Desert Plant Chemurgy: A Current Review[1]

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Extractives from, and utilization of, Cactaceae *(cacti),* Liliaceae *(yucca),* Amaryllidaceae *(agaves), and other desert plants are reviewed. Work is reported in the fields of pharmaceuticals with special reference to an antidiabetic factor, cosmetics, cellulose and fibers, stock feeds, plant growth regulators, sterols, oils and oilseeds, surfactants, waxes, and several miscellaneous extractives. Mesquite, ironwood, and catclaw are considered as artists' woods. Possibilities and problems of cultivation are considered.*

Introduction

Research on desert plants during the 1960's has been largely basic in emphasis. Commercial development has been essentially confined to small, individual operations. The author has reviewed the overall field of the xerophytes twice previously (52, 53); this article will review research and development activities taking place in the general field of desert plant chemurgy since the previous summary. Considerable development opportunities still exist, provided adequate economic surveillance is maintained.

Pharmaceuticals

Alkaloids

The current problems of drug abuse, both domestic and international, have tended to cause reduction or cessation of all but the fundamental plant physiology associated with the anhalonium, or mescaline alkaloids. Even the Native American Church, whose members utilize peyote (*Lophophora williamsii*) containing mescaline as the primary active ingredient in their religious ceremonies (236), are under closer scrutiny now than at any time in the past by Food & Drug and Bureau of Narcotics officials to make sure that the peyote is used only for the actual religious ceremonies and not for any additional non-religious purposes. Earlier use made of the mescaline extracts to detect incipient schizophrenia has been essentially discontinued, apparently over fear of side effects, including possible addiction. However, considerable additional exploratory work on the alkaloids, including occurrence and biochemical synthesis pathways, has been done by Agurell, Lundstrom, and associates in Sweden (1, 2, 3, 61, 123–7); McLaughlin, Paul, and associates at the Universities of Michigan and Washington (26, 35, 109, 141–3, 158, 161, 170, 180); Brown (37, 38); Kapadia and associates (103, 104); Leete (117, 118); and O'Donovan (162, 163). A number of additional extractives were isolated and identified by sophisticated separation and identification techniques available in the 1960's; among them hordenine [4-(2-dimethylaminoethyl) phenol] (2, 35, 61, 142, 143), N,N-dimethyl-3,4-dimethoxyphenethylamine (2); N-methyl-4-methoxyphenethylamine; ℓ,α-(3, 4 - dimethoxyphenyl) - ℓ - dimethylamino) ethanol (20); N-methyl tyramine (35, 61, 139, 142); tyramine (61); 3-demethylmescaline (103, 170); 3,4-dimethoxy-β-phenethylamine and N-methyl-4-methoxy-β-phenethylamine (158). Although the great mass of the work on alkaloids was carried out using the peyote (*Lophophora williamsii*), Turner and Heyman (216) showed

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the presence of mescaline in *Trichocereus pachanoi* (reported through a misidentification as *Opuntia cylindrica*) to the extent of 0.9% of the dry weight of cactus. Braga and McLaughlin (35, 142) isolated hordenine and N-methyltyramine from two varieties of *Ariocarpus retusus,* a plant utilized by the Mexican Indians for medicinal and narcotic purposes. Agurell (1) screened 120 species of cacti for alkaloids, using a combination of thin-layer and gas chromatography and mass spectrometry; 40% contained alkaloids. Fourteen Uruguayan cactus species similarly screened showed the presence of hordenine, tyramine, and N-methyltyramine (61). Brown (37, 38) screened 16 species by gas chromatograph and Mayer's reagent; 12 contained extractable alkaloids and 2 contained quaternary compounds (detectable, but not recoverable). *Selenicereus grandiflorus, Echinocereus eneacanthus* var. *stramineus,* and *E. chloranthus* contained alkaloids having higher molecular weights than the known β-phenethylamine, or isoquinoline compounds, indicating that alkaloids having basic structures other than these two may be present in some species of cacti. O'Donovan (162) isolated dolicotheline [(N-imidazol-4-yl-ethyl) isovaleramide] from the cactus *Dolicothele sphaerica.* Histamine and leucine were postulated as precursors.

Biochemical syntheses pathways of the various alkaloids were elucidated by tracer studies. 4-hydroxy-3-methoxyphenethylamine-^{14}C was incorporated into mescaline by *Lophophora williamsii* to a much larger extent than 3,4,5-trihydroxyphenethylamine, 3-hydroxy-4-methoxyphenethylamine, or 5-hydroxy 3,4-dimethoxyphenethylamine (109). Leete (117, 118) demonstrated the incorporation of DL-2-^{14}C-tyrosine [4-(HO)-C_6H_4-CH_2-$^{14}CH(NH_2)COOH$] into mescaline having β-^{14}C in the side chain. Administration of DL-phenylalanine-3-^{14}C did not yield labelled mescaline. Lundstrom and Agurell (123–7) and McLaughlin, Paul and associates (141, 142, 170, 180) essentially confirmed these results. The biosynthesis of pilocereine, shown by Djerassi and associates (67) to be a trimer, rather than a dimer of lophocereine, was elucidated by Schuette and Seelig (194) and by O'Donovan, et al. (163). The material is formed directly, by oxidative coupling (etherification) of the phenolic groups in lophocereine.

Downing (75) has reviewed the chemistry of psychotomimetic substances. Trichocereine (N,N-di-methyl mescaline) had no effect; mescaline did.

Steroids

Most recent emphasis in the field of steroidal sapogenins from xerophyte sources has been on extraction of the various materials. Hecogenin and tigogenin, important cortisone precursors, appear to be the most prevalent materials (13); occurrence is mainly of the order of 0.1–1.0% on a wet basis (22, 28, 30, 41, 53, 59, 60, 63) in the leaves and stalks. The sapogenins are isolated by aqueous or ethanolic extraction of the wet plant material; acid or enzymatic hydrolysis of the saponins thus extracted, and solvent extraction and crystallization of the steroids (30, 41, 59, 86, 90, 102, 113, 183, 193, 199, 201, 222, 231, 234). The leaves and/or stems (aerial portions) of the plants constituted the main sources of steroids. However, the roots were utilized by Waclaw-Rozkrutowa (223); the concentrations of steroids (sarsasapogenin, tigogenin, and hecogenin primarily) were essentially the same as in the leaves. Wall and associates (224, 234) found the steroidal content of the seeds of 1 nolina, 2 agave, and 12 yucca species to be greater than in the leaves or stems, ranging as high as 12%. The use of yucca as a source of steroids may go back farther than at first indicated, since the Chinese investigators, Wu, Huang, and Minlon (235) refer to the ". . . Chinese drug, *Yucca filamentosa.*" Presumably dried yucca pulp, from plants in the more arid regions of China, served as the medication; dried plant materials were commonly so used in the older eras. The sapogenins have also been isolated using aqueous Ca $(HSO_3)_2$ (28); $FeCl_2$ precipitation (30); phenolic precipitation of the extraneous matter in the aqueous extract (43); butanol extraction (127, 223); infrared treatment to rupture the plant cells, especially of *Agave lecheguilla,* and subsequent diffusion and hydrolysis (160); methanolic extractions of the dried yucca rhizomes (165); and extraction of yucca leaf meal with isopropyl alcohol (224). The subject of steroidal sapogenins, essentially from xerophytic sources has been reviewed by Ikram and Miana (100); Martin (131); and Wall, et al. (226). Dawidar and Fayez (60) have outlined the distribution of the sapogenin contents in sisal. Gitogenin, as a first step in the bulbils, gives tigogenin as a second step in the sapogenin biogenesis, which transforms to hecogenin and neotigogenin as a third step. At the end of the life cycle, neotigogenin and hecogenin are reversibly transformed to tigogenin in the flowering top, which, as the new life approaches, reverts to gitogenin. Blunden and Hardman (29) report that, in experiments with cultivated plants, the yield of sapogenins increases from July to January, and decreases the other six months. This would partially confirm earlier hypotheses that these steroids are a cold-resistant and also a possible drought-resistant component of the plant makeup.

Similar materials other than sapogenins have been isolated from cacti. Devys, et al. (62) obtained 31-norcycloartenol from the unsaponifiable fractions of the pollen of the saguaro cactus (*Carnegia gigantia*). 7-stigmasten-3β-ol, isolated from the senita cactus, *Tophocereus schottii,* was shown to be essential to the life cycle of *Drosophila phachea,* which breeds only in the fermenting pockets of the cactus (91). A petroleum ether extraction of the flowers of *Opuntia ficus-indica* gave β-sitosterol (0.04% dry basis, and a mixture of free fatty acids and esters (C_{12}-C_{18}) (14).

Kenney and Wall (106) isolated a 12-oxo sapogenin, willagenin, from *Yucca filifera* by ethanolic extraction. Wall and associates have extensively reviewed the substantial work on sapogenins (227).

Hypoglycemic Extracts

Despite indications by previous literature that a therapeutic factor exists in *Opuntia* spp. (52, 53), little, if any, work has been carried out in the past decade to prove the efficacy of the material, or to determine its composition adequately. A 1961 review of antidiabetic agents from raw materials in Azerbaijan (6) confirms that extractives beneficial to diabetic conditions are present in plants. Sulman and Menczel isolated antidiabetic plant products from *Eragrostis bipinnata, Opuntia ficus-indica, Opuntia vulgaris, Teucrim polium, Trigonella feonum-graecum,* and *Zea styles* (205). The cactus extracts contained reducing sugars which were identified as glucose. This is surprising, since glucose is generally associated with diabetic disorder. Molnar, et al. (153) made a study of the effects of anabolic steroids on diabetes. The steroids, per se, (i.e., the nucleus only), such as methandrostenolone, testosterone, or stanozolol were ineffective in treating the diabetic symptoms. This study, plus previously reported work, indicate that the active antidiabetic factor in cacti and other xerophytes is most likely a saponin, i.e., the steroid nucleus with all the original attached sugars or other molecular moieties, connected to the nucleus by oxygen or nitrogen linkages. However, no work has been reported on the characterization of this factor. Since L-arabinose is one of the main sugars isolated from various xerophytic plants, it is possible that the presence of this sugar in the saponin may be part of the reason for the antidiabetic activity. The therapeutic mechanism of the factor is unknown in an official sense, but it can be hypothesized that the factor causes the Islets of Langerhans, located in the pancreas, to secrete the necessary insulin, thus compensating for, or otherwise counteracting the dominant genetic deficiency which causes the ability of the Islets of Langerhans to secrete insulin to diminish gradually.

Miscellaneous Pharmaceutical Applications

A yucca leaf infusion was found to exert inhibitory action *in vitro* against cercariae (larva) of *Schistosoma mansoni* at dilutions of 1:200,000 to 1:20,000,000 (56). Dominguez et al. extracted *Ariocarpus retusus*, a Mexican hallucinogenic cactus, by conventional methods and isolated retusine, a tetramethylated quercitin (0.04%, dry weight basis) (72). This was the first report of the natural occurrence of retusine. Floch (80) reported yuccas to contain 4–1032 mg and agaves 24–1538 mg of ascorbic acid per 100 gms of plant tissue — an exceptional content and variation. Extracts of the two cacti; viz, *Pachycereus pectin-aboriginum* from Mexico, and *Opuntia maxima* from South Africa, were reported by Hartwell (89) to have effected cures of a histologically diagnosed abdominal adenocarcinoma (cancer). A water-soluble, crystalline substance termed peyocactin, separated from the ethanolic extract of *Lophophora williamsii* exhibited antibiotic activity against a wide range of bacteria, and several fungi. Peyocactin was active against 18 strains of penicillin-resistant *Staphylococcus aureus* (138, 139); the material was subsequently shown to be hordenine (174). The phenolic group in hordenine should be expected to show biochemical activity.

Enzymes

A considerable number of enzyme systems have been shown to be present in xerophytic plants. Aiazzi (4) showed the presence of glucose-6-phosphatase in the stem of the Italian cactus *Echinopsis* by hydrolytic studies. A dialyzed extract of *Opuntia* spp. cactus was shown by Master (135) to hydrolyze dioses. Peroxidase, catalase, and phosphatase were found in *Agave veracruz* by Nagabhushanam and associates (156). Sanwal and Kirshnan ground tender phyllocades of *Nopalea dejecta* with water and showed the resulting mash to contain aldolase activity (187). The aldolase was particulate bound. The activity was diurnal, being minimal at 4 p.m., and reaching a maximum at 8 a.m. (188). The enzyme system was associated with particulate fractions settling at $<1600 \times g$, and passed into the soluble fraction at pH 9 (189, 190). The principal enzyme was subsequently shown to be a non-specific phosphomonoesterase, with optimal activity at pH 5 (191). Sisini (200) studied the activity of glucose-6-phosphate isomerase from *Opuntia ficus-indica*. The enzyme activity was found in the soluble fraction of a homogenate of the cactus, but not in the nuclei, chloroplasts, or mitochondria. Divalent cations, e.g. Mg, Co, or Mn were inhibitory. *In vivo*, the level of activity was maximal in the late afternoon and minimal in the morning. Chlorophyllase was shown to be present in cacti by Vlasenok et al. (222). *Micrococcus* spp. from retting effluents of sisal were shown to possess pectolytic activity by Jayasankar et al. (101).

Triterpenes

In addition to the steroid-type compounds, a number of triterpenoids (cyclopentanoperhydrochrysene nucleus) have been isolated from cactus sources — the cacti apparently contain more of the triterpenoids than the steroids. Djerassi and associates found the cactus triterpene queretaric acid to be 30-hydroxyoleanolic acid (66); and chichipegenin, from *Myrtillocactus* spp. and *Lemairocereus* spp. to be 12-oleanene-$3\beta,16\beta,22\alpha$, 28-tetrol (186). Kasprzyk, et al. isolated thurberin from *Lemaireocereus thurberii* (105) and found this triterpene to be identical with calendualadiol, isolated from *Calendula officinalis* flowers. Djerassi (65) has reviewed the field of cactus triterpenes.

Essential Oils

A number of the xerophytic plants contain essential oils and/or odoriferous components. Perhaps the most striking is that emitted by the desert night-blooming cereus (*Cereus greggii*) on blooming. Since the flower opens for only one night, the aroma is most likely generated to attract pollenator insects. The next morning, the magnificent and heady aroma can be detected over a large area (several hundred square miles in the Santa Cruz River Valley near Tucson, Arizona).

McCaughey and Buehrer (137) studied the essential oil content of 35 plants of the *Compositae, Labiatae,* and *Verbenaceae.* Volatile steam distillates, the majority of pleasant odor, were obtained from 29 of the plants.

It is of interest, in connection with essential oils, to note that the essential oil of sagebrush depressed the appetites of grazing deer (157). Oil of sage is one of many essential oils known to be bacteriocidal and/or fungicidal; hence, in ingestion, the rumen microorganisms are inhibited or reduced in population, presumably causing a loss of appetite, or inadequate digestion of the sage and other forage ingested.

Feeds and Animal Nutrition

The presence of mesquite (*Prosopis* spp.) on many grazing ranges has provided some nourishment for the livestock present for many decades. Despite the presence of considerable nutritional value, a fairly recent report (9) indicates that, in large amounts, mesquite beans cause malnutrition in cattle. Dollahite and Anthony pinpointed the high sucrose content as the cause. The sucrose causes changes in the bacterial flora of the rumen, preventing digestion of cellulose or effective *invivo* synthesis of Vitamin B. Cows fed mesquite beans alone or in combination with oat straw, developed jaw and tongue trouble, which became fatal on extension of the diet (71). Foliar applications of urea to pasture grasses and prickly pear cacti subsequently utilized for cattle feed assisted in causing greater digestive rates of dry matter, protein, and cellulose (24). Urea nitrogen was rapidly taken up by the plants. The ecological aspects of prickly pear were discussed by Houston (98). Medeiros, in Brazil, (146) analyzed *Nopalea cochenilifera, Opuntia* spp., and *Cereus jamacaru* for crude protein, fat, ash, fiber, carbohydrates, P_2O_5, and CaO. The dry plants made valuable additions to animal feeds because of the high calcium and phosphorus contents. Prikhod'ko and associates examined *Opuntia camanchica* (173). During summer blossoming, the water content was $\geq 90\%$. In September and October, the concentration of carbohydrates on a dry weight basis was about 22%, giving the plant a high nutritive value. Cellulose content was about 8%. Coates (49) hydrolyzed the saponins from agaves (presumably the residues from fiber decortication), mixed the pulp with distiller's slop and fermented the mixture. *Agave sisalana* residues after fiber removal were found by Lajolo (116) to contain 14.8% H_2O, 3.69% crude fat, 3.63% protein, 17.07% ash, 17.73% fiber, and 42.76% NFE (carbohydrates). The product was useful with urea as a cattle feed. *Agave lecheguilla* was converted to cattle feed (180) by ethanolic extraction to remove saponins and toxic materials, notably hypericin. The residual material was superior to cured dried hay. The saponins can be recovered by acetone precipitation of the ethanolic extract; fiber was also recovered from the process. Mangan (129) discussed effects of triterpenoids and yucca steroids on bloat in cattle. Triterpenoid foams were independent of pH; foams from yucca were pH-dependent below 4 and above 7.5. Apparently, the yucca steroid foams were below the level of stability associated with bloat. The amino acid profile of prickly pear (*Opuntia ficus-indica*), determined using an automatic analyzer, indicated the amino acid content to be acceptable, although lysine, one of the essential and limiting amino acids, was deficient. Diets with 25%

prickly pear protein and 75% fish flour protein were quite acceptable nutritionally (221).

Cellulose and Fibers

Although little effort has been expended recently in the direction of cellulose production and recovery from xerophytic plants, it is of interest to note (11) that a *Yucca brevifola* can be utilized for newsprint cellulose. Banerji, et al. extensively characterized the hemicelluloses from *Agave americana* (17). D-xylose was the principal sugar; 4-o-methyl-a-D-glucopyranosyl uronic acid, the main uronide moiety.

Fibers have been more extensively studied. Baumann and associates (18) prepared a rod of refined sisal fibers with a bonding agent for use as a cigarette filter. A flexible, self-supporting sheet was prepared from sisal fibers and cellulose acetate by hot-pressing at 100-1000/psig, and 250–350°F (152). Carbonized fibers were prepared by heating sisal fibers at 150°–400°C for 1 min to 15 hrs, presumably in a closed or inert atmosphere (21). The fibers were extracted once during the process with chlorinated organic solvents. Crompton (51) prepared heat-sealing paper for teabags by combining polypropylene with sisal, or sisal-type fibers. A flame-resistant resin composition was prepared by Roberts and Nakagawa (176) from 40–55% polyester, 25–40% inert filler, 10–20% chopped sisal fiber, and 5–10% fire retardant additive. Sisal cultivation for fiber and pulp purposes gave about 5 tons of raw, wet plant material per acre (12 tons per hectare) (128). After expressing the juice, 6.8 kg of useable pulp and 16 kg of oven dry fiber were obtained. Heating of sisal fibers at 25–100% relative humidity showed a small gain in moisture content (0.5% per 10°C increase) as the fibers were warmed (42); however, the characteristics were only qualitative. Das Gupta and Mukhergee (57) characterized the hemicelluloses of sisal fibers by extracting with alkali solutions of increasing concentration, and finally with alkali borate. As with the previous studies, xylose was the main sugar and methyl glucuronic acid the main acid moiety. Bell and associates (25) have reviewed the field of long vegetable fibers, including jute and sisal.

Gums and Mucilages

The gums and mucilages of the xerophytic plants are a rather remarkable group of materials. According to recent radio promotions, Aloe vera gel (mucilage) dates back to Cleopatra; other records confirm the antiquity of the extract (34). The activity of the mucilaginous material is the more remarkable when it is considered that the interior matrix of the leaf is 99+% water. Aloe and prickly pear mucilages are reported to be effective therapeutics for sunburn, burns and scalds, scratches, cuts and wounds (34, 52, 53); also, that burns or skin ulcers caused by radioactivity are healed by the gel. There is a beneficial effect on peptic ulcers also (34). Marsh (130) mashed the gel matrix through a 60-mesh screen and freeze-dried the material. The dry powder reconstituted well, and was utilized in cosmetics, pharmaceuticals and toiletries. Several commercial operations manufacturing and marketing the gel and cosmetics using the gel as a base or an additive component are located in Texas, and at least one in Missouri. Brambilla (36) obtained juices from the leaves and fruit of *Opuntia ficus-indica* which had endermal and emollient, hydrating, and decongestive action. A stable and homogeneous water-in-oil cosmetic emulsion was prepared from 8% beeswax, 40% white mineral oil, 0.1% each of methyl- and propyl-p-hydroxbenzoate, 1% zinc stearate, 0.3% sodium borate, 0.75% perfume, 1% glycerine, 2.5% *Opuntia vulgaris* plant extract (2% solids), and the balance distilled water. The action of these mucilages would indicate a structure and make-up different from the usual glucose polymer. Amin and associates (8) obtained a homogeneous mucilage from the tissues of *Opuntia ficus-indica,* and showed this to contain 1,4-linked galactose residues, terminal residues of arabinose, 1,2-linked rhamnose residues, and xylose residues in the approximate ratio 35:37:12:16. Lewis and Smith (121) showed that mesquite gum was a homogeneous polysaccharide by electrophoresis. Tabak and Pueschel isolated a polysaccharide in 15% yield from the Brazilian cactus *Cereus triangularis* which was composed of galactose, arabinose, rhamnose, and galacturonic acid (206). A small amount of free glucose was present.

Foods

No attempt will be made here to review again the food products, such as cactus candy, nopalitos, etc., which are marketed particularly in the Southwest, and in gift and gourmet shops elsewhere. The flowers of *Yucca elephatipes* (150) are used as a food in Central America. The ascorbic acid content is very high, e.g., raw buds, 474.8 mg/100 gms; cooked buds 489.7 mg; raw flowers 371.3 mg, and cooked flowers 360 mg. Rojas (179) conducted a bromatological study of tunas (fruit) of *Opuntia ficus-indica.* Calcium, phosphorus, and ascorbic acid were high, largely confirming other investigations. Tuna cordoba is used in a number of ways (208). The fruit is mashed and fermented; the unfermented mash can be concentrated to a marmalade or paste. On further concentration, a solid called queso de tuna is obtained.

Saponins may, under some circumstances, offer problems in the use of xerophytic plants as foods. Oser (166) studied the hemolytic activity of a hot aqueous extract of *Yucca mohavenis,* which was compared to that of soap bark, sea cucumber, and soybean saponic extracts. The yucca extract had the least activity. Samuel and Srinivasan (184) removed saponins from fructose syrup prepared from agave stems with 1% activated charcoal. The extracts contained about 30 mg of saponins.

Cleaners

The saponins present in xerophytic plants have long been known for their surfactant properties. The subject, with respect to Russian plant sources, has been reviewed by Gluzman and Dashevskaya (87). Gambill (82) utilized prickly pear extract in an oilwell cleaner, together with phosphates and ethylenediamine tetracetic acid (EDTA). Lewin, et al. (119) isolated saponins from agave leaves by concentrating the aqueous extract, and solvent partition. The foam index of the final product isolated was 10,000. A detergent mixture containing sisal extract was patented by Rubin (182). The composition was Nacconol SF, 2% EDTA (30%), 5%; sisal extract from *Agave sisalana* or *A. fourcroydes,* concentrated 30-fold, 5%; and water, 88%. Oil storage tanks, dairy utensils, and autos were effectively cleaned with the product. Spray (202) utilized 1 part by volume of raw agave leaf juice to 400–1000 parts of saline water to stimulate descaling in evaporators used to produce fresh water. The use of the agave juice allows higher operating temperatures and greater capacity in existing equipment. The juice must either be added immediately after extraction, or treated to prevent fermentation. Tschesche and Wulff (213) have reviewed the constitution and properties of saponins.

Glucosides

C-glucosyl anthraquinone compounds were found in juice of the leaves of 40 aloe species by McCarthy (134). Aloin was found in *Aloe alooides; A. gerstneri,* and *A. petricola;* hemonataloin in *A. comosa, A. arenicola, A. volkensii, A. gariepiensi, A. nyeriensis, A. spectabilis,* and *A. krapohliana;* aloesin (C-glycosyl benzopyrone) was found in *A. alooides, A. arenicola, A. volkensii, A. gerstneri, A. petricola,* and *A. thraskii.* Reznik (175) separated quercitin-7-glycoside and quercitin-3-glycoside as copigments in several species of cacti, notably the notocactus genus. Mesquite (*Prosopis*

TABLE I

WAX PRODUCTS ISOLATED FROM AGAVE LEAF PULP AND EPIDERMIS (119)

Solvent	Product Type	M.P., °C
A. Pulp		
Naphtha	Yellow grease	—
Petroleum ether	Yellow grease	—
Acetone	Green, hard wax	82.2
Benzene	Yellow wax	94.5
Carbon tetrachloride	Yellow powder	94.0
B. Epidermis		
Naphtha	Yellow wax	68
Petroleum ether	Yellow wax	70
Acetone	Hard, yellow wax	85.6
Benzene	Hard, yellow wax	96.4
Trichloroethylene	Hard, yellow wax	97.1
Ethanol	Yellow brown mass	—

juliflora) was found by Hegnauer (92) to be cyanogenetic (up to 1000 mg HCN /kg of plant material). This may explain some of the problem existing with feeding mesquite beans to cattle.

Fats, Oils, and Waxes

Most xerophytic plants produce seeds which are good to excellent oil sources. Also, the cuticular waxes of cacti are notably water-impervious. Practically all the true cactaceae as well as other xerophytes take up water during rainy or wet weather and store it in their body or leaf matrix, expanding considerably in so doing. The exterior cuticle waxes serve as impervious moisture barriers for the water so stored. Herbin and Robins studied the chemotaxonomy of alkanes and alkenes present in the cuticular waxes of aloes (93). The waxes were chromatographed on 80-100 mesh celite, containing 1.25% apiezon L. The hydrocarbons obtained were specific for the individual plant species; some branched-chain hydrocarbons were found. Kurtz (114) isolated waxes from 42 species of plants native to Arizona. The percentage of waxes in the xerophytes studied was generally $<0.3\%$. Khan and Bhatnagar (108) utilized sisal wax for magnetoelectrets (electrostatic analogs of magnets from waxes and polymers). Sisal wax developed negative charges on both surfaces. Lewin, et al. (119) isolated waxes from agave leaf pulp, also from the epidermis, utilizing various solvents. The products isolated are presented in Table 1.

Earle and associates (76) investigated yucca seeds, particularly *Y. elata* as an oil source. The seeds, on a dry basis, contained 29.1% oil, 20.6% crude protein (Nx6.25). The oil had the following properties: iodine no., 128; N^{40}_{D}, 1.4679; linolenic acid, 0%; linoleic acid, 52%; conjugated dienoic acids, 2.8%, saturated (e.g. stearic) acids, 8.8%; oxirane (as 9,10-epoxyoleic acid), 6%. No special bonding was determined by infrared spectra. *Yucca constricta* and *Yucca glauca* gave oils having respective iodine values of 128 and 142, mainly dienoic acids. A trace of hydroxy acid was present (77). Lotti and Averna (122) studied the fatty acid composition of the seed oils of 29 varieties of *Opuntia* spp; no details were available. Mhashar, et al. (149) utilized the wax recovered from sisal fiber decortication in place of carnauba wax. Sisal wax resembles carnauba wax in solvent take-up and heat-resistant properties that determine the suitability of a wax for use in polishes. Miwa (151) studied jojoba (*Simmondsia chinensis*) oil. Major constituents were: C_{40} wax ether, 30%; C_{42} wax ester, 50%, and C_{44} wax ester, 10%. Major acids were: octadecenoic, 6%; eicosenoic, 35%; docosenoic, 7%.

Fatty alcohols were eicosenol, 22%, docosenol, 21%, and tetracosenol, 4%. The wax esters are made up of a disproportionately large percentage of docosenyl eicosenate and are not a random combination of constituent acids and alcohols. A recent anonymous press release indicates that research in the USSR has determined that jojoba oil, utilized as a salad or cooking oil, is nonfattening. Sen Gupta and Chakrabarty (195) investigated the seed fat composition of the East Indian desert plant *Gynandropsis pentaphylla.* The seed contained about 17.6% of a dark-colored oil, having an odor typical of the species. After 3 months storage, the oil had a high acid value, indicating the presence of lipolytic factors. Some properties of the oil were: $N^{40}{}_D$, 1.4617; acid value, 131.1; iodine no., 114.5; unsaponifiables, 3.5%. The fatty acid profile was: myristic acid, 0.31%; palmitic acid, 18.41%; stearic, 8.07% arachidic, 1.96%, oleic, 15.39%; linoleic, 53.82%; and linolenic, 2.04%.

Miscellaneous Extractives

A chromone, aloesin, was found in 9 aloe species by Holdsworth (96). It was the first such report and also the first C_5-methyl chromone known. In the course of recovery of other products from agaves, Nord (159) separated chloroplasts from the press juice by acidification (pH 4.2–4.8) and precipitation with borax. Chlorophyll was then extracted from the chloroplasts. Piatelli (171) found betacyanins in 44 species. Vasquez (219) investigated the chemistry and economics of a wood distillation plant in Peru, to use mesquite (*Prosopis juliflora*) as a feedstock. Hecogenin and tigogenin from *Coleus rhenaltianus* were utilized by Vendrig (220) as growth regulators. Sanchez-Marroquin, et al. studied 4 yeasts in the fermentation of agave juice (185). The best conditions were: sugar concentration, 8° Brix; pH 6.8; temperature 26–8°, 5% inoculum.

A number of multiple extract surveys have been made. Dominguez and associates (73) made petroleum ether, ethanol, and water extracts of *Corypantha palmerii* and a species of *Echinocactus* (73). β-sitosterol and galactose were found in both plants. A tetracyclic triterpenoid and a crude alkaloid were present in *C. palmerii*; an aliphatic saturated tetrol and a polyhydroxysteroid in *E. grandis.* The same group also conducted a phytochemical tudy of 8 Mexican plants (74), including *Agave schottii,* for alkaloids, saponins, flavones, and tannins. Saponins and alkaloids were found in *A. schottii.* Young and old stems of senita cacti were examined for sterol, alkaloid, and fatty acid content by Kircher (110). No correlation between phytochemical characteristics and plant location was observed. Mesquite (*Prosopis juliflora*) was found by Sharma (197) to be rich in foliar phosphorus and nitrogen, but poor in foliar magnesium, and in wood ash, wood silica sodium and phosphorus; and bark ash, silica, and potassium.

Weinstein, Nickell and associates (229) conducted biochemical and physiological studies of *Agave toumeyana.* The original plant tissues and tissue cultures of the corresponding plant parts were examined for amino acids, organic acids, sugars, and nucleic acids. The tissue cultures were found to contain more of the components than the original plant tissue. In addition to the author's previous general reviews (52, 53), the Committee on Desert and Arid Zones Research, Southwestern and Rocky Mountain Division, AAAS, has presented a symposium on native plant and animal resources in arid lands of the Southwest (83).

Artists' Woods

The heartwood of several trees common to the American Southwest has a dark color, an attractive grain, and when properly dried, an appearance similar to walnut or mahogany with a density equal to or exceeding oak. Although popular as a firewood and a raw material for barbecue charcoal, these woods have much greater — and remunerative — possibilities as replacements for non-xerophytic hardwoods, especially in the field of small gift and souvenir items. When young (<2–3 years), mesquite trunks and limbs have a light yellow, or light yellow-brown hue, which completely covers the cross-section, or nearly so (sapwood). As a trunk or limb matures, the darker, lignified portion of the heartwood takes over, and after 5 years or so, the sapwood becomes a progressively narrower band adjacent to the cambium. The wood handles about like oak — brittle, perhaps somewhat softer, but workable with ordinary sawing and sanding tools. The desert ironwood, *Olneya tesota,* has perhaps an even more beautiful grain and is much denser and harder. It, too, has been used for desert souvenirs and novelties, but for a production operation using ironwood, carbide-tipped tools would be desirable, if not essential. Some specimens of ironwood will sink in water; others, when weather-cured, have a lovely purple hue in addition to the dark brown usually associated with the dry heartwood. Catclaw, *Acacia greggii,* likewise has a walnut- or mahogany-like heartwood, and is utilized for souvenirs. Catclaw is more of a shrub, however, than a tree like mesquite or ironwood. Both catclaw and ironwood, particularly the knotty burls, should be an excellent substitute for the far more expensive and imported briar in smoking pipe bowls. With cultivation management, mesquite and perhaps ironwood should be capable of producing trees 18″ in diameter.

Cultivation: Its Possibilities and Problems

Any sustained utilization of xerophytic plants will generally dictate that cultivation be undertaken in order to assure a continued and orderly supply of raw materials. The wild plants would not offer a safe enough long-range source, and there is growing public sentiment against stripping some areas of the wild xerophytic vegetation. A number of southwestern states, notably Arizona, have severe and stringent laws against removal of the native flora, and many ranchers are also becoming more selective in what they will remove, or allow to be removed, from their grazing ranges.

Mesquite, for example, is not considered desirable, and work on herbicidal control or eradication has continued intensively (10, 19, 20, 32, 33, 78, 79, 88, 97, 99, 144, 147, 154, 177, 178, 209, 217). 2,4,5-T and its esters, picloram, bromacil, paraquat, dicamba, silvex, 2,4DB, MCPA, and sodium azide were the principal herbicides used. Prickly pear is still under debate. *Opuntia* spp., particularly thorny varieties, really overran grazing ranges in South Africa and Australia in the early part of the century, and were controlled by the Cactoblastis moth; and also, chemical weed control utilizing silvex (48, 94, 232), fenoprop (48, 95), alkali metal or amine salts of hexafluoroarsenic acid (54), nopalmate (70), 2,4,5-T (85, 94, 95, 145, 209, 232), dichlorprop (85), MSMA (monosodium methane arsonate) (112), 2,3,6 TBA (209), picloram and dicamba (232). Silvex, pilcloram, and dicamba have been utilized as far north as Nebraska against prickly pear (232). However, since the Texas drought of 1949-56, a number of ranchers have refused to initiate eradication or control programs for prickly pear, preferring to preserve the plants for future drouth emergencies. Also some work has been done, notably by the King Ranch, on breeding prickly pear, presumably an improved thornless variety. Yucca, likewise, is considered to be a range pest in some areas (31, 177) as is wholla, *Opuntia spinosior* (85). The considered necessity of control of these xerophytes as weeds indicates fast growth under favorable conditions, and presumably, satisfactory growth under adverse conditions for cultivation considerations. The prickly pear is cultivated in only two places in the United States, both in California, primarily for the fruit. The canned leaves, known as Nopalitos, are generally imported from

Mexico. The plants are watered and fertilized about like citrus. Some cacti have natural insect enemies — use of these was made by Australia and South Africa to control prickly pear on sheep ranges; control was effected about 1925. Mann (130) has extensively cataloged cactus-feeding insects and mites. Caspar (39) treated *Opuntia tuna* with tetracyclines to suppress witches' broom growth. It was shown that mycoplasmas associated with the disease are the etiological agents of the disease. Sisal is apparently susceptible to anthracnose (215); this was controlled with fungicides, such as sulfur, bordeaux, or Granosan. *Opuntia monocantha* is attacked by an albuminous spindle virus (7). The particles appeared to be a combination of protein and nucleic acid. Cook and Goebel (50) correlated plant vigor with physical stature and chemical content. When boron is deficient in the soil, leaf cracking of sisal occurs.

It is quite well known that the prickly pear and cholla cacti (*Opuntia* sp.) will grow not only from seeds, but from joints planted, or even dropped on the ground (214). Some agaves and yucca will grow from both root shoots and seeds. The cacti of the *Cereus* species, however, require seeds, and there has been much concern by custodians of the Saguaro National Monument in Arizona that the cactus is not reproducing as fast as is desirable to maintain population. Alcorn and Kurtz (5) found that germination of the seeds of saguaro was stimulated by daylight, or red light (655 nm) but counteracted by dark, or far red light (735 nm). Germination was increased in either the light or dark by addition of 500–1000 ppm of gibberelin. Gibberelins also produced favorable physiological action on prickly pear (115). McDonough (140) reported on germination responses of saguaro and of *Lemaireocereus thurberii.*

There seems to be some difference of opinion on physiological activity of *Opuntia* species. Chow et al. compared *O. laevis* and *O. polyacantha* to corn and soybeans (46). The cacti exhibited little water loss, exceptional viability, low nutrient requirements and low transpiration as compared to the non-xerophytes. The cell mucilage had high water-binding ability (cf. section on Gums and Mucilages). Water extracts of prickly pear tissue applied to corn seedlings induced pronounced growth. The xerophytes' ability to utilize CO_2 and radiant energy contribute to their special growing properties (55, 84, 210). Gates and associates (84) found that leaf temperatures of Opuntias were 10–16° hotter than the ambient air (46°C vs. 30°C; soil temperature, 60°C). The protein structure is stable at high temperatures. Ting and Dugger (210) found that CO_2 uptake was 1° kinetics. Dark CO_2 fixation was intermediate between leaf succulents and non-succulents. Salt concentration has some effect on some xerophytic plants. McNulty (144) showed that greasewood (*Sarcobatus vermiculatus*) growth was inhibited, and leaves became shorter, thicker, and more succulent with increasing Cl concentration. The more succulent leaf was apparently less efficient in absorbing CO_2. Mukerji and Ting (155) isolated chloroplasts from *Opuntia ficus-indica* and found CO_2 metabolism to be associated with chloroplast metabolism. Soil pH may also be a factor. Most soils in which cacti and other xerophytes are native are alkali. Ojeda and Mayagoitia (163) found that *Agave fourcroydes* develops well in soils of pH 7.2–7.9, and rich in calcium and organic matter. Growth failure was considered due to low assimilable calcium and low pH. Strain and Chase (204) studied the effect of temperature on CO_2 exchange in woody desert perennials, while in other temperature studies, Wendt, et al. (230) measured water loss in mesquite (*Prosopis glandulosa* var. *glandulosa*) using a thermoelectric method. Wiersum, et al. (233) showed the movement of calcium-45 in *Yucca flaccida.* A concentration of 0.02 M was indicated to be necessary for uptake of Ca as indicated by radiometric measurements. Khan and associates (107) found that enzymic activity in *Nopalea* *dejecta* was increased at midnight as compared with noon activity. Pieratt (172) reviewed agaves on the Texas Gulf Coast. Tripi and del Frari (212), studying the effect of 1-naphthalene acetic acid on *Opuntia ficus-indica*, found the formation of seeds in the fruit was not affected. A dose of 20 mg of auxin per liter increased the weight of the fruit; a dose of 20–100 mg/l increased fruit yield.

Discussions and Conclusions

Sufficient evidence is considered to exist to warrant further study of the chemurgic utilization of the xerophytic plants. However, economic studies, in addition to the chemical and biological studies are strongly indicated. The semi-arid lands of the American Southwest have become much in demand during the past 20 years or so, and land values have increased to an almost unbelievable extent (from $125/acre in 1951 to $5000 /acre, undeveloped, in 1971 in some areas of Pima County, Arizona, for example). Such land value increases obviously carry concurrent property taxes with them. Also, labor costs for agricultural operations have gone up steeply in the past decade, and machine operations are coming in as fast as circumstances permit. Some of the extractives from xerophytic plants would be amenable to machine harvesting and processing; others might require considerable hand labor on a large scale. In the developing countries, cultivation might be a family, or one-man operation. Marginal land, or land adjacent to, or in floodways would offer a more reasonable basic land cost; the presence of the plants might, under some circumstances, assist in preventing erosion; e.g. a heavy stand of mesquite or ironwood adjacent to an arroyo having a tendency to flash-flood. To have a chance for success, a systematic correlation of all factors is essential — something which has largely been left undone.

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