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Morphological leaf-variability of West Caucasian *Hedera* L. (Araliaceae) species

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Summary: Two ivy species from Russia and Ukrainia, *Hedera helix* and *H. colchica*, were investigated to clarify which metric leaf characters are most suitable for distinguishing these species in fieldwork conditions. Multivariate visualisation methods (like principal component analysis and classification trees) show that the most practicable characters are the lengths of lamina "diagonal", petiole and internode. Crimean ("*Hedera taurica*") populations do not differ significantly from Caucasian *H. helix*.

Zusammenfassung: Wir untersuchten zwei Efeu-Arten aus Russland und der Ukraine, *Hedera helix* und *H. colchica*, um herauszufinden, welche Blattmerkmale sich am ehesten dazu eignen, diese beiden Arten bei der Feldarbeit zu unterscheiden. Multivariate Methoden zeigen, dass die Länge der Diagonale der Lamina sowie die Längen von Blattstiel und Internodium die am besten geeigneten Merkmale sind. Populationen der Halbinsel Krim (*H. taurica*) unterscheiden sich nicht signifikant von *H. helix*-Populationen aus dem Kaukasus.

Keywords: *Hedera helix*, *Hedera colchica*, *Hedera taurica*, Araliaceae, leaf characters, morphometrics, determination

Two ivy (*Hedera* L.) species are growing in South Russia and the Ukraine: *Hedera helix* L. and *H. colchica* (C. Koch) C. Koch. Some authors accept a third species, *H. taurica* Carr. for Crimean plants (RUBTSOV, 1972). Usually, it is very hard to distinguish these species from each other. The situation is related with a high variability of leaf shapes and sizes, which are commonly used for determination. Another characters to distinguish ivy species are the **number of chromosomes** [*H. helix* 2n = 48, *H. colchica* 2n = 192] (VARGAS et al. 1999), **smell** [pungent and nutmeg-like] (ZERNOV 2002) and the **structure of leaf trichomes** [stellate or plate-like] (LUM & MAZE 1989; ACKERFIELD 2001; ACKERFIELD & WEN 2002). Unfortunately, all mentioned characters are more or less unsuitable for fieldwork. So the goal of our investigation was to find out some optimal metric characters which can be used for determination of these species during field observations.

Materials & Methods

The analysed material was collected in the Krasnodar region of Russia (Tuapse and Big Sochi districts) and Crimea. Only these regions of European Russia and the Ukraine have warm temperate weather conditions. The work was carried out in spring 2002 and 2003. We investigated 8 localities in Caucasus and 20 localities in Crimea. Totally 346 leaves were measured. Most characters (except structure of trichomes) were measured during fieldwork.

Ivy has at least three types of shoots: (1) vegetative, ground-based; (2) vegetative, trunk-based and (3) generative. Shoots with long and short internodes also exist, but we used leaves only from long-internode shoots. On each shoot, leaves periodically change their size from the shoot base upwards: at the beginning of each "period" they are small, than they become bigger and at the end of the period smaller again. Such period we called “series” according to KRENKES (1933) point of view. We measured all leaves in one (usually top) series from several shoots in each locality.

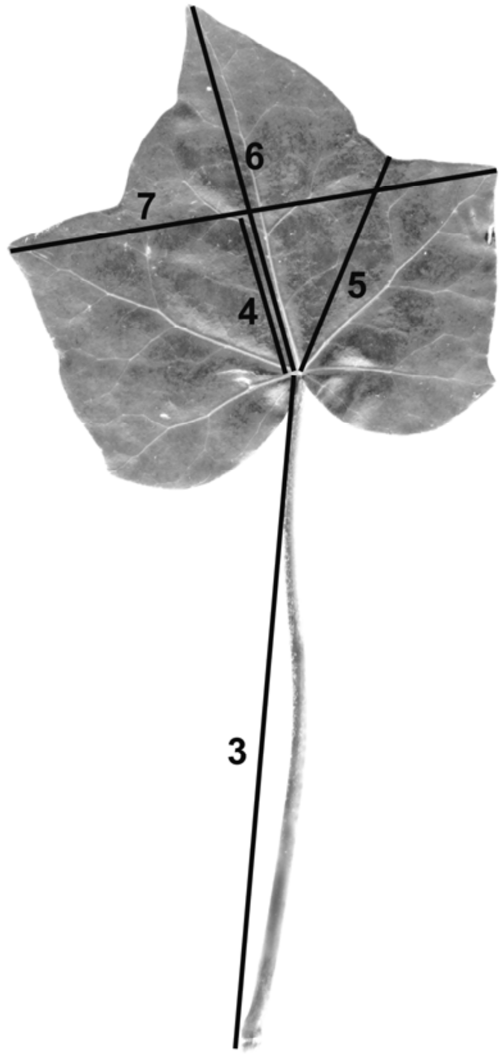

Figure 1. Main metric characters.

The following characters were observed (Fig. 1):

(1) TIP.POB: shoot type (0 — ground-based; 1 — trunk-based; 2 — generative);
(2) L.MEZHD: length of an internode (from the base of the petiole), mm;
(3) L.CHER: length of a petiole, mm;
(4) W.LOC: position of a greatest width of a leaf, mm;
(5) DIAG: length of the “diagonal” of a lamina i.e. the distance from the lamina base point to the right apical cut, mm;
(6) L.MAX: highest length of a lamina, mm;
(7) W.MAX: highest width of a leaf, mm;

(8) PARTS: number of the leaf lobes;
(9) SMELL: smell type from pulverised leaves (pungent or nutmeg-like) and
(10) TRICH: structure of the trichomes (stellate or plate-like).

Besides, we calculated some "secondary" characters which utilise measured ones:

(a) L.MAX/L.CHER = relative length of petiole;
(b) L.MAX/W.MAX = leaf "circularity";
(c) W.LOC/L.MAX = leaf "oblongness" and
(d) DIAG/(sqrt(2)*W.MAX) = diagonal fraction, i.e. fraction between "theoretical diagonal" (supposing that leaf is round-shape) and real one.

Thus we have different group of characters:

(i) primary metric characters (L.MEZD, L.CHER, W.LOC, DIAG, L.MAX, W.MAX);
(ii) categorical ones (SMELL, PARTS, TRICH) and
(iii) secondary metric characters.

The analysis of these multivariate data was performed by means of the statistical software **R** (VENABLES & SMITH 2002).

Results & discussion

All primary leaf-based characters, petiole length and internode length are correlated to each other (Spearman r = 0.5–0.8; $p < 0.05$). PARTS also correlates with most of leaf-based characters ($r \approx 0.5$; $p < 0.05$). Unfortunately, SMELL is strongly associated with person who performs measurements and hereby this character is very subjective. Further investigations showed that most people could recognise pungent smell of *H. helix*, but nutmeg-like smell of *H. colchica* is very hard to distinguish. All leaf characters had low correlations ($r < 0.4$; $p < 0.05$) with trichome type. All secondary characters more or less correlate with each other and with primary leaf characters. They also have much less variation than primary characters.

Table 1. Character loadings to the first three principal components, first PCA (see text).

	Comp.1	Comp.2	Comp.3
L.MEZHD	-0.250	0.527	-0.475
L.CHER	-0.373	0	-0.412
W.LOC	-0.386	-0.251	0.216
DIAG	-0.422	-0.106	0
L.MAX	-0.437	-0.195	0
W.MAX	-0.401	-0.238	-0.271
PARTS	0.283	-0.136	-0.641
TRICH	-0.203	0.731	0.247

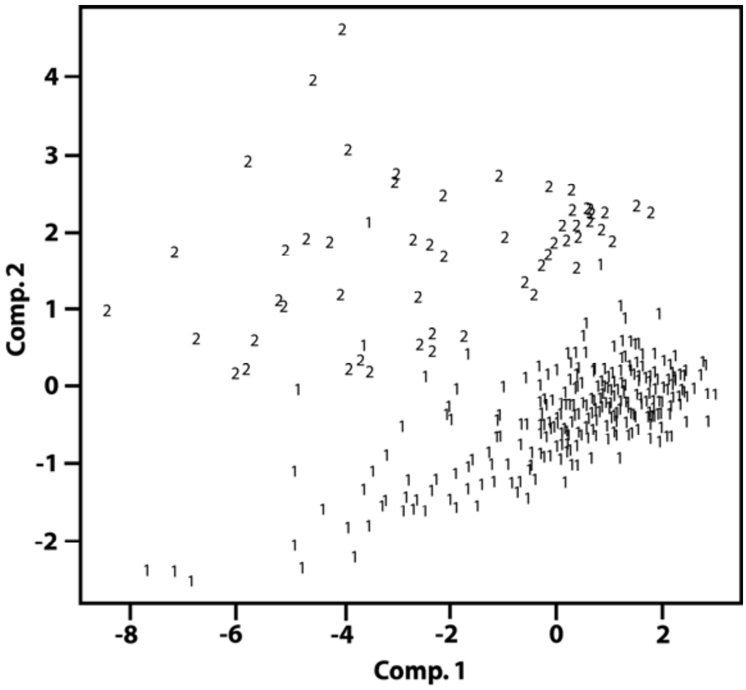

Figure 2. Scatterplot of two first principal components from first PCA (see text). Numbers correspond with trichome type (1 — stellate, 2 — plate-like).

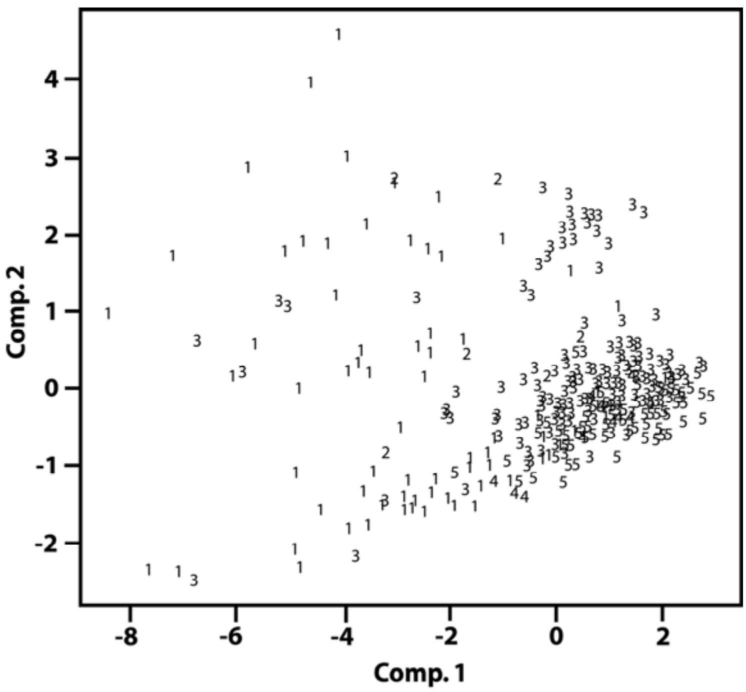

Figure 3. Scatterplot of two first principal components from first PCA (see text). Numbers correspond with numbers of leaf lobes.

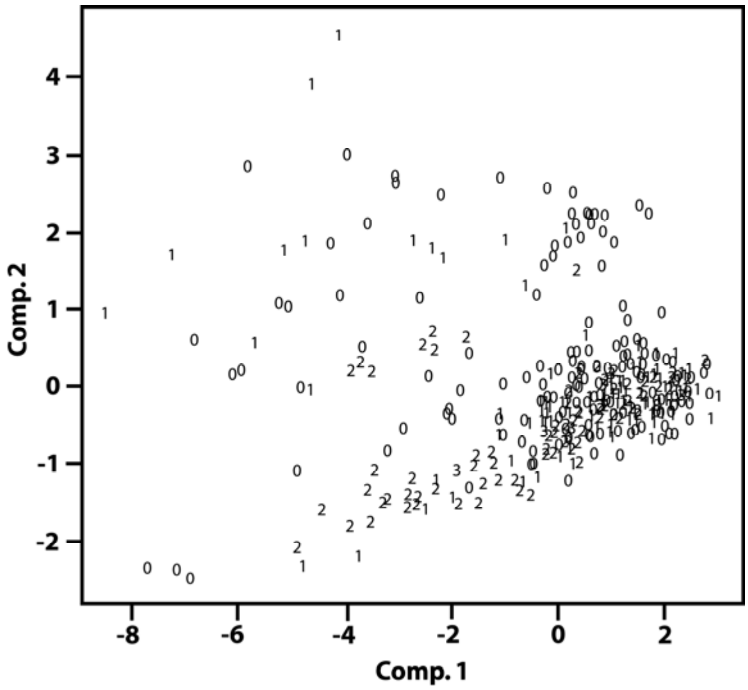

Figure 4. Scatterplot of two first principal components from first PCA (see text). Numbers correspond with shoot type (0 — ground-based, 1 — trunk-based, 2 — generative).

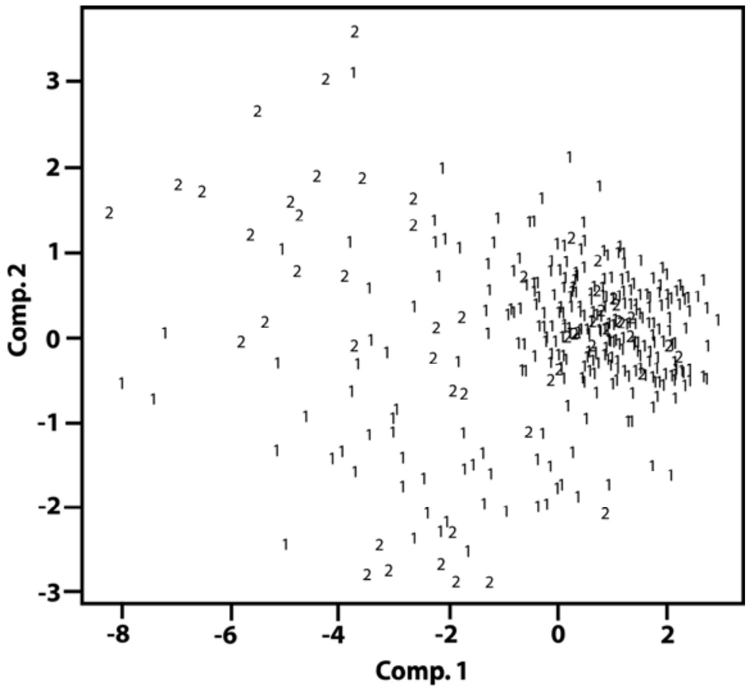

Figure 5. Scatterplot of two first principal components from second PCA (see text). Numbers correspond with trichome type.

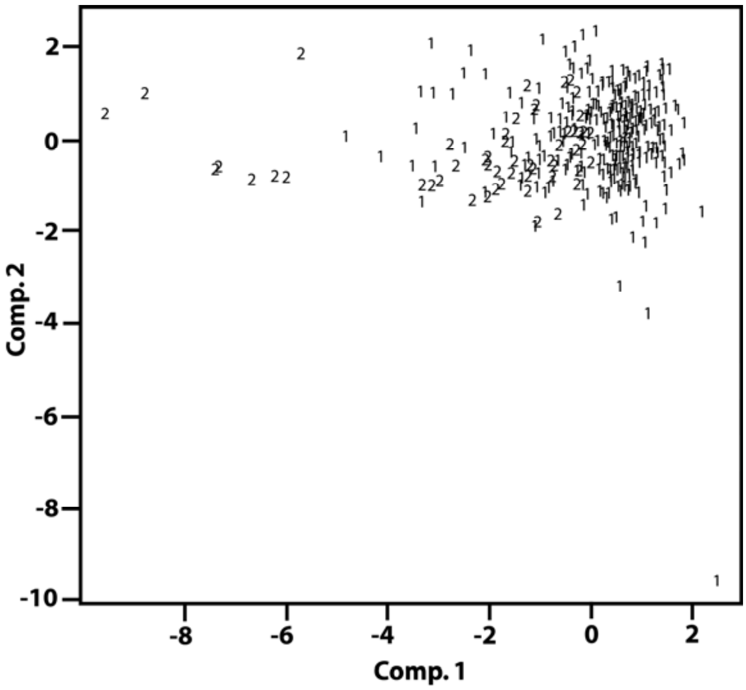

Figure 6. Scatterplot of two first principal components from third PCA (see text). Numbers correspond with trichome type.

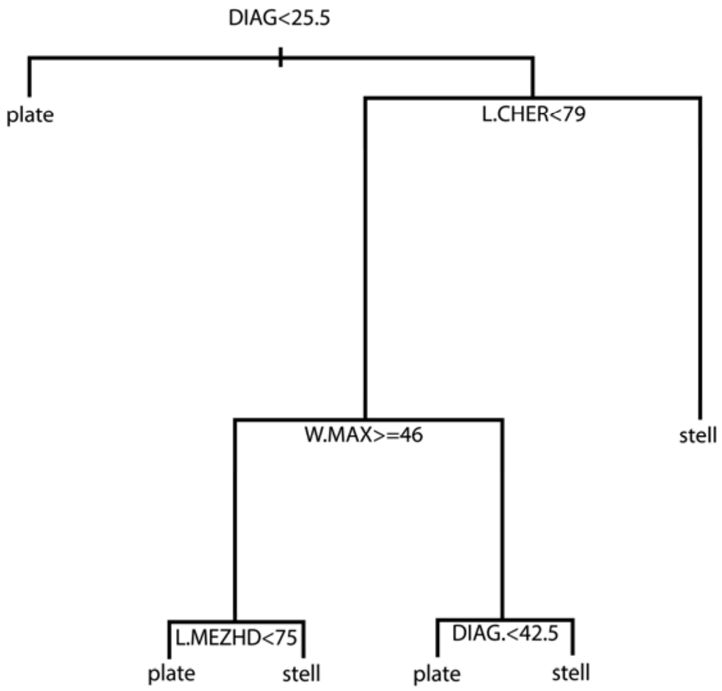

Figure 7. Regression tree of all primary metric characters according to classification by trichome type. Each node marked by character value of left branch.

To explore the overall diversity of measured leaves we performed several principal component analyses (PCA). **First PCA** was performed with primary metric characters, PARTS and TRICH. The resulted classification is relatively clear and generally according with the distribution of TRICH characters (Fig. 2). However, this classification does not correspond with the distribution of PARTS (Fig. 3). This means that whereas classification from first PCA does not contradict with primary metric characters, PARTS does not play a big role here. The classification does not depend from shoot type (Fig. 4); and all leaves from one series are placed together. Crimean populations do not differ from Caucasian *H. helix*, so we have an argument against a separate species status for Crimean ivy. Analysis of principal components' loadings (Table 1) shows that the biggest loadings in this case have DIAG, L.MAX and L.MEZHD.

For proving the role of trichome type character we removed it and than repeated the principal component analysis with remained characters. This **second PCA**, however, cannot return clear groups (Fig. 5).

A **third PCA** was performed with the set of secondary characters. The resulting classification (Fig. 6) is not clear and there are no groups. The TRICH character has much less loading than in first PCA. This can mean that "classification behaviour" of secondary characters contradicts with TRIH and primary leaf characters and thereby are not suitable for classification.

Discriminant analysis was also performed to elucidate relationships between classification by metric characters and trichome type. The last two characters were used as classifying variables: Percent of correctness (number of correct classifications / number of objects * 100) in this case is relatively large (88.4%). Then we used a recursive partitioning analysis (VENABLES & RIPLEY 2002) to clarify which metric characters are most useful for classification. This analysis usually returns so-called regression trees that correspond with contributions of all characters in classification models. Our tree (Fig. 7) shows that DIAG character plays the most important role in classification: most leaves (92%) having DIAG less than 25.5 mm are leaves with plate-scale trichomes. Consequently, some metric characters (especially DIAG, L.CHER and L.MEZHD) could be used for diagnostic purposes.

Conclusion

Lengths of leaf "diagonal", petiole and internode are the most perspective characters for field determination of *Hedera colchica* and *H. helix*.

Crimean ("*Hedera taurica*") populations do not differ from Caucasian *H. helix*.

Caucasian localities usually contain both groups (*Hedera helix* and *H. colchica*). Unfortunately, there is no clear evidence of coexistence, hybridisation or introgression between this species.

The number of leaf lobes does not correspond with a classification by trichome types.

Classification by trichome types does not distinguish the different types of the shoots.

Acknowledgements

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