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# FOLIAR ASCORBIC ACID IN SOME ANGIOSPERMS

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**Key Word Index**—Angiospermae; leaves; ascorbic acid; vitamin C; nutrition; chemotaxonomy.

**Abstract**—The ascorbic acid (vitamin C) content of the leaves of 213 angiosperm species is recorded. The nutritional and taxonomic significance of the results is discussed.

## INTRODUCTION

The distribution of ascorbic acid (L-xyloascorbic acid, vitamin C) in edible fruits and vegetables is reasonably well-documented (e.g. [1]). Information about its more widespread occurrence in plants is, however, sparse and uneven. Plants supposedly valuable as antiscorbutics were frequently referred to in herbals and medical botany texts (see Discussion) but their ascorbic acid content has never been fully assessed. Recent indications that the optimal intake of ascorbic acid could well be in excess of the recommended daily amount (30 mg), coupled with the possibility that ascorbic acid from natural sources is of greater value to the body than the synthetically-produced vitamin [2, 3] prompted us to make a survey of foliar ascorbic acid concentrations in some angiosperm species.

Ascorbic acid is easily assayed in plant material. It is widely distributed in plants and although the value of such 'ubiquitous' molecules as a taxonomic aid has been discounted by some workers, nevertheless any clearly definable areas of unevenness in the distribution pattern would be of taxonomic interest.

## RESULTS AND DISCUSSION

The results are summarized in Table 1. Perhaps the most interesting finding to emerge from the survey was the comparatively high concentration of ascorbic acid in the leaves of a wide range of angiosperms. It would appear that cultivated leafy vegetables are, on balance, a poorer source of vitamin C than their 'wild' counterparts. The calculated mean ascorbic acid concentration for 'foliar' vegetables (broccoli, Brussels sprouts, cabbage, celery, cress, leeks, mustard, parsley, spinach, water-cress) is 57.3 $\pm$ 8.3 mg/100 g (mean with standard error of mean) [1]. The corresponding value for the 213 wild species analysed in our survey was 161.7 $\pm$ 7.5 mg/100 g. If, at some stage in its evolution, humankind ingested substantial amounts of angiosperm foliage, its ascorbic acid intake could have been quite considerable; this would lend credence to the suggestion that it was during such a 'foliarphagic' phase of human evolution that the ability to synthesize the vitamin was lost.

Equally so, the consumption of the leaves of virtually any species would have provided a cure for scurvy. The emergence of scurvy grass (*Cochlearia officinalis*) as the traditional antiscorbutic agent was therefore purely fortuitous and was in no way related to any superiority as a source of vitamin C. Of the 213 species analysed by us, 158 had an ascorbic acid content greater than that of *Cochlearia officinalis* (Table 1), whose ascorbic acid content (82.8 mg/100 g) is only half the mean value for the total sample. John Ray [4] (quoting Solemander) could hardly have been less correct when he wrote "... from the frequency of the plants that sprung up naturally in any region he would easily gather what endemial Diseases the Inhabitants thereof were subject to: So in Denmark, Friezeland and Holland, where the scurvy usually reigns, the proper remedy thereof, Scurvy grass, both plentifully grow".

By the same token, virtually any of the 'antiscorbutic' plants favoured by writers in the eighteenth and nineteenth centuries would almost certainly have cured scurvy. Amongst these were *Cardamine pratense* [5, 6], *Cochlearia officinalis* [7–10], *Fumaria officinalis* [8, 11], *Galium aparine* [12], *Nasturtium officinale* [9, 10] and *Urtica dioica* [9, 12]. The remedies most widely favoured by sixteenth and seventeenth century writers were *Cochlearia officinalis*, *Nasturtium officinale* and *Veronica beccabunga* (see for example [13]).

It is somewhat surprising that none of the richer sources of ascorbic acid emerged as an antiscorbutic, especially as there is evidence that some of them, such as *Primula* spp., were extensively used not only in medicine (see for example [14]) but also as dietary adjuvants ["Their leaves (*Primula veris*) may be used promiscuously" [9]; "The leaves were formerly eaten in salad ..." [5]]. On the other hand, herbals cautioned their readers against the indiscriminate use of *Mercurialis perennis*—another good source of ascorbic acid—because of the poisonous properties. It may be noted that the mean values for the ascorbic acid content of *Primula vulgaris*, *P. veris* and *Mercurialis perennis* rank with the highest hitherto recorded for foliar ascorbic acid; the concentration in some individual samples of *P. vulgaris* exceeding 1% of the fresh weight. Booth and Constable [15] regarded the concentrations of up to 0.5% which they found in the leaves of *Iris* spp. as the highest reported in the literature at the time of their work. They attributed the high concentration in part to the 'exceptionally low' ascorbic acid oxidase activity of *Iris* leaves. Our own studies with *Primula vulgaris* tended to confirm this; after 90 min at

Table 1.

| Family | Species | Ascorbic acid (mg/100 g) |
|---|---|---|
| Alismataceae | *Alisma plantago-aquatica* L. | 80.7 ± 1.9 (2) |
| Aquifoliaceae | *Ilex aquifolium* L. | 72.3 ± 4.1 (4) |
| Araceae | *Arum maculatum* L. | 170.4 ± 26.5 (3) |
| Araliaceae | *Hedera helix* L. | 50.4 ± 7.6 (4) |
| Balsaminaceae | *Impatiens glandulifera* Royle | 212.1 ± 14.3 (3) |
| Betulaceae | | *357.9 ± 29.9* |
| | *Alnus glutinosa* (L.) Gaertner | 273.2 ± 32.5 (4) |
| | *Betula pubescens* Ehrh. | 415.0 ± 25.1 (6) |
| Boraginaceae | | *47.5 ± 4.2* |
| | *Echium vulgare* L. | 50.5 ± 5.2 (4) |
| | *Myosotis arvensis* (L.) Hill | 32.9 ± 6.2 (5) |
| | *Pentaglottis sempervirens* (L.) Tausch ex L. H. Bailey | 43.7 ± 10.4 (3) |
| | *Symphytum × uplandicum* Nyman | 66.4 (1) |
| | *S. officinale* L. | 65.4 ± 1.7 (3) |
| Buxaceae | *Buxus sempervirens* L. | 146.2 ± 12.5 (5) |
| Caprifoliaceae | | *239.8 ± 34.8* |
| | *Lonicera periclymenum* L. | 119.5 ± 7.8 (4) |
| | *Sambucus nigra* L. | 291.0 ± 21.4 (3) |
| | *Symphoricarpos rivularis* Suksdorf | 349.1 ± 24.9 (3) |
| Caryophyllaceae | | *176.9 ± 25.2* |
| | *Cerastium glomeratum* Thuill | 83.2 ± 3.0 (3) |
| | *Lychnis flos-cuculi* L. | 165.0 ± 5.3 (4) |
| | *Saponaria officinalis* L. | 401.3 ± 5.9 (4) |
| | *Silene dioica* (L.) Clairv. | 214.7 ± 80.8 (2) |
| | *S. vulgaris* (Moench) Garcke | 86.9 ± 7.2 (4) |
| | *Stellaria graminea* L. | 217.9 ± 21.9 (3) |
| | *S. neglecta* Weihe | 62.9 ± 1.9 (3) |
| Celastraceae | *Euonymus europaeus* L. | 218.6 ± 22.3 (3) |
| Cistaceae | *Helianthemum nummularium* (L.) Miller | 239.7 ± 32.6 (4) |
| Compositae | | *60.3 ± 2.7* |
| | *Achillea millefolium* L. | 49.7 ± 6.5 (3) |
| | *Artemisia vulgaris* L. | 41.2 ± 14.3 (4) |
| | *Bellis perennis* L. | 72.7 ± 14.2 (4) |
| | *Centaurea nigra* L. | 111.9 ± 2.6 (3) |
| | *Cicerbita macrophylla* | 20.6 ± 5.8 (6) |
| | *Cichorium intybus* L. | 56.3 ± 3.4 (4) |
| | *Cirsium arvense* (L.) Scop. | 51.6 ± 7.3 (3) |
| | *Eupatorium cannabinum* L. | 85.5 ± 14.9 (3) |
| | *Hieracium brunneocroceum* Pugsley | 28.1 ± 1.4 (4) |
| | *Hypochoeris radicata* L. | 42.8 ± 3.6 (4) |
| | *Inula crithmoides* L. | 26.5 ± 1.1 (4) |
| | *Lapsana communis* L. | 81.4 ± 5.1 (4) |
| | *Leucanthemum vulgare* Lam. | 91.7 ± 9.6 (7) |
| | *Matricaria matricaroides* (Less.) Porter | 81.2 ± 5.6 (4) |
| | *M. recutita* L. | 64.9 ± 5.2 (4) |
| | *Pulicaria dysenterica* (L.) Bernh. | 57.7 ± 3.7 (4) |
| | *Senecio jacobaea* L. | 88.1 ± 5.7 (4) |
| | *S. squalidus* L. | 26.5 ± 8.0 (4) |
| | *S. vulgaris* L. | 51.0 ± 7.0 (2) |
| | *Sonchus oleraceus* L. | 48.9 ± 10.1 (3) |
| | *Tanacetum parthenium* (L.) Schultz Bip. | 54.7 ± 6.4 (4) |
| | *T. vulgare* L. | 55.3 ± 4.6 (4) |
| | *Taraxacum officinale* Weber | 72.6 ± 9.0 (5) |
| Convolvulaceae | | *140.3 ± 9.9* |
| | *Calystegium sepium*, subsp. *sepium* (L.) R. Br. | 137.1 ± 10.1 (4) |
| | *C. sepium*, subsp. *silvatica* (Kit) Maire | 141.1 ± 13.5 (3) |
| Cornaceae | *Cornus sanguinea* L. | 169.5 ± 14.8 (4) |
| Corylaceae | *Corylus avellana* L. | 318.5 ± 38.7 (3) |
| Crassulaceae | *Sedum acre* L. | 50.8 ± 3.8 (3) |
| Cruciferae | | *146.1 ± 15.4* |

1. (*Contd.*)

| ly | Species | Ascorbic acid (mg/100 g) |
|---|---|---|
| | *Alliaria petiolata* (Bieb.) Cavara & Grande | 304.4 (1) |
| | *Arabidopsis thaliana* (L.) Heynh. | 132.1 ± 8.0 (2) |
| | *Capsella bursa-pastoris* (L.) Medicus | 136.2 ± 12.0 (4) |
| | *Cardamine pratensis* L. | 333.3 (1) |
| | *Cochlearia officinalis* L. | 82.8 ± 16.7 (6) |
| | *Nasturtium officinale* R. Br. | 83.1 ± 4.3 (4) |
| | *Rorippa sylvestris* (L.) Besser | 134.7 ± 3.0 (2) |
| | *Sinapis arvensis* L. | 129.6 ± 5.8 (2) |
| | *Sisymbrium officinale* (L.) Scop. | 216.5 ± 27.2 (4) |
| :oreaceae | *Tamus communis* L. | 164.4 ± 9.1 (4) |
| ıcaceae | | *82.5 ± 10.9* |
| | *Dipsacus fullonum* L. | 132.4 ± 3.6 (3) |
| | *Knautia arvensis* (L.) Coulter | 76.6 ± 10.9 (6) |
| | *Succisa pratensis* Moench. | 44.5 ± 3.6 (3) |
| ;naceae | *Hippophae rhamnoides* L. | 357.6 ± 21.1 (2) |
| setaceae | *Equisetum sylvaticum* L. | 87.7 ± 3.0 (4) |
| .ceae | | *297.0 ± 26.2* |
| | *Calluna vulgaris* (L.) Hull | 267.6 ± 36.4 (3) |
| | *Erica tetralix* L. | 394.1 ± 20.8 (3) |
| | *Vaccinium myrtillus* L. | 246.1 ± 29.0 (4) |
| ıorbiaceae | | *359.3 ± 49.5* |
| | *Euphorbia amygdaloides* L. | 402.1 ± 14.3 (3) |
| | *E. heliosopia* L. | 185.0 ± 24.2 (4) |
| | *E. paralias* L. | 228.8 ± 23.3 (3) |
| | *Mercurialis perennis* L. | 598.3 ± 50.2 (4) |
| ariaceae | | *223.9 ± 18.4* |
| | *Corydalis lutea* (L.) DC. | 194.5 ± 6.1 (4) |
| | *Fumaria officinalis* L. | 253.4 ± 31.1 (4) |
| ianaceae | | *248.5 ± 8.5* |
| | *Centaurium erythraea* Rafn | 230.3 ± 13.2 (4) |
| | *C. littorale* (D. Turner) Gilmour | 263.1 ± 5.8 (5) |
| ıniaceae | | *175.2 ± 13.8* |
| | *Erodium cicutarium* (L.) L'Hér | 149.0 ± 4.8 (4) |
| | *Geranium dissectum* L. | 261.2 ± 2.6 (4) |
| | *G. lucidum* L. | 121.4 ± 14.5 (4) |
| | *G. molle* L. | 200.1 ± 41.4 (2) |
| | *G. robertianum* L. | 156.8 ± 21.4 (4) |
| mineae | | *156.4 ± 16.5* |
| | *Avena fatua* L. | 247.7 ± 9.1 (3) |
| | *Dactylis glomerata* L. | 87.5 ± 16.1 (4) |
| | *Holcus lanatus* L. | 160.7 ± 14.1 (3) |
| | *Phleum pratense* L. | 154.7 ± 12.2 (6) |
| ıericaceae | | *326.7 ± 25.7* |
| | *Hypericum elodes* L. | 202.5 ± 13.0 (3) |
| | *H. humifusum* L. | 381.1 ± 14.4 (3) |
| | *H. perforatum* L. | 359.4 ± 22.8 (4) |
| | *H. tetrapterum* Fries | 393.4 ± 63.7 (3) |
| aceae | | *141.8 ± 43.2* |
| | *Iris foetidissima* L. | 225.7 ± 72.0 (2) |
| | *I. pseudacorus* L. | 85.8 ± 24.0 (3) |
| caceae | *Juncus effusus* L. | 95.8 ± 10.4 (3) |
| ıiatae | | *103.3 ± 6.2* |
| | *Ajuga reptans* L. | 121.2 (1) |
| | *Clinopodium vulgare* L. | 75.8 ± 4.8 (4) |
| | *Galeopsis tetrahit* L. | 175.3 ± 18.4 (4) |
| | *Glechoma hederacea* L. | 78.9 ± 16.7 (4) |
| | *Lamium album* L. | 153.4 ± 12.4 (4) |
| | *L. purpureum* L. | 45.4 ± 11.9 (4) |
| | *Lamiastrum galeobdolon* (L.) Ehrend & Palatschek | 135.3 ± 41.5 (4) |
| | *Lycopus europaeus* L. | 99.2 ± 6.6 (5) |
| | *Mentha aquatica* L. | 84.4 ± 13.8 (4) |

Table 1. (*Contd.*)

| Family | Species | Ascorbic acid (mg/100 g) |
|---|---|---|
| | *Origanum vulgare* L. | 98.4 ± 16.9 (4) |
| | *Prunella vulgaris* L. | 144.0 ± 4.5 (4) |
| | *Stachys palustris* L. | 146.5 ± 10.8 (4) |
| | *S. sylvatica* L. | 56.9 ± 4.6 (6) |
| | *Teucrium scorodonia* L. subsp. | 126.7 ± 16.6 (4) |
| | *Thymus praecox* Opiz subsp. *arcticus* (Durand) Jalas | 68.7 ± 26.1 (3) |
| Lauraceae | *Laurus nobilis* L.* | 72.0 ± 3.1 (4) |
| Liliaceae | | *158.3 ± 21.5* |
| | *Hyacinthoides non-scripta* (L.) Chouard ex Rothm. | 110.6 ± 8.0 (3) |
| | *Narthecium ossifragium* (L.) Hudson | 122.1 (1) |
| | *Polygonatum multiflorum* (L.) All. | 218.1 ± 5.1 (3) |
| Lythraceae | | *209.0 ± 27.2* |
| | *Lythrum hyssopifolia* L. | 276.5 ± 19.6 (4) |
| | *L. salicaria* L. | 141.5 ± 5.5 (4) |
| Magnoliaceae | | *82.3 ± 17.2* |
| | *Magnolia denudata** | 49.6 ± 5.0 (3) |
| | *M. saligipolia** | 132.1 ± 10.1 (3) |
| | *M. stellata** | 65.2 ± 12.0 (3) |
| Malvaceae | | *142.1 ± 14.4* |
| | *Malva moschata* L. | 157.2 ± 17.1 (4) |
| | *M. sylvestris* L. | 127.0 ± 22.8 (4) |
| Menyanthaceae | *Nymphoides peltata* (S. G. Gmelin) O. Kuntze | 25.0 ± 5.8 (3) |
| Oleaceae | *Fraxinus excelsior* L. | 151.9 ± 7.3 (3) |
| Onagraceae | | *176.5 ± 9.4* |
| | *Chamerion angustifolium* (L.) J. Holub | 223.7 ± 1.8 (4) |
| | *Circaea lutetiana* L. | 154.3 ± 9.8 (4) |
| | *Epilobium hirsutum* L. | 221.9 ± 12.2 (5) |
| | *E. montanum* L. | 179.1 ± 16.2 (3) |
| | *Oenothera biennis* L. | 132.3 ± 13.8 (3) |
| | *O. erythrosepala* Borbás | 136.8 ± 3.1 (3) |
| Orchidaceae | | *65.2 ± 3.1* |
| | *Dactylorhiza incarnata* (L.) Soó | 60.7 (1) |
| | *Orchis mascula* (L.) L. | 67.4 ± 3.6 (3) |
| Papaveraceae | | *127.6 ± 9.5* |
| | *Chelidonium majus* L. | 162.4 ± 29.4 (3) |
| | *Glaucium flavum* Crantz | 129.8 ± 17.6 (4) |
| | *Meconopsis cambrica* (L.) Vig. | 99.8 ± 15.1 (4) |
| | *Papaver dubium* L. | 127.2 ± 7.2 (4) |
| Papilionaceae | | *230.8 ± 13.7* |
| | *Lathyrus latifolius* L. | 98.4 ± 28.8 (4) |
| | *L. pratensis* L. | 379.2 ± 16.6 (3) |
| | *Lotus corniculatus* L. | 167.3 ± 18.9 (4) |
| | *Lupinus arboreus* Sims | 218.8 ± 4.4 (3) |
| | *Medicago lupulina* L. | 291.3 ± 25.6 (4) |
| | *Melilotus altissima* Thuill. | 256.5 ± 8.1 (4) |
| | *Ononis repens* L. | 136.0 ± 10.0 (5) |
| | *Trifolium dubium* Sibth. | 313.8 ± 10.1 (4) |
| | *T. pratense* L. | 221.1 ± 26.5 (5) |
| | *T. repens* L. | 222.0 ± 5.5 (4) |
| | *Vicia cracca* L. | 348.6 ± 15.3 (4) |
| | *V. sepium* L. | 226.9 ± 93.0 (4) |
| Plantaginaceae | | *49.9 ± 4.1* |
| | *Plantago lanceolata* L. | 52.1 ± 5.2 (3) |
| | *P. major* L. | 49.4 ± 7.1 (4) |
| Polygalaceae | *Polygala vulgaris* L. | 195.4 ± 17.7 (4) |
| Polygonaceae | | *126.9 ± 6.1* |
| | *Polygonum persicaria* L. | 123.7 ± 9.5 (4) |
| | *Rumex obtusifolius* L. | 134.9 ± 8.9 (4) |
| Primulaceae | | *391.3 ± 46.2* |
| | *Anagallis arvensis* L. | 153.2 ± 32.3 (4) |
| | *A. tenella* (L.) L. | 207.2 ± 9.5 (3) |

Table 1. (*Contd.*)

| Family | Species | Ascorbic acid (mg/100 g) |
|---|---|---|
| | *Glaux maritima* L. | 155.9 ± 13.3 (3) |
| | *Lysimachia nemorum* L. | 234.0 ± 15.1 (5) |
| | *L. vulgaris* L. | 194.2 ± 11.6 (4) |
| | *Primula denticulata* Smith* | 367.4 ± 6.2 (3) |
| | *P. veris* L. | 590.2 ± 57.5 (9) |
| | *P. vulgaris* Hudson | 804.8 ± 148.4 (5) |
| Ranunculaceae | | *121.3 ± 10.0* |
| | *Anemone nemorosa* L. | 92.0 ± 21.0 (4) |
| | *Aquilegia vulgaris* L. | 236.6 ± 14.7 (3) |
| | *Caltha palustris* L. | 98.9 (1) |
| | *Clematis vitalba* L. | 103.8 ± 22.5 (7) |
| | *Ranunculus bulbosus* L. | 105.5 ± 11.7 (3) |
| | *R. ficaria* L. | 176.1 ± 23.6 (2) |
| | *R. flammula* L. | 122.5 ± 7.3 (4) |
| | *R. omiophyllus* Ten. | 104.9 (1) |
| | *R. repens* L. | 81.4 ± 2.4 (3) |
| | *R. sceleratus* L. | 102.8 ± 2.0 (3) |
| Resedaceae | *Reseda lutea* L. | 259.9 ± 5.6 (4) |
| Rosaceae | | *275.9 ± 15.5* |
| | *Agrimonia eupatoria* L. | 275.6 ± 18.1 (4) |
| | *Crataegus monogyna* Jacq. | 441.5 ± 23.3 (3) |
| | *Filipendula ulmaria* (L.) Maxim | 216.0 ± 19.0 (4) |
| | *Fragaria vesca* L. | 351.6 ± 10.3 (3) |
| | *Geum urbanum* L. | 188.9 ± 33.1 (4) |
| | *Potentilla anserina* L. | 316.0 ± 39.4 (5) |
| | *P. erecta* (L.) Raüschel | 270.5 ± 28.7 (3) |
| | *P. reptans* L. | 248.7 ± 22.0 (3) |
| | *Rubus fruticosus* L. | 227.1 ± 19.6 (5) |
| | *Sorbus aucuparia* L. | 247.5 ± 27.2 (3) |
| Rubiaceae | | *78.2 ± 7.8* |
| | *Galium aparine* L. | 83.8 ± 6.0 (3) |
| | *G. odoratum* (L.) Scop. | 46.7 ± 4.7 (3) |
| | *G. saxatile* L. | 70.0 ± 8.0 (4) |
| | *G. verum* L. | 114.9 ± 12.7 (3) |
| Saxifragaceae | *Saxifraga spathularis* × *umbrosa** | 213.9 ± 17.0 (4) |
| Scrophulariaceae | | *118.5 ± 9.4* |
| | *Cymbalaria muralis* P. Gaertner, B. Meyer et Scherb. | 92.3 ± 4.6 (4) |
| | *Digitalis purpurea* L. | 76.5 ± 25.8 (4) |
| | *Euphrasia officinalis* L. | 70.6 ± 2.3 (4) |
| | *Linaria purpurea* (L.) Miller | 169.4 ± 2.3 (3) |
| | *L. repens* (L.) Miller | 181.0 ± 38.3 (2) |
| | *L. vulgaris* Miller | 119.6 ± 13.0 (5) |
| | *Odontites verna* (Bellardi) Dumort | 105.1 ± 6.4 (5) |
| | *Rhinanthus minor* L. | 94.4 ± 14.2 (5) |
| | *Scrophularia nodosa* L. | 231.9 ± 37.1 (4) |
| | *Veronica agrestis* L. | 74.4 ± 7.5 (2) |
| | *V. arvensis* L. | 121.4 (1) |
| Solanaceae | | *132.3 ± 14.9* |
| | *Solanum dulcamara* L. | 140.4 ± 18.0 (7) |
| | *S. nigrum* L. | 103.9 ± 13.2 (3) |
| Taxaceae | *Taxus baccata* L. | 132.9 ± 7.2 (3) |
| Umbelliferae | | *146.4 ± 11.9* |
| | *Apium nodiflorum* (L.) Lag. | 139.6 ± 5.9 (4) |
| | *Berula erecta* (Hudson) Coville | 163.9 ± 1.8 (2) |
| | *Foeniculum vulgare* Miller | 127.0 ± 7.7 (3) |
| | *Heracleum sphondylium* L. | 179.2 ± 22.1 (4) |
| | *Oenanthe crocata* L. | 152.8 ± 23.7 (2) |
| | *Sanicula europaea* L. | 56.6 ± 6.3 (3) |
| | *Smyrnium olusatrum* L. | 249.1 (1) |
| Urticaceae | *Urtica dioica* L. | 169.2 ± 13.6 (4) |

Table 1. (*Contd.*)

| Family | Species | Ascorbic acid (mg/100 g) |
|---|---|---|
| Valerianaceae | | *96.7 ± 13.7* |
| | *Centranthus ruber* (L.) DC. | 120.0 ± 15.2 (4) |
| | *Valeriana officinalis* L. | 65.6 ± 2.1 (3) |
| Verbenaceae | *Verbena officinalis* L. | 111.8 ± 10.6 (3) |
| Violaceae | | *187.6* ± 25.9 |
| | *Viola palustris* L. | 243.5 ± 10.6 (3) |
| | *V. riviniana* Reichenb. | 131.7 ± 10.4 (3) |

Mean values with standard errors; the figures in parentheses are the number of 'sites' from which samples were analysed. Each sample, in turn, consisted of pooled leaves from four plants. Where more than one species from a family was analysed, a mean value for the family was calculated; these values are italicized.

*Cultivated species.

room temperature a 10% w/v buffered homogenate of *Primula vulgaris* had lost 26.5% of its initial ascorbic acid concentration compared with a loss of 24.0% in a control solution matched for pH and ascorbic acid concentration.

The possible taxonomic significance of these results merits some discussion. Plant biochemists frequently introduce into their science a somewhat arbitrary and artificial distinction between primary and secondary metabolites. The widespread, but quantitatively disparate, distribution of ascorbic acid in angiosperm leaves underlines the difficulties inherent in such a division. The apparently ubiquitous presence of ascorbic acid in angiosperm tissues would appear to point to an essential role in the "survival and well-being of the organism"—a characteristic of primary metabolites [16]. On the other hand, the failure to ascribe to ascorbic acid a specific and universal role in plant metabolism would be more in keeping with the features of a secondary metabolite.

It is generally assumed that secondary metabolites (such as flavonoids) with a disparate, 'all or none' type of distribution pattern are a more useful taxonomic aid than the more generally distributed primary metabolites. "Substances that are ubiquitous in living organisms are valueless for such purposes as, for example, glucose and other sugars, about twenty common amino acids which form the basis of all proteins, simple fatty acids, etc." [17].

It is difficult, unreservedly, to accept statements of this type. Differences of degree (or, in chemical terms, of concentration) as well as of kind, may have a considerable taxonomic value. Ascorbic acid, although present in the leaves of all angiosperms studied, has a very uneven pattern of concentration distribution. The concentration in a particular plant will reflect, primarily, a balance between three main factors: (i) the biosynthetic capacity for ascorbic acid; (ii) the activity of enzymic degradative systems (mainly ascorbate oxidase, EC 1.10.3.3) and dehydroascorbatase [18]; and (iii) the activity of the glutathione: dehydrogenase (ascorbate) 'protective' system, EC 1.8.5.1 [3].

The respective activities of these systems will reflect, in the final analysis, the genetic potential of the plant and unevenesses in the ascorbic acid concentration distribution pattern could therefore have a taxonomic significance, albeit one of limited application. Two features, however, would vitiate, to a certain extent, the widespread, and uncritical, use of ascorbic acid as a taxonomic aid, namely: (i) the belief that evolutionary parallelism and convergence have introduced disparities at a number of separate points in the distribution pattern; and (ii) the possibility that environment-induced changes occur in the concentration pattern.

There are, in any case, considerable difficulties in using a single chemical characteristic as an arbiter in deciding between alternative evolutionary trends. In the case of ascorbic acid one may fairly ask whether it is an increase in ascorbic acid concentration or a decrease that is to be regarded as a feature of the more advanced taxons. Too often one is forced to assemble chemical data against a poorly-structured taxonomic background. As Heywood [19] has pointed out, "one is forced to deal with 'precise' chemical characteristics in an imprecise taxonomic-evolutionary background". Takhtajan's point [20] that chemical surveys are of more value in helping systematists to decide between alternative views, than as a pointer to evolutionary trends, would appear to be particularly apposite in the case of ascorbic acid; it could even be argued that attempts to reveal an overall pattern in ascorbic acid distribution are likely to tell us more about the evolution of plant ascorbic acid than about the evolution of angiosperms *per se*.

Bearing in mind these limitations, reference to the ascorbic acid distribution pattern reveals some interesting features. Distribution between families is obviously non-random as evidence by the highly significant difference between different families.

A relatively low concentration (all species examined < 120 mg/100 g) is characteristic of certain families (e.g. Boraginaceae, Compositae, Rubiaceae) and a high concentration (all species > 150 mg/100 g) of others (e.g. Ericaceae, Euphorbiaceae, Primulaceae). Of interest is the picture that emerges when the distribution pattern is viewed against some of the tentative structures proposed for angiosperm evolution. Thus the Compositae (and, to a certain extent, the Boraginaceae and the Rubiaceae) regarded by most taxonomists as an 'advanced' taxon has a significantly lower ascorbic acid concentration than families usually regarded as closer to the more basal Ranalean complex. It would appear that the highest concentrations are associated with families of more or less intermediate evolutionary location, such as the Euphorbiaceae and the Primulaceae [20–22].

The mean ascorbic acid concentration of those families falling within the Asteridae grouping in Cronquist's system (Boraginaceae, Compositae, Convolvulaceae, Labiatae, Plantaginaceae, Rubiaceae, Scrophulariaceae, Solanaceae, Valerianaceae) was $112.4 \pm 16.7$ mg/100 g; this compared with corresponding values of $217.7 \pm 22.0$ for the Rosidae (Buxaceae, Euphorbiaceae, Leguminosae, Rosaceae, Saxifragaceae, Umbelliferae) and $244.2 \pm 36.2$ for the Dilleniidae (Cruciferae, Ericaceae, Malvaceae, Primulaceae, Violaceae). Statistical analyses (Student's $t$-test and Mann test) revealed a highly significant ($P < 0.01$) difference between the mean value for the Asteridae and the means of both the Rosidae and the Dilleniidae. Of the eighteen families in which four or more species were examined, the three with lowest ascorbic acid concentrations (Boraginaceae, Compositae, Rubiaceae) were from Cronquist's Asteridae. Results of this type could perhaps offer some support for the type of classification outlined by Cronquist, but obviously a much greater range of species should be analysed before any firm conclusions may be drawn.

## EXPERIMENTAL

*Samples.* Almost all the samples were from sites in southern Wales within a 25 mile radius of Cardiff (Caerdydd). In the majority of cases leaves from at least three plants were sampled from each of four separate sites. With less common plants this sampling procedure was obviously not always practicable. In the majority of cases leaves were removed without uprooting the plants. Analyses were completed within 2–4 hr of collection during which period there was no significant fall in the foliar ascorbic acid concn. All plants were assayed when in the flowering stage. This was done: (i) to determine the ascorbic acid content in all plants at the same stage in their physiological development; and (ii) to facilitate identification of the samples. Only specimens that were positively identified by two observers working independently were analysed. All the species were analysed during the period April–October 1982. The nomenclature is that of Clapham *et al.* [23].

*Ascorbic acid.* This was determined by the 2,6-dichlorophenolindophenol dye method [24, 25]. The ascorbic acid was extracted by grinding a weighed sample of the leaves (between 0.5 and 2.0 g) with a small amount of sand and 6% w/v metaphosphoric acid. The extract was made up accurately to a suitable vol. (usually 10–20 ml), mixed and filtered. 5 ml of the filtrate was titrated against standard 2,6-dichlorophenolindophenol dye of which 1 ml ≡ 0.2 mg ascorbic acid; the dye had been previously standardized by titration against a 0.02% standard soln of ascorbic acid in 6% metaphosphoric acid. When the colour of an extract interfered with the detection of the titration end-point (as for example with species of *Hypericum* and *Linaria*), an electrometric titration modification was used) [26]. In some cases where the apparent ascorbic acid concn was abnormally high (e.g. in the *Primula* genus and in *Mercurialis perennis*), the identification of the ascorbic acid was confirmed by TLC of an HOAc extract on silica gel plates using $C_6H_6$–$Me_2CO$–HOAc–MeOH (14:1:1:4) and 2,6-dichlorophenolindophenol soln (1 ml ≡ 0.1 mg ascorbic acid) for detection.

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