

Effect of Propylene Glycol on Cigar Mainstream Smoke TNCO Yields *

by

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SUMMARY

1,2-Propylene glycol (PG) is one of the most utilized humectants in the tobacco industry.

The impact of PG on smoke yields has been extensively studied on cigarettes, but the results are still inconclusive, and, to our best knowledge, nothing has yet been published on the impact of PG on cigar smoke.

In this study we investigate the effects of PG on cigar smoke yields, analyzing nicotine, carbon monoxide (CO), water and nicotine-free dry particulate matter (NFDPM or “tar”) content in mainstream smoke from different cigars. We performed a statistical retrospective analysis of four years of internal laboratory data of three cigar brands flavored with blends containing low, medium and high concentrations of PG.

Furthermore, to avoid any interference other than PG, experimental cigars with only PG added were produced and analyzed.

As for the retrospective analysis, smoke yields seem to be statistically related to tobacco PG content. Cigars with increasing amounts of PG show an increase in water and CO and a decrease in nicotine content. For NFDPM the trend seems quite ambiguous, since it doesn't show the

roughly linear correlation with PG contents shared by the other analytes. For these cigars, the effective influence of PG is more difficult to determine due to the presence of complex flavoring blends.

In the experimental cigars, the increase in CO, NFDPM and water is clearly related to a higher PG content. PG determines such increase triggering of some still unclarified mechanisms. Among them a variation in combustion conditions perhaps plays an important role.

The increase in water content is also related to its higher percent per gram of cigar tobacco, due to the PG effects in both replacing tobacco and attracting and binding moisture. Thermal degradation of PG could also contribute to the increase in CO, while the increase in NFDPM is partly due to pure PG amount delivered from tobacco to smoke.

The decrease in nicotine content seems totally related to reduced quantity of tobacco, due to the higher presence of PG. [Contrib. Tob. Nicotine Res. 34 (2025) 191–199]

KEYWORDS

Cigar tobacco; mainstream cigar smoke; cigar smoke chemistry

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ZUSAMMENFASSUNG

1,2-Propylenglykol (PG) ist eines der am häufigsten verwendeten Feuchthaltemittel in der Tabakindustrie.

Die Auswirkungen von PG auf die Rauchkondensat-Ausbeuten wurden bei Zigaretten bereits umfassend untersucht, die Ergebnisse sind jedoch uneinheitlich. Nach unserem Kenntnisstand gibt es bisher keine veröffentlichten Studien zum Einfluss von PG auf den Rauch von Zigarren.

In dieser Studie untersuchen wir die Auswirkungen von PG auf die Rauchzusammensetzung von Zigarren. Analysiert wurden die Gehalte an Nikotin, Kohlenmonoxid (CO), Wasser und nikotinfreiem Trockenkondensat (NFDPM, auch „Teer“ genannt) im Hauptstromrauch verschiedener Zigarren.

Wir führten eine statistische retrospektive Analyse von vier Jahren interner Labordaten zu drei Zigarrentypen durch, die mit Aromamischungen unterschiedlicher PG-Gehalte (niedrig, mittel, hoch) versehen waren.

Darüber hinaus wurden, um Einflüsse anderer Zusatzstoffe auszuschließen, experimentelle Zigarren hergestellt und analysiert, denen ausschließlich PG zugesetzt wurde.

Die retrospektive Analyse zeigt, dass die Rauchausbeuten statistisch mit dem PG-Gehalt des Tabaks korrelieren. Mit zunehmendem PG-Anteil steigt der Gehalt an Wasser und CO, während der Nikotingehalt abnimmt. Für NFDPM zeigt sich hingegen ein uneinheitlicher Trend: Hier lässt sich keine annähernd lineare Korrelation mit dem PG-Gehalt erkennen wie bei den anderen Analyten. Die tatsächliche Wirkung von PG ist bei diesen Zigarren schwerer zu bestimmen, da die komplexen Aromamischungen zusätzliche Einflüsse ausüben.

Bei den experimentellen Zigarren hingegen ist der Anstieg von CO, NFDPM und Wasser klar mit höheren PG-Gehalten verknüpft. PG bewirkt diesen Anstieg durch bislang nicht vollständig geklärte Mechanismen – Änderungen der Verbrennungsbedingungen könnten dabei eine wichtige Rolle spielen.

Der erhöhte Wassergehalt steht auch im Zusammenhang mit dem höheren Wasseranteil pro Gramm Zigarrentabak, da PG sowohl Tabak ersetzt als auch Wasser anzieht und bindet.

Die thermische Zersetzung von PG könnte zusätzlich zur Zunahme von CO beitragen, während der Anstieg von NFDPM teilweise auf den direkten Übergang von unverändertem PG aus dem Tabak in den Rauch zurückzuführen ist. Die Abnahme des Nikotingehalts ist dagegen vollständig auf die verringerte Tabakmenge zurückzuführen, die durch den höheren PG-Anteil bedingt ist. [Contrib. Tob. Nicotine Res. 34 (2025) 191–199]

RESUME

Le 1,2-propylène-glycol (PG) est l'un des agents humectants les plus utilisés dans l'industrie du tabac.

L'impact du PG sur les rendements de fumée a été largement étudié pour les cigarettes, mais les résultats demeurent contradictoires. À notre connaissance, aucune étude n'a encore été publiée concernant l'effet du PG sur la fumée des cigares.

Dans cette étude, nous examinons les effets du PG sur les

rendements de fumée de cigares, en analysant les teneurs en nicotine, monoxyde de carbone (CO), eau et matières particulaires sèches sans nicotine (NFDPM, ou “goudron”) dans la fumée principale de différents cigares.

Nous avons réalisé une analyse statistique rétrospective portant sur quatre années de données internes de laboratoire concernant trois marques de cigares aromatisées avec des mélanges contenant des concentrations faibles, moyennes et élevées de PG. De plus, afin d'éviter toute interférence autre que celle du PG, des cigares expérimentaux contenant uniquement du PG ajouté ont été fabriqués et analysés.

L'analyse rétrospective montre que les rendements de fumée étaient statistiquement liés à la teneur en PG du tabac. Avec une augmentation de PG, on a observé une hausse des teneurs en eau et en CO, ainsi qu'une diminution de la nicotine. Pour la NFDPM, la tendance était plus ambiguë, car elle ne présente pas la corrélation quasi linéaire avec la teneur en PG observée pour les autres analytes. L'influence réelle du PG est ici plus difficile à déterminer, en raison de la présence de mélanges aromatiques complexes.

Pour les cigares expérimentaux, l'augmentation du CO, de la NFDPM et de l'eau était clairement liée à un contenu plus élevé en PG. Le PG provoque cette augmentation par des mécanismes encore mal élucidés, parmi lesquels une modification des conditions de combustion pourrait jouer un rôle important.

L'augmentation de la teneur en eau est également due à la proportion plus élevée d'eau par gramme de tabac, le PG remplaçant partiellement le tabac tout en attirant et retenant l'humidité.

La dégradation thermique du PG pourrait aussi contribuer à l'augmentation du CO, tandis que la hausse de la NFDPM est en partie due à la quantité de PG non dégradé transférée de la matrice tabac vers la fumée.

La diminution de la nicotine semble quant à elle entièrement liée à la réduction de la quantité de tabac, conséquence directe de la présence accrue de PG. [Contrib. Tob. Nicotine Res. 34 (2025) 191–199]

ABBREVIATIONS

CI	Confidence interval
CO	Carbon monoxide
CRM	CORESTA recommended method
MST	Manifatture Sigaro Toscano
NFDPM	Nicotine-free dry particulate matter
NFDPM-PG	NFDPM without PG
PG	1,2-Propylene glycol
TPM	Total particulate matter

1. INTRODUCTION

1,2-Propylene glycol (PG) is one of the most utilized humectants in tobacco industries.

Humectants are added to tobacco to raise its propensity to retain moisture, increasing its plasticity. This helps to maintain the tobacco in a physical condition that is most suitable for cigar and cigarette manufacturing and allows the maintenance of smoking quality by avoiding water loss

after production and during storage.

Several studies on PG impact on cigarette mainstream smoke yields were performed.

In some early studies, it was found that PG reduces the delivery of nicotine, while the formation of NFDPM is increased (1). Furthermore, a reduced nose irritation was observed (2) suggesting that the presence of PG can cause reduced release of nicotine with a subsequent variation of the NFDPM/nicotine ratio, and thus be important for the sharpness of the smoke (1, 3). Afterwards many studies were conducted, and the results are often contradictory.

In most studies, especially when PG was used as single additive, no significant effects were found on CO, nicotine, NDFPM and water yields, with sporadic exceptions.

For example, GAWORSKI, OLDHAM AND COGGINS (4) concluded that cigarettes with PG as single additive at different concentrations showed, if compared to zero PG cigarettes as control, an increased water content and reduced nicotine yields.

The decrease in nicotine was attributed by the authors to the lower presence of tobacco due to its displacement by PG. A similar conclusion was previously reported (5).

In an extensive report of the PRIORITY ADDITIVES TOBACCO CONSORTIUM almost all of the available literature on PG was analyzed and a series of analyses on smoke chemistry, additive transfer, *in vitro* toxicology and human clinical studies were commissioned to independent contract research organizations (6). The report is summarized in three different publications (7–9).

Limited to the interests of this study, the analysis of the available scientific literature led to the conclusion that the inclusion levels between 0.57% and 10% PG in test cigarettes resulted in isolated, inconsistent instances of significant increases and decreases in emissions when compared to control cigarettes.

As for the commissioned analysis, the conclusion was that PG added to cigarette tobacco as a single additive slightly changed the smoke chemistry, resulting in decreases in *m*- and *p*-cresols and phenol, but no statistical difference was observed in nicotine, CO and NFDPM. A significant increase in water was observed only when PG was used in a mixture containing other additives (i.e., glycerol, sorbitol and additional top flavors as geraniol, fenugreek extract, maltol and guaiacol).

About these findings and the real impact of PG on smoke yields, some questions have been raised by two publications supported by the European Union's Health Program (2014–2020) (10, 11). The authors argued that the role of the humectants on the combustion was not adequately assessed to clarify the influence on smoke chemistry. This led to the conclusion that the influence of this humectant on smoke chemistry still remains unclarified.

To date all the available literature refers exclusively to cigarette smoke yield studies.

To the best of our knowledge nothing has been published on the effects of PG on cigar smoke yields.

Obviously, the studies on cigar smoke yields are more difficult than those on cigarettes due to the cigar intrinsic high variability, also among cigars of the same brand, and the lack of certified reference products and standardized methodologies (12). Unlike cigarettes, ISO smoking

procedures for cigars are not available. Currently the only official procedures are CORESTA Recommended Methods (CRM) available on CORESTA's web site (<https://www.coresta.org/>).

The aim of this study is to investigate whether and to what extent the presence of PG in cigar tobacco can influence the cigar mainstream smoke yields.

Manifatture Sigaro Toscano (MST) cigars, consisting exclusively of Kentucky dark fire-cured tobacco filler and wrapper, are routinely produced and commercialized. The tobacco filler undergoes a fermentation process described in a previous publication (13).

Several flavored brands are produced and marketed under the Toscanello® trade name. They all have similar physical characteristics and the same tobacco filler and wrapper, but flavored with different blends, in which PG is present to different extents.

When a study is conducted on such a sample, attention must be paid to the cigars' actual amount of tobacco which can be influenced by the presence of substances other than tobacco when total weight is maintained as constant.

2. MATERIALS AND METHODS

2.1 Physical measurements

Cigar diameter and draw resistance measurements were performed using a Borgwaldt KC Size Tester S10 and a Draw Resistance Meter A 11 Z (Borgwaldt, Hamburg, Germany), respectively.

2.2 Total alkaloids in tobacco product

Tobacco total alkaloids (reported as nicotine) were determined by continuous flow analysis following CORESTA Recommended Method (CRM) No. 85 (14).

2.3 Water in tobacco product

Water content in tobacco was determined by CRM No. 57 (15).

2.4 Moisture content

For the determination of cigar moisture content, as oven volatiles, CRM No. 76 was used (16).

2.5 Smoke analysis

Before smoking, cigars were conditioned following CRM No. 46 (17). The analysis of cigar smoke yields is based on CRM No. 65 (18). A Cerulean smoking machine SM410CV (Cerulean, Milton Keynes, UK) was used.

The filter pads were extracted with isopropanol containing as internal standards *n*-heptadecane for nicotine and ethanol for water. For the experimental cigar analysis, 1,3-butane-diol was added as internal standard for PG.

Aliquots of the extracted sample were used to determine nicotine (CRM No. 66 (19)), water (CRM No. 67 (20)) and PG (CRM No. 60 - (21)).

CO was quantified according to CRM No. 68 (22).

Table 1. Main physical characteristics of a flavored Toscanello® cigar. Diameter-1 and -2 are measured at cigar's head (mouth end) and foot (fire end), respectively. Values are expressed as mean $\pm$ standard deviation.

Cigar	Weight (g)	Length (mm)	Draw resistance (mmWG)	Diameter-1 (mm)	Diameter-2 (mm)
Flavored Toscanello®	3.996 $\pm$ 0.368	77.62 $\pm$ 1.14	94.38 $\pm$ 23.49	10.07 $\pm$ 0.61	13.89 $\pm$ 0.49

Table 2. Main physical characteristics of three flavored Toscanello cigars routinely produced in Manifatture Sigaro Toscano with low (M1), medium (M2), and high (M3) propylene glycol (PG) content in the flavoring blend. Diameter-1 and -2 are measured at cigar's head (mouth end) and foot (fire end), respectively. Values are expressed as mean $\pm$ standard deviation.

Cigar	Weight (g)	Length (mm)	Draw resistance (mmWG)	Diameter-1 (mm)	Diameter-2 (mm)
M1	3.806 $\pm$ 0.343	77.34 $\pm$ 1.25	91.26 $\pm$ 22.47	10.19 $\pm$ 0.61	13.76 $\pm$ 0.41
M2	3.932 $\pm$ 0.330	77.55 $\pm$ 1.12	89.50 $\pm$ 23.61	9.84 $\pm$ 0.52	13.72 $\pm$ 0.44
M3	4.142 $\pm$ 0.346	77.81 $\pm$ 1.04	99.41 $\pm$ 23.02	10.18 $\pm$ 0.65	14.19 $\pm$ 0.47

2.6 PG analysis in cigar tobacco

PG content analysis in whole cigar tobacco (filler + wrapper) is based on the CRM No. 60 (21).

2.7 Experimental cigar production and analysis

Three experimental Cigars A, B and C were produced with the same fermented tobacco blend, routinely used for flavored Toscanello® production for varied PG content targets of 0%, 3.11% and 8.50%, respectively.

Thus, 2 kg tobacco for each type were treated with 400 mL of water containing 0%, 22% and 81.5% of PG, respectively.

In detail, the three different solutions were applied by spraying with a manual nebulizer using a cement mixer under constant stirring to ensure right delivery of PG.

After nebulization, the three tobacco batches were sealed in airtight plastic containers to prevent PG loss and left for two days to ensure homogeneous diffusion of PG through the tobacco. Throughout the process of tobacco preparation, the weight and the relative humidity of tobacco samples were monitored. Cigars were prepared by using MST standard production processes and transferred to a conditioning chamber set at 22 °C and 60% relative humidity.

After conditioning, 6 cigars for each cigar type were used to evaluate water and PG content in whole cigar tobacco, while 30 cigars for each cigar type were submitted to complete smoking analysis, including TPM's (Total particulate matter) PG content analysis.

2.8 Statistical analysis

Statistical analyses were performed by using Minitab 20 Statistical Software (2021) (www.minitab.com).

The differences of the means were evaluated by analysis of variance (One-Way ANOVA) at $\alpha = 0.05$, with Bonferroni correction for multiple testing. If the ANOVA showed a statistically significant result, comparison of the means was performed by Tukey pairwise comparisons procedure (95% confidence).

3. RESULTS AND DISCUSSION

3.1 Statistical retrospective analysis

Several flavored brands are produced and commercialized under the Toscanello® trade name.

They are machine-made, singly-wrapped cigars with a truncated cone shape and are made entirely with Kentucky dark fire-cured tobacco. They have similar physical characteristics and the same filler and wrapper tobacco but are flavored with different blends.

In Table 1 and Figure 1 the main physical characteristics and a picture of a typical flavored Toscanello® are reported. Three brands produced with flavoring blends containing low (Cigar M1), medium (Cigar M2) and high (Cigar M3) concentrations of PG were selected for data analysis. The physical characteristics of these brands are reported in Table 2.



Figure 1. Picture of a typical flavored Toscanello®.

The mean and 95% confidence interval (CI) of the cigar PG content were 3.11% (95% CI: 2.95; 3.27) for Cigar M1, 5.71% (95% CI: 5.42; 6.01) for Cigar M2 and 8.50% (95% CI: 8.23; 8.77) for Cigar M3, as determined by gas chromatographic analysis of 12 samples for each brand.

Tobacco and tobacco smoke yields data from our quality control laboratory, produced in a period of 4 years, have been evaluated by statistical analysis.

The means of total alkaloids as nicotine, expressed in % on a dry weight basis, obtained from 25, 32 and 51 batches (Cigar M1, M2 and M3, respectively) were M1 2.448% (95% CI: 2.322; 2.574), M2 2.415% (95% CI: 2.290; 2.540) and M3 2.483% (95% CI: 2.410; 2.558). No statistically significant difference was found, as expected given that the

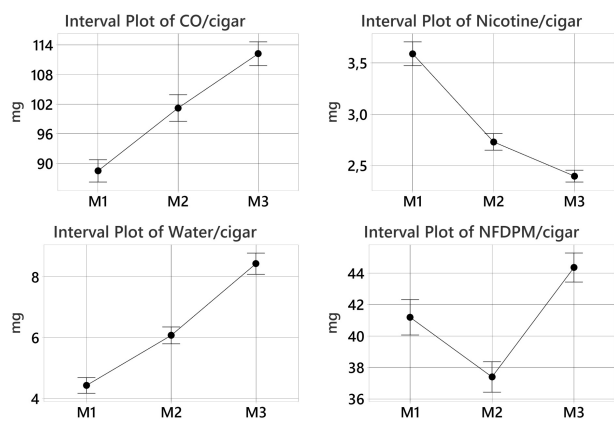


Figure 2. Plots of means and 95% CI, expressed in milligram per cigar, of CO, nicotine, water and NFDPM in mainstream smoke of M1, M2 and M3 cigars.

brands are made with the same tobacco blend. Afterwards we performed a statistical analysis on the smoke yields data. The analysis was performed on a total of 175, 222 and 324 cigars for M1, M2 and M3, respectively.

Values and plots of means and 95% CI, expressed in milligram per cigar, of CO, nicotine, water and NFDPM are reported in Table 3 and Figure 2, respectively. In Table 3 TPM and puff number are also reported.

The statistical analysis showed differences between the three cigars for all the analytes.

We can therefore state, with good confidence, that the presence of increasing quantities of PG results in smaller quantities of nicotine and increasing quantities of CO and water in cigar mainstream smoke. For NFDPM the trend seems quite ambiguous; the three values are statistically different, but they don't show the roughly linear correlation with PG contents shared by the other analytical parameters. Obviously, the analysis conducted on "mg per cigar" basis could be affected by the weight of cigars and possible differences in tobacco content.

Furthermore, it is clear that the greater the presence of PG,

other components of the flavoring blend and water, the lower the tobacco content.

To normalize the smoke yields on the basis of the actual tobacco content, we would have to subtract the weight of all substances other than tobacco from the weight of the cigar.

Unfortunately, no PG or other flavoring additives content analysis was routinely performed. Only data on the pre-smoking cigar moisture content, determined by CORESTA Recommended Method No. 76, were available (16).

It must be emphasized that, as stated in CRM 76, the results of moisture content determination by oven drying may be higher than the results of water content analysis when using a specific method. The difference is due to the loss of volatile materials, other than water, among them most of the flavoring blend, including PG.

So, in this kind of study, the normalization for the dry weight obtained by volatile substances determination could be a good compromise to get as close as possible to the actual values of the tobacco content.

By determining the dry weight and normalizing all smoke yields per gram of tobacco, mean and 95% CI of CO, nicotine, water and NFDPM were calculated and are reported in Table 4.

The results from statistical analysis were quite like those obtained without tobacco weight normalization.

The analysis confirmed that all the smoke analytes were different between the three cigars, except NFDPM, for which no statistically significant difference was found between M1 and M3 by Tukey pairwise comparison.

3.2 Experimental cigars

As for statistical retrospective analysis, it must be emphasized that the flavoring blends differ not only in PG contents, but also in some other additives which could play a role in the variation of smoke yields.

With the aim of avoiding any interference by substances other than PG, experimental cigars consisting only of

Table 3. Mainstream smoke yields of CO, nicotine, water, NFDPM, TPM and puff number for M1, M2 and M3 cigars. Given are the mean values and 95% confidence intervals (CI) in mg/cigar.

Cigar ^a	CO (mg/cig)		Nicotine (mg/cig)		Water (mg/cig)		NFDPM (mg/cig)		TPM (mg/cig)		Puff number	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
M1	88.45	86.19;90.71	3.588	3.472;3.704	4.432	4.174;4.689	41.18	40.06;42.31	49.13	47.76;50.50	58.27	56.57;59.97
M2	101.19	98.50;103.88	2.729	2.648;2.809	6.075	5.798;6.353	37.39	36.43;38.36	46.20	45.02;47.37	65.44	63.91;66.98
M3	112.20	109.79;114.61	2.395	2.337;2.453	8.430	8.082;8.778	44.34	43.42;45.27	55.17	53.97;56.37	65.53	64.38;66.68

Table 4. Mainstream smoke yields of CO, nicotine, water and NFDPM for M1, M2 and M3 cigars. Given are the mean values and 95% confidence intervals (CI) in mg/g tobacco.

Cigar ^a	CO (mg/g)		Nicotine (mg/g)		Water (mg/g)		NFDPM (mg/g)	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
M1	26.95	26.23;27.68	1.104	1.060;1.148	1.362	1.278;1.445	12.67	12.22;13.11
M2	30.28	29.48;31.08	0.827	0.797;0.857	1.833	1.744;1.921	11.31	10.94;11.67
M3	33.19	32.44;33.95	0.716	0.695;0.737	2.517	2.404;2.630	13.23	12.89;13.58

^a M1, M2 and M3 are commercially available cigars with low (M1), medium (M2) and high (M3) propylene glycol content.

Table 5. Main physical characteristics of experimental cigars (A, B, C). Diameter-1 and -2 are measured at cigar's head (mouth end) and foot (fire end), respectively. Values are expressed as mean $\pm$ standard deviation.

Cigar ^a	Weight (g)	Length (mm)	Draw resistance (mmWG)	Diameter-1 (mm)	Diameter-2 (mm)
A	4.089 $\pm$ 0.231	77.07 $\pm$ 0.98	111.93 $\pm$ 18.93	9.44 $\pm$ 0.61	13.68 $\pm$ 0.43
B	4.042 $\pm$ 0.306	77.03 $\pm$ 0.72	92.13 $\pm$ 13.42	9.39 $\pm$ 0.67	13.98 $\pm$ 0.60
C	4.171 $\pm$ 0.155	77.13 $\pm$ 0.73	99.90 $\pm$ 20.39	9.95 $\pm$ 0.61	14.44 $\pm$ 0.77

Table 6. Propylene glycol (PG) and water percent content in whole cigar (filler + wrapper) of the three experimental cigars produced by adding an aqueous solution containing 0 (A), low (B) and high (C) PG amount. Target PG% are also reported.

Cigar	%PG (Target)	%PG (Actual)	% Water
A	0	0	8.35
B	3.11	3.06	8.29
C	8.50	8.56	8.96

tobacco and water with different concentrations of PG were produced and conditioned. The main physical characteristics of the experimental cigars are reported in Table 5. Tobacco from 6 cigars for each sample were analyzed for total alkaloids. The percentage of total alkaloid on dry weight basis were 2.46%, 2.43% and 2.45%, respectively for Cigars A, B and C, without statistically significant difference.

An additional 6 cigars for each sample were used to analyze water and PG content by gas-chromatography. Mean values expressed as percent of cigar weight are reported in Table 6.

30 cigars for each sample were selected for smoke yields analysis.

Cigars were smoked by Cerulean SM410CV smoking machine and analyzed.

Values and plots of means and 95% CI of CO, nicotine, water and NFDPM are reported in Table 7 and Figure 3, respectively. In Table 7 TPM and puff number are also reported.

Statistical analysis showed that the three cigars differ for all the smoke yields but nicotine, for which cigar B showed no difference to Cigar A.

Therefore, if we look at the values of analytes expressed per cigar, we can state that the presence of increasing quantities of PG determine increasing amount of all smoke analytes, except for nicotine.

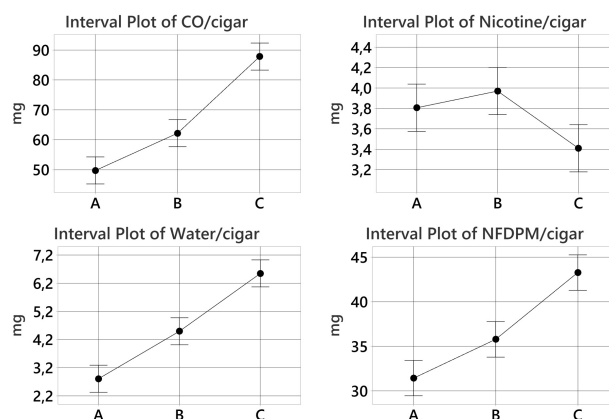


Figure 3. Plots of means and 95% CI, expressed in mg/cigar, of CO, nicotine, water and NFDPM in mainstream smoke of A, B, and C Cigars.

As for nicotine, higher quantity of PG led to a reduced delivery of nicotine to smoke, while smaller quantity of PG seems to have no effects.

Unlike the retrospective statistical analysis on M1, M2 and M3 cigars, in this case, where only water and PG were added to tobacco, we can make a more accurate estimate of the actual amount of tobacco present in cigars and we can better define the relationship between smoke yields and cigar tobacco amounts.

Subtracting PG and water amounts, as previously determined, from the weights of the 30 smoked cigars, we can calculate the actual amount of tobacco in each cigar and can express smoke yields on a "g of tobacco" basis.

Means and 95% CI of smoke analytes expressed in mg/g of tobacco, are reported in Table 8.

Statistical analysis confirmed that the three cigars differ in all smoke analytes except nicotine for which no differences were found between the three cigars.

It seems that the reduced amount of nicotine in Cigar C, shown by analysis on mg/cigar basis, as previously reported (4, 5), is simply due to a reduced presence of tobacco,

Table 7. Mainstream smoke yields of CO, nicotine, water, NFDPM, TPM and puff number for the experimental Cigars A, B and C. Given are the mean values and 95% confidence intervals (CI) in mg/cigar.

Cigar ^a	CO (mg/cig)		Nicotine (mg/cig)		Water (mg/cig)		NFDPM (mg/cig)		TPM (mg/cig)		Puff number	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
A	49.74	45.13;54.35	3.806	3.536;4.077	2.807	2.440;3.174	31.43	29.33;33.53	38.04	35.44;40.64	76.16	73.11;79.21
B	62.20	58.00;66.41	3.970	3.728;4.212	4.491	4.004;4.978	35.78	33.86;37.70	44.24	41.84;46.63	69.01	65.73;72.29
C	87.84	82.75;92.94	3.409	3.212;3.606	6.541	5.947;7.135	43.26	41.16;45.35	53.21	50.54;55.88	68.94	66.58;71.31

^a Cigars A, B and C are experimental cigars produced with the same fermented tobacco blend with propylene glycol content of 0%, 3.06% and 8.56%, respectively.

Table 8. Mainstream smoke yields of CO, nicotine, water and NFDPM for the experimental cigars A, B, C. Given are the mean values and 95% confidence intervals (CI) in mg/g tobacco.

Cigar ^a	CO (mg/g)		Nicotine (mg/g)		Water (mg/g)		NFDPM (mg/g)	
	mean	95% CI	mean	95% CI	mean	95% CI	mean	95% CI
A	13.40	12.02;14.79	1.026	0.936;1.116	0.756	0.652;0.860	8.46	7.78;9.15
B	17.42	16.25;18.59	1.119	1.034;1.204	1.264	1.115;1.414	10.07	9.39;10.74
C	25.55	24.07;27.03	0.994	0.931;1.058	1.909	1.724;2.093	12.60	11.93;13.28

^a Cigars A, B and C are experimental cigars produced with the same fermented tobacco blend with propylen glycol content of 0%, 3.06% and 8.56%, respectively.

Table 9. Mainstream smoke yields of NFDPM and NFDPM minus PG (NFDPM-PG) for the experimental Cigars A, B and C.

Cigar	NFDPM (mg/g)		NFDPM-PG (mg/g)	
	Mean	95% CI	Mean	95% CI
A	8.46	7.78;9.15	8.46	7.78;9.15
B	10.07	9.39;10.74	9.34	8.70;9.98
C	12.60	11.93;13.28	10.39	9.84;10.94

while the increase in all other smoke yields is actually related to the presence of PG.

It is pretty difficult to define how PG determines the variations in CO, water and NFDPM.

It is very probable that the presence of PG causes some modification of the combustion conditions that influence the way the cigars are smoked, and this leads to an increase of water, CO and NFDPM. Regarding the increase in CO, the possibility that carbonyls, like propanal and acetone, could be produced by thermal degradation of PG and further be degraded to CO should also be considered. The identification and quantification of potential thermal decomposition products of PG are certainly relevant from a regulatory point of view and therefore deserve to be further investigated in future work.

Humectants have the effect of drawing water into tobacco making it more available for vaporization, and this could contribute to increasing the water content in the smoke. But the displacement of tobacco amount by PG, as with nicotine yield, may also play a role.

In fact, although the % of water content per cigar shown in Table 6 was quite the same for the three samples, the water content per gram of actual tobacco was quite different. These values were respectively 91.1 mg, 93.5 mg and 108.6 mg.

Therefore, the water content per gram of tobacco in the Cigar C was higher than that of the other two cigars.

3.3 Contribution of PG to NFDPM yield

A final aspect we wanted to investigate is the possible contribution of PG to NFDPM yield.

It is known that PG doesn't undergo excessive pyrolysis during smoking and is transferred to cigarette smoke in its pure form.

BAKER AND BISHOP (23) reported that 86.3% of transferred

PG (and 6.2% 1,3-propylene glycol) was in its pure form. PURKIS, MUELLER AND INTORP (24) stated that under pyrolysis conditions, propylene glycol was transferred 99.4% intact.

Obviously, PG is partly retained in the filter pad during smoking, contributing to TPM and NFDPM yields.

It is also known that only a small percentage of PG is transferred to smoke during pyrolysis.

In a set of analyses performed on ventilated cigarettes for the PRIORITY ADDITIVES TOBACCO CONSORTIUM it was found that 0.9–0.97% of PG is transferred into the mainstream gas phase (6).

A previous study demonstrated much higher transfer rates of 7.3–8.8% using unventilated cigarettes (24).

In this study, we determined PG content in the TPM of the 30 smoked cigars, as described in the section Materials and Methods.

The mean value of PG in Cigar B is 2.59 mg (95% CI: 2.47; 2.71), representing 5.86% of TPM, while in Cigar C it is 7.60 mg (95% CI: 7.18; 8.02), representing 14.28% of TPM.

We can estimate that 2.1–2.2 % of the PG of the whole cigar tobacco has been delivered intact to TPM.

By subtracting measured PG content from the NFDPM, we obtained the value of NFDPM consisting of all particulate substances except PG (NFDPM-PG).

For statistical analysis we normalized the values of NFDPM-PG per gram of tobacco. In Table 9 the NFDPM/g and NFDPM-PG/g values are reported (obviously, Cigar A didn't contain PG).

While statistical analysis for NFDPM/g showed differences between the three samples, in the case of NFDPM-PG/g no difference was detected between Cigars A and B.

So, in the case of small amounts of PG in the cigar, it seems that the increase of NFDPM is simply due to the delivery of PG into the mainstream smoke, while the presence of higher quantities of PG in tobacco leads to an increase in NFDPM for other reasons as well.

We can deduce that the increase in NFDPM yields is partly due to the mere presence of pure PG in NFDPM and partly due to some mechanism that is complex to elucidate.

It should also be emphasized that the presence of PG might affect moisture and burning properties, perhaps leading to modified NFDPM constituents' levels simply due to the modified combustion conditions.

In our experience, we have often noticed that the presence of higher quantities of PG in tobacco reduces the need for relighting during cigar smoking.

4. CONCLUSION

In the experimental cigars obtained with the addition of PG only, we can see an increase of CO, NFDPM and water yields in mainstream smoke.

These increases are certainly due to mechanisms, currently undefined, which occur in the presence of PG, among which the effect on combustion conditions certainly plays an important role.

The thermal degradation pathway of PG could also contribute to the increase in CO, while for water increase PG could act in both replacing tobacco and drawing water into the tobacco making it more available for vaporization. As for NFDPM the increase is partly due to the presence of PG in its pure form which contributes to the total amount of TPM trapped on the filter pad during smoking.

The decrease in nicotine yield seems to be simply related to a lower content of tobacco in the cigar with higher PG content.

The different behavior of the commercial cigars (M1, M2 and M3) compared to the experimental ones may be due both to the different estimation of the actual tobacco content in the cigar, and to the presence of other substances in addition to PG in the flavoring blends used for the commercial cigars.

For example, as previously reported (6), different effects on water yield were observed when PG was used as a single component or in a blend of flavoring substances.

In conclusion, it can be stated that the true effect of PG on smoke chemistry still has some aspects to be clarified and further studies are needed.

Our study adds substantial insights and data to the discussion on cigar smoke chemistry, as no studies on this topic have yet been published to our knowledge.

Furthermore, we provided data on the contribution of pure PG to the NFDPM smoke yield.

Finally, we think that the data produced in this study could be useful both to scientists engaged in tobacco research and to the industry involved in cigar production.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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