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The Effect of Cigarette Design on the Content of Phenols in Mainstream Tobacco Smoke*

by

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SUMMARY

The influence of cigarette design on the content of phenols in mainstream tobacco smoke was studied. The most abundant phenols - catechol, hydroquinone, phenol, *o*-, *m*- and *p*-cresol, and resorcinol - were determined by HPLC with fluorescence detection. Hydroquinone and catechol made the most significant contribution to the total content of phenols with maximum values of 135.0 µg/cig and 95.7 µg/cig, respectively. The highest total content of phenols (330.9 µg/cig) was measured in the smoke of a Virginia tobacco cigarette. The total content of phenols (µg/cig) in cigarette mainstream smoke decreased linearly with increased filter ventilation, $R^2 = 0.9536$. The results obtained indicate that filtration and ventilation can strongly influence the mainstream tobacco smoke content of phenol and its less polar derivatives, *o*-, *m*- and *p*-cresol, which were reduced by up to 85%. Hydroquinone and catechol are less affected and only cigarettes with the special "recessed charcoal filter system" and cigarettes with filter ventilation over 50% showed significant reductions. On a per mg 'tar' basis the largest contributor to phenols in cigarette mainstream smoke was the selection of the tobacco type. The use of any standard commercial filter on an unfiltered cigarette can substantially reduce the yield of phenols in cigarette mainstream smoke. The use of special filters (e.g., the "recessed charcoal filter system") or high levels of cigarette ventilation does not reduce the amount of phenols in tobacco smoke considerably when normalized on a per mg 'tar' basis. [Beitr. Tabakforsch. Int. 24 (2011) 187–193]

KEY WORDS: mainstream tobacco smoke, cigarette design, phenols, HPLC, fluorescence detection.

ZUSAMMENFASSUNG

Der Einfluss des Zigarettendesigns auf den Gehalt von Phenolen im Hauptstromrauch wurde untersucht. Mit Hilfe der Hochleistungs-Flüssigkeits-Chromatographie (HPLC) und der Fluoreszenzmethode wurden die Phenole, die im Hauptstromrauch in den höchsten Konzentrationen vorkommen - Brenzcatechin, Hydrochinon, Phenol, *o*-, *m*- und *p*-Kresol, sowie Resorcin - bestimmt. Den höchsten Anteil am Gesamtvorkommen der Phenole hatten Hydrochinon und Brenzcatechin mit 135,0 µg und 95,7 µg pro Zigarette. Im Rauch von Virginia-Zigaretten wurde der höchste Gesamtgehalt an Phenolen (330,9 µg/Zig.) gemessen. Der Gesamtgehalt der Phenole (µg/Zig.) verringerte sich linear ($R^2 = 0{,}9536$) mit ansteigender Filterventilation. Die erzielten Resultate deuten darauf hin, dass Ventilierung und die Verwendung von Filtern den Gehalt von Phenolen und seiner weniger polaren Derivate im Hauptstromrauch stark beeinflussen können. Dabei wurden *o*-, *m*- und *p*-Kresol um bis zu 85% reduziert. Hydrochinon und Brenzcatechin wurden in geringerem Maße reduziert und lediglich Zigaretten mit einem speziell vertieften Kohlefilter oder Zigaretten mit einer Filterventilation von über 50% wiesen eine signifikante Reduzierung auf. Der stärkste Faktor bei der Entstehung von Phenolen im Hauptstromrauch war die Auswahl des Tabaks. Die Verwendung von handelsüblichen Filtern jeglicher Art kann den Phenolgehalt im Hauptstromrauch von Zigaretten wesentlich reduzieren. Die Verwendung spezieller Filter, wie z.B. vertiefter Kohlefilter, oder ein intensiver Grad an Ventilation verringert dagegen den Gehalt von Phenolen im Zigarettenrauch - bei Normalisierung auf pro mg Kondensat - nicht wesentlich. [Beitr. Tabakforsch. Int. 24 (2011) 187–193]

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RESUME

L'influence de la conception des cigarettes sur le contenu en phénols dans la fumée principale du tabac a été étudiée. Les phénols les plus nombreux, le catéchol, l'hydroquinone, le phénol, l'o-crésol, le m-crésol et le p-crésol ainsi que le résorcinol ont été déterminés par CLHP (Chromatographie Liquide à Haute Performance) avec détection de fluorescence. L'hydroquinone et le catéchol constituent l'apport principal du contenu total en phénols avec des valeurs maximales de 135,0 µg/cig. et 95,7 µg/cig., respectivement. Le contenu total le plus élevé en phénols (330,9 µg/cig.) a été mesuré dans la fumée d'une cigarette contenant du tabac de Virginie. La quantité totale en phénols (µg/cig.) dans la fumée principale de cigarettes a diminué de façon linéaire avec l'augmentation de la ventilation du filtre, R^2 = 0,9536. Les résultats obtenus indiquent que la filtration et la ventilation peuvent fortement influencer le contenu en phénols de la fumée principale de tabac et de ses dérivés moins polaires, l'o-crésol, le m-crésol et le p-crésol, qui ont été réduits de 50% à 85% environ. L'hydroquinone et le catéchol ont été moins affectés et seules les cigarettes avec le « système de filtre au charbon intégré » spécial et les cigarettes avec une ventilation du filtre de plus de 50% ont montré des réductions significatives. En goudron par mg, le choix du type de tabac a été le principal contributeur en phénols dans la fumée principale de cigarettes. L'utilisation d'un filtre commercial standard quel qu'il soit sur une cigarette sans filtre peut réduire de façon significative le rendement en phénols de la fumée principale des cigarettes. L'utilisation de filtres spéciaux (par exemple le «système de filtre au charbon intégré») ou les niveaux élevés de ventilation ne diminuent pas notablement la quantité de phénols dans la fumée de tabac lorsque ce chiffre est normalisé sur une base de goudron par mg. [Beitr. Tabakforsch. Int. 24 (2011) 187–193]

INTRODUCTION

Phenols are environmental pollutants, the sources of which range from the industrial production of chemicals and pharmaceuticals to tobacco smoke. These compounds were identified in water, air and various biological matrices. Studies on the carcinogenic action of phenols have shown that phenol and its derivatives affect enzyme activity and cellular metabolism (1, 2, 3). During the last decade there was consistently strong public interest in the analysis of tobacco smoke with regard to the determination and control of its toxic constituents, including phenols (7, 8, 16). The most abundant phenols in cigarette mainstream smoke are catechol, hydroquinone, phenol, *o*-, *m*-, and *p*-cresol and resorcinol (6, 14). Hydroquinone and catechol were found to be more harmful toxins than phenol as they provoke statistically significant changes in erythrocyte function and lymphocyte proliferation (2, 3, 12). These compounds specifically inhibit lymphocyte proliferation without affecting cell viability and may create favorable conditions for tumor cell growth (12). It has been reported that the presence of phenols in tobacco smoke results mainly from the decomposition of chlorogenic acid, carbohydrates and lignin (6). There were many attempts to reduce the content of phenols in cigarette mainstream smoke by the utilization of various filters and/or selection of tobaccos with lower levels of chlorogenic acid (6, 15). The efforts to reduce the content of phenols in cigarette smoke were not very successful because phenols are natural constituents of tobacco and play an important role for the overall flavor and taste of tobacco products. According to many authors the utilization of filters and/or the incorporation of cigarette ventilation can reduce significantly only the most volatile compound in this group-phenol (6). There is a wide range of contemporary chromatographic methods for the determination of phenols but the most accessible and precise procedure is HPLC analysis with fluorescence detection (10, 11, 14). Most publications related to the phenols in tobacco smoke studied several reference cigarettes and commercial cigarette brands (4, 9, 16). Much less is known about the influence of cigarette design on the content of phenols in mainstream tobacco smoke (13).

This paper analyzes the effect of cigarette design on the content of phenols in smoke and the amounts of toxic phenols inhaled by tobacco users.

EXPERIMENTAL

Sample collection

The description of the samples studied, along with their 'tar', nicotine and carbon monoxide content is given in Table 1. Samples 1 and 2 were selected to compare the same style of cigarettes with and without a filter. Note that sample 1 had no ventilation. Samples 3–6 were the same style of filter cigarettes without ventilation (sample 3) and with varying degrees of ventilation (samples 4–6). Samples 7 and 8 were the same style of ventilated filter cigarettes and chosen to evaluate tobacco rods of different length (burned tobacco 0.713 g/cig and 0.536 g/cig, respectively). Samples 9–11 were filter cigarettes without ventilation containing a single type of tobacco (Burley, Virginia or Oriental). Samples 12 and 13 belonged to the same cigarette brand, had the same blend and ventilation, the only differences being the filter design (recessed charcoal filter system vs. plain acetate filter) and diameter (king size vs. slim). The recessed charcoal filter system had three parts: charcoal filter, acetate filter and ventilation chamber. Samples 14 and 15 (blends D and E) were commercial cigarettes containing different blends; however, they had identical filters, ventilation and size as well as similar specifications for 'tar' (< 10 mg/cig), nicotine (~ 0.8 mg/cig) and carbon monoxide (~ 10 mg/cig). The various cigarette construction parameters were chosen to provide a wide range of differences in filtration, filter ventilation, length of tobacco rod burned, tobacco type, blend and size of the cigarettes (Table 1). All cigarettes in this study were selected, prepared and smoked under ISO standard conditions in the Tobacco and Tobacco Products Institute, Plovdiv, Bulgaria.

Table 1. Cigarette description, 'tar' (mg/cig), nicotine (mg/cig) and carbon monoxide content (mg/cig) in cigarette mainstream smoke.

Sample No.	Cigarette description	'Tar' mg/cig	Nicotine mg/cig	Carbon monoxide mg/cig
1	American blend (A) filter cigarettes 97 mm without ventilation, filter length 27 mm	6.24	0.53	12.38
2	American blend (A) non-filter cigarettes	18.49	0.66	12.35
3	American blend (B) filter cigarettes 97 mm without ventilation, filter length 27 mm	11.34	0.89	12.30
4	American blend (B) filter cigarettes with ventilation 42,7 %	7.37	0.68	7.77
5	American blend (B) filter cigarettes with ventilation 57,5 %	5.43	0.51	5.22
6	American blend (B) filter cigarettes with ventilation 67,8 %	4.10	0.42	3.63
7	American blend (F) ventilated filter cigarettes 97 mm, filter length 27 mm, burned tobacco 0.713 g/cig	8.58	0.61	12.74
8	American blend (F) ventilated filter cigarettes 84 mm, filter length 27 mm, burned tobacco 0.536 g/cig	6.31	0.53	10.37
9	Filter cigarettes without ventilation with Burley tobacco, burned tobacco 0.580 g/cig	18.87	1.19	19.13
10	Filter cigarettes without ventilation with Virginia tobacco, burned tobacco 0.653 g/cig	19.60	1.26	15.80
11	Filter cigarettes without ventilation with Oriental tobacco, burned tobacco 0.766 g/cig	22.60	0.98	13.70
12	American blend (C) king size ventilated cigarettes with recessed charcoal filter system, burned tobacco 0.694 g/cig	6.87	0.60	8.96
13	American blend (C) slims ventilated cigarettes with cellulose acetate filter, burned tobacco 0.548g/cig	7.37	0.68	7.77
14	American blend (D) king size ventilated filter cigarettes 84 mm, filter length 21 mm	9.01	0.81	10.74
15	American blend (E) king size ventilated filter cigarettes 84 mm, filter length 21 mm	7.82	0.70	8.74

Chemicals

Hydroquinone, resorcinol, catechol, phenol, *o*-cresol, and *m*-cresol were purchased from Merck (Germany) certified quality, 99.9% pure, and *p*-cresol from Supelco (USA) certified quality, 99.9%. Mobile phases were prepared from acetonitrile and acetic acid, HPLC grade, Merck, Germany. Standard solutions with concentrations of 10, 5.0, 1.0, 0.5, and 0.1 μg/mL were obtained by dissolving each phenol in water/acetic acid (99:1, v/v). The working standards had concentrations of 4 μg/mL for hydroquinone, resorcinol, catechol and phenol; 2.5 μg/mL for *p*-cresol, and 2.0 μg/mL for *o*-cresol.

Smoke collection and sample preparation for chromatography

The cigarettes were smoked on an 8-channel smoking machine Filtrona SM302 in accordance with ISO standard conditions, 35 mL puff volume, 2 sec puff duration, one puff per min (ISO 4387). Total particulate matter (TPM) from five cigarettes was collected on 44 mm Cambridge filter pads. The pads were extracted with 20 mL 1% acetic acid for 30 min on a mechanical shaker (14). The extracts were filtered through a 0.45 μm filter and the phenols analyzed by HPLC with fluorescence detection after RISNER and CASH (14). Nicotine and carbon monoxide were determined in accordance with ISO standard conditions.

HPLC and fluorescence detection of phenols

The instrumentation used for HPLC analysis consisted of two Knauer pumps and a RF-10 A_{XL} scanning fluorescence detector (Knauer, Germany). The separation was achieved on a Purospher ^{R}star RP-18e 25 cm × 4.6 mm i.d., 5 μm particle size (Merck, Germany). The analysis took place under gradient conditions using two solutions prepared from water, acetonitrile, and acetic acid. Solution A was a mixture of 90 parts of 1% acetic acid in water and 10 parts of solution B. Solution B was prepared by mixing 99 parts acetonitrile and 1 part 1% acetic acid in water. The flow rate was 1 mL/min. The composition of mobile phase A was changed linearly in 25 min to reach 100% B, by modifying the conditions after RISNER and CASH (14). The fluorescence of the phenols was measured initially at 304 λex and 338 λem. The conditions were changed after 9 min to 284 λex and 313 λem, after 11 min to 280 λex and 325 λem and after 14 min to 274 λex and 310 λem. The injection volume was 10 μL.

Statistics

The linearity of the fluorescence response of the detector was examined by using five standards in the concentration range of phenols from 0.1 to 10 μg/mL. Calibration curves representing quantity versus peak area were generated for each compound and used for measuring the content of the phenols. These curves were linear and the R^2 values for the

dependence were all above 0.998. The limits of detection (LOD) calculated as three times SD (SD is the standard deviation for a low sample) were between 0.1–0.4 µg/mL. The limits of quantification (LOQ) calculated as three times the peak area of the lowest sample (0.1 µg/mL) showed values for the phenols between 0.5 µg/cig and 2.3 µg/cig. The standard deviations (SD) were calculated from five HPLC replicates of the working standard and a sample smoked and analyzed in five repetitions. The RSD varied from 4% to 10%. The results for the content of phenols are presented as means of three HPLC replicates per sample, calculated as µg phenols per cigarette and µg phenols per mg of 'tar'.

RESULTS AND DISCUSSION

In this study, the effect of cigarette design on the content of phenols in mainstream tobacco smoke was evaluated using HPLC analysis with fluorescence detection.

Figure 1 illustrates the chromatographic profile of phenols in cigarette mainstream smoke. The peaks were sharp and well resolved; retention times (t_R, min) were: hydroquinone (t_R = 8.13), resorcinol (t_R = 10.77), catechol (t_R = 11.80), phenol (t_R = 14.57), *m*- and *p*-cresol (t_R = 16.07), and *o*-cresol (t_R = 16.47). The peaks of the isomeric phenols, *m*- and *p*-cresol, were not resolved and these compounds were detected simultaneously, which was in accordance with earlier observations (11).

The content of phenols (µg/cig, µg/mg 'tar') in the cigarette mainstream smoke of the 15 samples studied is presented in Table 2. The total yield of phenols varied from 73.6 µg/cig to 330.9 µg/cig. The most significant contribution was from hydroquinone and catechol with maximal contents of 135.0 µg/cig and 95.7 µg/cig, respectively. The highest total yield of phenols (330.9 µg/cig) was measured in the smoke of a Virginia tobacco cigarette, whereas the lowest total content of phenols (73.6 µg/cig) was measured in the mainstream smoke of the cigarette with the highest ventilation (67.8%). When the total yield of phenols was calculated on a per mg 'tar' basis, the highest value (22.8 µg/mg 'tar') was obtained from the ventilated filter cigarette (sample 8, total yield of phenols: 143.7 µg/cig) having a very low 'tar' yield (6.31 mg/cig).

Filter effect

The data for samples 1 and 2 showed a 46.4% reduction of the total content of phenols in the mainstream smoke of the filtered cigarette (sample 1, 'tar' yield 6.24 mg/cig) compared to the unfiltered one (sample 2, 'tar' yield 18.49 mg/cig). The largest reduction was observed for phenol (65.5%) and *o*-cresol (74.1%). However, there was small difference in the hydroquinone content in the mainstream smoke of the filtered and unfiltered cigarettes (Table 2).

Filter type effect

This effect was observed in sample 12, where the special "recessed charcoal filter system" retained phenols better than the plain acetate filter in sample 13 on a per cigarette basis. This observation is in accordance with previous studies on the efficiency of these types of filters (9). The cigarettes in sample 13 had a smaller diameter (slims) and the mass of burned tobacco in sample 13 was smaller than in sample 12. Despite that, the total content of phenols in the smoke of sample 13 was slightly higher (Table 2). When the yield data was calculated for each phenol on a per mg 'tar' basis there were no major differences in the relative yields of any of the phenols measured.

Ventilation effect

With ventilation increasing from 0% (sample 3) to 67.8% (sample 6) the total content of phenols in cigarette mainstream smoke decreased by half (from 155.9 µg/cig to 73.6 µg/cig). Again, the highest reduction (85.0%) was observed for phenol. Compared to the filter effect, ventilation had a stronger influence on the reduction of the yield of both phenol and hydroquinone (51.8%) in cigarette mainstream smoke.

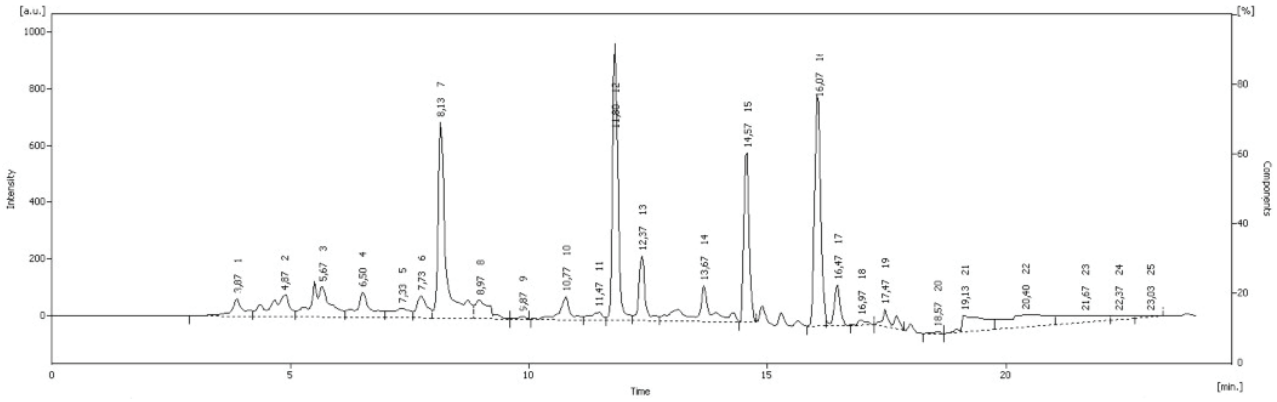

Figure 1. HPLC fluorescence detection profile of phenols in cigarette mainstream smoke. The retention time (min) of each peak is indicated. Retention time of phenols: hydroquinone (t_R = 8.13), resorcinol (t_R = 10.77), catechol (t_R = 11.80), phenol (t_R = 14.57), *m*- and *p*-cresol (t_R = 16.07) and *o*-cresol (t_R =16.47).

Table 2. Content of phenols (µg/cig and µg/mg 'tar') in cigarette mainstream smoke. Data are the means of 3 HPLC replicates. Samples studied: (Sample 1: cigarettes with filter, Sample 2: without filter); (Samples 3–6: cigarettes with different degrees of ventilation); (Samples 7 and 8: cigarettes with different quantities of burned tobacco); (Samples 9–11: cigarettes made from different types of tobacco); (Samples 12 and 13: commercial same American blend cigarettes with different filters, sizes and quantities of burned tobacco); (Samples 14 and 15: commercial cigarettes with different American blends and same filter, ventilation and size).

Samples[a] No.	Phenols													
	Hydroquinone		Resorcinol		Catechol		Phenol		*m* -+ *p*-Cresol		*o*-Cresol		Sum of phenols	
	µg/cig	µg/mg 'tar'	µg/cig	µg/mg 'tar'	µg/cig	µg/mg 'tar'	µg/cig	µg/mg 'tar'	µg/cig	µg/mg 'tar'	µg/cig	µg/mg 'tar'	µg/cig	µg/mg 'tar'
1	35.2	5.6	5.1	0.8	28.3	4.5	11.0	1.8	11.3	1.8	4.1	0.7	95.0	15.2
2	36.0	1.9	14.3	0.8	48.8	2.6	31.9	1.7	26.9	1.5	15.8	0.9	173.7	9.4
3	53.5	4.7	13.1	1.2	44.3	3.9	30.1	2.7	11.1	1.0	3.8	0.3	155.9	13.7
4	34.7	4.7	2.6	0.4	39.9	5.4	27.8	3.8	9.5	1.3	3.5	0.5	118.0	16.0
5	28.4	5.2	6.2	1.1	33.7	6.2	19.7	3.6	8.3	1.5	3.0	0.6	99.3	18.3
6	25.8	6.3	6.0	1.5	30.7	7.5	4.5	1.1	5.0	1.2	1.6	0.4	73.6	18.0
7	65.8	7.7	7.6	0.9	68.1	7.9	20.5	2.4	15.4	1.8	6.0	0.7	183.4	21.4
8	54.2	8.6	6.9	1.1	46.7	7.4	17.2	2.7	15.1	2.4	3.6	0.6	143.7	22.8
9	37.9	2.0	6.6	0.3	30.9	1.6	33.4	1.8	8.4	0.4	7.0	0.4	124.2	6.6
10	135.0	6.9	26.2	1.3	95.7	4.9	35.8	1.8	28.1	1.4	10.1	0.5	220.9	16.9
11	122.8	5.4	18.8	0.8	54.2	2.4	33.4	1.5	25.0	1.1	10.5	0.5	264.7	11.7
12	42.4	6.2	9.0	1.3	46.2	6.7	7.9	1.1	10.5	1.5	3.9	0.6	119.9	17.5
13	42.8	5.8	10.4	1.4	52.7	7.2	10.9	1.5	9.0	1.2	3.0	0.4	128.8	17.5
14	86.4	9.6	7.2	0.8	55.7	6.2	19.3	2.1	15.9	1.8	3.5	0.4	188.0	20.9
15	67.7	8.7	6.2	0.8	46.2	5.9	17.5	2.2	8.0	1.0	3.6	0.5	149.2	19.1

The total content of phenols in the cigarette mainstream smoke decreased linearly with increased of filter ventilation, $R^2 = 0.9536$ (Figure 2). Linear correlations were also observed for hydroquinone ($R^2 = 0.9958$) and catechol ($R^2 = 0.8965$). The data show that filtration and ventilation influence predominantly the content of phenol and its less polar derivatives, *o*-, *m*-, and *p*-cresol, which were reduced by up to 85%. The 'tar' yields of samples 3–6 decreased from 11.34 mg/cig to 4.10 mg/cig. When the yield data for each phenol were normalized on a per mg 'tar' basis, no correlation with ventilation was observed.

Effect of the quantity of burned tobacco

The comparison of the smoke yields for samples 7 and 8 shows that as the amount of tobacco burned decreased, the total content of the phenols (µg/cig) in mainstream smoke also diminished (Table 2). The decrease in the total content of phenols here was only 21.6%, which was significantly lower than the decrease in samples comparing filter and ventilation effects, where up to 85% reduction was measured. According to the literature, most efforts directed towards reducing the content of phenols in cigarette mainstream smoke concentrated on modifications of filtration and ventilation (1, 11, 16). From a manufacturing point of view the production of viable cigarettes that burn lower amounts of tobacco (e.g., inclusion of expanded tobacco or cigarettes of lower fill ratios) is undesirable and often problematic. The 'tar' yields in sample 7 and sample 8 were 8.58 mg/cig and 6.31 mg/cig, respectively. When the smoke yield data for each phenol was normalized on a per mg 'tar' basis, no differences in the content of phenols between the two samples 7 and 8 were observed.

Effect of tobacco type

Mainstream tobacco smoke is a complex matrix containing thousands of components generated during the cigarette burning process. The data obtained in this study is in accordance with previous findings concerning chlorogenic acid as the most significant contributor to catechol and hydroquinone formation (6). Chlorogenic acid and rutin are the main components of the polyphenol complex of tobacco (5) and their quantity varies with tobacco type. Virginia tobacco has the highest content of chlorogenic acid (up to 3.0%); in Oriental tobacco it is lower (up to 2.0%) and lowest in Burley tobacco (about 0.1%). In this study the analytical results for the total yield of phenols in cigarette mainstream smoke follow this pattern (5). The highest total yield of phenols (330.9 µg/cig) was measured in the smoke of Virginia tobacco (sample 10). The smoke from Oriental tobacco (sample 11) contained 264.7 µg/cig and the smoke from Burley tobacco (sample 9) had 124.2 µg/cig (Table 2). The 'tar' yield of samples 9–11 were 18.87 mg/cig, 19.60 mg/cig and 22.60 mg/cig, respectively. It is known that American blend cigarettes contain moderate levels of Virginia tobaccos, with lower levels of Burley and Oriental tobaccos (15). The American blend cigarettes (samples 14 and 15) show both lower 'tar' yields (9.01 mg/cig and 7.82 mg/cig, respectively) and lower total yields of phenols (188 µg/cig and 149.2 µg/cig, respectively) in mainstream smoke compared to cigarettes with only Virginia or Oriental tobaccos, Table 2). When the smoke yield data for each phenol were normalized on a per mg 'tar' basis there was a significant trend indicating that Virginia tobacco produced more phenols than Oriental tobacco while Burley tobacco produced the lowest amount of phenols.

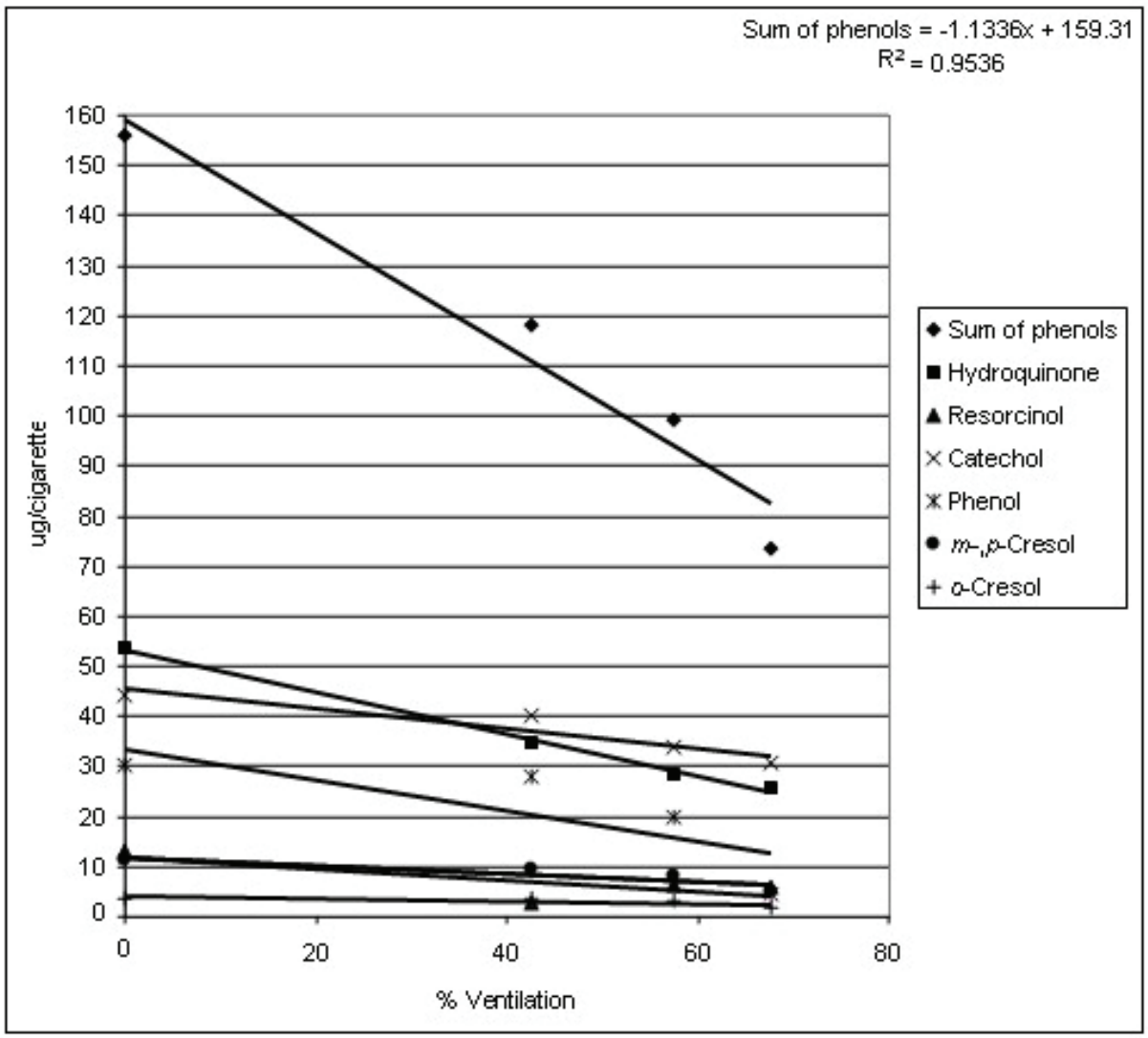

Figure 2. Relationship of the content of phenols (µg/cig) in cigarette mainstream smoke with the degree of filter ventilation (%).

Effect of tobacco blend

Samples 14 and 15 were commercial brands with the same design but different American tobacco blends. The total yield of phenols of these cigarettes were different with sample 14 having higher levels of nearly all phenols analyzed. Sample 14 also had a higher 'tar' yield compared to sample 15 (9.01 mg/cig vs. 7.82 mg/cig). When the ratio of phenols to 'tar' was calculated for these two cigarettes the values for hydroquinone, catechol and *m*- and *p*-cresol were higher for sample 14 than for sample 15 (Table 2).

CONCLUSIONS

From the data presented we conclude that the amount of phenols in cigarette mainstream smoke depends to a great extent on the type of tobacco employed in the blend. The predominant source of the phenols in mainstream smoke is Virginia tobacco. Any standard commercial filter can be used effectively on an unfiltered cigarette to reduce substantially the yield of phenols in cigarette mainstream smoke, whereas hydroquinone and catechol are less affected. The use of special filters (e.g., the "recessed charcoal filter system") or a high degree of cigarette ventilation cannot reduce the amount of phenols in the tobacco smoke considerably when normalized on a per mg 'tar' basis.

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