Dry lime-sulfur is made by adding a stabilizer such as cane sugar to liquid lime-sulfur and evaporating to dryness. Self-boiled lime-sulfur is made by utilizing the heat of hydration or slaking of quicklime, CaO, to carry on the reactions with sulfur.

Ammonium polysulfide and sodium polysulfide are made by passing hydrogen sulfide gas, H_2S, into ammonium or sodium hydroxide containing excess sulfur. It is supposed that the chemical reactions are similar to those taking place in the preparation of lime-sulfur.

Sulfur is used under some conditions for the control of potato leafhopper, the cotton fleahopper, tomato psyllid, mites, and plant bugs.

Organic sulfur compounds, including thiocyanates, xanthates, and thiuram disulfides, have some insecticidal properties although they are used largely as fungicides.

Sulfur dioxide, SO_2, made by burning sulfur, is sometimes used to kill insects in closed spaces.

Thallium sulfate, Tl_2SO_4, sometimes is used as the toxic agent in ant poisons.

Several zinc compounds are in limited use as insecticides. Zinc sulfate, $ZnSO_4$, is sometimes used in place of copper sulfate in reactions with hydrated lime to form a zinc bordeaux mixture that has special uses. Zinc chloride, $ZnCl_2$, is used to protect against termites.

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Insecticides From Plants

Louis Feinstein

More than 2,000 species of plants are said to have some value as insect killers. They belong to 170-odd families. Commercial insecticides of plant origin are found in five families: Nicotine in the Solanaceae family; pyrethrum in Compositae; derris, cube, and timbo in Leguminosae; hellebore in Liliaceae; and anabasine in Chenopodiaceae. Anabasine is also found in Solanaceae.

Who first discovered the insecticidal value of plants is not known. The Romans divided poisons into three groups, animal, plant, and mineral. They used two species of false hellebore in medicines and in rat and mice powders and insecticides. The Chinese discovered the insecticidal value of derris.

Chemists in the Bureau of Entomology and Plant Quarantine since 1927 have conducted research on the principal insecticides of plant origin, such as nicotine, nornicotine, anabasine, rotenone, deguelin and related rotenoids, quassin, and the pyrethrins. They also have worked on more than 450 plants in an effort to discover new sources of these and other insecticides, as well as attractants, repellents, and adjuvants. They have learned that many of the species in the 170 families do not warrant further investigation and that botanical classification is not a dependable guide in the search for insecticidal plants.

Plant insecticides are only a small fraction of the insecticidal material used each year. Yet in the development of new insecticides they deserve careful consideration: Often they are highly effective against many insect enemies that are not successfully controlled by inorganic insecticides. The plant insecticides often are relatively nontoxic to

man and other plants. Poisonous spray residues on fruits and vegetables may menace public health. The relative safety of plant insecticides to man helps to maintain their continued use.

In this article I discuss the commercial plant insecticides and other plants that appear promising as insecticides. Included here are plants only of the higher orders (phanerogams). They are listed alphabetically according to plant family and genus. The plants are sufficiently promising to warrant intensive chemical and toxicological studies.

The lower orders of plants (cryptogams) include the algae, fungi, mosses, ferns, and horsetails. A more complete study of them may also prove to be worth while.

Aesculaceae (*Horsechestnut Family*). *Aesculus californica* is called the California buckeye. The horsechestnut is a highly prized street and lawn shrub and tree. The common horsechestnut casts the densest shade of almost any cultivated tree. George H. Vansell and his coworkers in California found that bees feeding on buckeye blossoms became paralyzed and died. Reports of other investigators, however, show that the insecticidal value of species of the horsechestnut family varies.

Annonaceae (*Custard-Apple Family*). The genus *Annona* includes some 90 species of trees and shrubs, mainly in tropical America. S. H. Harper, C. Potter, and E. M. Gillham in England extracted *Annona reticulata* and *A. squamosa* seeds and roots with ether. The petroleum ether solution of this extract at 0° C. precipitated out an insecticidal material that was 50 to 100 times more potent than the original ether extract. Against some insects the concentrate had about the same toxicity as rotenone. More work should be done with the custard-apple.

Apocynaceae (*Dogbane Family*). *Haplophyton cimicidum,* the cockroach plant, has been used to combat cockroaches, flies, mosquitoes, fleas, lice, and other insects in Mexico. The dried leaves are toxic to the Mexican fruit fly. The water extract of the stems of plants grown in Arizona is toxic to adult house flies. The crude alkaloid from this plant is effective against most insects. It is as toxic as pyrethrum to the squash bug.

Boraginaceae (*Borage Family*). *Heliotropium peruvianum.* The borage family contains many well-known garden plants and often is called the heliotrope family. The compound heliotropine was one of the best chemicals tested against the body louse, being apparently nontoxic to the skin and lasting more than 168 hours when used in cocoa butter.

Tournefortia hirsutissima is used as a general insecticide in Haiti.

Cannaceae (*Canna Family*). Members of this family mostly have tuberous rootstocks, stately, broad leaves, and showy flowers. The leaves and stems of canna plants contain an insecticide that gives results similar to tobacco in greenhouse fumigation.

Celastraceae (*Staff-Tree Family*). *Tripterygium wilfordii,* the thunder-god vine, is a common insecticidal plant in southern China. The poison in it has been found in the root bark. Its chemistry has been investigated by M. Beroza, who reported that wilfordine is a mixture composed mainly of two similar alkaloids, α- and β-wilfordine. Both are insecticidally active ester alkaloids. Powdered fresh small roots are toxic to first-stage larvae of the codling moth, the diamondback moth, and the imported cabbageworm. Alcoholic extracts of the roots are more toxic. Small roots, powdered, are about half as toxic as pyrethrum to the American cockroach. The large and medium roots are nontoxic.

Chenopodiaceae (*Goosefoot Family*). *Anabasis aphylla* contains the alkaloid anabasine, closely related to nicotine. It is the only commercial source for the alkaloid. It grows mainly in Russia and is not available in the United States. *Anabasis aphylla* is related to the American tumbleweed. In this country my coworkers and I extracted anabasine from *Nicotiana glauca.*

Clusiaceae (*Balsam Tree Family*). *Mammea americana* is known as mamey, "mamey de Santo Domingo." Harold K. Plank of the Federal Experiment Station at Mayaguez, P. R., believes that this indigenous West Indian tree has greater insecticidal potentialities than any other plant he examined. The active principle in the mature seeds, the most toxic part, is a type of substance somewhat similar in composition and effect to pyrethrins. Plank found that six of the nine parts of the plant were appreciably or highly toxic to one or more insects. The bark has little toxic material.

Cochlospermaceae. Cochlospermum gossypium. Kutira gum increases the effectiveness of nicotine sulfate sprays. The kutira appears to be a synergist to nicotine sulfate in its action against the bean aphid.

Compositae (*Thistle or Aster Family*). This large family of plants includes thousands of herbs, vines, trees, and shrubs. The dahlia, chrysanthemum, coreopsis, marigold, aster, cosmos, and many other garden flowers are composites. To the dried flowers of *Chrysanthemum cinerariaefolium* the name pyrethrum is applied. Pyrethrum, a safe and effective insecticide, is widely used in household sprays. Four compounds exist in pyrethrum—pyrethrins I and II and cinerins I and II. Pyrethrins are practically nontoxic to warm-blooded animals and can be safely used in the home.

Heliopsis scabra is called oxeye. M. Jacobson, at the Agricultural Research Center, discovered that these plants contain compounds toxic to the house fly. Nearly all the toxic material is extracted by petroleum ether. Jacobson purified the petroleum ether extract and named one of the toxic materials scabrin. W. A. Gersdorff and N. Mitlin, entomologists in the Department of Agriculture, reported that scabrin compares well with pyrethrum in killing value.

Cucurbitaceae (*Gourd Family*). The cucumber family is often called the gourd, melon, or squash family. *Cucurbita pepo* commonly is called pumpkin. Freshly cut pumpkin leaves rubbed on cattle and horses reputedly repel flies. Acetone extracts of pumpkin seeds killed mosquito larvae in experiments conducted by A. Hartzell and F. Wilcoxon of Boyce Thompson Institute.

Euphorbiaceae (*Spurge Family*). *Croton tiglium* contains croton oil. The plant is cultivated in China, where the seeds are the source of a homemade insecticide. The plant has insecticidal value against aphids. J. R. Spies, a chemist in the Department of Agriculture, reported that an acetone extract of the seeds was more toxic to goldfish than derris extract and that croton resin was more toxic than rotenone.

Ricinus communis, the castor-bean plant, is said to have some insecticidal value. If that is true, the insecticidal principle is present only under certain conditions with respect to variety, cultural practice, and environment. A valuable synergist is prepared from isobutylamine and undecylenic acid, which results from the chemical decomposition by heat of castor oil. By the action of sulfuric acid on castor oil, we get a useful emulsifier for insecticidal oils.

Flacourtiaceae. Ryania speciosa. The active principles of the plant are alkaloids and are effective in the control of the European corn borer. The roots and stems contain the insecticide, which is commercially prepared for use as dusts and sprays.

Fagaceae (*Beech Family*). *Castanea dentata* is called the American chestnut. F. W. Metzger and D. H. Grant found that a commercial dyeing and tanning extract of the American chestnut was a good repellent against the Japanese beetle.

Labiatae (*Mint Family*). *Ocimum basilicum* is known as common basil or sweet basil. Its oil killed 95 percent of the mosquito larvae tested at a concentration of 50 parts per million, but an extract made from the whole plant killed none. H. D. Hively obtained a patent in 1940 for the use of the plant

as an insecticide. It is successful as a contact poison against flies, Colorado potato beetles, and many other insects.

Salvia officinalis, or garden sage. Salvias are grown for their flowers and for their leaves. The leaves of some species are used for seasoning. Hartzell and Wilcoxon found that acetone extracts of the leaves killed 80 percent and extracts of the roots killed 95 percent of the mosquito larvae they tested.

Leguminosae (*Pea Family*). The pea family is one of the most important group of garden plants in the world. *Haematoxylon campechianum* is called logwood. Hematoxylon is from the Greek for blood and wood, in allusion to the red wood. Metzger and Grant reported that two commercial extracts were good repellents against the Japanese beetle.

Millettia pachycarpa, fish-poison climber, is worth further investigation. The ground seeds kill several species of insects. Alcoholic extracts of the roots from China paralyze the bean aphid. The plant contains a large amount of saponin and rotenone. The plant acts as a contact and stomach poison when it is mixed with soap.

Mundulea sericea, or *M. suberosa,* is a promising insecticidal plant. It was discovered in the 1930's. It is a rotenone-yielding species. The plants from India are toxic, but those from various locations in Tanganyika and Zanzibar fall into two main divisions, those with smooth barks, which are toxic, and those with rough, corky barks, which are nontoxic.

Pachyrhizus erosus, or the yam bean. In some tropical countries the seeds of the yam bean plant are used as an insecticide and fish poison. Tests in the United States by R. Hansberry and C. Lee gave promising results against the bean aphid and the Mexican bean beetle.

Tephrosia virginiana is known as devils-shoestring. It is a pretty little native plant, which prefers dry, open, somewhat sandy places. It has long been known to possess insecticidal properties. The most toxic samples of devils-shoestring were slightly more poisonous than pyrethrum, but less poisonous than derris. Against five species of insects the plants showed promise as a contact spray. Technical Bulletin No. 595 of the Department of Agriculture outlines studies of the possibilities of devils-shoestring as a commercial source of insecticides.

Liliaceae (*Lily Family*). The foliage and rootstock of most species contain a poisonous juice. *Amianthium muscaetoxicum,* crowpoison, shows promise as an insecticide against the house fly, cockroaches, grasshoppers, and bees. It is inefficient against tent caterpillars and aphids. The powdered bulbs and leaves are used as dusts. Water extracts show a slow but considerable insecticidal effect against Colorado potato beetle larvae and cockroaches.

Melanthium virginicum, bunchflower. L. H. Pammel in 1911 stated that the bunchflower had long been used to poison flies.

Schoenocaulon officinale is commonly known as sabadilla. R. J. Dicke in a thesis submitted to the University of Wisconsin in 1943 reviewed 76 references on this plant, which has been used as an insecticide since the sixteenth century. The University of Wisconsin has patented a method for increasing the toxicity of sabadilla: Heating the powdered seed in kerosene or other solvent to 150° C. for 1 hour. Sabadilla is effective against squash bugs, chinch bugs, harlequin bugs, and lygus bugs. Scientists in the Department of Agriculture in 1949 began a chemical study of the constituents of sabadilla seed.

Veratrum. Three plants are popularly called hellebore—*Veratrum album, V. viride,* and *Helleborus niger.* The term hellebore is incorrect when it is applied to the first two plants. The last, which is the true hellebore, grows in Europe and is not a commercial product in the United States. *V. viride* is the American plant. Powdered roots of the first two plants prevent the emergence of house flies from horse manure.

Veratrum viride is often called

American false-hellebore, swamp hellebore, Indian poke, and itchweed in the United States. Its active principles are alkaloids, which are toxic to man. Its value as an insecticide for the control of chewing insects on ripening fruit is due to its rapid loss of toxicity on exposure to light and air.

Meliaceae (*Mahogany Family*). *Melia azedarach* is called chinaberry. Water extracts of the berries affect cockroaches slightly but are more toxic against honey bees. Leaves applied to the soil greatly reduce attacks of termites. An alkaline extract of the fruits is effective against aphids. Cultivated plants sprayed with extracts of the chinaberry leaves are not touched by locusts. The active principle is soluble in hot water, alcohol, chloroform, or benzene but not in petroleum ether.

Myrtaceae (*Myrtle Family*). *Pimenta racemosa* is the bay-rum tree. The oil of the leaves is toxic to mosquito larvae. Bay rum has been used in Venezuela to kill insects. A foreign patent covers its use in a mixture of several substances. Applied to summer garments, it protects the wearer against gnats. Effective as baits to attract Japanese beetles are 90 parts of geraniol and 10 parts of the leaf oil of a *Pimenta* species, or 90 parts of anethole and 10 parts of the oil.

Pedaliaceae. Sesamum inducum, sesame. The seeds yield sesame oil, which contains sesamin, a powerful synergist for pyrethrum. In the Second World War the Armed Forces used more than 40 million aerosol bombs containing pyrethrum, liquefied gas, and sesame oil. The later bombs used 8 percent of the oil in the formula. Sesame oil also acts as a synergist for rotenone.

Ranunculaceae (*Crowfoot Family*). *Delphinium consolida* is called field larkspur. The oil from larkspur seed tested as a contact spray (2-percent emulsion) was effective against spider mites and aphids but had little value against some other insects. The alkaloids of this plant were also effective against insects in various degrees.

Rutaceae (*Rue Family*). *Phellodendron amurense,* the Amur corktree, is native to several Asiatic countries and was introduced into the United States in 1856. The unsaponifiable portion of the oil of the fruit is toxic to house flies in acetone solution but not in high-boiling kerosene. The residue of the fruit, the oil having been removed, is toxic to mosquito larvae, house flies, and larvae of codling moth. The material is a fast-acting poison like pyrethrum and nicotine.

Zanthoxylum clavaherculis, the southern prickly-ash, contains asarinin, a compound structurally related to sesamin and, like it, a good synergist for pyrethrum against house flies. The southern prickly-ash also contains herculin, a pungent substance highly toxic to house flies. It is closely related to several other isobutylamides previously isolated from plant materials. A trace of the active material, when placed on the tongue, produces an intense burning, paralytic effect on the tongue and on the mucous membranes of the lips and mouth. Herculin has approximately the same order of paralyzing action and toxicity to house flies as the pyrethrins.

Sapindaceae (*Soapberry Family*). *Sapindus marginatus.* This tree, up to 30 feet high, is native in Florida. It is planted occasionally for interest or ornament. The word sapindus comes from the Latin for soap, combined with Indian, in allusion to the Indians' use of the berries for soap; the pulp lathers easily like soap. S. L. Hoover obtained a patent for the use of the berries of the tree as an insecticide or insectifuge. Three berries protected a bushel of wheat against infestation. In powdered or liquid form and mixed with dried foodstuffs, it repelled weevils and other insects.

Simarubaceae (*Ailanthus or Quassia Family*). This tree stands smoke and city conditions well, but the male flowers have a strong odor, which is offensive to some persons. The bark and wood contain insecticidal principles, which are used on only a few crops.

Solanaceae (Nightshade or Potato Family). The potato family, often called the tobacco or tomato family, includes vegetables of world-wide cultivation, narcotics, drugs, tobacco, and a large number of garden flowers. *Duboisia hopwoodii,* called pituri, is an Australian species and often is mentioned in discussions of nicotine. C. V. Bowen, a chemist in the Department of Agriculture, analyzed the dried leaves and larger stems and found the leaves to contain 3.3 percent and the larger stems 0.5 percent of nornicotine. H. H. Smith and C. R. Smith of the Department studied 29 wild species of *Nicotiana.* They found that 5 species contained the alkaloid nornicotine only and 18 a mixture of nornicotine and nicotine. Against some insects, nornicotine is superior to nicotine. Nornicotine is more toxic to a nasturtium aphid and the pea aphid; about equally toxic to the cabbage aphid, the citrus red mite, and other spider mites; but less toxic to the celery leaf tier, the large milkweed bug, and larvae of codling moth.

Nicandra physalodes is also known as the Peruvian groundcherry or shoofly plant. It repels insects. In India it is used as an insecticide. Stories told about it are many: The plant distributed around a room repels flies; in a greenhouse it causes the whitefly to disappear; a few hundred planted near a barn apparently keep the animals from being bothered by flies.

Physalis mollis is commonly known as smooth groundcherry. Thomas A. Nuttall described it in 1834. It grows throughout Oklahoma. Before the development of prepared fly sprays, the fresh plant was used to control house flies. The bruised leaves and stems, mixed with a little water and sugar, killed flies. L. E. Harris of Ohio State University isolated a glycoside in an impure form; it was toxic to flies. He also isolated an alkaloid, but it was not toxic to flies in the small dosage used.

Nicotiana glauca, tree tobacco, is a wild, fast-growing plant in Texas, Arizona, and California. Patrick J. Hannan and I were granted patents covering two methods useful in extracting the alkaloids from *Nicotiana* species, including the alkaloid anabasine from *Nicotiana glauca.* Anabasine is a liquid alkaloid that closely resembles nicotine in its physical, chemical, toxicological, and insecticidal properties. It has been reported to be four or five times as toxic as nicotine to certain aphids of economic importance.

Nicotiana spp. Tobacco and its chief alkaloid, nicotine, have been used since 1690 as insecticides. Nicotine forms salts with acids and most of the nicotine used for insecticidal purposes in the United States is in the form of the sulfate. More than 29 species of *Nicotiana* have been analyzed for their alkaloid content. Some American tobaccos used in making cigars of low nicotine content contain as much as 0.7 percent of nornicotine. One-eighth of the total alkaloids in certain samples of commercial nicotine sulfate solutions was nornicotine. Most species of aphids may be controlled with concentrations of 1 part nicotine to 1,000 parts of water. Nicotine is recommended against only those insects that have soft bodies and those that are minute in size, such as aphids, whiteflies, leafhoppers, psyllids, thrips, spider mites, and some external parasites on animals.

Stemonaceae. Stemona tuberosa, or paipu, has long been known and used in China as an insecticide. Decoctions of the dried roots are said to be toxic to crickets, weevils, and the caterpillars of moths and butterflies. A 50-percent alcoholic extract of the plant is effective against lice and fleas.

Umbelliferae (Carrot Family). Carum carvi is called caraway and contains oil of caraway, which will help cure scaly-leg of poultry. Hartzell and Wilcoxon found that acetone extracts of the seed killed 90 percent of the mosquito larvae they tested.

Conium maculatum, poison hemlock, contains an alkaloid, coniine, which is related to nicotine.

Coriandum sativum, or coriander, contains an oil that repels screwworms. Applied in a 2-percent oil emulsion spray, it kills spider mites and cotton aphids. Coriander oil repels house flies, green bottle flies (*Lucilia sericata*), and black blow flies.

Pimpinella anisum is anise. Clothing treated with a soapy emulsion of anise oil protects wearers from the sting of gnats. Anise oil repels black blow flies, house flies, and green bottle flies.

Vitaceae (Grape Family). Parthenocissus quinquefolia, or Virginia creeper. An old reference to it states that a bunch of leaves rubbed on an infested area of an apple tree and crushing all the woolly apple aphids, made the tree entirely free of aphids a week later. Formerly the tree could not be kept free of aphids for any length of time.

THE PLANT WORLD contains many interesting and useful insecticides that have not been investigated yet. Only a few have been mentioned here. The entomologists and chemists have passed by many thousands of plants in their search for an insecticide that kills insects but is safe to people and animals.

Once a scientist discovers a plant useful as an insecticide, he must take the plant apart and discover the active principles in it. The discovery is only the first step toward the commercial usefulness of the plant. The next steps take time and effort.

That a plant is poisonous to other animals or is a common weed rarely attacked by insects is not a positive indication of insecticidal properties. The insecticidal principles may be present in one or more of the following parts: Leaves and leaflets, flowers, petioles, seeds and seed hulls, fruits, twigs and stems, roots, bark, and wood.

Often the plant will be insecticidal when it is ground up, but the extract of the material will not be poisonous.

The farmer and the general public share in the discovery and development of new insecticides from plants. Growing new plants for insecticides means new income to the farmer; the public gets farm products that are clean and free from insects and poisonous residues. Since 1947 Department research on plant insecticides covering only six plants—tree tobacco, oxeye, sabadilla, devils-shoestring, thunder-god vine, and sesame—has led to the publication of more than 17 papers and the granting of three public service patents.

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Oil Sprays for Fruit Trees

P. J. Chapman, L. A. Riehl
G. W. Pearce

Petroleum oils are used in several ways to control pests. Some kill insects and mites directly through their own action. Some supplement the action of other insecticides as co-toxicants, solvents and carriers, stickers, or stabilizers.

In the water-borne oil sprays commonly applied to fruit trees, the oil usually is the sole or primary insecticidal agent. That is also true of oils used to rid bodies of water of mosquitoes.

Light petroleum fractions are widely used as solvents and carriers for many insecticides. The original fly sprays are a good example. The introduction of DDT and other organic insecticides has meant a great increase in the use of oil as the carrier for applying insecticides, especially the chemicals used to control household and building pests. These oil-insecticide mixtures usually are applied in the form of fine mists. With heat and a suitable generator they can be applied also as thermal fogs, which remind one of military smoke screens.

Often oils are added to insecticidal and fungicidal spray, dust, and poison-bait formulations as stickers, stabilizers, and conditioning agents.

In this chapter we discuss the water-borne oil sprays as they are used to control pests of citrus and deciduous fruit trees.

Kerosene was apparently the first petroleum product used for the control of plant pests in the United States. A. J. Cook of Michigan State College introduced in 1877 a kerosene-soap emulsion which was widely employed to combat aphids and scale insects.

Entomologists sought something more effective and turned to crude pe-