash, acacia, cedar, mesquite, Mountain mulberry	Bermuda, grama, witchgrass	Amaranth, scales, tumbleweeds
Great Basin	As in Rocky Mountains and Arid Southwest	Bermuda, Johnson, witchgrass	Marshelders, rabbitbrush, scales, tumbleweeds
Southeastern Coastal	As in Eastern Agricultural; ash, bald cypress, box elder, elm, hackberry, hickory hornbeams, oak, pecan, sweet gum	As in Eastern Agricultural; bahia, dallisgrass	As in Eastern Agricultural, baccharis
Subtropical Florida	Bald cypress, eucalyptus, mulberry, oak, palm, palmetto, pine	Bahia, Bermuda, dallisgrass, Johnson,	Baccharis, goosefoots, pigweed, short ragweed

Adapted from Weber.[10]

ragweed, and maple as well as the morphologically complex flowers of orchids and sunflowers. Examples of these flowering structures are depicted in Figure 1, *C*, *D*, *E*, *F*, and *G*. All flowering plants produce pollen and ovaries although there is a large array of variability in how this is achieved. For example, tulip, poppy, orchid, and magnolia flowers include all the reproductive and accessory parts in one flower called a "perfect" flower. These parts are arranged in concentric whorls. The outermost are the sepals, inside these are the petals, next is a whorl of stamens, and in the center are 1 or more carpels containing the ovaries and stigmas. The stamens produce pollen, and the stigmas receive pollen through a deposition process.

In contrast, other angiosperms have separate male and female flowers containing only stamens or carpels, respectively. These are known as "imperfect" (and incomplete) flowers. Staminate and carpellate flowers may occur on the same plant, which is called monoecious, or on separate plants, which are known as dioecious. Among wind-pollinated plants, petals and sepals usually are vestigial or absent, and many species are monoecious. Showy perfect flowers are almost always entomophilous (Figure 1), whereas imperfect, and inconspicuous flowers like grasses (Figure 1) and ragweed are typically anemophilous.

In many anemophilous plants, the flowers occur in inflorescences (clusters of small flowers) rather than as solitary flowers. There are many different types of inflorescences, based on the arrangement of the flowers in the cluster. Many wind-pollinated trees including oaks, birches, and mulberries produce male catkins; each catkin is a long, slender inflorescence of staminate flowers (Figure 1, *C*). A list of anemophilous plants and common aeroallergens is presented in Table I. Most anemophilous plants produce large quantities of pollen grains; for example, an elm tree can produce roughly 1 billion pollen grains and an oak tree 500 billion.[1] Most pollen released from these plants falls in proximity to the source, with estimates of 90% deposited from less than 100 m to 2.7 km.[9] The remaining percent can become entrained in the turbulent layer of the atmosphere and travel from hundreds to thousands of kilometers under certain meteorological conditions. A few known examples of long distance transport of relevant aeroallergens include mountain cedar pollen in North America,[2-4,8] birch pollen in northern Europe,[5] and ragweed pollen in various parts of eastern and central Europe.[6,7] In fact, a recent molecular detection study has tracked mountain cedar (*Juniperus ashei*) pollen from Texas into London, Ontario, in Canada.[8]

Although there are some exceptions, allergenic plants tend to be anemophilous (Table I), whereas most entomophilous plants are not a risk at the community level. So, a general rule of thumb for landscaping is to use plants with showy, insect-pollinated flowers. However, allergic sensitization and symptoms are a matter of whether or not exposure occurs. Induction of pollen allergen symptoms has the further consideration of exposure to cross-reactive allergens. Pollen-allergic subjects can suffer symptoms from allergens specific for a plant to which they have become sensitized. In other cases, specific IgE can cross-react to homologous proteins produced by other taxonomically related and even distant species. Examples of cross-reactive allergens produced by plants have been reviewed by Ferreira et al[11] and Weber.[12] Polcalcins illustrate the potential breadth of this.[13] From different parts of the plant kingdom, homologous allergens from alder and ragweed (families in different orders) and from juniper and olive cross-react (classes in different

TABLE II. A selection of insect-pollinated trees, deciduous shrubs, and herbaceous perennials commonly used in the US landscape industry*

Type	Species	Common name	Family	Hardiness zone†
Tree	*Amelanchier arborea*	Down Serviceberry	Rosaceae	4-9
	Cercis canadensis	Eastern redbud	Fabaceae	4-8
	Chionanthus virginicus	Fringe tree	Oleaceae	3-9
	Cornus florida	Flowering dogwood	Cornaceae	5-9
	Crataegus phaenopyrum	Washington hawthorn	Rosaceae	3-8
	Diospyros virginiana	Persimmon	Ebenaceae	4-9
	Ilex opaca	American holly	Aquifoliaceae	5-9
	Kalmia latifolia	Mountain laurel	Ericaceae	4-9
	Liriodendron tulipifera	Tulip	Magnoliaceae	4-9
	Magnolia × soulangeana	Saucer magnolia	Magnoliaceae	4-9
	Sassafras albidum	Common sassafras	Lauraceae	4-9
	Sophora japonica	Japanese Pagoda	Fabaceae	4-8
Deciduous shrubs	*Aesculus parviflora*	Bottlebrush Buckeye	Sapindaceae	4-8
	Hydrangea arborescens	Smooth hydrangea	Hydrangeaceae	3-9
	Ilex verticillata	Winterberry	Aquifoliaceae	3-9
	Spiraea × bumalda	Bumald Spirea	Rosaceae	4-8
	Viburnum × burkwoodii	Burkwood viburnum	Adoxaceae	5-8
Herbaceous perennial	*Amsonia tabernaemontanta*	Bluestar	Apocynaceae	3-9
	Asclepias tuberosa	Butterfly weed	Apocynaceae	3-9
	Aster tataricus	Tartarian aster	Asteraceae	3-9
	Baptisia australis	Blue false indigo	Fabaceae	3-9
	Boltonia asteroides	False aster	Asteraceae	3-10
	Coreopsis verticillata	Threadleaf coreopsis	Asteraceae	3-9
	Echinacea purpura	Purple coneflower	Asteraceae	3-8
	Helleborus orientalis	Lenten rose	Ranunculaceae	4-9
	Heuchera micrantha var. *diversifolia* "Palace Purple"	Coral bells	Saxifragaceae	4-9
	Lobelia cardinalis	Cardinal flower	Campanulaceae	3-9
	Penstemon digitalis	Beardtongue	Plantaginaceae	3-8
	Phlox divaricate	Wild sweet William	Polemoniaceae	3-8
	Polygonatum odoratum var. *pluriflorum*	Solomon's seal	Asparagaceae	3-8
	Rudbeckia fulgida var. *sullivantii* "Goldstrum"	Black-eyed Susan	Asteraceae	3-9
	Sedum ternatum	Three-leaved stonecrop	Crassulaceae	4-8
	Symphyotrichum novae-angliae	New England aster	Asteraceae	4-8

*This list presents candidate nonallergenic plants that can grow within a broad range of hardiness zones. This list was adapted from several online and peer-reviewed sources[14,17-21] and is intended to be a guide of candidate plants that could be used in the design of a nonallergenic plant landscape.
†Reference to plant hardiness zones presented by the United States Department of Agriculture, Agricultural Research Service.[15]

phyla/divisions). Much information has appeared recently and continues to appear on this topic. In addition to using plants with showy, insect-pollinated flowers, a patient's allergen reactivity profile and potential sources of cross-reactivity should be considered.

LOW-ALLERGENIC PLANTS

Selection of low-allergenic plants for landscaping

Selecting plants for landscaping can be a challenging task. Lists of recommended plants are included in gardening magazines and for every category or planting. There are recommended lists for ground covers, annual and perennial flowers, trees, shrubs, and turf grass species, sometimes considering particular purposes, for example, swimming pool plantings and landscaping. These lists are driven by popularity and influenced by what is new and available at garden centers. However, considerations about hardiness and floristic zones are important parameters in the selection of the most appropriate landscape plants for a particular location. Climate gradients and microclimates exist in particular zones, and often the same botanical species grow in different geographic locations under natural conditions.[14] The United States Department of Agriculture, Agricultural Research Service has published a selection of plant hardiness zone maps that date back to 1960 and are freely available online to the public.[15] In addition, anthropogenic alterations associated with landscaping are important elements to consider when designing a low-allergenic landscape. Regardless of whether or not plants are allergenic or can grow within a particular hardiness or floristic zone, those considered invasive or toxic should not be planted. The United States Department of Agriculture has prepared a list of noxious plants,[16] which should be used as a reference for plants to avoid.

In addition to the aesthetic value of candidate plant species and the general landscape design, the allergic patient should evaluate plants for reduced allergenicity. Because of the climatic

ARTICLE IN PRESS

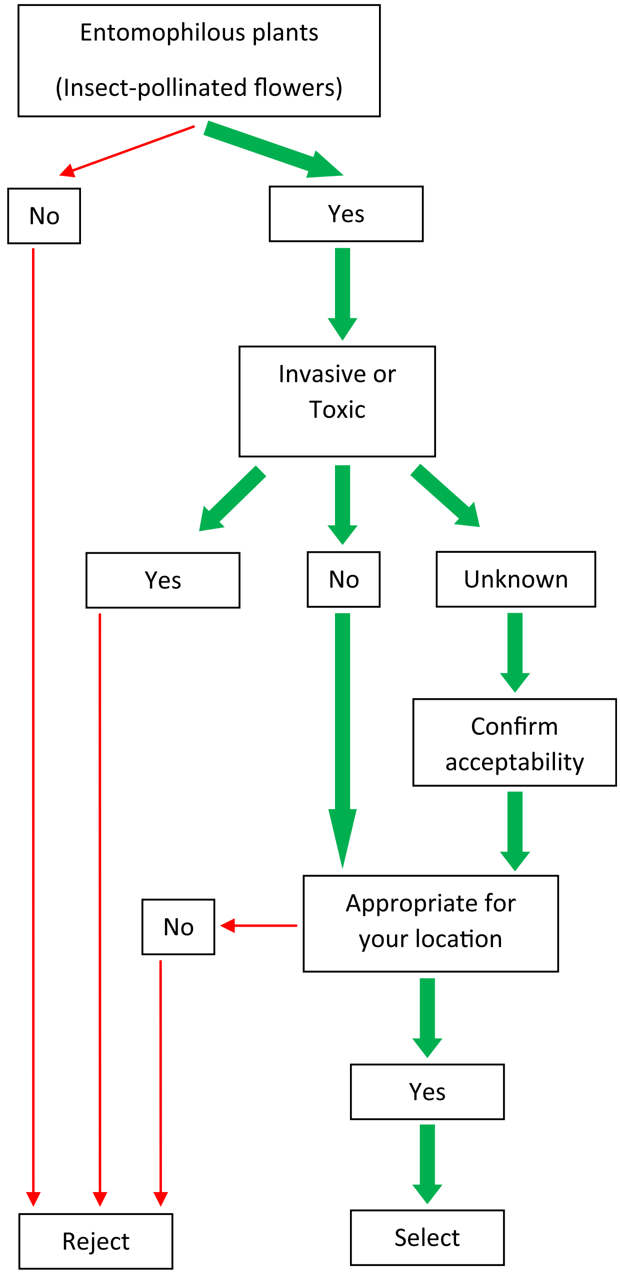

FIGURE 2. Algorithm for the selection of low-allergenic landscaping plants.

and biologic diversity within the continental United States, specific recommendations are beyond the scope of this article. Instead, a brief list of low-allergenic plants often recommended is provided in Table II (written communication, D.L. Edwards, PhD, 2015).[22] If a desired plant is not given within Table II, it could still be vetted in the same fashion to determine its suitability for the intended location. To assist the clinician and patient to make such a selection, the workgroup proposes the algorithm shown in Figure 2 to facilitate the plant selection process. As part of the selection process, known allergenic plants should not be planted, especially if the individual is sensitized to them, as determined by *in vivo* and/or *in vitro* tests.[17,23-25]

A combination of native and ornamental anemophilous species typically make up the vegetation profiles of urban environments.[26,27] In many cities, the selection of uniform species and dioecious male trees has eliminated fruit and litter production. This approach has resulted in homogeneous pollen profiles with a high community prevalence of allergy.[1] In the United States, examples of common anemophilous trees planted in urban environments include maples (*Acer rubrum* and *A saccharum*), American sweetgum (*Liquidambar styraciflua*), pine (*Pinus taeda* and *P ponderosa*), beech (*Fagus grandifolia*), aspens and poplars (*Populus* species), Douglas-fir and fir (*Pseudotsuga menziesii* and *Abies balsamea*), white oak (*Quercus alba*), and sycamore (*Platanus* species).

The selection and design phases of a low-allergenic plant landscape should avoid anemophilous species, as shown in the algorithm presented in Figure 2. Minimizing personal pollen exposure to allergenic plant species should also be a major aim to select appropriate plants in a landscape setting. However, eliminating seasonal pollen exposure is not completely feasible and can present some landscape design challenges. Although removal of anemophilous species from an existing landscape should ultimately reduce but not eliminate pollen exposure, this option is not always possible due to cost-benefit considerations. Although the removal of existing anemophilous species should reduce the immediate pollen load, pollen sources from surrounding areas cannot be eliminated. Reducing the pollen concentration in the immediate vicinity to the level of the regional background would likely reduce allergic symptoms in sensitized subjects. Other challenges may arise depending on the sensitization profile of the patient. Individuals sensitized to grass species may need to evaluate other low-allergenic plant species or hardscaping alternatives. The selection of alternate species also depends on geographic, meteorological, and soil-related variables that determine the ability of a species to grow at a specific site, as described in the preceding section.

A low-allergenic landscape should ultimately consist of entomophilous plant species. Examples of common entomophilous plants in the United States are presented in Table II and include the flowering dogwood (*Cornus florida*), various magnolias (*Magnolia* species), and the tulip poplar (*Liriodendron tulipifera*). Entomophilous species can be mistakenly identified as causes of allergic rhinoconjunctivitis due to the emergence of their flowers at the same time and location as anemophilous allergenic species such as goldenrod intermixed with ragweed.[28] Selection of female plants from dioecious species can reduce the pollen burden further in a landscaped environment but could result in the production of unwanted fruits and/or seeds. Selecting a broad diversity of plant species not known to cross-react may also be a strategy to reduce the pollen burden for a low-allergenic landscape. Using this plant selection approach could have occupational health implications and reduce work-related pollen exposures for landscape and arborist workers.

The preliminary landscape design phase should consist of the selection of entomophilous species with no documented history of allergy, if possible. However, this approximation may be challenging because the allergenicity for many pollen species has not been studied, and allergen extracts have not been prepared or tested on patients. For example, allergic sensitization to Indian bean (*Catalpa speciose*)[29] and horse chestnut (*Aesculus hippocastanum*)[30] demonstrate that allergen cross-reactivity can occur among entomophilous species. The suggestion that allergen cross-reactivity is a relevant selection factor requires further evaluation as proposed for horse chestnut.[30] Understanding the taxonomic and phylogenetic relationships of various plant species is critical for the selection of a low-allergenic landscape.[12]

To avoid selecting plant species that could exacerbate seasonal allergies in individuals sensitized to them, the following selection criteria/guidelines should be considered during the design stages of a low-allergenic landscape.

- Eliminate existing anemophilous species from your landscape if possible.
- Reduce grass pollen exposure and consider placement of shrubs or hardscaping. Grass allergens may also become aerosolized in the absence of pollen with mowing, in combination or not with rainfall episodes.
- Select a broad diversity of entomophilous, low-allergen producing species with little seasonal pollen production.
- Consider planting female plants derived from dioecious species.
- Ensure that selected species do not cross-react with other characterized allergenic plant species to the best possible extent.
- Select noninvasive plant species capable of growing in the specific geographic area.

OTHER BIOLOGICAL HAZARDS

In addition to pollen exposures, the gardener or landscape worker may encounter other biological hazards. A few examples include insect stings, exposure to microbial bioaerosols, and other plant-derived products (eg, trichomes, sap, bark, and leaves). Exposure to these other hazards may result in coexacerbations of allergy symptoms and other adverse health effects. Awareness of these hazards may assist in the development of avoidance programs when working in a low-allergenic landscape.

Many of the plants listed in Table II are insect pollinated. Flowers produced by these species attract various insects that forage for pollen and nectar. Flying stinging insects from the order Hymenoptera (bees, wasps, yellow jackets, and hornets) may increase in frequency during flowering intervals and present opportunities for the gardener or landscape worker to be stung. Insect stings can cause adverse health effects ranging from large local allergic reaction[31,32] to anaphylaxis.[32,33] The preventative steps that can be taken to minimize exposure to stinging insects include wearing protective clothing such as long sleeves, hat, safety glasses, and gloves. If there is a risk of a systemic allergic reaction, self-injectable epinephrine should be carried at all times.[33] Allergy/immunology evaluation and prescribing of venom immunotherapy for patients with IgE-mediated (anaphylactic) potential to hymenoptera venom should also be considered.

Handling plants that contain thorns, spines, glochids, trichomes, and sharp-edged leaves can result in skin injuries (scratches, lacerations).[34] These can occur when handling plants without protective equipment. In most cases, the individual resolves these injuries; however, it may result in infection by pathogenic microorganisms such as the dimorphic fungal pathogen, *Sporothrix schenckii*,[35,36] that can grow on sphagnum moss[36] or thorned plants.[37] Leaves and flowering structures of trees such as the London Plane tree (*Platanus acerifolia*) also produce microscopic leaf hairs called trichomes that can detach and aerosolize following disturbance. Inhalation of trichomes may result in upper respiratory tract irritation.[38,39]

Plants can produce products that can lead to various forms of dermatitis following cutaneous exposure. For example, stinging nettle (*Urtica*), poison ivy (*Toxicodendron radicans*), and other urushiol-producing species such as poison oak (*T diversilobum* or *T pubescens*) and poison sumac (*T vernix*) are representative examples.[40] In addition to *Toxicodendron* species, more than 180 species included in the Asteraceae family have been reported to cause allergic contact dermatitis following cutaneous exposure.[40,41] Examples include Chrysanthemum (*Chrysanthemum* species), Dahlia (*Dahlia* species), and several weed species, including ragweed.[42] Plants in the Apiaceae family are also frequent sources of furocoumarins and causal agents of phytophotodermatitis. Gardeners and landscapers in direct contact with plants that produce these products are at highest risk for developing allergic dermatitis. Fisher's Contact Dermatitis (6th edition) is a helpful resource that reviews and lists plant species known to cause dermatitis.[43]

Personal exposure to microorganisms that colonize dried leaves, mulch, wood chips, and compost may also be encountered, often in high concentrations during disturbance events such as shoveling or raking mulch or woodchips. Similarly, workers can be exposed to arthropods such as the red spider mite (*Tetranychus urticae*) and other parasites of plants cultivated in occupational settings (greenhouses and farms). These exposures can exacerbate preexisting adverse health conditions including allergic sensitization,[44] asthma and hypersensitivity pneumonitis,[45,46] work-related cough symptoms as well as decreases in work-shift lung function.[42] Additional botanically derived allergens such as grass pollen[47] and respirable particles containing grass allergen[48] may also disperse into the environment following disturbance. For example, Rowe et al[47] showed that lawn mowing resulted in increased nasal and ocular symptoms in patients with high serum concentrations of total IgE and specific IgE to grass pollens but not fungi or grass leaf extract. It was hypothesized that grass pollen settles within the lawn and becomes airborne again during mowing activities.[47] In a subsequent study, grass allergen concentrations increased 8-fold during mowing activities and quickly decreased following the completion of this activity.[49]

Health and safety precautions used in the landscape industry can be used by gardeners, landscapers, and arborists to reduce or eliminate exposure to these other biological hazards. There are several helpful resources available from the United States Occupational Safety and Health Administration[50] and the Canadian Centre for Occupational Health and Safety.[51] Precautionary steps to minimize exposure to these agents include the following:

- Wear protective clothing and equipment including long-sleeved shirts, long pants, gloves, and head and eye protection.
- Apply insect repellent to prevent insect exposure and stings.
- Wear respiratory protection during disturbance activities such as digging soil, distributing mulch or compost, and mowing.
- Carry self-injectable epinephrine for those susceptible to anaphylaxis following an insect sting.
- Be aware of the season and potential exposure to pollen from neighboring areas.
- Remove poison ivy (*Toxicodendron radicans*) or other plants identified to cause skin injuries and toxic reactions.

- Landscaping employers should educate workers about pollen exposure and other biological hazards.

CONCLUSIONS AND RECOMMENDATIONS FOR THE CLINICIAN

This article described the basic biology of plants and the main principles that should be considered in designing a low-allergenic landscape, including the selection of entomophilous plants instead of anemophilous plants. These basic plant biology concepts can guide us to safer plant selections.

Many allergenic plants are already characterized with numerous references appearing in the scientific literature. These plants should be avoided when designing landscapes. However, it is difficult to avoid pollen entirely because under ideal circumstances, pollen may eventually be dispersed for hundreds or thousands of miles from their sources. Therefore, total avoidance in the landscape environment of the patient is not possible. Rather, the use of known low-allergenic entomophilous plants (Table II) is recommended whenever possible. The algorithm in Figure 2 guides the selection of plants on a general basis using the basic information contained in this article augmented with the knowledge of plants that are suitable for the specific location. This article also provides selection criteria and guidelines when designing a low-allergenic landscape. Once it is determined what plants are generally safe to grow, then reasonable decisions can be made as to what plants to use in the patient's landscape to minimize the likelihood of provoking allergic reactions. Although a completely allergy-free garden space outdoors is unrealistic, a reduced allergen or low-allergen landscape is feasible to design using the information and principles described in this article. Allergic patients should work closely with their local allergist who would determine specific clinical sensitization to outdoor allergens by *in vivo* and/or *in vitro* tests. Knowing the outdoor allergens that sensitize individuals along with the information provided in this reference article will assist the clinician in providing patients with useful recommendations to design their landscapes.

Acknowledgements

We thank Mr Jerome Schultz, AAAAI project manager, for his assistance in coordinating the completion of this article. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

REFERENCES

1. Molina RT, Rodríguez AM, Palaciso IS, López FG. Pollen production in anemophilous trees. Grana 1996;35:38-46.
2. Levetin E, Buck P. Evidence of mountain cedar pollen in Tulsa. Ann Allergy 1986;56:295-9.
3. Rogers CA, Levetin E. Evidence of long-distance transport of mountain cedar pollen into Tulsa, Oklahoma. Int J Biometeorol 1998;42:65-72.
4. Levetin E, Van de Water PK. Pollen count forecasting. Immunol Allergy Clin North Am 2003;23:423-42.
5. Wallin J-E, Segerström U, Rosenhall L, Bergmann E, Hjelmroos M. Allergic symptoms caused by long-distance transported birch pollen. Grana 1991;30:265-8.
6. Lorenzo C, Marco M, Paola DM, Alfonso C, Marzia O, Simone O. Long distance transport of ragweed pollen as a potential cause of allergy in central Italy. Ann Allergy Asthma Immunol 2006;96:86-91.
7. Šikoparija B, Skjøth C, Kübler KA, Dahl A, Sommer J, Radišić P, et al. A mechanism for long distance transport of Ambrosia pollen from the Pannonian Plain. Agr Forest Meteorol 2013;180:112-7.
8. Mohanty RP, Buchheim MA, Anderson J, Levetin E. Molecular analysis confirms the long-distance transport of *Juniperus ashei* pollen. PLoS One 2017;12:e0173465.
9. Traverse A. Paleopalynology. Boston, Mass: Unwin Hyman; 1988.
10. Weber RW. Floristic zones and aeroallergen diversity. Immunol Allergy Clin North Am 2003;23:357-69.
11. Ferreira F, Hawranek T, Gruber P, Wopfner N, Mari A. Allergic cross-reactivity: from gene to the clinic. Allergy 2004;59:243-67.
12. Weber RW. Patterns of pollen cross-allergenicity. J Allergy Clin Immunol 2003;112:229-39.
13. Kleine-Tebbe J, Jakob T. Molecular allergy diagnostics: innovation for a better patient management. Cham, Switzerland: Springer; 2017.
14. Bridwell FM. Landscape plants: their identification, culture and use. College Park, Md: Delmar Publishers; 1994.
15. United States Department of Agriculture, Agricultural Research Service. Plant hardiness zone map; 2012. Available from: http://planthardiness.ars.usda.gov/PHZMWeb/. Accessed January 30, 2017.
16. Federal noxious weed list; 2016. Available from: https://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/weedlist.pdf. Accessed January 30, 2017.
17. Lewis WH, Vinay P, Zenger VE. Airborne and allergenic pollen of North America. Baltimore, Md: Johns Hopkins University Press; 1983.
18. Missouri Botanical Garden. Plant finder; 2017. Available from: http://www.missouribotanicalgarden.org/plantfinder/plantfindersearch.aspx. Accessed February 27, 2017.
19. Perennial encyclopedia from Walters Gardens, Inc; 2017. Available from: http://www.perennialresource.com/encyclopedia/2017. Accessed February 27, 2017.
20. Cronquist A. Vascular flora of the southeastern United States. Asteraceae: UNC Press Books; 2001.
21. Gleason HA, Cronquist A. Manual of vascular plants of northeastern United States and adjacent Canada. New York, NY: van Nostrand; 1963.
22. Barrick WE, American Horticultural Society. American Horticultural Society 75 great American garden plants. Birmingham, AL: Oxmoor House; 1998.
23. Jelks M. Allergy plants. Tampa, Fla: World-Wide Printing; 1986.
24. Solomon W, Mathews K. Aerobiology and inhalant allergens. In: Allergy: principles and practice. St Louis: Mosby Co; 1998. p. 367-403.
25. White JF, Bernstein DI. Key pollen allergens in North America. Ann Allergy Asthma Immunol 2003;91:425-35.
26. Levetin E, Buck P. Non-allergenic native and cultivated plants in Oklahoma: landscaping without hay fever. Ann Allergy 1984;52:166-71.
27. Cariñanos P, Casares-Porcel M. Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. Landsc Urban Plan 2011;101:205-14.
28. Bass DJ, Delpech V, Beard J, Bass P, Walls RS. Late summer and fall (March-May) pollen allergy and respiratory disease in Northern New South Wales, Australia. Ann Allergy Asthma Immunol 2000;85:374-81.
29. Swineford O. Catalpa as a cause of hay fever. J Allergy 1940;11:398-401.
30. Popp W, Horak F, Jager S, Reiser K, Wagner C, Zwick H. Horse chestnut (*Aesculus hippocastanum*) pollen: a frequent cause of allergic sensitization in urban children. Allergy 1992;47:380-3.
31. Antonicelli L, Bilo MB, Bonifazi F. Epidemiology of Hymenoptera allergy. Curr Opin Allergy Clin Immunol 2002;2:341-6.
32. Pesek RD, Lockey RF. Management of insect sting hypersensitivity: an update. Allergy Asthma Immunol Res 2013;5:129-37.
33. Tankersley MS, Ledford DK. Stinging insect allergy: state of the art. J Allergy Clin Immunol Pract 2015;3:315-22.
34. Modi GM, Doherty CB, Katta R, Orengo IF. Irritant contact dermatitis from plants. Dermatitis 2009;20:63-78.
35. Conias S, Wilson P. Epidemic cutaneous sporotrichosis: report of 16 cases in Queensland due to mouldy hay. Australas J Dermatol 1998;39:34-7.
36. Hajjeh R, McDonnell S, Reef S, Licitra C, Hankins M, Toth B, et al. Outbreak of sporotrichosis among tree nursery workers. J Infect Dis 1997;176:499-504.
37. Flournoy DJ, Mullins JB, McNeal RJ. Isolation of fungi from rose bush thorns. J Okla State Med Assoc 2000;93:271-4.
38. Ross AF, Mitchell JC. Respiratory irritation by leaf hair of the tree *Platanus*. Ann Allergy 1974;32:94-7.
39. Sercombe JK, Green BJ, Rimmer J, Burton PK, Katelaris CH, Tovey ER. London Plane Tree bioaerosol exposure and allergic sensitization in Sydney, Australia. Ann Allergy Asthma Immunol 2011;107:493-500.
40. Stoner JG, Rasmussen JE. Plant dermatitis. J Am Acad Dermatol 1983;9:1-15.
41. Jovanovic M, Poljacki M. Compositae dermatitis. Med Pregl 2003;56:43-9.

42. Heldal KK, Madso L, Eduard W. Airway inflammation among compost workers exposed to actinomycetes spores. Ann Agric Environ Med 2015;22:253-8.
43. Rietschel RL, Fowler JF, Fisher AA. Fisher's contact dermatitis. Hamilton, ON: BC Decker; 2008.
44. Kronqvist M, Johansson E, Kolmodin-Hedman B, Oman H, Svartengren M, van Hage-Hamsten M. IgE-sensitization to predatory mites and respiratory symptoms in Swedish greenhouse workers. Allergy 2005;60:521-6.
45. Michael L, Hatton N. Hypersensitivity pneumonitis in a gardener masquerading as sarcoidosis, caused by *Phanerochaete chrysosporium*. Chest 2011;140:157A-A.
46. Weber S, Kullman G, Petsonk E, Jones WG, Olenchock S, Sorenson W, et al. Organic dust exposures from compost handling: case presentation and respiratory exposure assessment. Am J Ind Med 1993;24:365-74.
47. Rowe MS, Bailey J, Ownby DR. Evaluation of the cause of nasal and ocular symptoms associated with lawn mowing. J Allergy Clin Immunol 1986;77:714-9.
48. Taylor PE, Jonsson H. Thunderstorm asthma. Curr Allergy Asthma Rep 2004;4:409-13.
49. Kernerman SM, McCullough J, Ownby DR. Increased concentrations of airborne grass allergen during lawn mowing. J Allergy Clin Immunol 1992;90:131-3.
50. United States Department of Labor. OSHA Safety and health topics: Landscape and Horticultural Services. Available from: http://www.osha.gov/SLTC/landscaping/index.html. Accessed January 30, 2017.
51. Canadian Centre for Occupational Safety and Health. Available from: http://www.ccohs.ca/oshanswers/safety_haz/landscaping/general.html. Accessed February 17, 2017.