Differences in Aroma, Chemistry, Solubilities, and Smoking Quality of Cured Flue-Cured Tobaccos with Aglandular and Glandular Trichomes

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The chemistry, aroma, solubilities (hexane and 95% ethanol), and smoking quality of cured tobacco from three typical flue-cured varieties that produce glandular trichomes on the surface of the green leaf and an atypical aglandular breeding line were compared. The glandular tobaccos produced more characteristic tobacco aroma than the aglandular tobacco. More hexane-extractable solute was obtained from the aglandular tobacco than from the glandular flue-cured tobaccos, but more alcohol-extractable solute was obtained from the glandular types. A trained smoke panel gave higher scores to the aglandular tobacco than the three glandular varieties. Larger quantities of total volatiles were obtained from the aglandular tobacco. Solanone and oxysolanone identified from the glandular tobacco were absent in the aglandular breeding line. The aglandular tobacco was higher in total alkaloids and lower in reducing sugars than the glandular types.

INTRODUCTION

A typical green tobacco leaf is tacky due to the accumulation of exudate produced by the tiny cellular trichomes on the leaf surface. Trichomes are spindly with three cells per stalk or blunt and unicellular, and these microscopic organelles are either glandular or aglandular (Avery, 1933). Tall trichomes are either glandular or aglandular, but the blunt trichomes are only glandular (Horner and Lersten, 1968).

Some of the earlier investigations involving tobacco trichomes focused upon the accumulation of tobacco alkaloids on the surface of the leaf and in the trichomes. Chakraborty and Weybrew (1963) removed trichomes from the surface of 20 000 frozen green tobacco leaves with a hair harvester designed by the North Carolina State University Department of Agricultural Engineering specifically for harvesting the frozen trichomes. When the collected trichomes were extracted with diethyl ether in a Soxhlet and the basic fraction was removed from the ether extract with 6 N sulfuric acid, nicotine was the primary alkaloid produced. Further analysis of the ether solution revealed alkanes, diterpenes, and fatty acids, and examinations of the sticky residue obtained from harvesting of the trichomes indicated carbohydrates and other compounds were produced by the trichomes.

Thurston et al. (1966) collected the exudate from trichomes of several aphid-resistant *Nicotiana* species: *N. gossei*, *N. benthaniana*, *N. megalosiphon*, with capillary tubes; exudate from *N. repanda*, *N. nesophila*, *N. stocktonii*, and *N. tabacum*, too viscous to collect with capillary tubes, was collected with camel hair brushes. Thin-layer and paper chromatography and ultraviolet spectra identified the alkaloids obtained by capillary tubes from *N. benthaniana* as nornicotine, anabasine, and nicotine; those from *N. gossei* as nicotine, nornicotine, and anabasine; and that from *N. negalosiphon* as nicotine. Leaf extracts of *N. gossei* gave the same results as the exudate from *N. negalosiphon*. Paper chromatography of leaf brushings from *N. repanda*, *N. stocktonii*, and *N. nesophila* all confirmed nicotine in the exudate. Ky-14, *N-tabacum*, L., contained predominantly nicotine in the trichome exudate. Akers (1975) also reported total alkaloids as nicotine obtained from methanol extracts of cheesecloth laden with trichomes harvested from green flue-cured tobacco.

Diterpenes found from green trichomes are of two classifications, duvanes and labdanes, derived from the ancestral species of *N. tabacum*, *N. sylvestris*, and *N. tomentosiformis*. *N. sylvestris* produces duvanes, and *N. tomentosiformis* produces labdanes in addition to duvanes (Chang and Grunwald, 1976). The concentration of duvanes is dominant to the concentration of labdanes in most tobaccos. These two groups of compounds are labile, and during curing and ageing produce compounds that influence tobacco aroma and smoke flavor (Enzell and Wahlberg, 1980).

Aroma emitted from cured tobacco leaves is characteristic of the class of tobacco, stage of maturity, and moisture of the cured leaf. Aroma implies "a distinctive, agreeable fragrance or odor perceived by the sense of smell from a volatile or semi-volatile source in the leaf" (Roberts, 1988). The concentrations of many compounds in tobacco are too low to measure from headspace; therefore, the identity of all compounds contributing to aroma is not accessible (Roeraade and Enzell, 1972). Rix et al. (1977), however, were successful in measuring some compounds contributing to headspace from flue-cured tobacco following volatile trapping with Tenax and performing GC/MS analyses directly from the traps. Cured tobacco was characterized primarily by five carbonyl compounds: isovaleraldehyde, 2-methylbutyraldehyde, 1-valeraldehyde, 1-hexanal, and 6-methyl-5-hepten-2-one. These compounds were common to all flue-cured tobaccos examined in their study. Differences in these compounds among grades were quantitative rather than qualitative. Rix et al. (1977) states that volatile compounds contributing to headspace aroma were easily lost from drying out when samples were finely ground and the moisture was reduced below 4%, but tobacco maintained at 7-9% moisture retained headspace aroma.

In the past 10 years, researchers have attempted to link the chemistry of tobacco trichomes to aroma. Chang et

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al. (1985) collected trichomes from the bottom and upper surfaces of 8000 freshly harvested, fully ripened leaves of a single flue-cured variety onto cheesecloth preextracted with chloroform; a second 8000 leaf samples acquired from yellowed leaves of the same harvest were also taken to monitor chemical changes of harvested trichomes and exudate through the rest of curing. Analysis of the trichome-laden cheesecloths increased from 7 to 13 mg/1000 leaves for solanone from the cheesecloth preps from harvest to the end of the yellowing, but the concentration decreased to 9 mg/1000 leaves by the end of curing. Oxysolanone, an oxidative product of solanone, decreased from 9 to 7.5 mg/1000 leaves from the end of yellowing to the end of curing. Analysis of leaf surface washings from tobacco leaves taken during curing from Chang's experiment gave similar results.

Kaneko (1980) described more than 70 compounds including solanone, oxysolanone, keto acids, and branched aliphatic acids as duvane degradation products from cured tobacco leaves with glandular trichomes.

Trichome research has convinced tobacco breeders of the importance of trichome chemistry associated with tobacco aroma and smoke flavor. Flavor implies "an overall integrated perception of the contributing senses of smell, taste, and feel at the time of consumption" (Lindsay, 1985).

The development of tobaccos with increased quantities of duvanes, labdanes, and sucrose esters has been achieved (E. A. Wernsman, personal communication, 1988). Selection of Oriental tobaccos with increased levels of sucrose esters produced by trichomes has resulted in Oriental tobacco with superior smoking quality (Smeeton, 1987).

This study was conducted to compare cured-leaf chemistry, aroma, and smoking quality between flue-cured tobaccos with glandular and aglandular trichomes on the leaf surface. Tobaccos differed physiologically in that glandular tobaccos produced exudate on the surface of the green leaf but aglandular tobacco failed to produce exudate.

MATERIALS AND METHODS

Three glandular cultivars, NC-2326, DB-101, and Speight G-70, and an aglandular flue-cured breeding line, C-110, were compared for total volatiles, alkaloids, reducing sugars, 95% alcohol- and hexane-extractable solutes, and smoking quality. C-110 is considered an atypical flue-cured tobacco because it produces trichomes without glands. C-110 was the only aglandular flue-cured tobacco available for this study. The older cultivar, DB-101, developed in the 1950s and since discontinued because of poor performance, was used because of the large leaf surface area and wide internode spacing between the leaves. The wide internode spacing was a characteristic which DB-101 has that was different from other flue-cured varieties available at the time of this study. NC-2326 was chosen because it is used as a check variety with NC-95 in the Regional Small Plot Tests and Variety Testing Program to measure performance of new flue-cured varieties before they are released. Speight G-70, an excellent aromatic intermediate alkaloid producing cultivar, was chosen because it has given excellent results in previous subjective smoking experiments (Weeks et al., 1989).

The tobaccos were obtained in 1988 from the North Carolina Tobacco Research Station at Oxford. Leaves from the fourth priming from three replicated plots of each tobacco were used. Trashy leaves and debris were removed; only quality leaves from each tobacco were compared. The midrib was removed by hand, and 1 kg from each replication was cut into rag for cigarettes. Five hundred grams of each sample was preconditioned to 11% moisture, sealed in a 1.9-L jar, and allowed to equilibrate. After equilibration, headspace aroma of the four tobaccos was carefully compared by the sniffing panel described below.

Four participants from the NCSU Tobacco Program were pretested with other varieties of cut tobaccos (not used in this study) that emitted aromas with different intensities. Each person was instructed to arrange four tobaccos in descending order from highest to lowest without any previous knowledge or identification of the samples to determine if the sensory perception was sensitive enough to discriminate among tobaccos with different aroma intensities. Following this exercise, each participant was subjected to test samples coded from one to four and a check. Panel members were blindfolded and instructed to score the tobaccos, according to each panelist's perception of the aroma emitted from the samples, on a scale from 5 to 15, relative to the check sample (NC-95), which was assigned a score of 10. Participants administered the test to one another and rearranged samples as each participant completed the test. Comparisons between two samples were made during the test, but the blindfold was not removed until all participants had completed the test and scores were compiled. The test was administered four times to each participant.

Twenty 85-mm filtered cigarettes were made from each of the tobaccos using a hand-operated cigarette machine. Cigarettes were evaluated by two tobacco company smoke panels (Brown and Williamson Tobacco Co. and Lorillard Tobacco Co.) using NC-95 as a check because of the chemical and smoking similarities to NC-2326 (Weeks et al., 1991). Check cigarettes were assigned a score of 10; panelists were instructed to score the cigarettes on a scale from 5 to 15, relative to panelist's individual perception.

The following technique was followed to prepare tobacco samples that would contain only lamina for analytical analyses. Samples were cleaned by hand, sprayed with a water mist, ground with a coffee mill for 1 min, and sieved through a 25-mesh screen. Tobacco collected on top of a 40-mesh screen was redried and reground in a coffee mill for 1 min. Samples were resieved through a 40-mesh screen and collected for analyses. This eliminated 8% of the sample weight contributed by the lateral veins and produced a sample composed primarily of lamina.

Each replication was analyzed for total alkaloids and reducing sugars by autoanalyzer (Harvey et al., 1969). One gram of each of the tobaccos was extracted for alkaloids and chromatogrammed on thin-layer chromatography to determine the concentration of nornicotine, anabasine, and anatabine in the samples (Hodgson et al., 1965). Ten grams from each replication was analyzed for steam volatiles by capillary gas chromatography using a 60-m (WCOT), 1-μm film, 0.75-mm i.d. megabore Supelcowax column. The oven of the GC was programmed from 60 to 210 °C with a multilinear program, allowing a 5-min delay at 140 and 180 °C to enhance separation for an overall program of 1.5 °C/min. Injector and detector temperatures were run at 250 and 270 °C, respectively. Helium was used as carrier and makeup gas at 8 and 30 mL/min, respectively. Hydrogen and air were calibrated at 30 and 375 mL/min. Tetradecane (0.32 μg/μL) was used as an internal standard with a response factor of 1 to obtain chromatographic data, and a Hewlett-Packard 3393-A integrator interfaced with a Zenith XT computer was used for data collection. Peaks large enough to quantify from each chromatogram were summed to give total volatiles. Samples from NC-2326 and C-110 were analyzed by GC/MS using a VG-20-253 quadrupole mass spectrometer by Brown and Williamson to identify duvanes, duvane derivatives, and other compounds proposed as components of trichomes. The GC column and gas flows described above were also used for collection of GC/MS data.

Due to functional differences between glandular and aglandular trichomes of the green leaf, cured tobaccos were extracted with hexane and 95% ethanol to compare the amounts of polar and apolar solutes obtained from cured tobaccos. Fifty grams of tobacco was dried at 66 °C and extracted in a Soxhlet using hexane followed by 95% ethanol for 48 h with each solvent (Elliot and Birch, 1958).

Data were analyzed by the analysis of variance. Total volatiles, reducing sugars, alkaloids, aroma, and hexane and 95% alcohol solutes were treated as independent variables and tobaccos as dependent variables by one-way classification. After significant differences of the tobaccos were assured, individual T-test was performed by comparing C-110 with other tobaccos, individually

Table I. Subjective Aroma Evaluation of Flue-Cured Tobaccos

	panelist score			
tobacco variety	1	2	3	4
NC-95 (check)	10.00	10.00	10.00	10.00
NC-2326	10.70	10.60	10.70	10.70
Speight G-70	11.40	11.40	11.40	11.40
DB-101	8.60	8.60	8.60	8.60
C-110	7.10	5.70	7.10	7.10

contrast	DF	SS	*F* value	PR > *F*
C-110 vs NC-2326	1	15.68	133.68	0.0001
C-110 vs Speight G-70	1	43.25	368.70	0.0001
C-110 vs DB-101	1	1.05	8.96	0.0151

and collectively, to determine if there were significances at 1 or 5% for all of the comparisons (SAS, 1988).

RESULTS AND DISCUSSION

Tobacco aroma is unique among flue-cured tobaccos, and it is usually easily distinguished because of sweet, pleasant, and nonirritating essence. When tobacco is equilibrated to 11% moisture in a closed container and allowed to stand, headspace aroma in the vessel becomes characteristic of the tobacco. Better quality tobacco usually has the most intense aroma (Rix et al., 1976). The exact site and chemistry responsible for aroma are not known except for duvanes and sucrose esters, which have been identified from trichomes (Keene and Wagner, 1985). Some sensory perceptions of smoke and tobacco aroma result from breakdown of labile compounds in the green leaf and chemical interactions that occur during curing and ageing. After tobacco is cured, cut into rag, and stored, aroma from internal cells of the leaf and aroma from trichome structures equilibrate. It is inconceivable to try to determine the exact source of the aroma that is detected at that time. Chang (1983) observed rupturing of trichomes trapped on cheesecloth as well as color changes of detached trichomes during curing on cheesecloth; green leaves with intact trichomes from the same harvest exhibited different degrees of stickiness from exudate on the leaf surface that disappeared by the time the leaves were cured.

Tobaccos stored in sealed jars emitted different aroma intensities (Table I). Aroma from C-110 was very bland and lower than that of all of the tobaccos compared. C-110 was statistically different from each of the glandular tobaccos ($P < 0.01$; Table I). Differences in aroma intensity were detected among the glandular tobaccos. Speight G-70 and NC-2326 scored higher than the check and DB-101 lower. DB-101, the variety with the largest leaves, had the most leaf surface area per leaf of all of the glandular tobaccos, but this does not necessarily imply that the leaves from DB-101 had the largest number of trichomes per unit area. Aroma scores from NC-95 and NC-2326 were approximately the same, but NC-2326 was slightly higher. NC-2326 and NC-95 are checks used in evaluating the performance of flue-cured test varieties in the Regional Variety Testing Program; therefore, it was no surprise that the aromas of NC-95 and NC-2326 were similar. Frequently, performances of these two tobaccos are similar in chemistry and smoking quality (Weeks et al., 1990). Speight G-70 was the most aromatic of the glandular tobaccos; therefore, it was scored the highest of the three glandular tobaccos and the check (NC-95) by the panelists. Aroma from DB-101 was the lowest of the glandular tobaccos but still more intense than C-110. Poor aroma obtained from C-110 was likely due to differences in the lipophilic concentration of the intact membranes which encapsulated the aroma. This was reflected by the amount of solute obtained from hexane extractions from C-110, which was significantly different from that of glandular tobaccos (Table II). Mohapatra and Johnson (1973) showed distinctly with electron microscope studies that the membrane of the cured tobacco leaf collapses but remains intact; consequently, the membrane will still surround the solute in the cell after curing.

Table II. Hexane- and 95% Ethanol-Extractable Solutes[a] of Flue-Cured Tobaccos

	extract, %			extract, %	
tobacco variety	hexane	95% ethanol	tobacco variety	hexane	95% ethanol
NC-2326	6.67	47.67	DB-101	7.89	47.33
Speight G-70	7.00	49.67	C-110	10.89	40.33

contrast (hexane)	DF	SS	*F* value	PR > *F*
C-110 vs others	1	4.00	16.00	0.0071

contrast (ethanol)	DF	SS	*F* value	PR > *F*
C-110 vs others	1	49.00	88.20	0.0001

[a] Each value is the mean of three replications.

Table III. GC Analysis of Steam Volatiles from Flue-Cured Tobaccos

tobacco variety	steam volatiles,[a] μg/g	tobacco variety	steam volatiles,[a] μg/g
NC-2326	1520	DB-101	1296
Speight G-70	1214	C-110	1853

contrast	DF	SS	*F* value	PR > *F*
C-110 vs NC-2326	1	13 448	5.55	0.0429
C-110 vs Speight G-70	1	817 281	337.08	0.0001
C-110 vs DB-101	1	186 660	76.99	0.0001

[a] Each value is the mean of three replications.

The 95% ethanol extractions demonstrated C-110 produced higher quantities of apolar constituents. The lower quantities of polar materials from C-110 probably influenced the distribution of water in the tobacco along with the apolar composition of the membrane which impaired the liberation of aroma from C-110.

Steam volatiles from the four tobaccos showed no relationship to headspace aroma (Table III). Speight G-70 produced the lowest total steam volatiles of the four and C-110 the highest. C-110 volatiles were higher than volatiles from glandular tobaccos, which indicates total steam volatiles did not significantly contribute to headspace aroma. Since C-110 does not produce secreting trichomes on the surface of the leaf, the weak aroma produced came from an endogenous source. These results are similar to those reported by Chang (1983) that most of the total neutral volatiles from cured leaves were obtained after cured leaves were dipped in chloroform for 30 s. This would tend to exclude compounds from the surface of the leaf from contributing to total neutral volatiles, which also suggested that aroma from this breeding line came from an endogenous source. Higher concentration of total volatiles obtained from C-110 could also help explain the difference in smoke panel scores (Table IV).

Chromatographic profiles of steam volatiles of the four different tobaccos were similar qualitatively with few exceptions (Figure 1). Solanone and oxysolanone were missing from the C-110 profile. This was determined from GC/MS analysis comparing the spectra of the peaks from the two profiles (C-110 and NC-2326). Solanone and

Table IV. Subjective Evaluation of Cigarette Smoke from Flue-Cured Tobaccos

tobacco variety	panel score[a] A	B	tobacco variety	panel score[a] A	B
NC-95 (check)	10	10	DB-101	5	7
NC-2326	10	10	C-110	12	12
Speight G-70	11	11			

[a] Each value is the mean of ratings of four panelists.

oxysolanone were identified by MS using the five largest ions in each spectrum. The peaks shown at retention time (RT) 59.018, *m/z* 93 (100%), 43 (80%), 60 (52%), 121 (36%), 136 (30%), were comparable to literature spectra for solanone. The peak at RT 103, *m/z* 43 (100%), 97 (33%), 95 (13%), 41 (12%), was identified as oxysolanone. Both compounds were missing in C-110 (Figure 1). The sum of the two compounds appeared in sizeable quantities in each glandular cultivar (Speight G-70, 67 μg/g; NC-2326, 62 μg/g; and DB-101, 51 μg/g). This confirms that C-110 did not produce duvanes. However, C-110 produced 142 μg/g 5-hydroxy-6,7-dimethylbenzofuran [RT 141.245, *m/z* 43 (100%), 162 (83%), 147 (82%), 81 (64%), 55 (58%)]. The spectrum of this compound was not found in MS data obtained from NC-2326 or in the chromatograms of the other glandular cultivars (Figure 1).

The four flue-cured tobaccos were analyzed for total alkaloids and reducing sugars by the autoanalyzer technique. C-110 produced significantly higher quantities of total alkaloids than NC-2326, DB-101, and Speight G-70 (Table IV). These tobaccos are not nicotine converters; therefore, secondary alkaloids, nornicotine, anabasine, and anatabine, are found in very minute amounts in the cured leaf of these four tobaccos. Extracts from 1 g of each of the four tobaccos separated on thin-layer chromatography showed nicotine was the only alkaloid compound that was measurable from a 1-g quantity. Consequently, we felt that the autoanalyzer analyses for total alkaloids using nicotine as a quantitative standard was a good comparison of total alkaloids among the tobaccos.

The works of Chakraborty and Weybrew (1963), Akers (1975), and Thurston et al. (1966) produced evidence that tobacco trichomes contained alkaloids; nevertheless, they failed to prove trichomes as the site of synthesis for alkaloids found in the exudate and from the trichome extracts. Dawson (1942, 1944) showed that nicotine originates solely in the root tip of *N. tabacum* and *N. glauca* but anabasine, on the other hand, is formed in the root and shoot of *N. glauca*. Dawson (1945) also confirmed that nornicotine is formed in the leaf at the expense of nicotine by transmethylation. Solt (1957) confirmed nicotine synthesis in excised scions fed through cut ends with tritium-labeled nicotinic acid. From these studies, one could conclude that the tobacco trichomes could possibly produce nornicotine at the expense of nicotine and, at the same time, synthesize small amounts of anabasine in glandular trichomes; however, the tobaccos were too low in nornicotine and anabasine to make this postulation. Under the circumstances, conclusions can also be drawn that trichomes are not necessarily the site of alkaloid synthesis since C-110 produced the largest quantity of total alkaloids and C-110 does not have glandular trichomes (Table V).

Nicotine is not considered a flavor compound but does improve perception during smoking, and a positive correlation exists between nicotine and tar in smoking (Matzinger et al., 1984). Although tar was not determined, we predicted C-110 would produce more tar during smoking than the glandular tobaccos because of the higher total alkaloids and the significant differences in apolar material recovered from C-110 hexane extracts. This hypothesis is analogous to results obtained by Tso (1990) that the more high molecular weight lipid, nicotine, and resinous constituents contained in tobacco the higher the tar. Difference in hexane-soluble solute between C-110 and glandular tobaccos was probably due to difference in the waxes from the cuticle and lipid materials from the cellular membranes (Table II).

Akers (1975) reported chloroplasts and starch grains in green tobacco trichomes but proposed that trichomes were storage sites for starch rather than a site of synthesis. Starch in green tobacco leaves is converted to reducing sugars during the yellowing phase of flue-curing. Reducing sugars were significantly lower in C-110 than in the glandular tobaccos ($P < 0.01$; Table V). When the alcohol solute was analyzed for reducing sugars by autoanalyzer, only 90% of the reducing sugars obtained by the autoanalyzer extraction technique used for routine reducing sugar analysis was recovered from the alcohol extract from C-110; however, 95+% was recovered from the glandular tobaccos. The discrepancies in extraction between glandular and aglandular tobacco cannot be explained; however, it is known that 95% alcohol is not as efficient for extracting sugars as the aqueous solutions used in the autoanalyzer procedure for determining reducing sugars. Although we could not account for a quantitative difference in the two extraction techniques, the margins of difference in reducing sugars obtained from the tobaccos by the two techniques were the same.

Tobaccos were equilibrated to 11% moisture before the panel sniffed the tobaccos; one can rationalize that differences in the lipophilic properties among the different tobaccos (hexane-extractable solute, Table II) were responsible for the difference in aroma detected among the tobaccos. It is documented that odoriferous substances in plant tissue are often dissolved in terpenoid hydrocarbons and other lipophilic substances localized in plant tissue; therefore, aroma-producing compounds must be freed from complex mixtures that exist in order to obtain characteristic aroma of odoriferous compounds (Haard, 1985). In this case, water absorbed by the tobacco during equilibration of the samples prior to sniffing probably formed a shell surrounding the lipid complex and further shielded the aroma. This could very well explain why C-110, which produced considerably more hexane-extractable solute than any of the other tobaccos in this test, was significantly lower in aroma when compared to the glandular tobaccos.

Data from the smoke panelists are shown in Table IV. There was no comparison between the smoking panel rank and order and the order in which tobaccos were scored from the headspace aroma from the jars (Table I). Rix et al. (1977) demonstrated that differences in headspace analyses among tobacco grades were quantitative and better tobacco grades produced greater quantities of headspace volatiles. The aroma emitted from C-110 was insipid and significantly lower than that of Speight G-70, NC-2326, and DB-101 (Table I). Comparing these data with those of Rix et al. (1977), C-110 would have been judged poor smoking tobacco; however, steam volatiles obtained from C-110 were higher than those from either of the glandular tobaccos with which C-110 was compared. This indicated the smoke panel's perception of the cigarettes was affected by volatiles generated while smoking.

Reducing sugars were significantly lower in C-110 than in glandular tobaccos, indicating that smoke pH was

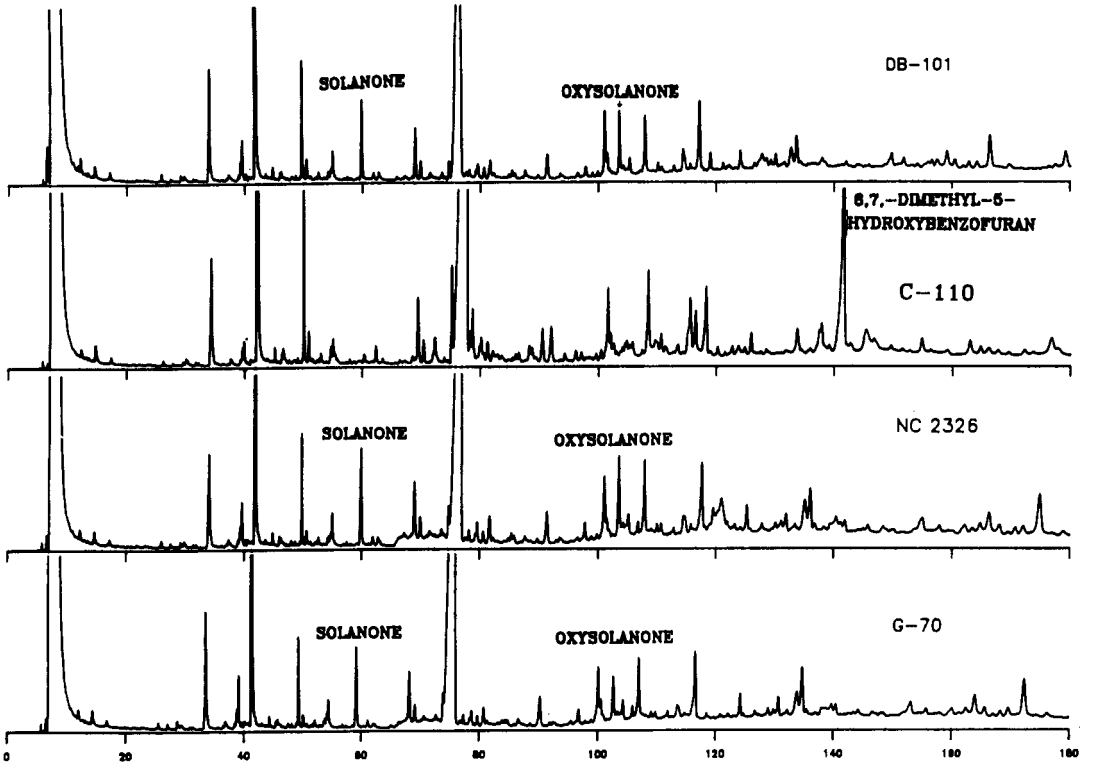

Figure 1. Profiles of glandular and aglandular flue-cured tobaccos.

Table V. Total Alkaloids and Reducing Sugars[a] of Flue-Cured Tobaccos

tobacco variety	% alkaloids	% reducing sugars	tobacco variety	% alkaloids	% reducing sugars
NC-2326	2.65	20.00	DB-101	3.12	17.00
Speight G-70	2.85	17.90	C-110	3.69	12.00

contrast (alkaloids)	DF	SS	*F* value	PR > F
C-110 vs others	1	0.2567	359.60	0.0001

contrast (sugars)	DF	SS	*F* value	PR > *F*
C-110 vs others	1	8.4100	160.19	0.0001

[a] Each value is the mean of three replications.

probably higher from C-110 cigarettes than smoke pH from cigarettes of glandular tobaccos. Smoke pH was not determined, but it is well documented that reducing sugars in flue-cured tobacco affect the pH of smoke (Shmuk, 1953; Sensabaugh and Cundiff, 1967) because tobaccos with lower quantities of reducing sugars produce fewer acid-producing substances during smoking which affects delivery of compounds in the smoke. This phenomenon affects smoke delivery and flavor perception, which partially helps to explain the smoke panel scores of the different tobaccos. C-110 also gave higher quantities of hexane-extractable solute, previously discussed, which also affected aroma and smoke flavor in different ways.

CONCLUSION

Major differences in aroma, leaf chemistry, polar and apolar solutes, and subjective smoke scores were obtained among flue-cured tobaccos with glandular and aglandular trichomes. C-110, a aglandular breeding line, produced more total volatiles than glandular tobaccos, but GC/MS data of steam volatile compounds demonstrated duvane degradation compounds were absent in the aglandular tobacco. Aglandular tobacco also produced significantly greater amounts of hexane-soluble solute than the glandular tobaccos. C-110 produced 5-hydroxy-6,7-dimethylbenzofuran, which was not found in the glandular tobaccos. The amount of alcohol-soluble material from glandular tobaccos was statistically significant to that from the aglandular tobacco, which was similar to the amount of reducing sugars found between the tobacco types. Tobaccos with glandular trichomes produced more aroma than the aglandular tobacco; however, the perception of the smoking panel was affected not only by compounds emitting aroma detected from the headspace but also by total chemistry contributing to smoke flavor such as steam volatiles, total alkaloids, and other components. Although trichome compounds produced by glandular trichomes influence tobacco aroma and contribute to smoke flavor, compounds produced endogenously in tobacco appear to have more influence on smoke flavor than aroma. In this study, tobacco with aglandular trichomes was given higher scores by two smoke panels than tobaccos with glandular trichomes.

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