THE CONTRIBUTION OF SURFACE CHARACTERS TO THE WETTABILITY OF LEAVES

BY S. B. CHALLEN

From the Department of Pharmacognosy, School of Pharmacy, University of London, Brunswick Square, London, W.C.1

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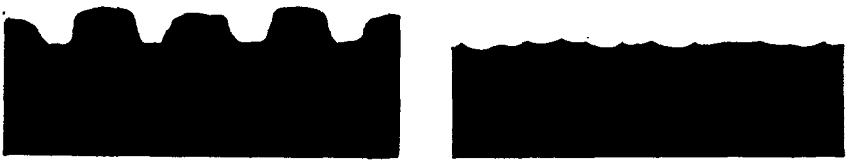
A method of preparing carnauba wax positive replicas of leaf surfaces is described and these have been used with other techniques to study some of the factors which govern the wetting of leaves by water. Leaves from four species of plants were used. It was found that macroscopic surface roughness was the chief factor preventing the wetting of *Festuca pratensis*. The contribution of surface chemistry and surface roughness is discussed also for results obtained with leaves of *Agropyron repens* and two species of *Papaver*.

THE distribution and retention of chemicals, which are applied to crops, is affected by the morphology of leaves, in particular the detailed structure of the surface. Variation of surface structure between plants affects the wetting when sprays are applied and this in turn affects the efficiency of the formulation[1]. Experiments have been made to assess the effects of various physical factors on the retention of spray droplets like surface tension of spray liquid, size, velocity and angle of incidence of impinging droplets[2]. Fundamental studies have shown that the magnitude of the contact angle for a liquid on a solid surface is influenced by the surface chemistry[3], the surface roughness, and the presence or absence of air films between droplet and surface[4]. According to Adam[3], the effect of roughness is to *increase* the apparent contact angle if the true (advancing) angle is greater than 90°, but to *decrease* it if the true angle is less than 90°. It is believed that the sub-microscopic surface roughness of some leaves, attributed to minute wax extrusions[5], is responsible for high contact angles (greater than 90°) in most plants[6] and the waxy coverings of leaves have been isolated, fractionated and analysed[7]. Reflection of droplets from surfaces or "droplet bounce" has been shown to occur with contact angles of 140° and the roughness of waxy leaf covering has been held responsible for reflection from pea leaves[2]. The contribution of macroscopic surface roughness as distinct from microscopic roughness of leaves has not been fully investigated. Furthermore, the separate effects of macroscopic surface roughness and surface chemistry of leaves in relation to wetting have not been studied and the object of the present work was to devise a method which could be used for this purpose.

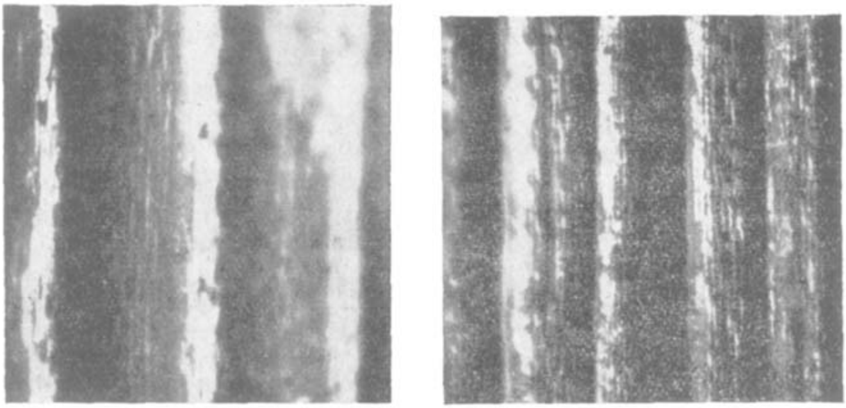
EXPERIMENTAL

Leaves were chosen of four species which showed marked macroscopical differences. Two of the species showed macroscopical differences between upper and lower surfaces. All were collected from plants cultivated in the same plot. The measurement of advancing contact angle was selected as a criterion of the wetting of leaf surfaces by water droplets and the method described by Fogg[8] was used. Determinations were made on water droplets of standard size placed on four different surfaces: (*a*) fresh leaves; (*b*) ether-washed leaves; (*c*) positive replicas of leaves prepared from carnauba wax the normal contact angle of which is 84°; and (*d*) carnauba wax replicas coated with beeswax the normal contact angle of which is 90°. Measurements were not attempted near major veins on leaves or near impressions of major veins on replicas. Leaves were washed in ether as described by Martin and Batt[7]. Carnauba wax



FIGS. 1 and 2. Wax replicas of the upper surfaces of *Festuca pratensis* and *Agropyron repens* respectively (end view × 35).

replicas, prepared as described below, were coated with a thin film of beeswax by immersion in a solution of white beeswax 5 per cent w/v in chloroform and then allowed to dry. With all wax replicas coated with beeswax the film was thin and did not alter the macroscopic roughness of the surface, although fine epidermal detail was not as clear as in the original. Smooth carnauba wax was similarly coated with beeswax as a reference surface for comparative experiments.



FIGS. 3 and 4. Wax replicas of the upper surfaces of *Festuca pratensis* and *Agropyron repens* respectively (photograph of surfaces × 70).

The Preparation of Carnauba Wax Replicas

A brass mould (5 cm. × 3 cm. × 1 cm.) consisting of two L-shaped pieces, resting on a separate brass plate generally used for section embedding, was found to be the most convenient receptacle. The brass plate was first greased with soft paraffin and a piece of fresh leaf, cut to size, placed on the surface. The mould was then put into position and a natural rubber latex* poured over the leaf surface until it was covered to a depth of ½ cm. and a square of linen placed on the surface of the liquid, to render the preparation stiffer when dry. After 24 hours the mould was taken apart and the leaf stripped from the negative replica. From this a positive replica on carnauba wax was prepared by pouring molten wax over the negative placed in the brass mould to a depth of ½ cm. After 24 hours the mould was taken apart and the negative stripped from the wax replica.

RESULTS

The wax replicas gave good facsimiles of the surface contours, especially the prominence of veins (Figs. 1 and 2) as well as the more detailed structure of the epidermis (Figs. 3 and 4). Carnauba wax gave better preparations than beeswax or hard paraffin and despite the brittle nature of the

TABLE I

RESULTS FOR LEAVES AND UNCOATED REPLICAS*

	Fresh leaves. Apparent contact angles		Ether washed leaves. Reduction in contact angle. Per cent of fresh leaves		Wax replica Reduction in contact angle. Per cent of smooth wax	
	upper surface	lower surface	upper surface	lower surface	upper surface	lower surface
Agropyron repens Ridges slight and trichomes on both surfaces	135°	138°	50	35	34	38
Festuca pratensis Ridges prominent only on upper surface, trichomes only on upper surface ..	110°	66°	30	Nil	58	16
Papaver somniferum Both surfaces glaucous (waxy)	149°	155°	51	65	23	30
Papaver orientale Only lower surface glaucous (waxy). Trichomes on both surfaces	30°	138°	Nil	50	35	16

* Each figure represents a mean of five determinations and no individual determination differs from the mean by more than 8 per cent.

replicas, the surfaces were hard, and therefore not easily damaged by scratching. The natural rubber latex was satisfactory for the preparation of negative replicas as these could be made without damaging the leaf surface and were sufficiently pliable to be stripped from the final wax positive replica. At least two wax replicas could be made from a single negative without loss of detail, but the negatives deteriorated on storage.

The contact angle for water droplets on smooth carnauba wax was found to be 84° and on carnauba wax coated with white beeswax 90°. The beeswax coated wax replica of *Festuca* (upper surface) gave a value of 154°, while the beeswax coated wax replicas of other leaves (different surfaces) gave values of about 90°. The only beeswax coated replica from which droplet reflection occurred was of the upper surface of *Festuca*. Other numerical information is tabulated (Table I).

* Natural rubber latex (H807) obtainable from S. Jones & Co., New Bridge Street, London, E.C.4.

Discussion

Leaves and Uncoated Replicas

For *Agropyron repens* the largest reduction in contact angle was observed after washing the leaf upper surface with ether. This suggests that the dominant factors affecting wetting of the upper surface are surface chemicals and their sub-microscopic roughness, these factors appear to be less effective on the lower surface. The largest reduction in contact angle for *Festuca pratensis* was obtained on wax replicas prepared from the upper surface and therefore it may be concluded that surface roughness, arising from ridges or trichomes or both, is the chief factor governing wettability. For the lower surface only a small reduction in contact angle was obtained by the wax replica method, and the ether washing method made no change in the contact angle. The lower surface is therefore more easily wetted than the upper; lack of roughness and surface wax being the main reasons.

For both *Papaver* species the largest reduction in contact angle was observed after washing leaves with ether; this occurred on the lower surfaces and would suggest that the main anti-wetting factors are the ether-removable surface chemicals and perhaps sub-microscopic roughness. The apparent contact angle for the upper surface of *P. orientale* is low and is not influenced by ether washing.

The limit of accuracy of the method does not permit further conclusions to be made about differences between other surfaces. The replicas do not record roughness contributed by trichomes and therefore their effect on water repellancy cannot be determined.

Coated Replicas

Provided there are no large differences in sub-microscopic wax roughness between coated replicas and the reference surface, the high contact angle obtained with *Festuca pratensis* can be attributed to macroscopic roughness already suggested by the results for uncoated replicas. This roughness is caused by the prominent parallel ridges of the leaf and allows air films to be trapped below water droplets and explains the reflection of droplets from the surface. This phenomenon cannot occur on the surface of uncoated replicas as the true contact angle is less than 90° when the liquid penetrates the hollows.

As the values obtained for coated replicas of *Agropyron* and *Papaver* were the same as for the reference surface and as droplet reflection did not occur; the high contact angles found for the fresh leaves may be attributed to sub-microscopic roughness of the surface chemicals; an examination of the waxy bloom of the leaf, by electron microscopy might confirm this. It was impossible to assess the effects of microscopic roughness with the beeswax coating technique since the detailed structure was impaired by the coating.

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