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The Feasibility of Improving Eating Quality of Table Carrots by Selecting for Total Soluble Solids[1]

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Abstract. **Roots from 8 advanced generation breeding lines of carrot (*Daucus carota* L.) repeatedly selected for high or low total soluble solids content, and 2 selections of 'Imperator 58', one with high and one with low soluble solids, were evaluated for perceived sweetness and eating quality by taste panels. Most taste evaluations were made using the Quantitative Descriptive Analysis method. Two breeding lines, 5158 and 5164, had high levels of solids ($\overline{X}$'s averaging 10.4 and 10.8% respectively) but were downgraded in perceived sweetness in panel evaluations. The ranking of the other lines according to their mean preference scores for perceived sweetness was related to total soluble solids content. Bitter taste and harsh flavor characteristics were associated with 5158 and 5164. No perceived sensory differences were found between the high and low selections of Imperator 58 by a technological panel. A consumer preference taste panel, however, showed a slight preference for eating carrots from the high solids selection. The background constituents of carrot flavor appear to play an important role in the perception of sweetness at all levels of soluble solids.**

Total soluble solids content is important to fresh market and processing quality in many fruits and vegetables (1, 5, 7, 10, 12, 15, 20). Refractometer readings have been used routinely by plant breeders and other researchers as an indication of the flavor and taste for certain crops. A phenotypic correlation of 0.86 between solids and overall quality scores rendered by a taste panel was reported in muskmelon (6). Perceived acidity in tomatoes was found to be mainly dependent on sugar and acid content, two components of total soluble solids (22). High solids content of watermelons was generally associated with high total sugar, and melons with high solids were sweeter than melons with lower solids content (14).

In carrots, soluble solids content has been shown to be associated with percentage of dry matter, total sugar content, and overall eating quality (3, 4, 15, 21). The correlations of 0.79 and 0.84 between soluble solids and total sugar (4) justify using these terms interchangeably. Furthermore, Carlton and Peterson (4) reported a correlation of 0.93 between soluble solids and nonreducing sugar. Since the major nonreducing sugar found in carrot roots is sucrose (2, 13), taste preference might be expected to relate closely to sucrose content.

In a study examining roots from the cultivar Chantenay, Brown et al. (3) found a correlation of 0.63 between desirable taste and the solids content of expressed juice. Other studies have suggested that reducing sugars might also be important to eating quality. Taste panel evaluation of cooked carrots showed that reducing sugar content although present in low concns had a marked bearing on flavor, and in general, roots with high levels of reducing sugar were significantly preferred (8). No information was presented, however, as to the relationship of nonreducing sugar content (sucrose) and flavor acceptability. Carlton and Peterson (4) found a correlation of –0.60 between soluble solids and percentage of reducing sugars. They suggested that it might be possible to breed sweet carrots low in solids.

While many researchers use total soluble solids and sensory quality interchangeably, determinations are often made by one or more "experts" who taste a sample for eating quality and render a decision. Kramer (11) suggests that because the ultimate evaluation of eating quality is determined by the consumer, accurate estimates of taste and flavor can be made using taste panels. Recent approaches in sensory measurement have employed a new method of data analysis (19) called Quantitative Descriptive Analysis (QDA). The focus of QDA is on the psychophysical aspects of perception and the application of an internal scaling technique to the problem of flavor characterization. The QDA method requires that taste panelists be trained beforehand on the test material to be evaluated (19).

Previous work (3) designed to evaluate taste and soluble solids content of carrot roots was done on material not repeatedly selected for either factor. This paper reports the results of a study on eating quality of table carrots from an open-pollinated cultivar and advanced breeding lines selected several generations in succession for high and low total soluble solids. Specific objectives were to: 1) evaluate, by QDA, the relationship of total soluble solids with perceived sweetness and eating quality, and 2) ascertain the feasibility of improving table carrot breeding material for eating quality by selection for total soluble solids.

Materials and Methods

Genetic materials. Roots from 8 advanced breeding lines and from 'Imperator 58' (a widely grown open-pollinated table carrot cultivar) were used in this study. The lines, USDA 5158, 5160, 5164, 5168, 5176, 5183, 5185, and 5187 were selected several successive generations for color, type, and uniformly high or low levels of total soluble solids. No prior selection occurred in the 'Imperator 58' population.

USDA 5158 and 5160 are related S_2 lines derived from par-

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Table 1. Soluble solids levels and means determined by QDA for taste and flavor attributes of fresh carrot samples from inbred lines and 'Imperator 58' evaluated by trained (technological) taste panels.

	Total dissolved solids[z]			Sensory attributes[y]				
Taste panel carrot lines	No. of roots analyzed	Mean[x]	Range	No. of judges	Sweetness[x]	Bitterness[x]	Flavor intensity[x]	Flavor type[x]
Panel evaluation-I				26				
5160[w]	34	8.0a	7.0–10.0		3.65ab	3.21ab	3.71a	3.32ab
5176	27	9.2b	8.4–10.5		4.00ab	3.16a	4.29a	4.18c
5158[w]	29	10.4c	8.8–11.6		3.35a	3.82b	4.39a	2.94a
5187	22	11.2d	10.0–12.4		4.33b	2.67a	4.02a	3.97c
Panel evaluation-II				24				
5185	45	8.3a	6.7–9.5		4.34ab	2.92a	4.13a	3.91a
5168	29	9.6b	8.2–11.6		4.69b	3.32ab	4.42a	3.83a
5164[w]	42	10.8c	8.6–12.5		4.07a	3.57b	4.50a	3.44a
5183	34	11.3d	9.8–13.2		5.50c	2.73a	4.59a	4.69b
Panel evaluation-III				26				
Imperator 58	300	7.9	6.5–10.0					
High selection	60	8.9a	8.5–10.0		3.88a	3.02a	3.71a	4.57a
Low selection	60	7.0b	6.5–7.3		3.63a	2.79a	3.45a	4.60a

[z] Expressed as % sucrose.

[y] Endpoint value descriptions of magnitude estimation scales for:

Sweetness	1 = Imperceptible –	7 = Extremely sweet
Bitterness	1 = Imperceptible –	7 = Extremely bitter
Carrot flavor intensity	1 = Weak carrot flavor –	7 = Strong carrot flavor
Carrot flavor type	1 = Course, harsh – (unbalanced)	7 = Smooth, typical (balanced)

[x] Means with different letters in each evaluation session are significantly different at the 5% level of probability according to Duncan's multiple range test.

[w] Lines derived from crosses of 8549; lines with footnote absent were derived from 68-27.

ent plants selected for high and low soluble solids content following the cross of Michigan State University (MSU) 8549 and MSU 3367. F_2 roots from this cross judged to be superior for color and horticultural acceptance were propagated for 3 generations by mass selection prior to the initial plant-to-progeny row selections for solids content. USDA 5164 is an F_6 breeding line derived from the cross of MSU 8549 and MSU 5931, and was the result of 4 cycles of plant-to-progeny row selection of an initial F_2 root with a high level of soluble solids. The other 5 lines are related to each other and originated from a USDA synthetic population, Syn 68-27.

Syn 68-27 originated in 1968 by compositing 6 F_1 roots resulting from random single plant crosses of 'Imperator' type parents selected from established maintainer (male-fertile counterpart) lines in the Michigan State Univ. breeding program. Syn 68-27 underwent 3 cycles of mass selection for color and root type before evaluation of roots for soluble solids. All material used in the present study derived from this synthetic, except for 5187, are S_2 lines originating from parent roots which underwent 2 cycles of plant-to-progeny row selection for extremes in soluble solids content. Breeding line 5187 is an S_1 and underwent one cycle of plant-to-progeny row selection for high solids.

The breeding lines and 'Imperator 58' were produced during the winter of 1974–75. Roots of the lines were grown on the USDA Field Station near Brawley, California in 2-row, 1.8 m (6 ft) long plots spaced 15.2 cm (6") apart on beds. Standard cultural practices for commercially grown carrots were used. At harvest, sound roots were selected at random from each plot and packed immediately. Roots of 'Imperator 58' were grown on the William Bolthouse Farm near Bakersfield, California. At harvest, 300 roots were taken at random from a field in commercial production. All roots from each location were shipped to Madison, Wisconsin, within 2 days of their respective harvests. Roots were washed, and prepared immediately for soluble solids determination and sensory quality evaluation by taste panels.

Soluble solids determinations. Disks (3 mm thick) were sliced from the middle-third region of individual roots, placed in small plastic bags, and frozen at -10°C. Soluble solids were determined by reading a drop of expressed liquor from the thawed samples with an Abbe, Model 3L, refractometer.[4] Data recorded for individual roots of each breeding line and the high and low selections from 'Imperator 58' were subjected to an analysis of variance appropriate to a completely random design (18). Mean soluble solids % was determined for each breeding line and the high and low selections of 'Imperator 58'. Means were compared using Duncan's multiple range test (18).

Sample preparation. Immediately before each taste panel evaluation, roots were peeled (epidermis removed) and sliced into sticks (cut longitudinally, then transversely in 5 cm lengths). Each panelist received 2 sticks of each sample of carrots held at 7°C until served. In order to eliminate within line variation in sensory perception, sample preparation was modified for taste evaluation II. Here, samples were homogenized by grating.

Taste panels. Four taste panel evaluations were conducted in March and May, 1975, at the Sensory Evaluation Laboratory, Department of Food Science, University of Wisconsin, Madison. These taste tests were designed to assess the relationship among total soluble solids, sweetness, and overall eating quality of carrot roots.

Taste evaluations were of two types: technological panels, employing trained panelists (evaluations I, II, III) and a consumer preference panel, utilizing untrained persons (evaluation IV). In panels I, II, and III, samples were profiled for overall sensory quality using a modification of the QDA method. Ballots presented to panelists consisted of dimensionless magnitude estimation scales for each sensory attribute, and numerical attribute scores were obtained by assigning appropriate values to judgements on a 1.0 to 7.0 scale (19).

For taste evaluation IV, the high and low selections of 'Imperator 58' were evaluated by panel judges not informed of the test purpose. This was done to eliminate preconditioned biases. Taste responses marked by panelists were converted to numerical values for statistical analysis.

All data from organoleptic evaluations were subjected to

Table 2. Analyses of variance for perceived sensory attributes rendered on experimental breeding lines and selections from 'Imperator 58' by trained (technological) taste panelists.

Evaluation no. and source of variation	d.f.	Mean squares			
		Sweetness	Bitterness	Flavor intensity	Flavor type
Evaluation-I					
Tasters	25	270.4*	430.3**	207.0	204.2
Samples (lines)	3	469.3*	581.1**	241.8	862.5**
Error	75	158.2	131.1	163.5	164.3
Evaluation-II					
Tasters	23	146.6**	243.9**	298.0**	250.9**
Samples (lines)	3	917.9**	350.8*	93.0	628.5**
Error	69	50.2	104.5	71.3	110.0
Evaluation-III					
Tasters	25	127.6	208.1**	227.6**	193.7**
Samples (selections)	1	81.3	66.9	88.9	0.9
Error	25	70.1	45.3	54.0	55.3

*,**Significant at the 5% (*) and 1% (**) probability level.

analyses of variance appropriate to a randomized complete block design (18). Individual analyses were performed on each quality attribute profiled by panelists when the QDA method (panels I, II, III) was used. Means from all evaluations were compared using Duncan's multiple range test (18).

Results and Discussion

Sensory evaluations. Mean comparisons of the breeding lines for total soluble solids levels revealed that inbreeding and repeated selection for solids separated the material into 4 significance groups. These were: a) 5160 and 5185; b) 5168 and 5176; c) 5158 and 5164; and d) 5183 and 5187. The 8 lines comprised too large of a sample to be reliably judged in one taste session; hence, one line from each significance group was selected and profiled organoleptically in separate evaluations (Table 1). Since lines derived from 8549 and Syn 68-27 were represented in each panel (I and II), sensory comparisons could be made between the 2 germplasm pools. There was sufficient variability for soluble solids in 300 roots of 'Imperator 58' to separate roots according to the significant mean differences. Sixty roots with the highest ($\bar{X}$ = 8.9, range 8.5–10.0%) and 60 with the lowest ($\bar{X}$ = 7.0, range 6.5–7.3%) total soluble solids made-up high and low subpopulations, respectively. Hereafter, these will be referred to as high and low selections.

Results of taste evaluations I, II, and III are given in Table 1 and 2. Analyses of variance (Table 2) confirmed differences among breeding lines for sweetness, bitterness, and flavor balance. No differences among lines were detected in either evaluation for flavor intensity. This indicated that the overall product flavor (i.e., flavor of carrots) among lines, as perceived by judges, was similar. Differences among judges (Table 2) were noted for all sensory attributes (except flavor intensity and flavor type in evaluation I) in evaluations I and II. This variation was largely due to disagreement on the relative magnitude of difference between samples for a perceived stimulus and, is to be expected. Essentially the same amount of genetic variability was measured in both panel sessions, but error mean squares (Table 2) were smaller in taste evaluation II. This suggests that judge × sample confusion was less in evaluation II; in other words, judges agreed more on the ranking of samples according to the intensity of stimulus perceived for a given sensory attribute. The elimination of root to root variation by grating the samples may have caused lower error mean squares in this evaluation. Further experimentation is needed to determine the effect of sample preparation on a panelist's response to attributes in question. Panelists detected no significant differences between the high and low selections of 'Imperator 58' (evaluation III) for any of the sensory attributes. However, differences among tasters were noted for bitterness, flavor intensity, and flavor type.

Mean comparisons among lines for sensory attributes (Table 1) show that 5158 was perceived to be less sweet than 5187 and differ in flavor type from 5176 and 5187. Line 5158 was also judged to be more bitter than 5176 and 5187 but not different in perceived bitterness from 5160. In evaluation II, line 5183 was perceived as being sweeter than the other three lines, while 5164 was perceived to be less sweet than 5168 and 5183 and more bitter than 5183 and 5185. Line 5183 was perceived to have a more balanced flavor than the other three lines. Table 3 gives results of the consumer preference taste panel (evaluation IV). Both the high and low selections were generally acceptable, but judges significantly (5% probability level) preferred eating carrots from the high soluble solids sample. Reasons for this choice were not obvious and could not be determined from the test design used.

Percentage soluble solids, perceived sweetness, and carrot taste. Considering first the breeding lines, mean taster scores (except for 5158 in evaluation I and 5164 in evaluation II) for perceived sweetness agreed with a line's mean level of total soluble solids (Table 1). In other words, the ranking of lines according to their mean solids level was the same as their ranking for mean sweetness perception. Line 5158 (taste evaluation I) had the second highest solids level ($\bar{X}$ = 10.4%) but the lowest mean score in perceived sweetness of the 4 lines (Table 1). Moreover, mean scores also categorized 5158 as the most bitter and possessing the most unbalanced (harsh) carrot flavor. Although a different sample of breeding lines were profiled in taste evaluation II, they were derived from the same two parent populations as lines evaluated in panel session I. In evaluation II, 5164 showed a similar interaction between solids level and perceived sweetness as did 5158 in evaluation I. Line 5164 ($\bar{X}$ for soluble solids = 10.8%) was perceived to be significantly less sweet than 5183 and 5168 which had means for soluble solids of 11.3 and 9.6%, respectively. In addition, 5164 was among the most bitter and harsh in flavor type of the lines evaluated. Results of sensory evaluations implicate background constituents to play a major role in taste perception.

Taster inability to perceive the sweetness of 5158 and 5164 (high in total soluble solids) appeared to be largely due to judge distraction and confusion by bitter taste and harsh flavor that obscured the sweetness sensation. It is tempting, however, to speculate that sugar composition might also be involved. Sucrose and glucose are the predominant sugars in carrots (2, 13, 16); fructose, which is sweeter (9), is also present but in lesser quantities (2). Because both 5158 and 5164 were derived from F_2's involving 8549, they possibly possess genes conditioning low fructose although their respective total sugar concen-

Table 3. Preference frequency of high versus low soluble solid selections of Imperator 58 rendered by a 172 member consumer preference taste panel (panel evaluation-IV).[z,y]

Preference category & mean score[x]	Preference description	Selection	
		High	Low
7	Like extremely	18	15
6	Like very much	72	52
5	Like moderately	60	59
4	Like slightly	13	32
3	Dislike slightly	7	13
2	Dislike moderately	1	1
1	Dislike very much	1	0
Mean preference score		5.43b	5.12a

[z] Nontechnological panel (untrained judges).

[y] Roots were identical to those used in technological evaluation-III.

[x] Means with different letters are significantly different at the 5% level of probability according to Duncan's multiple range test.

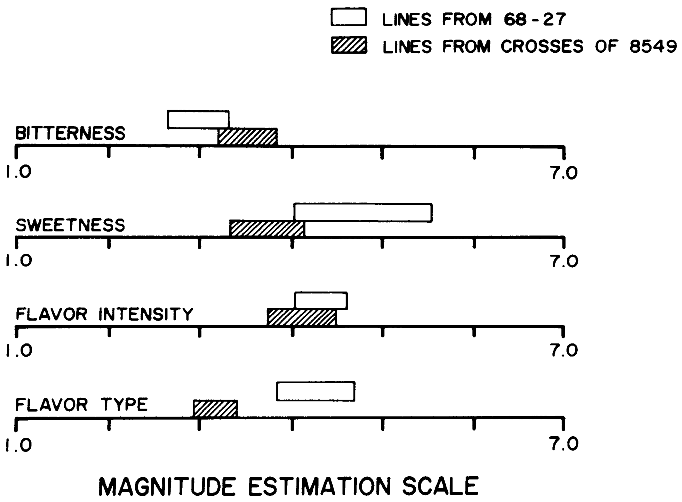

Fig. 1. Quantitative descriptive analysis profiles of mean judge scores from taste evaluations I and II arranged according to the genetic sources from which breeding lines were derived (see Table 1 for endpoint descriptions).

trations are relatively high. Further work is needed to corroborate this suggestion, but Carlton and Peterson (4) showed that some carrot lines did, in fact, have significantly lower levels of reducing sugars than others. These authors did not report information concerning perceived sweetness, but Scheerens (17) in a separate study showed that panelists were able to discriminate between sugar solutions (sucrose, glucose, and fructose) differing in % composition of fructose when total sugar was high. Solutions comprised of 2% fructose, 4% glucose, and 4% sucrose were judged significantly less sweet than solutions made up of 4% fructose, 2% glucose, and 4% sucrose. One criticism of making sweetness perception comparisons between sugars in solutions and the raw product might be that sweetness perceived from a solution is set on a relatively flavorless background, while sweetness in carrots must be perceived through a background of concerted flavor and taste stimuli imparted by naturally occurring compounds.

The behavior of 5158 and 5164 in their respective taste evaluations prompted us to consider both taste sessions I and II simultaneously and pictorially describe (Fig. 1) the range of sensory score means of the 8 inbreds with respect to the germplasm from which they were derived. Lines 5158, 5160, and 5164 were derived from crosses involving MSU 8549; Fig. 1 shows lines from this parent as being bitter, low in perceived sweetness, and having poor flavor balance (harshness). On the other hand, lines derived from Syn 68-27 were perceived as being nonbitter, sweet, and possessing a balanced carrot flavor. The contrasts between lines derived from 68-27 and 8549 for taste and flavor perception were striking and suggested that the makeup of the 2 germplasm sources was inherently different with respect to genes affecting the expression of background sensory stimuli. This conclusion warrants further study. Future research should include examining a larger sample of lines from each source population than we used in the present study.

Several lines of evidence support the point of view of a difference in genetic background. The strongest case comes from the fact that the 2 segregating parent populations were essentially unrelated. Even though some coancestry between gene pools may have been involved, Wright (23) has shown that any genetic contribution from a remote common ancestor has little effect on the coefficient of relationship of selected individuals. As regards to background flavor, lines derived from the 68-27 gene pool were more similar to each other for taste and flavor perception than lines derived from 8549. This is typical since the lines would reflect the genetic variability existent in the segregating parent population as genes not under pressure from selection (those conditioning background flavor characteristics) were randomly fixed during ensuing generations of inbreeding.

A second line of support is given in Fig. 1. Lines differed sharply for flavor type as perceived by taste panelists and fell into discrete profile groups depending on the source from which they were derived. Thirdly, we have noted for a number of years that MSU 8549 and progeny from crosses with this inbred generally are bitter tasting with harsh flavor.

Total soluble solids of the high and low selection of 'Imperator 58' – unlike the breeding lines – were set on a common genetic background, and no taste or flavor deficiencies were noted for either. Since technological and consumer preference panels provide different information, no direct comparison between the 2 taste designs could be made. However, the fact that technological panelists (evaluation III) could not perceive significant sweetness differences between the 2 selections, yet consumer preference tasters (evaluation IV) judged the high solids sample to be more preferable was surprising. It is possible that consumer panelists found the high selection sweeter and thus, more sensory appealing.

Consumer preference judge responses noted for categories 6 ("like very much") and 4 ("like slightly") had the largest differences among samples and presumably had the greatest impact on the mean preference score. On the other hand, closer inspection of these data (Table 3) suggests that taste designs of this type may reflect an intrinsic bias (positive or negative) a panelist may have toward a product. This conclusion is supported by the fact that 22 individuals cast ballots in categories 4, 3, 2, 1 for the samples they tasted with high solids. It follows that a sufficiently large population of tasters should employed to eliminate the impact of product bias. In theory, bias is not encountered with the use of technological panels which employ trained tasters. These judges are coached beforehand and should be unbiased. Thus, a trained panelist's reaction toward a given stimulus should reflect a true sensory perception regardless of the product being tasted.

Implications in breeding. Our results suggest that selection for total soluble solids *per se* is not sufficient for improving the eating quality of table carrots. To maximize progress in the breeding program, it would be more efficient to practice selection for additional sensory characteristics. Since perceived sweetness of the sugars present may be overshadowed by bitter and harsh taste sensations, it would be wise for the breeder to select for nonbitterness and balanced flavor simultaneously with high soluble solids. The breeder should not neglect root color, shape, and type, and once these features are set on an appealing sensory background, emphasis could be placed on selection for sugar composition. If phenotypes are identified that exhibit high levels of fructose, the breeder might consider breeding for succulence (low solids) and sweetness (4).

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Cross Compatibility in the Genus *Anthurium*[1]

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Additional index words. pollination, incompatibility

Abstract. **A total of 1592 cross- and self-pollinations were made among 56 species of *Anthurium* Schott. These pollinations included 20 different selfs, 19 different intraspecific cross-combinations, 315 different intragroup interspecific cross-combinations (including reciprocals), and 29 different intergroup cross-combinations (including reciprocals); 280 fruiting spadices yielded 181 seedling populations which flowered and were evaluated both morphologically and chromosomally. Six morphological groups were constructed using primarily the characters considered as important by Engler (1905). Generally the integrity of these 6 groups was confirmed with the possible exception of Groups V and VI. Groups V and VI were more closely related to each other than to any other group, and the characters used in the division of these 2 groups were not as distinctive as those used to divide the other groups. Crossabilities in *Anthurium* tend to follow morphological similarities in the crosses that were attempted.**

The genus *Anthurium* comprises over 500 species which inhabit central Mexico to central South America and the West Indies. Schott (11) grouped 180 *Anthurium* species into 28 sections. Engler (3, 4, 5, 6) described additional species and divided 486 species into 18 sections. Approximately 100 new species have been described since Engler's monograph (6) was published, but the sectional placement of many of these has remained obscure.

Anthurium andreanum Linden is an important cut flower crop in Hawaii, while *A. scherzerianum* Schott is popular as a potted plant in Europe. Other species of horticultural interest are those with variegated, velvety foliage such as *A. warocqueanum* J. Moore and *A. magnificum* Linden.

Anthurium breeding programs have generally been limited to intraspecific hybridizations within *A. andreanum* (1, 7, 8, 9, 10) and *A. scherzerianum*. Engler (6) compiled 18 interspecific hybrids produced before 1905. The present study was initiated to determine cross compatibilities among species within and between constructed morphological groups which might aid future hybridization programs in the genus *Anthurium*.

Materials and Methods

The 57 *Anthurium* species studied are a part of the University of Hawaii collection. Most of the species were collected in Panama and neighboring countries in 1968, but others were obtained from private and commercial sources.[2] The identification of the specimens was based principally upon the taxonomic treatments by Standley (13) and Engler (6). Voucher specimens were prepared and deposited in the Herbarium of the Botany Department, University of Hawaii.

Since the species identifications and sectional placements were initially unknown, the species were divided into 6 distinct morphological groups on the basis of the important Englerian characters of the number of ovules per locule, color and shape of the berry, shape of the inflorescence, and shape and texture of the leaf (Table 1). After the species were identified, comparison of these Groups were made with Engler's sections. Group I (Fig. 1 & Fig. 2) and II (Fig. 3) were separated on the basis of the number of ovules per locule. Groups III (Fig. 4) and IV (Fig. 5) are Engler's Sections *Pachyneurium* and *Schizoplacium*, respectively. Groups V (Fig. 6 & Fig. 7) and VI (Fig. 8) include the remaining species organized into 2 groups on the basis of leaf texture and berry shape and color.

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