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# A Survey of Some Plant Waxes of Southern Arizona [1, 2]

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IT IS COMMONLY STATED in textbooks that plants native to arid regions possess thick, waxy cuticles. Presumably these help to prevent water loss. Candelilla (*Euphorbia antisyphilitica*) is an outstanding example of this general concept, but relatively little information is available about other species indigenous to dry and hot climates. In the present survey 42 species indigenous to southern Arizona were studied. Although some of these species are representative of wide ranges of environmental conditions of altitude, rainfall, incident light intensity, temperature, and edaphic factors, most of them are from areas of high temperatures (110°F. or more), high light intensities (up to 12,000 foot-candles), and low rainfall (12 in. or less per year).

## Experimental

The species were selected for the occurrence of wax-like material or a heavy bloom on the stems or leaves, the occurrence of a thick cuticle, and availability of the species. Several kilograms of each species were collected in the field. Herbarium specimens were also collected for use in checking identifications. All plant names used are those given in Kearney and Peebles (3). Leaves from both the "female" and "male" plants of three dioecious species were included. In preparing samples of *Agave parryi* var. *huachucensis*, the thick, bloomy epidermal layers were stripped from the leaves and the remainder of the leaves discarded. In the case of *Asclepias albicans* only the white bloom that can be readily shaken from the stems was analyzed although the yield of wax has been expressed on the basis of the dry weight of the stems. All plant material was air-dried; the residual moisture was less than 5%.

A modification of the method of Chibnall *et al.* (2) was used to extract and separate the so-called wax and nonwax fractions of each species. The plant material was refluxed for 2 hrs. with petroleum ether (B.P. 30–60°C.). Decantation of the extract, followed by several rinses of the plant material with fresh hot solvent, completed the extraction. The extract was reduced to 250 ml. and 500 ml. acetone were added. After standing at 5°C. over-night, the acetone-insoluble precipitate, the wax fraction, was removed by filtration and washed with cold acetone. The nonwax fraction was recovered from the filtrate by evaporation of the solvent.

Yields of both the wax and nonwax fractions were calculated on a dry-plant weight basis. The yield of wax for a number of species was also calculated on the basis of a standard unit of plant surface; that is, the surface area of 1 g. of dry plant was measured with a planimeter, and the weight of wax/square meter was calculated. This expression of wax yield, which is based on the assumption that the major portion of wax in a plant shoot occurs in the cuticular layers, permits the direct comparison of yields of any plants because the effect on yield of nonwaxy plant structures is nullified.

The wax fractions were characterized physically by determination of the drop-point melting point (1) and general color, hardness, and odor. In a few cases the capillary-rod-drop melting point (4) was determined because only small quantities of wax samples were available. These two procedures gave almost identical results. Relative hardness was determined by comparison with beeswax (soft) and refined carnauba wax (hard). The waxes were characterized chemically by determination of the acid, saponification, and Wijs iodine numbers (7). All characterization numbers given are the mean of at least three determinations.

## Results and Discussion

The results of this survey are presented in Table I. A species may rank very poorly in regard to yield of wax when the yield is expressed on a plant weight basis, but the same species may actually have a relatively large amount of wax per unit of plant surface. For example, the yield of wax of *Asclepias albicans* and male and female leaves of *Simmondsia chinensis* is very low on a plant weight basis, but on the basis of yield of wax per unit surface area these species rank high. Indeed, in comparison with the carnauba palm (*Copernicia cerifera* Mart.), which was found to have approximately 4 g. of wax/$m^2$ of mature leaf surface, the stems of *Asclepias albicans* and *A. subulata* have cuticles that contain half as much wax, but because of the bulk of nonwaxy tissues in the stems of these species, the yield of wax on a weight basis is quite low in comparison to the carnauba palm. Thus the expression of wax yield on a plant area basis gives a much clearer picture of the physiological productivity of wax of a plant.

Some effects of sex on plant waxes may be seen by comparing the results for the three dioecious species, *Baccharis sarothroides*, *Atriplex canescens*, and *Sim-*

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[2] Arizona Agricultural Experiment Station Technical Paper No. 453.

## TABLE 1

The Yields and Characteristics of Waxes and the Yields of Nonwaxes of Plants from Southern Arizona

| Family and species | Plant part extracted | Wax: Yield % | Wax: Yield g/m² | Wax: M.P. °C. | Wax: Iodine No. | Wax: Acid No. | Wax: Sapon. No. | Wax: Description | Nonwax % yield |
|---|---|---|---|---|---|---|---|---|---|
| Polypodiaceae | | | | | | | | | |
| *Pteridium aquilinum* var. *pubescens* | sporophylls | 0.24 | ...... | 70.0 | 3.0 | 8.2 | 98.3 | gray-yellow, soft | 0.19 |
| Cupressaceae | | | | | | | | | |
| *Juniperus deppeana* | branches | 0.38 | 0.91 | 71.5 | 1.6 | 5.7 | 25.4 | gray-green, soft, pleasant odor | 0.15 |
| Gramineae | | | | | | | | | |
| *Heteropogon contortus* | leaves and culms | 0.17 | ...... | 78.5 | 2.4 | 22.2 | 84.9 | cream color, hard, brittle | 0.10 |
| *Heteropogon melanocarpus* | leaves and culms | 0.10 | ...... | 78.5 | 4.2 | 28.0 | 83.4 | gray, soft | 0.13 |
| *Chloris virgata* | leaves and culms | 0.25 | ...... | 80.0 | 2.1 | 13.0 | 54.9 | white, medium hard, sl. brittle | 0.11 |
| *Bouteloua aristidoides* | leaves and culms | 0.16 | ...... | 73.0 | 10.5 | 23.4 | 65.4 | dark blue-green, very soft, not tacky | 0.58 |
| *Trichachne californica* | leaves and culms | 0.29 | ...... | 78.0 | 3.0 | 23.4 | 79.7 | white, hard, brittle | 0.10 |
| *Aristida adscensionis* | leaves and culms | 0.12 | ...... | 75.0 | 3.7 | 15.6 | 17.9 | light gray-green, soft | 0.12 |
| *Phragmites communis* | old leaves | 0.05 | ...... | 80.0 | 0.8 | 26.0 | 83.2 | ........... | 0.22 |
| *Sorghum halepense* | whole shoot | 0.37 | ...... | ...... | ...... | ...... | ...... | dark brown, medium hard | ...... |
| Amaryllidaceae | | | | | | | | | |
| *Agave parryi* var. *huachucensis* | epidermis [a] | 0.38 | ...... | 72.0 | 8.2 | 14.9 | 47.0 | gray-yellow, medium hard | 0.4 |
| Malvaceae | | | | | | | | | |
| *Gossypium thurberi* | leaves | 0.20 | 0.06 | 70.0 | 15.9 | 14.1 | 69.4 | dark brown, very soft, unpleasant odor | 2.0 |
| Euphorbiaceae | | | | | | | | | |
| *Croton texensis* | leaves | 0.28 | 0.17 | 72.5 | 3.2 | 8.9 | 68.6 | dark orange, soft, pleasant odor | 0.33 |
| Zygophyllaceae | | | | | | | | | |
| *Larrea tridentata* | leaves | 0.54 | 0.95 | 73.5 | 16.5 | 13.7 | 102.8 | dark orange, odor of creosote, hard, brittle | 0.16 |
| Aizoaceae | | | | | | | | | |
| *Trianthema portulacastrum* | leaves | 0.05 | 0.001 | 78.0 | 2.6 | 26.4 | 49.1 | light brown, soft, not brittle | 0.10 |
| Polygonaceae | | | | | | | | | |
| *Rumex hymenosepalus* | leaves | 0.04 | 0.02 | 75.0 | 9.1 | 24.1 | 123.4 | dark brown, soft, unpleasant odor | 0.26 |
| *Eriogonum deflexum* | stems | 0.08 | ...... | 85.0 | 0.0 | 93.1 | 122.8 | dark green, medium hard, brittle, pleasant odor | 0.21 |
| Chenopodiaceae | | | | | | | | | |
| *Atriplex canescens* | leaves, female | 0.12 | ...... | 76.0 | 4.6 | 57.1 | 72.1 | orange, soft | 0.25 |
| | leaves, male | 0.15 | 0.11 | 76.5 | 2.7 | 63.1 | 65.9 | orange, medium hard, not brittle | 0.26 |
| Ericaceae | | | | | | | | | |
| *Arctostaphylos pungens* | leaves | 0.10 | 0.16 | 69.0 | 19.0 | 14.6 | 10.0 | olive drab, very soft, sl. tacky | 0.24 |
| Fouquieriaceae | | | | | | | | | |
| *Fouquieria splendens* | bark | 0.007 | ...... | ...... | ...... | ...... | ...... | ........... | 1.3 |
| | leaves | 0.33 | 0.11 | ...... | ...... | ...... | ...... | gray-green, soft | 0.6 |
| Asclepiadaceae | | | | | | | | | |
| *Asclepias subulata* | stems | 0.51 | 2.18 | 79.0 | 65.6 | 19.3 | 33.4 | dark orange, yellow, soft, tacky, unpleas. odor | 0.8 |
| *Asclepias albicans* | stem bloom [b] | 2.0 | 21.3 | 84.0 | 7.4 | 70.2 | 85.2 | dark brown, very hard | ...... |
| | pet. ether extr. of stem bloom | 0.43 | 4.58 | 68.5 | 20.6 | 3.4 | 19.9 | light green, medium hard | ...... |
| | wax of stem bloom | 0.20 | 2.13 | 68.0 | 6.5 | 1.3 | 4.3 | gray-green, soft | ...... |
| *Asclepias linaria* | old leaves | 0.30 | ...... | 70.0 | 13.1 | 11.2 | 24.7 | ........... | 0.6 |
| Solanaceae | | | | | | | | | |
| *Nicotiana glauca* | leaves | 0.72 | ...... | 66.5 | 51.1 | 9.2 | 44.5 | dark green, soft, not tacky, odor of tobacco | 1.6 |
| Acanthaceae | | | | | | | | | |
| *Beloperone californica* | old stems | 0.07 | ...... | 71.0 | 8.6 | 14.8 | 23.9 | ........... | 0.07 |
| Bignoniaceae | | | | | | | | | |
| *Chilopsis linearis* | leaves | 0.16 | 0.11 | 66.0 | 4.2 | 16.8 | 26.3 | dark yellow, medium hard, sl. brittle, pleas. odor | 0.25 |
| Rosaceae | | | | | | | | | |
| *Vauquelinia californica* | leaves | 0.17 | ...... | 67.0 | 9.8 | 7.4 | 41.6 | light gray-green, brittle, hard | 0.62 |
| *Cowania mexicana* var. *stansburiana* | leaves | 0.38 | ...... | 68.0 | 10.4 | 8.6 | 82.6 | light yellow-orange, very soft, easily crumbled, strong odor | 0.24 |
| Leguminosae | | | | | | | | | |
| *Prosopis juliflora* var. *velutina* | leaves | 0.81 | 0.57 | 74.5 | 9.5 | 9.4 | 23.5 | dark green, medium soft | 0.44 |
| *Olneya tesota* | old leaves | 0.38 | 0.24 | 73.0 | 1.2 | 6.9 | 53.4 | orange, medium soft, brittle, pleasant odor | 0.23 |
| *Acacia constricta* | old leaves | 0.30 | ...... | 75.0 | 1.1 | 9.1 | 88.3 | dark yellow, soft, pleasant odor | 0.20 |
| *Acacia vernicosa* | old leaves | 0.30 | ...... | 75.0 | 2.3 | 15.2 | 88.7 | dark orange, medium hard, pleasant odor | 0.15 |
| *Acacia greggii* | old leaves | 0.32 | ...... | 79.5 | 0.4 | 6.0 | 81.1 | cream color, very hard, not brittle, pleas. odor | 0.14 |
| Cactaceae | | | | | | | | | |
| *Opuntia fulgida* var. *mammillata* | stems | 0.19 | ...... | 71.5 | 14.4 | 5.4 | 62.3 | light green, brittle | ...... |
| Buxaceae | | | | | | | | | |
| *Simmondsia chinensis* | leaves, female [c] | 0.02 | ...... | 73.0 | 17.8 | 8.5 | 45.4 | medium hard | 0.06 |
| | leaves, male [c] | 0.05 | ...... | 76.5 | 6.0 | 49.6 | 88.9 | hard | 0.09 |
| | leaves, female [d] | 0.17 | 0.24 | 75.0 | 1.3 | 48.9 | 72.4 | light green, hard, slightly brittle | 0.06 |
| | leaves, male [d] | 0.17 | 0.25 | 77.0 | 6.0 | 51.8 | 81.3 | light yellow, medium hard, sl. brittle | 0.07 |
| Fagaceae | | | | | | | | | |
| *Quercus emoryi* | leaves | 0.04 | 0.03 | 72.5 | 0.0 | 13.2 | 148.4 | light brown, soft | 0.05 |
| *Quercus gambelii* | leaves | 0.22 | 0.08 | 72.5 | 4.8 | 19.5 | 56.8 | olive drab, soft | 0.28 |
| *Quercus oblongifolia* | leaves | 0.21 | ...... | 72.0 | 3.1 | 24.5 | 71.4 | gray-green, medium hard, brittle, pleas. odor | 0.10 |
| Compositae | | | | | | | | | |
| *Aplopappus tenuisectus* | old leaves [e] | 0.12 | ...... | 73.0 | 48.6 | 6.0 | 5.6 | dark brown, hard, strong odor | ...... |
| | old leaves [f] | 0.34 | ...... | 72.0 | 24.0 | 12.1 | 27.3 | light green, soft, strong odor | 0.56 |
| *Aplopappus laricifolius* | old leaves | 0.15 | ...... | 66.5 | 9.7 | 34.6 | 34.6 | olive drab, medium hard, brittle, strong odor | 0.28 |
| *Guardiola platyphylla* | leaves | 1.05 | ...... | ...... | ...... | ...... | ...... | dark brown, very tacky | ...... |
| *Baccharis sarothroides* | old leaves, female | 0.15 | ...... | 80.0 | 17.0 | 52.7 | 89.3 | ........... | 0.42 |
| | old leaves male | 0.21 | ...... | 78.5 | 53.8 | 14.2 | 66.6 | ........... | 0.57 |

[a] Percentage of yield based on dry weight of epidermal strips. [b] Stem bloom analyzed directly without extraction. [c] Collected April 24, 1948. [d] Collected June 4, 1949. [e] Collected October 18, 1947. [f] Collected October 11, 1948.

*mondsia chinensis*. Sex definitely influences lipide metabolism, but these effects apparently vary with each species. In an earlier study (5) sex was found to exert a greater effect on plant waxes than plant maturity.

*Acacia vernicosa* has been combined with *A. constricta* by some taxonomists, and their waxes are remarkably similar. In fact, the waxes of all members of the Leguminosae that were studied are quite similar. The waxes of the two species of *Heteropogon* are similar to each other, as are also the waxes from three species of *Quercus*.

The bark of *Fouquieria splendens* is reported by Lewkowitsch (6) to contain 9% wax. In the present study the yield of acetone-insolubles of the petroleum ether extract of the bark of *F. splendens* was only 0.007% of the dry bark. There was 1.3% of a nonwax fraction. However an acetone extraction of the bark, following the petroleum ether extraction, yielded 11.3% of an orange-brown, semi-solid, tacky, resinous substance. This material was not further characterized, but it appears that the bark of *F. splendens* contains a high proportion of an acetone-soluble resin rather than wax. The ephemeral leaves are not very waxy either because they contained only 0.33% wax on a dry leaf weight basis.

As previously mentioned, it is often stated in textbooks that plants native to arid regions possess thick waxy cuticles. Table I shows that a few species do produce considerable wax *(Asclepias subulata, A. albicans, Larrea tridentata, Juniperus deppeana, Prosopis juliflora* var. *velutina)*, but the majority of xerophytes and succulents in this survey contain only small amounts of wax *(Agave parryi* var. *huachucensis, Croton texensis, Trianthema portulacastrum, Atriplex canescens, Eriogonum deflexum, Fouquieria splendens, Beloperone californica, Cowania mexicana* var. *stansburiana, Olneya tesota, Acacia constricta, A. greggii, A. vernicosa,* and *Opuntia fulgida* var. *mammillata)*. Apparently the thick cuticles of many desert plants, such as *Agave, Opuntia,* and even *Asclepias albicans*, are composed mainly of substances that are not waxes.

### Summary

The yield and characteristics of the waxes from 42 species of plants native to southern Arizona were determined. Although a few have high yields of wax when expressed on the basis of amount of wax per unit area of plant surface, the majority of species contains only a small amount of wax. It was concluded that the often quoted statement, "plants indigenous to arid and hot regions have waxy cuticles," is untenable and should be modified to read "... wax-like cuticles." Some taxonomic relationships and some effects of sex on plant waxes were discussed.

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# Crystallization of Indian Beef Tallow Fatty Acids from Aqueous Ethanols

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THE EMERSOL continuous process (1) for commercial crystallization of beef tallow fatty acids into unsaturated (mainly oleic) and saturated (usually a 45:55 eutectic of palmitic and stearic) acids employs 90% methanol as solvent, a crystallization temperature of −12°C., and a solvent/acid ratio of 4. The choice of a polar solvent is based on the formation of needle-like crystals with good filtering and washing characteristics, the absence of the need for low crystallization temperatures, and the added advantage of miscibility with water by which further reduction of fatty acid solubility can easily be attained. In India, unlike industrially-advanced countries, methanol is scarce, but ethanol is comparatively cheap and abundant. Indigenous beef tallows, and indeed most Indian vegetable, animal, and fish fats, are considerably more saturated than their American or European counterparts (2, 3) so that crystallization conditions may well differ.

Emery Industries state that 95% ethanol can be used for solvent crystallization by the Emersol process, but details, to our knowledge, are unpublished and other dilutions have not been mentioned. Kane and Patel (4) have studied the crystallization of the mixed fatty acids of several fats, not including tallow, from aqueous 80% ethanol at 0°C. at a solvent/acid ratio of 10. Their choice of conditions was based on theoretical solubility considerations. Their aim was to replace the Twitchell lead-salt separation of saturated from unsaturated acids as an analytical procedure. Earlier studies on the use of ethanol for fatty acid crystallization include those of Raymond (5) and of Wolff (6). Ku (7) and Ralston and Hoerr (8) determined the solubilities of pure fatty acids in various dilutions of ethanol. Intersolubility effects limit the application of these values to a complex mixture. A study of the behavior of Indian beef tallow fatty acids on single-stage crystallization from ethanol in various aqueous dilutions is reported in this paper.