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Cultivar classification in *Tulipa* L. (Liliaceae)

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SUMMARY

A total of 43 *Tulipa gesneriana* (section *Tulipa*) cultivars, 25 cultivars and wild accessions belonging to 11 species of sections *Tulipa* and *Eichleres* and three species hybrids were subjected to multivariate analysis based on data of 30 morphological characters recorded in two subsequent years. The main division according to earliness of flowering, which has been in use since Clusius made this division early in the 17th century, was confirmed by the distribution of the accessions in the principal component plots. The repeatability of measurements is high for most characters, as is deduced from the Pearson correlation coefficient per character between years. A cultivar classification system is proposed with two levels. The acceptance of a two-level cultivar classification is based on the structure of variation encountered and is a continuation of four centuries of tulip cultivar classification. The top level should include three supergroups for Early, Mid-season and Late flowering cultivars. Recommendations are made concerning the restoration of certain cultivar-groups and the placement of some cultivars. It can be concluded that multivariate methods provide basic insight in the diversity among cultivars. This information can be used as a basis for the construction of cultivar classifications.

Key-words: cultivar classification, earliness, Liliaceae, multivariate analysis, *Tulipa*, *Tulipa gesneriana*.

INTRODUCTION

Tulipa gesneriana L. (section *Tulipa*, subgenus *Tulipa*; Van Raamsdonk & De Vries 1995) is the collective species that contains most modern cultivars. In section *Tulipa* some other species related to *T. gesneriana* are classified growing in the Balkan peninsula and the Caucasus. A special group is the so-called Neotulipae (Hall 1940). Representatives of this group are found at the south and west borders of the Alps and can be considered as early escapes of cultivated tulips (Van Raamsdonk & De Vries 1995). A second important section (*Eichleres* (Hall) Van Raamsdonk) consists of a range of species of which at least one has contributed to modern cultivar-groups (*T. fosteriana*) or which are cultivated in several selections of hybrid forms (*T. greigii*, *T. kaufmanniana*, *T. eichleri*, *T. vvedenskyi*). Species of section *Eichleres* are interfertile with *T. gesneriana* to a certain extent (Van Raamsdonk *et al.* 1995).

A large variation in forms was known soon after the introduction of the genus *Tulipa* into western Europe. This has since led to the use of cultivar-groups within *Tulipa* in

horticulture. In the first monograph on *Tulipa* (Clusius 1601) three main groups were recognized: Early-, Late- and Mid-season flowering. This grouping was based mainly on the flowering period and the length of the stalk. The division in three main supergroups remained more or less unaltered through the ages and was used by authors such as Parkinson (1629) and Van Kampen (1760). A more detailed history can be found in Hall (1917), Krelage (1946) and Van Scheepen (1996).

Within the three main supergroups a range of groups was soon recognized. A range of groups and further subdivisions were added and the general view was lost completely (Maddock 1810). This situation continued and by the end of the 19th century the General Bulbgrowers' Association at Haarlem, the Netherlands and the Royal Horticultural Society in England began trials to sort out the problems. In 1914–1915 a joint committee conducted a survey including synonymy of cultivars, which resulted in a report. This report (Royal Horticultural Society 1917) can be regarded as the start of the tulip cultivar registration. Only two main groups were recognized: Early flowering and May flowering, with a third main group: species. In 1929 a tentative list (Royal Horticultural Society 1929) was published with the same classification. Since then a series of *Classified Lists* has been produced (Simmonds 1939; Dix & Simmonds 1948, 1952; Dix 1958, 1960, 1963, 1965; Stuurman 1969, 1971, 1976, 1981, 1987). The 1929 cultivar classification included the following supergroups and groups:

1. The first supergroup contained: Duc van Tol tulips, Single and Double tulips. The Duc van Tol group is the earliest flowering group of short-stemmed tulips. This group dates from the 17th century. The Single Early group goes back to Clusius' time.
2. The May flowering supergroup contained a total of 14 groups, each subdivided according to colour, the groups of Cottage cultivars, Parrots, Doubles, Breeders and Darwin tulips among them. Cottage tulips were in fact the continuation of the 17th century English Single Late tulips. Parrot tulips are supposed to be known since 1610 (Jacob 1917). The first double tulip was mentioned by Besler (1613).

After trials in 1931 and 1932 Mendel tulips and Triumph tulips were added in the 1939 *Classified List* (Simmonds 1939). The former resulted from crosses between Duc van Tol and Darwin tulips with long stems and narrow leaves. The latter were raised from crosses of Single Early tulips with Dutch Breeder, Cottage and Darwin tulips. Both the Mendel and Triumph tulips were included in the Early flowering main group because of their suitability for early forcing, but later both groups were placed in the restored supergroup of Mid-season flowering tulips (Dix 1958). Darwin Hybrid tulips were introduced as a subdivision of the Darwin tulips. They were defined as the result of crossing Darwin tulips with *T. fosteriana* (Dix 1958), but this definition was changed into the result of crosses of other tulips with botanical species, which have the same habit and in which the botanical species is not evident (Dix 1969). The group of Darwin hybrids concludes the supergroup of Mid-season tulips (Dix 1969).

Also in the supergroups of Early and Late flowering tulips cultivar-groups were raised or abandoned. The group of Lily-flowered tulips with pointed reflexed tepals was introduced (Dix 1958) after initial inclusion of these types in the group Late tulips. As the broken tulips, with flamed colour patterns due to virus infections, became less important in horticulture and slowly disappeared from cultivation, a start was made to group them all together in the group of Rembrandt tulips (Dix 1969). The Duc van Tol tulips, becoming less important to horticulture, were included in the Single Early tulips.

The Breeders were partly included in the Cottage tulips and some were included in Triumph or Darwin tulips (Dix 1969). The Mendel tulips disappeared as they no longer served a practical need for growers and trade (Stuurman 1981), and the remaining Mendel tulips were placed according to their flowering time in the Single Early group or in the Triumph group. A Single Late group was introduced to accommodate for the remaining Darwin and Cottage tulips. For 51 tulips with fringed tepal margins a Fringed group was introduced. The oldest cultivar 'Fringed Beauty' dates from 1931. The Viridiflora group was erected to accommodate cultivars with partly greenish tepals (Stuurman 1981). In the 17th century literature these tulips were described for the first time (e.g. Clusius 1601).

The continuing efforts in plant breeding on one hand and the changes in demand by growers and trade on the other hand led to the gradual disappearance of clear-cut cultivar-groups and obviously to changes in number of cultivars belonging to certain groups. Most groups which were originally described by parentage and form changed very quickly by the hybridization activities of the tulip breeders. Eventually this led to groups which changed not only in their parentage but also in their habit, such as the Darwin group originally missing the colours pure white and yellow, which were introduced by crossing Darwins with cultivars of the Single Late group. Occasionally cultivars are reclassified when it is thought that they do fit better into another group. A classical problem, for instance, is the classification of 'Couleur Cardinal' as the latest flowering cultivar of the Single Early group. It is envisaged that 'Couleur Cardinal' and its sports will be reclassified as Triumph tulips.

The aim of this paper is to present the variation in tulip cultivars and to compare this variation with the variation in some related *Tulipa* species which are in cultivation. The results of two experiments in 1990 and 1991 will be analysed, together with the results of two pilot studies of 1986 and 1987. The classification in cultivar-groups will be discussed.

MATERIAL AND METHODS

Experimental plots in 1990 and 1991 consisted of two repeats with two individuals each, four individuals per accession. The used accessions were:

T. gesneriana L.:

Duc van Tol: 'Duc van Tol Red and Yellow'[1], 'Duc van Tol Salmon';
Single Early: 'Christmas Marvel', 'Couleur Cardinal'[1], 'Van der Neer'[1], 'Wapen van Leiden'[1];
Double Early: 'Murillo'[1], 'Peach Blossom'[1], 'Vuurbaak'[1];
Triumph: 'Gander'[2,4], 'Kees Nelis'[1], 'Lustige Witwe'[3], 'Orient Express'[1], 'Telescopium'[1];
Mendel: 'Scarlet Wonder'[1], 'White Sail'[1], 'Zenober'[1];
Single late: 'Advance'[1], 'Dr. Euwe'[1], 'Fulgens', 'Mrs. Moon'[1];
Double late: 'Daladier'[1,2], 'Gerbrandt Kieft'[1], 'Lilac Perfection'[1], 'Golden Nizza'[1];
Darwin tulips: 'Bartigon'[1], 'Demeter'[1], 'La Tulipe Noire'[1], 'William Pitt'[1];
Darwin hybrids: 'Apeldoorn'[1], 'Dover'[1], 'Oxford'[1];
Breeder: 'Panorama', 'President Hoover'[1];
Lily-flowered: 'Adonis'[1], 'Captain Fryatt'[1], 'Dyanito'[1], 'Retroflexa';
Fringed: 'Fringed Lilac'[1];

Parrot: 'Admiral of Constantinople'[1], 'Karel Doorman'[1];
Viridiflora: 'Viridiflora'[1];
'T. acuminata';
Neotulipae: *T. didiera* Jord. (1 accession), *T. galatica* Freyn (1), *T. grengiolensis* Thommen (1), *T. marjolettii* Perr. et Song. (2), *T. planifolia* Jord. (1);
T. kaufmanniana Regel: 'Fashion'[3], 'Shakespeare'[2] and two wild accessions;
T. greigii Regel: 'Oriental Beauty', 'Zampa' and three wild accessions;
kaufmanniana × *greigii* hybrids: 'Giuseppe Verdi', 'Stresa', 'Zombie'[2,5];
T. albertii Regel (*T. vvedenskyi* Bochantzeva): two wild accessions;
T. eichleri Regel: 'Excelsa' and one wild accession;
T. fosteriana Hoog ex Irving: 'Cantata', 'Madame Lefeber', 'Reginald Dixon', 'Spector' and one wild accession;
T. hoogiana B. Fedtschenko: one wild accession.

Explanation of indices:
[1]: reference cultivar, i.e. a cultivar used in all experiments;
[2]: used only in 1990 experiment;
[3]: used only in 1991 experiment;
[4]: classified as Single late (Stuurman 1987) but reclassified as Triumph tulip;
[5]: indicated as *fosteriana* hybrid (Stuurman 1987) but regarded as *kaufmanniana* × *griegii* hybrid.

The most detailed division of groups has been followed in order to evaluate the variation within the large modern cultivar-groups (Dix 1958). However, assignment of cultivars to groups is not exclusively according to Dix (1958) or to the list currently in use (Stuurman 1987); more recent opinions have also been used.

The following characters were measured:
Flowering date; plant length[2]; stem diameter[2]; stem pubescence[2]; number of leaves[2]; width 2nd leaf[2]; leaf waviness[2]; leaf position[2]; leaf pubescence[2]; leaf margin ciliate[2]; number of flowers; number of tepals[1]; length outer tepal; width outer tepal; distance between base and widest point at outer tepal[1]; length inner tepal; width inner tepal; distance between base and widest point at inner tepal[1]; tepal not entire[1]; length fringed border[1]; outer tepal pubescence; shape tip of outer tepal (angle)[1]; shape tip of inner tepal (angle)[1]; tip outer tepal pubescence; tip inner tepal pubescence; width dorsal stripe from blotch to tip; blotch length at centre; blotch length at border; width blotch border; secondary blotch[1]; blotch bicolored[1]; anther length; filament length; colour filament contrasting; stigma hairy[2]; hairy coronet at bulb base[2]; tunic hairiness at base [2]; tunic hairiness at centre[2]; tunic hairiness at top[2]; hairy plume[2]; colour tunic[2]; number daughter bulbs[2].

[1]: not used in 1990 experiment;
[2]: not used in 1991 experiment.

Several characters concerning the outer and inner tepals were measured independently in order to investigate possible differences between the two whorls of tepals.

For each of the two experiments correlation coefficients between all characters were calculated separately. In both years the character pairs length of outer and inner tepal, and width of both tepals, and in the 1991 experiment the distance between base and widest point of outer and inner tepal, each appeared to be related very strongly. These relations were confirmed numerically by high correlation coefficients ($R>0{\cdot}85$). The

mentioned characters of the inner tepal were removed from the final analyses in order to avoid too high a level of redundancy in the datasets (Sneath & Sokal 1973; cf. De Vries & Van Raamsdonk 1994). Also, in 1991 the characters' blotch length at centre and at border of the tepal showed numerical relationship and therefore the latter one was deleted prior to analysis. In addition the character anther length was left out in the datasets of both years because many individuals showed degenerated anthers, which were not measured.

The raw data matrices containing 29 and 30 characters in the 1990 and 1991 dataset, respectively, were standardized prior to analysis. Multivariate analyses were carried out using the IRIS program package (Van Raamsdonk 1988). Principal component analysis was based on a correlation matrix with equal weights attached to each character. Principal components are uncorrelated linear combinations of the original characters representing maximum variation. The relations between the original characters and the principal components are expressed by factor loads, the objects are projected onto the newly calculated axes by means of component scores.

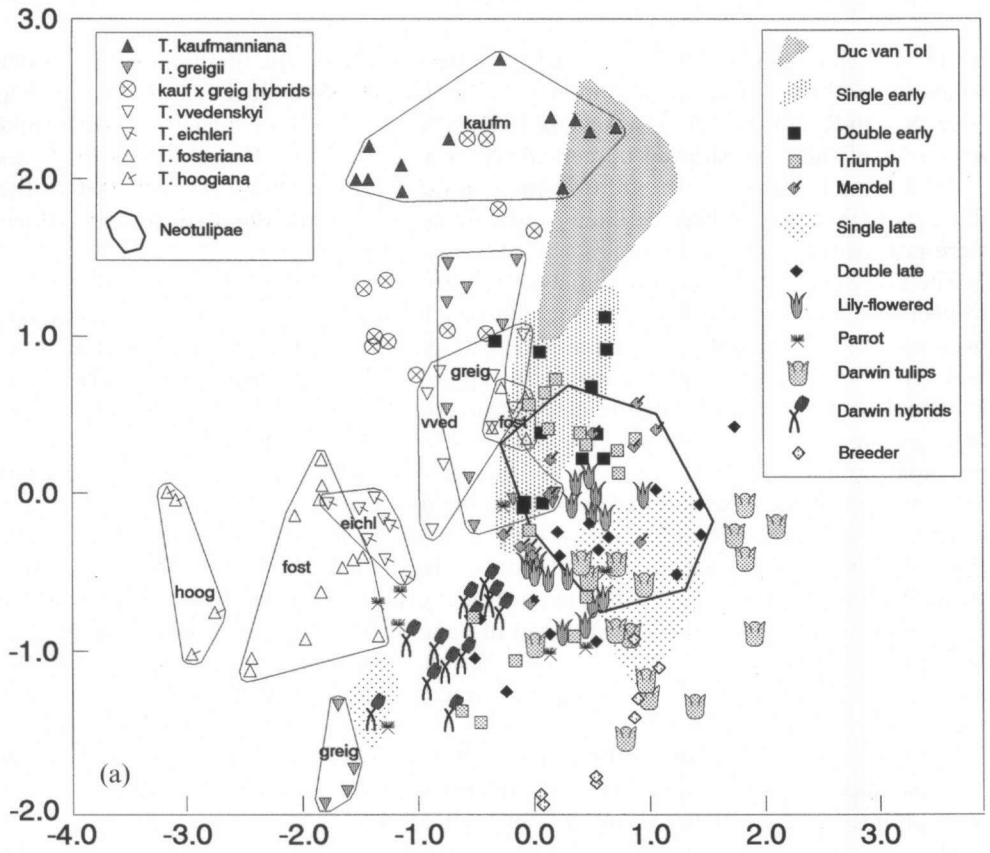
The input table was range-normalized per character prior to cluster analysis. Euclidian distance was used for calculation of the dissimilarity matrix. Agglomerative clustering was based on the unweighted arithmetic average cluster criterion (UPGMA). The dendrograms were cut off at the level of 12 and 14 clusters, respectively. The ratio between the within-cluster variance and the between-cluster variance was tested with the Kruskall–Wallis test and by ANOVA per character. The F statistic is used to present the results of the ANOVAS.

Pilot studies carried out in 1986 and 1987 consisted of material of 51 and 89 *T. gesneriana* cultivars, respectively. Of each accession mean values of a descriptor list were sampled and evaluated (Loos & Van Duin 1991).

The comparability of character values between years is tested by calculating the Pearson correlation coefficient per character between the measurements of 1986 and 1987, and between 1990 and 1991, based on the 29 reference cultivars.

RESULTS

The results of the principal component analysis of the 1990 experiment are presented in Fig. 1 and Table 1. The most important characters on the first principal component (PC) were related to hairiness (stem, bulb tunic, tepal) and size (length of blotch and of tepal; Table 1). The second PC was determined mainly by plant length, flowering date and width of tepal and of leaf. Bulb tunic hairiness and several characters related to width of several plant parts showed high loads on the third PC (Table 1). The measures of width of stem, leaves and tepals appeared to be related and load relatively high on both second and third PC. Some size-related characters, especially plant length, showed a relationship with flowering date. A separation between species and cultivar-groups was shown along the first PC. In particular, *T. hoogiana* and *T. fosteriana* p.p. were distinguished by their pubescent tepals and large blotch. The large size of the tepals is also found in other species, such as *T. eichleri* and *T. greigii*. The bulb tunics of *T. hoogiana* showed extreme hairiness. Differences among species and among cultivar-groups were shown along the second PC. *T. kaufmanniana* and the individuals of the cultivar-group Duc van Tol were the first flowering representatives of the genus. They also appeared to be relatively small. The hybrids between *T. kaufmanniana* and *T. greigii* appeared to be intermediate between the parents. This intermediate position


T. kaufmanniana
T. greigii
kauf x greig hybrids
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T. eichleri
T. fosteriana
T. hoogiana
Neotulipae
Duc van Tol
Single early
Double early
Triumph
Mendel
Single late
Double late
Lily-flowered
Parrot
Darwin tulips
Darwin hybrids
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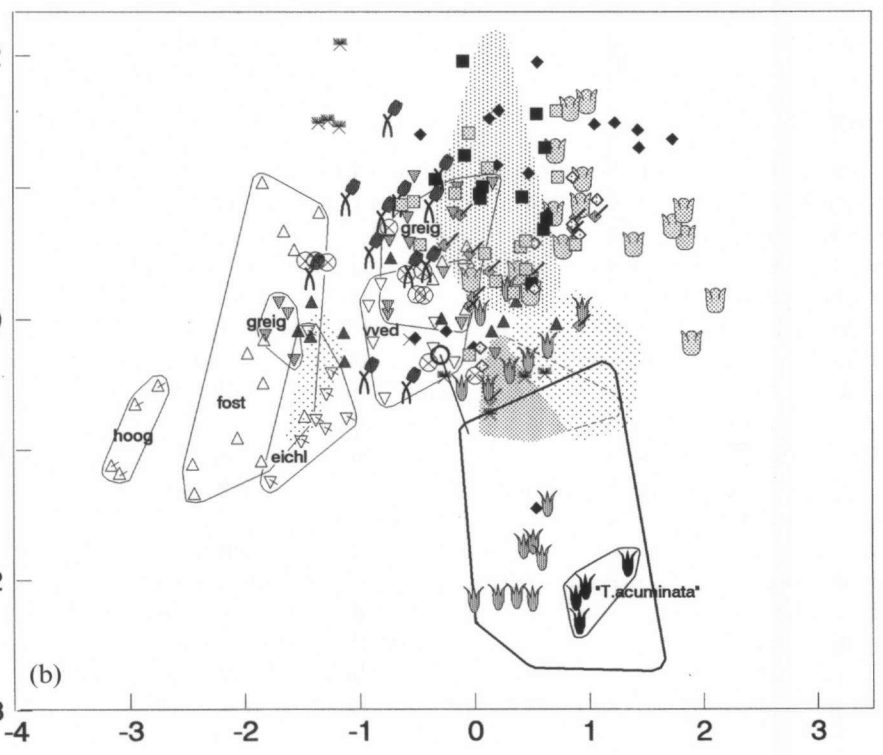
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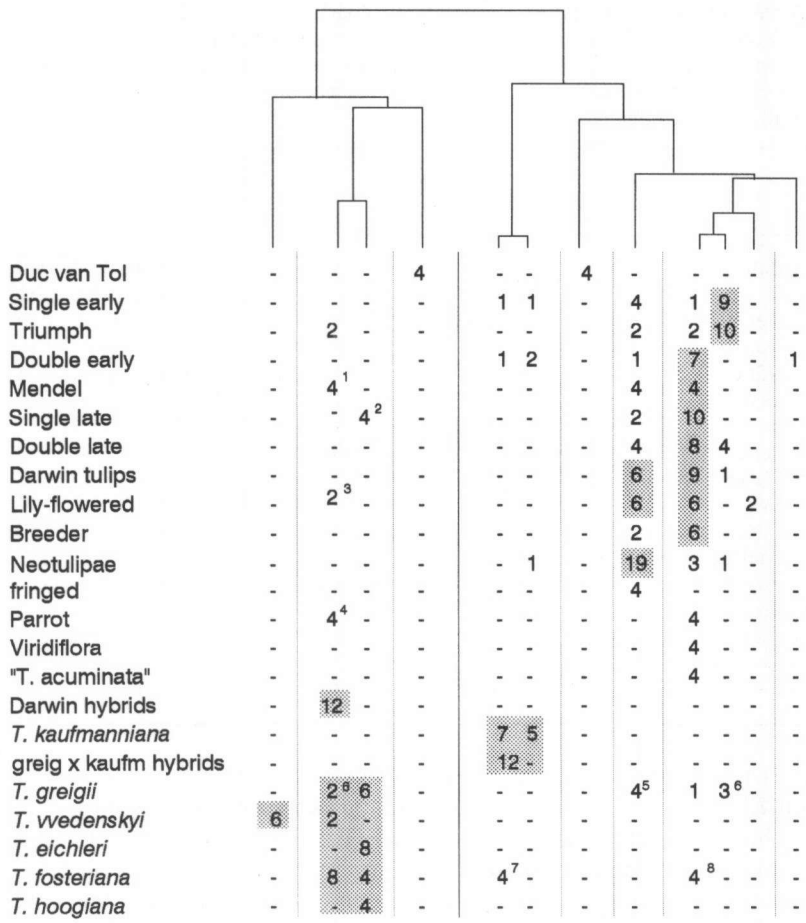
Table 1. Percentage of total variation and the factor loads of the most important characters on the first, second and third principal component (PC) of the 1990 analysis, and ordinal numbers in brackets. Kruskall–Wallis value (K–W) and *F*-value (*F*) of the most important characters indicate the difference between the within and among group variation of the 12 groups of the 1990 cluster analysis. und.: value undetermined

	PC 1 (17·56%)	PC 2 (11·37%)	PC 3 (8·87%)	K–W	*F*
Flowering date	0·365 (16)	−0·761 (2)	−0·144 (21)	242·064	43·269
Plant length	0·297 (21)	−0·826 (1)	−0·122 (22)	102·231	15·653
Stem diameter	−0·471 (11)	−0·417 (7)	0·455 (4)	31·840	5·275
Stem pubescence	−0·629 (1)	0·028 (27)	0·039 (24)	82·689	25·467
Leaf width (2nd)	−0·337 (19)	−0·584 (4)	0·506 (3)	68·704	9·692
Leaf waviness	0·532 (8)	−0·251 (13)	−0·248 (14)	90·999	13·063
Leaf position	0·275 (22)	−0·484 (6)	−0·221 (15)	41·721	6·524
Leaf pubescence	−0·524 (9)	−0·206 (15)	0·025 (27)	110·390	88·450
Outer tepal length	−0·570 (5)	−0·325 (8)	−0·315 (8)	161·388	12·083
Outer tepal width	−0·451 (13)	−0·602 (3)	0·450 (5)	76·547	15·689
Outer tepal pubescence	−0·578 (4)	−0·224 (14)	−0·163 (19)	32·732	89·932
Tip inner tepal pubescence	0·006 (29)	−0·480 (5)	−0·342 (7)	119·275	65·431
Blotch length at centre	−0·565 (6)	0·021 (29)	0·184 (16)	und.	3·435
Blotch length at margin	−0·586 (3)	0·117 (17)	0·276 (13)	und.	6·570
Tunic hairy at base	−0·543 (7)	−0·104 (19)	−0·582 (2)	47·250	7·801
Tunic hairy at centre	−0·522 (10)	−0·033 (26)	−0·665 (1)	49·027	7·909
Tunic hairy at top	−0·598 (2)	−0·028 (27)	−0·425 (6)	63·373	7·973

also applies to the group Darwin hybrids, originally originated after crossing Darwin tulips with *T. fosteriana.* Two cultivar-groups and two species possessed split areas in the PC plot. The Single Early tulip 'Advance' was deviating from the rest of the cultivar-group because of its hairiness of tepals and bulb tunic (lower part) and the large tepals. Parrot 'Karel Doorman' was found in the region of the species with low values for the first PC. Accession 78122 of *T. greigii* differed from the rest of the used accessions and cultivars of this species by later flowering. Two cultivars of *T. fosteriana* deviated from the rest of this species: 'Reginald Dixon' was found in the area with *kaufmanniana* × *greigii* hybrids and *T. greigii*, while 'Cantata' was located in the Single Early region.

The group division after cluster analysis of the 1990 experiment (Fig. 2) showed a clear separation in two main clusters, which is according to the division of the first PC of Fig. 1. Exceptions were the accessions of *T. kaufmanniana* and the *kaufmanniana* × *greigii* hybrids, which were located in the main cluster with *T. gesneriana* cultivars after the first division. On the other hand, the accessions belonging to the group of Darwin hybrids were located in the main cluster of the species, *T. fosteriana* among them. This is due primarily to the flowering date, which is the most important distinguishing character between the clusters (Table 1). Further subdivision revealed slight differences between some main cultivar-groups, i.e. between Single Early and Single Late. The cultivars of most groups are placed in more than one cluster. At least some representatives of most groups were placed in a cluster with most of the

Fig. 1. (a) A spatial plot of representatives of tulip cultivar-groups and species along the first (*x*-axis) and second (*y*-axis) principal component (1990 experiment). (b) A spatial plot of representatives of tulip cultivar-groups and species along the first (*x*-axis) and third (*y*-axis) principal component (1990 experiment). Meaning of symbols as in (a).



Indices

1 'Scarlet Wonder'
2 'Advance'
3 'Retroflexa' p.p.
4 'Karel Doorman'
5 'Oriental Beauty'
6 'Zampa' p.p.
7 'Reginald Dixon'
8 'Cantata'

Fig. 2. Cluster analysis with group division in 12 clusters. The distribution of individuals of the cultivar groups and species is indicated (1990 experiment).

Neotulipae. Most Triumph representatives were clustered together with the Single Early, while the cultivars of Double Early and Mendel grouped together with the Single late and Double late groups. The deviating cultivars after PC analysis took also a separate position after cluster analysis.

The PC analysis of the 1991 experiment (Fig. 3) showed a general distribution according to tepal shape and size. The shape of the tip of both the outer and inner tepals,

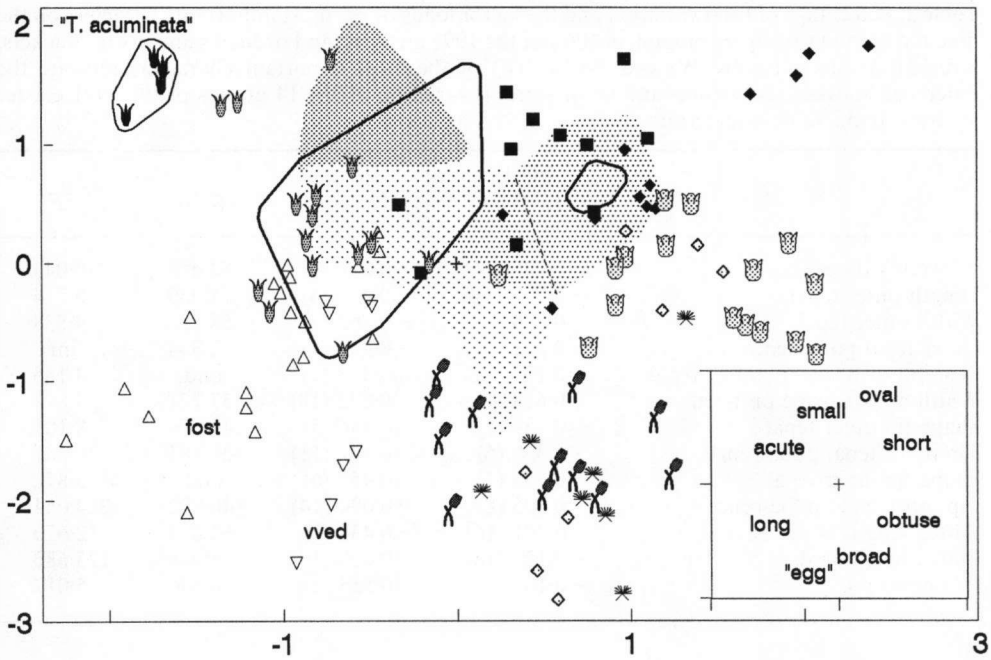


Fig. 3. A spatial plot of representatives of tulip cultivar-groups and species along the first (*x*-axis) and second (*y*-axis) principal component (1991 experiment). Meaning of symbols as in Fig. 1a. The separate frame covers the same area as the main plot with an indication of the distribution of some attributes; terms refer to flower shape (oval vs. 'egg'-shape), tepal shape (small vs. broad), tepal size (long vs. short) and tepal tip (acute vs. obtuse).

and the length of the outer tepal loaded high on the first PC (Table 2). The second PC was determined predominantly by the position of widest point of the outer tepal and the absolute width (Table 2). So, characters concerned with tepal shape appeared to be most important in this analysis. Lily-flowered cultivar 'Retroflexa', 'Viridiflora', 'T. acuminata' and Duc van Tol were located in the area with small and acute tepals. Broad and egg-shaped tepals were distinguishing for the Darwin hybrids and Breeder tulip cultivar 'Panorama'. *T. fosteriana* and *T. vvedenskyi* were characterized by long and more or less broad-based tepals, while the tepals of the Double late tulips, especially 'Lilac Perfection', were short. The position of the Darwin hybrids was more or less intermediate between the Darwin tulips and *T. fosteriana.*

The largest cluster after the cluster analysis of the 1991 experiment consisted of most of the individuals of the Mendel, Single late and lily-flowered cultivar-groups and the Neotulipae, as well as most species representatives (Fig. 4). On the other hand, most representatives of the groups Single Early and Darwin tulips and the greater part of the group Triumph were placed in a clearly separated cluster. Two cultivars of the Darwin hybrids, one accession of *T. kaufmanniana* and the *kaufmanniana* × *greigii* hybrids each possessed a cluster of their own. The most important distinguishing character was the pubescence of the outer tepal, which showed no variation within clusters (Table 2). Other important characters were the pubescence of the tepal tips, which also showed high K–W and *F* values in the 1990 experiment (Table 1), and the shape of the tepal tip.

The 1986 pilot study revealed a strong difference between Single Early and Double Early, and all other groups along the first PC (33·3% of total variation) mainly

Table 2. Percentage of total variation and the factor loads of the most important characters on the first and second principal component (PC) of the 1991 analysis, and ordinal numbers in brackets. Kruskall–Wallis value (K–W) and *F*-value (*F*) of the most important characters indicate the difference between the within- and among-group variation of the 14 groups of the 1991 cluster analysis. und.: value undetermined

	PC 1 (15·01%)	PC 2 (13·41%)	K–W	*F*
Flowering date	0·236 (14)	−0·057 (17)	80·488	10·043
Length outer tepal	−0·702 (3)	−0·472 (4)	74·039	6·774
Width outer tepal	0·328 (7)	−0·762 (2)	58·206	4·838
Outer tepal pubescence	−0·371 (5)	−0·310 (8)	72·344	inf.
Position of widest point of tepal	−0·273 (11)	−0·823 (1)	und.	4·135
Width dorsal stripe on tepal	0·623 (4)	−0·022 (18)	57·721	8·814
Shape tip outer tepal	0·759 (1)	−0·466 (5)	147·876	8·101
Tip outer tepal pubescence	−0·350 (6)	−0·141 (11)	129·185	47·301
Shape tip inner tepal	0·754 (2)	−0·459 (6)	und.	3·872
Tip inner tepal pubescence	−0·305 (8)	−0·094 (14)	140·892	214·054
Blotch length at centre	−0·201 (16)	−0·434 (7)	62·294	12·670
Blotch bicoloured	−0·128 (18)	−0·020 (19)	38·908	123·682
Filament length	−0·135 (17)	−0·555 (3)	46·546	5·017

determined by stem length and width of tepal and leaf. These two groups, together with Mendel, Triumph and Darwin hybrids, were located in the upper half of the PC diagram due to differences in flowering date and stigma shape, which load high on the second PC (12·8%). As in the 1986 pilot study, in 1987 the characters width of tepal and of leaf and stem length showed high loads on the first PC (26·7% of total variation). A distribution of the main cultivar-groups from early (left top corner: Duc van Tol, Single Early and Double Early) to late (right bottom corner: Single Late, Breeder and Darwin tulips) was found. The groups of Mendel, Triumph and Double Late tulips took a central position.

The reliability of the characters is studied by calculating the correlation between years over the measures of the reference cultivars. The results are presented in Table 3. Vegetative characters were not included in the 1990 experiment and therefore they are lacking in Table 3. The highest correlation was found between the years 1990 and 1991 for the pubescence of the outer tepal. The flowering date, tepal width and tepal length appeared to be most reliable in both yearwise comparisons. Although not included in the 1990–91 comparison, the characters stem length and leaf length with high correlation between 1986 and 1987 can also be considered reliable, since they show high loads on the second PC together with flowering date (Table 1).

DISCUSSION

Taxonomy

A general separation was found between the variation in representatives of section *Tulipa* (*T. gesneriana*, Neotulipae) and of section *Eichleres* (*T. kaufmanniana*, *T. greigii*, *T. fosteriana*, *T. vvedenskyi* and other species). This differentiation is in concordance with the revision of the subgenus *Tulipa* (Van Raamsdonk & De Vries 1995). The group of Neotulipae shares its variation with *T. gesneriana* (Figs 1 and 3) but for several

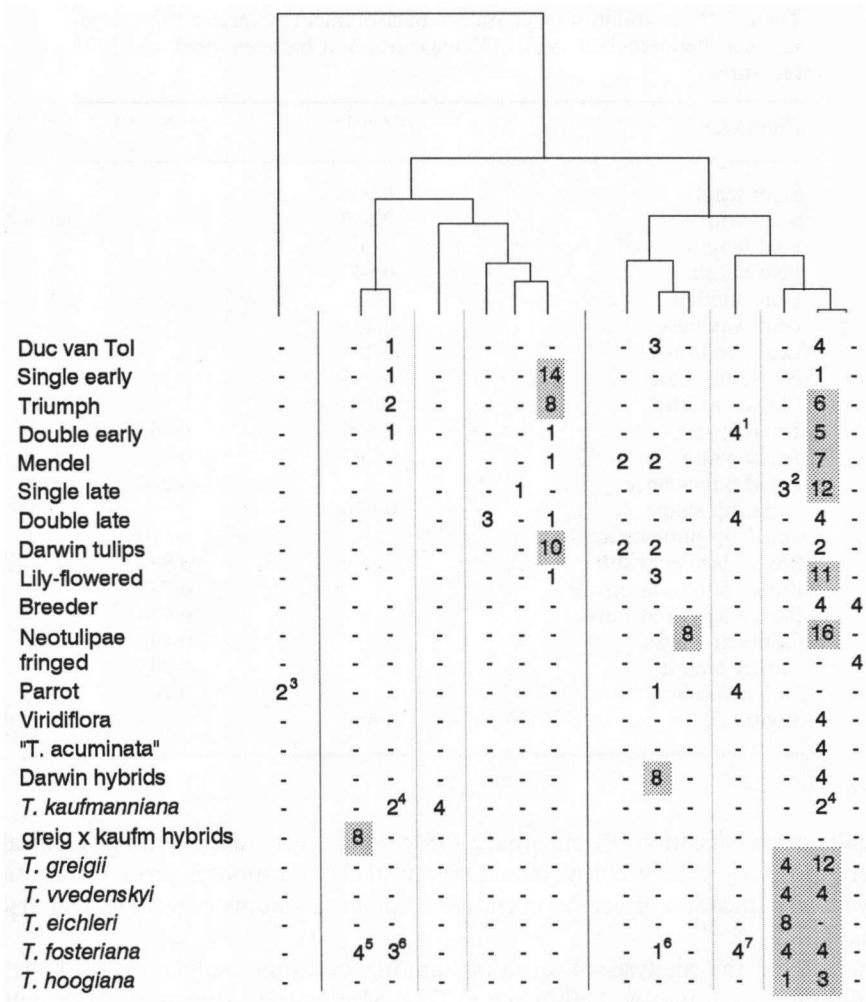


Fig. 4. Cluster analysis with group division in 14 clusters. The distribution of individuals of the cultivar groups and species is indicated (1991 experiment).

reasons it was accepted as one collective species, *T. didieri* (Van Raamsdonk & De Vries 1995).

Cultivar classification

Recent proposals for a general cultivar classification system include hierarchical systems (Lewis 1986) versus non-hierarchical systems (Hetterscheid & Brandenburg 1995). The

Table 3. Repeatability of character measurements expressed by correlation R between 1986 and 1987 measures and between 1990 and 1991 measures

Character	$R^{1986-1987}$	$R^{1990-1991}$
Stem length	0·901	
Stem width	0·632	
Leaf length	0·867	
Leaf width	0·847	
Leaf number	0·811	
Leaf waviness	0·435	
Leaf position	0·295	
Flowering date	0·915	0·860
Flower width	0·458	
Tepal length	0·800	0·852
Tepal width	0·767	0·888
Tepal pubescence		0·970
Tepal tip shape	0·636	
Tepal tip pubescence		0·810
Blotch border width		0·851
Blotch length at centre		0·756
Blotch length at border		0·620
Filament length		0·499
Anther length		0·855
Pollen colour		0·708
Stigma shape	0·660	

open cultivar classification (Brandenburg 1984, 1986) is essentially non-hierarchical, but is superimposed on a hierarchical, closed botanical classification. A further discussion of the several classification principles in cultivated plant taxonomy is given by Hetterscheid *et al.* (1996).

A model for the analysis of variation among cultivars using numerical methods was published by Baum & Lefkovitch (1972). Multivariate studies of both cultivars and wild relatives of a crop are relatively rare (Baum 1986). Some examples have been published in *Daucus* (Small 1978), *Medicago* (Small & Brookes 1984), *Lolium* (Loos 1993) and *Lactuca* (De Vries & Van Raamsdonk 1994). The present study includes both types of material which allows the comparison of the variation involved in and resulting from speciation as well as domestication (Van Raamsdonk 1993a).

One of the methods with a scientific basis is the a posteriori testing of a proposed hypothesis. Algorithms such as principal component analysis and cluster analysis do not need the inclusion of an a priori classification. The existing classification can then be used as a falsifiable hypothesis to be tested by using it as an a posteriori overlay over the final results of the analysing method used. Some comments on the scientific basis of this methodology are also given by Van Raamsdonk & Van der Maesen (1996). The decision upon the recommendation of a hierarchical classification system of tulip cultivars in this study will depend on the number of principal components which show a considerable contribution to the structure of the variation, and on the percentage of presented variation of the first two principal components.

Cultivar classification in Tulipa

No scientifically based attempt for cultivar classification in *Tulipa* has yet been published. Discussion of the present results should be worked out in the framework of current developments in the theory of cultivar classification (Van Raamsdonk 1993a; Hetterscheid & Brandenburg 1995), of common usage of groups of cultivated tulips (Van Scheepen 1996) and of recent attempts of classification in the genus *Tulipa* (Van Raamsdonk & De Vries 1992, 1995).

The present study reveals differences between the several cultivar-groups, although overlaps exist. The cluster analyses included all available variation, in contrast to the presentations of the principal component analyses which present only 37·8% in the first three PCs and 28·4% in the first two PCs of the 1990 and the 1991 principal component analyses, respectively. In both years there is a considerable amount of variation represented by the third and subsequent principal components. The percentages of explained variation of the first and second principal component in the 1991 experiment are almost identical to each other. Therefore, it may be concluded that the variation is multidimensionally distributed and that a set of correlations which is difficult to explain has been found between even the most important characters. The distribution of the cultivar-groups after the several analyses showed differences between groups according to characteristics as well as to descent, i.e. intermediacy between presumed parents. The large variation in tulip cultivars is also expressed by the polymorphism in esterase isozyme patterns. Seventy-eight of a total of 91 cultivars could be identified individually. Sports always showed the same pattern as the cultivar of which they have been derived (Booy *et al.* 1993). These results offer possibilities for establishing the origin of groups with a predominant mutant origin.

The character flowering time appears to be the most important distinguishing character from the first classification attempt until now (Krelage 1946; Stuurman 1987). This is due to the fact that this feature is a very important breeding objective and, apparently, can be measured adequately. The value of this character is indicated and supported by the present results. The several characters concerning pubescence and hairiness appeared to be important to distinguish between species and the cultivars of *T. gesneriana*, while several size measurements distinguish between cultivar-groups (Tables 1 and 2). Taking into account the repeatability of the characters (Table 3) the following list of characters will be recommended as descriptor list: flowering time, stem length, leaf width, and length, width and pubescence of outer tepal. Although not included in Table 3 for lack of data for the years compared, the hairiness of the upper part of the bulb tunic can be added. Special characters should be added to this descriptor list in order to distinguish between special groups, such as number of tepals (Double Early and Double Late), tepal tip shape (Lily-flowered) and entire, fringed or incised tepal border (Fringed and Parrot tulips).

The assumption that classifications based on characteristics which are an important breeding objective will be subjected to rapid changes (Benz & Iltis 1992) does not hold true for the general separation in Early, Mid-season and Late flowering. A basic division according to a characteristic with an important usage will meet the principles of Brandenburg & Schneider (1988). The stability of this general division may be due to an apparent relation between descent and flowering time, with reliable determination over different years.

Because of the enormous variation in the cultivated tulip (Loos & Van Duin 1991; Booy *et al.* 1993; Van Raamsdonk 1993b; present study) and because of the multi-dimensionally distributed variation, a hierarchical cultivar classification is most suitable, as was also found in lettuce (de Vries & Van Raamsdonk 1994).

The following recommendations for a classification system in tulip as based on the present results will be proposed.

1. Hierarchical classification on two levels. The main division should be in three major categories (indicated as supergroups) according to flowering time. This main division has a long history (Clusius 1601), is still in use (Stuurman 1987), and deserves formal status. These supergroups should be Early, Mid-season and Late flowering.

2. Descent as well as general appearance can be included in some group definitions. Descent in the strict sense may be applicable only to the group of Darwin hybrids and Lily-flowered tulips. Intermediacy between groups rather than descent may be suitable, i.e. the group of Darwin hybrids is intermediate between Darwin tulips and *T. fosteriana*. General characteristics should be added to statements of intermediacy in order to complete group definitions.

3. Certain cultivar-groups united with others should be restored. The groups Darwin and Breeder tulips deserve recognition. The assignment of early flowering and late flowering Mendel tulips to two different groups is confirmed in the present study. The inclusion of the late flowering types in the group of Triumph tulips (Stuurman 1981) is not likely, since the Triumph tulips themselves are mainly early or mid-season flowering.

4. Reconsidering the assignment of cultivars to groups is recommended. Several cultivars included in this study should be moved to another group, i.e. 'Advance' (Single late) shows characteristics of *T. fosteriana* and should be regarded a Darwin hybrid. The *T. fosteriana* cultivars 'Cantata' and 'Reginald Dixon' possibly arose after hybridization, although considering them to be Darwin hybrids is not appropriate.

The approval of a new cultivar classification system in tulip as proposed by the International Registration Authority, the Royal General Bulbgrowers' Association, depends on its acceptance in horticulture, i.e. by tulip breeders and traders. Therefore, restoration of cultivar-groups is not only dependent on scientific distinction but also on horticultural usage and demands of growers and trade. For that reason a proposal for a classification system of tulip cultivars will not be presented in this paper. It should be noted that this study and the conclusions drawn are based on a relatively low number of accessions. There are still living collections of more than a thousand tulip cultivars at hand in the 'Hortus Bulborum', maintained by a private foundation in the Netherlands, of which the oldest originated in the 17th century. A more comprehensive study may give more detailed information on the existing variation and the most appropriate classification.

The assignment of cultivars to species or to interspecific hybrids is important. For instance, typical *T. kaufmanniana* shows difficulties in hybridizing with *T. gesneriana*, while *T. kaufmanniana* hybrids are more easy to cross (Van Eijk *et al.* 1991). In this study the cultivars 'Shakespeare' and 'Reginald Dixon', frequently used in hybridization experiments, could be designated as belonging to *T. kaufmanniana* and as species hybrid, respectively. Assigning 'Cantata' as a representative of *T. fosteriana* is not likely for it appeared to be intermediate between Single Early tulips and typical *T. fosteriana.* However, an assignment of 'Cantata' as species hybrid of *T. gesneriana* is also hampered by the failing of one of the reciprocal crosses between *T. gesneriana* and 'Cantata' (Van Eijk *et al.* 1991).

The usefulness of multivariate methods for assessing variation within and between cultivar-groups is limited. A straightforward adoption of clusters or of the spatial distribution in the PCA plots as cultivar-groups is not possible and certainly not recommended. On the other hand, multivariate methods allow to indicate the distinguishing ability of characters. This information can be used in the process of circumscribing cultivar groups, and it allows a scientific basis for establishing a core collection of tulip cultivars, selected from the main collection in 'Hortus Bulborum' (Loos & Van Duin 1991). The present study gives an indication which characters could be used for an easy and reliable description of variation.

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