Selected Constituent Yield Variation in the Smoke of Commercial Cigarette Brands on the Japanese Market *

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SUMMARY

This study focused on the variation in the yields of constituents in smoke from commercial cigarette brands available on the Japanese market. Nineteen commercial cigarette brands were sampled five times every two months from 2009 to 2010. The target constituents were benzo[*a*]pyrene, 1,3-butadiene, benzene, formaldehyde, acetaldehyde, acrolein, *N*-nitrosonornicotine (NNN), 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK), carbon monoxide, “tar”, and nicotine. The results of this study showed that the coefficient of variation (CV) values varied greatly by brands, constituents, and smoking regimes. The yields of NNN and NNK in the smoke were strongly correlated to their yields in the tobacco filler blend for most brands. The yields of benzo[*a*]pyrene under the International Organization for Standardization (ISO) and the Health Canada Intense (HCI) smoking regimes and 1,3-butadiene under the HCI smoking regime were found to be influenced by the measurement. It was shown that factors for variation were highly varied among constituents. The grand mean of CV values for NNN and formaldehyde associated with cigarette manufacturing over ten months and measurement at the JT laboratory under the HCI smoking regimes were 17.1% and 6.6% respectively. The grand mean of CV values for NNN and formaldehyde associated with both cigarette manufacturing over ten months and measurement at different laboratories under the HCI smoking regimes were 23.7% and 22.9% respectively. This is due to the fact that formaldehyde showed the highest CV values for reproducibility among the constituents. Thus, in order to set realistic and robust confidence intervals, it is very important to take into account the variations associated with cigarette manufacturing and measurement within and between laboratories. [Beitr. Tabakforsch. Int. 27 (2017) 208–223]

ZUSAMMENFASSUNG

Diese Studie untersucht die Variation bei den Ausbeuten von Rauchbestandteilen von Zigaretten, die auf dem japanischen Markt im Handel erhältlich sind. Neunzehn im Handel erhältliche Zigarettenmarken wurden zwischen 2009 und 2010 fünf Mal jeweils im Abstand von zwei Monaten beprob. Die untersuchten Bestandteile waren Benzo[*a*]pyren, 1,3-Butadien, Benzol, Formaldehyd, Acetaldehyd, Acrolein, *N*-Nitrosonornikotin (NNN), 4-(Methylnitros-amino)-1-(3-pyridyl)-1-butanon (NNK), Kohlenmonoxid, “Teer” und Nikotin. Die Ergebnisse dieser Studie zeigten, dass die Variationskoeffizienten (VK) je nach Marke, Bestandteilen und Rauchprotokoll stark variierten. Der Gehalt von NNN und NNK im Rauch korreliert für die meisten Marken stark mit dem jeweiligen Gehalt in der Tabakfüllstoffmischung. Es wurde festgestellt, dass die Ausbeuten von Benzo[*a*]pyren nach den Rauchprotokollen der International Organization for Standardization (ISO) und Health Canada Intense (HCI) und von 1,3-Butadien nach dem HCI-Rauchprotokoll von der Messung beeinflusst waren. Es wurde gezeigt, dass die Faktoren für Variation unter den Bestandteilen stark variierten. Der Gesamtmittelwert von VK-Werten für NNN und Formaldehyd, der mit der Zigarettenherstellung über zehn Monate und der Messung im JT Labor nach den HCI-Rauchprotokollen assoziiert ist, betrug jeweils 17.1% und 6.6%. Der Gesamtmittelwert von VK-Werten für NNN und Formaldehyd, der sowohl mit der Zigarettenherstellung über zehn Monate als auch mit der Messung in verschiedenen Laboren nach den HCI-Rauchprotokollen assoziiert ist, betrug jeweils 23.7% und 22.9%. Der Grund dafür ist, dass Formaldehyd unter den Bestandteilen die höchsten KV-Werte für die Reproduzierbarkeit aufwies. Um demnach realistische und solide Konfidenzintervalle festzulegen, muss unbedingt die Variation berücksichtigt werden,

die mit der Zigarettenherstellung und der Messung innerhalb von und zwischen Laboren assoziiert ist. [Beitr. Tabakforsch. Int. 27 (2017) 208–223]

RESUME

La présente étude s'attarde sur la variation des rendements des composants de la fumée émise par les cigarettes dont la marque est commercialisée sur le marché japonais. Cinq fois tous les deux mois entre 2009 et 2010, des échantillons furent prélevés sur des cigarettes commercialisées sous dix-neuf marques. Les composants visés étaient le benzo[*a*]pyrène, le 1,3-butadiène, le benzène, le formaldéhyde, l'acétaldéhyde, l'acroléine, la *N*-nitrosornicotine (NNN), la 4-(méthylnitrosamino)-1-(3-pyridyle)-1-butanone (NNK), le monoxyde de carbone, le “goudron” et la nicotine. Les résultats de la présente étude démontrent que les valeurs du coefficient de variation (CV) varient grandement selon les marques, les composants et les paramètres de fumage. Les rendements de la NNN et de la NNK dans la fumée furent fortement corrélés à leurs rendements dans le mélange de tabac haché pour la plupart des marques. Les rendements du benzo[*a*]pyrène selon les paramètres de fumage de l'Organisation internationale de Normalisation (ISO) et de Santé Canada Intense (HCI) et ceux du 1,3-butadiène selon les paramètres de fumage de HCI s'avérèrent être influencés par le mesurage. Il fut démontré que les facteurs de variation variaient grandement parmi les composants. La moyenne générale des valeurs du CV pour la NNN et le formaldéhyde associées à la fabrication de cigarettes sur 10 mois et au mesurage réalisé par le laboratoire JT selon les paramètres de fumage de HCI fut respectivement de 17.1% et 6.6%. La moyenne générale des valeurs de CV pour la NNN et le formaldéhyde associées tant à la fabrication de cigarettes sur 10 mois qu'au mesurage réalisé par différents laboratoires selon les paramètres de fumage de HCI fut respectivement de 23.7% et 22.9%. Ces écarts s'expliquent par le fait que le formaldéhyde présente, parmi les composants, les valeurs de CV les plus élevées pour la reproductibilité. Par conséquent, afin de déterminer des intervalles de confiance réalistes et solides, il est essentiel de tenir compte de la variation associée à la fabrication de la cigarette et au mesurage au sein d'un même laboratoire et entre les laboratoires. [Beitr. Tabakforsch. Int. 27 (2017) 208–223]

INTRODUCTION

The regulatory pressure on tobacco products is being reinforced globally. The constituents of cigarette smoke, other than “tar” and nicotine, have received increasing attention in recent years. The World Health Organization (WHO) Study Group on Tobacco Product Regulation has recommended benzo[*a*]pyrene, 1,3-butadiene, benzene, formaldehyde, acetaldehyde, acrolein, *N*-nitrosornicotine (NNN), 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK), and carbon monoxide as the priority constituents in cigarette smoke that need to be reduced (1). Cooperation Centre for Scientific Research Relative to Tobacco (CORESTA) Recommended Methods (CRMs) provide analytical methods for yields of these constituents,

including their repeatability and reproducibility (2–5). In addition, the CRMs have been further developed at the International Organization for Standardization (ISO).

There are not a great number of studies on the variation in the yields of constituents in smoke within a given commercial cigarette brand over time (6–13). The important point from these studies was that the variation in the yields of smoke constituents is associated with cigarette manufacturing and measurement, and that they cannot be calculated separately. The variation associated with cigarette manufacturing, out of the total variability, was evaluated by comparing the coefficient of variation (CV) values of monitor cigarettes and commercial cigarette brands (7, 8). The measurement variation in the yields of 1,3-butadiene in smoke was highlighted since similar trends were observed in commercial cigarette brands and monitor cigarettes (7). PIADÉ *et al.* summarized the precursors and possible selective filtration of smoke constituents that were targeted in this study (14). The factors affecting the variation in the yields of NNN and NNK in smoke have been reported and explained by their yields present in the tobacco filler blend (7, 9, and 12).

Studies on variation in the yields of smoke constituents other than NNN and NNK have not been published with commercial cigarette brands available on the Japanese market. Many cigarette brands on the Japanese market use charcoal filters. The effect of charcoal filtration on carbonyl reduction in mainstream cigarette smoke was reported (15). The study used filters of commercial cigarette brands which were modified to contain three to four different levels of charcoal in filters. However, there are no studies that report the influence of the amount variation of charcoal in the filter on the yields of the constituents in the vapor phase within a given brand.

The cigarette itself and the laboratory measurement are two major sources of statistical variation. Both of these sources result in fluctuations over short and long term. Measurements may also vary between laboratories, even for matched cigarette samples. In the context of package labeling, the yields of “tar”, nicotine, and carbon monoxide are determined from laboratory tests carried out by the manufacturer on cigarettes sampled from production. Checks by a designated laboratory occur later, after the manufacturer has determined and printed its values on the cigarette package (16). ISO 8243 provides the estimated typical confidence intervals in the yields of “tar”, nicotine, and carbon monoxide (16). These confidence intervals are represented by repeatability and reproducibility calculated from matched cigarette samples (17). Currently, the confidence intervals have not been set for constituents other than “tar”, nicotine, and carbon monoxide under the ISO smoking regime. In addition, no studies have reported variation over time that accounts for both cigarette manufacturing and measurement between laboratories. CORESTA Cigarette Variability Task Force has been conducting a long term collaborative study since 2015 to improve the understanding of overall tobacco and smoke constituent variability relevant to commercial cigarette design features.

This study aimed to understand variations associated with cigarette manufacturing and measurements within a laboratory over time on the selected constituent yields in

Table 1. Cigarette brand specifications. Brand No. 20 was used for evaluating measurement variation during this study.

No.	Labeled "tar" (mg/cig)	Labeled nicotine (mg/cig)	Length ^a (mm)	Circumference ^b (mm)	Filter type ^c	Manufacturer
1	1	0.1	regular	regular	AC	JT
2	1	0.1	regular	regular	AC	non-JT
3	1	0.1	regular	regular	AC	non-JT
4	1	0.1	long	slim	A	JT
5	1	0.1	long	regular	AC	JT
6	3	0.3	regular	regular	AC	JT
7	3	0.3	regular	regular	AC	non-JT
8	3	0.3	regular	regular	AC	non-JT
9	3	0.2	long	slim	A	JT
10	3	0.3	long	regular	AC	JT
11	6	0.5	regular	regular	AC	JT
12	6	0.5	regular	regular	AC	non-JT
13	6	0.5	regular	regular	AC	non-JT
14	5	0.3	long	slim	A	JT
15	6	0.5	long	regular	AC	JT
16	6	0.5	regular	regular	AC	non-JT
17	10	0.8	regular	regular	AC	JT
18	12	1.0	regular	regular	AC	non-JT
19	14	1.2	regular	regular	AC	JT
20	6	0.5	regular	regular	A	JT

^a Cigarette length: regular = 83–85 mm, long = 97–100 mm

^b Cigarette circumference: regular = 24–26 mm, slim = 22–23 mm

^c Filter type: AC = acetate charcoal filter, A = acetate filter

the mainstream smoke of cigarette brands available on the Japanese market. This study investigated factors influencing the variations such as the measurement of the constituents, the yields of the constituents in the tobacco filler blend, and the yield of charcoal in filter. In addition, this study also aimed to explain the variation associated with cigarette manufacturing and measurement between laboratories based on data from this study and CRMs that describe variation between laboratories.

EXPERIMENTAL

Cigarette brands

Nineteen commercial cigarette brands from the Japanese market were selected based on labeled yield of "tar", cigarette length, and cigarette circumference. One commercial brand (No. 20) was selected for evaluating measurement variation during this study period. They are summarized in Table 1. Ten out of the nineteen brands have labeled yields of "tar" of 3 mg/cig or less. In addition, sixteen brands use a charcoal filter, one of the main features of cigarette brands in the Japanese market.

Sampling

Seven to ten cartons were collected from the same factory for Japan Tobacco (JT) group brands, and the same warehouse for non-JT group brands, five times every two months from 2009 to 2010. A single manufacturing lot was used for all testing of each sampling. All five batches were confirmed to be from different batches because batch codes

on the cartons were different for the five samplings. There were no changes in the labeled yield of "tar" and nicotine for each brand during the study period. Brand No. 20 was collected at the first sampling and refrigerated at 4 °C. This brand was measured at the same time the nineteen brands were measured every two months.

Analytical methods

All constituents and design parameters were measured at JT laboratories. Test cigarettes were conditioned at 22 °C and 60% relative humidity (18). Filter ventilation, draw resistance, circumference, cigarette weight, and tobacco weight were measured as basic physical properties. The charcoal amount in the filter was weighed after soaking the filter in acetone, separation into filter tow and charcoal, and drying. The target constituents in mainstream smoke were benzo[*a*]pyrene, 1,3-butadiene, benzene, formaldehyde, acetaldehyde, acrolein, NNN, NNK, "tar", nicotine, and carbon monoxide. "Tar", nicotine, and carbon monoxide yields were analyzed based on the relevant ISO standards (19–23). The total particulate matter (TPM) was calculated from the difference in weight of glass fiber filters (Cambridge filters) used for smoke collection before and after machine smoking. Nicotine and water yields were analyzed by gas chromatography after extraction from the Cambridge filters with 2-propanol. The yield of "tar" was calculated by subtracting the yields of nicotine and water from the TPM yield. Carbon monoxide was analyzed using a non-dispersive infrared analyzer. Benzo[*a*]pyrene was extracted from the Cambridge filters with cyclohexane, concentrated, then the yield was determined by high performance liquid chromatography with fluorescence detection (HPLC-FLD)

(24). 1,3-Butadiene and benzene were collected by passing mainstream smoke through Cambridge filters into cooled methanol in impingers, then the yield was determined using gas chromatography with mass spectrometry. Deuterated toluene was used as an internal standard in this study, although deuterated benzene was used in CRM70 (3). Formaldehyde, acetaldehyde, and acrolein were trapped as 2,4-dinitrophenylhydrazine derivatives and their yields were determined using high performance liquid chromatography with diode array detection (4). NNN and NNK were extracted from Cambridge filters used for smoke collection with an ammonium acetate solution, and their yields were determined by liquid chromatography with tandem mass spectrometry (5). Smoking was performed under ISO and Health Canada Intense (HCI) regimes. Puff volume, puff duration, and puff interval for the ISO smoking regime were 35 mL, 2 sec, and 60 sec, respectively (19). Puff volume, puff duration, and puff interval for the HCI smoking regime were 55 mL, 2 sec, and 30 sec, respectively, and filter ventilation holes were 100% blocked (25). Target constituents in tobacco filler blend were nicotine, NNN, NNK, and total reducing sugars. Nicotine yields were analyzed based on CRM62 (26). n-Hexane was used as a solvent. NNN and NNK were extracted from ground tobacco filler blend using an ammonium acetate solution and their yields were determined by liquid chromatography with tandem mass spectrometry (27). The level of reducing sugars was determined using a continuous flow analyzer by monitoring the decrease in color caused by reduction of yellow hexacyanoferrate(III) to colorless hexacyanoferrate(II) as measured at 420 nm. The smoke constituent measurement was replicated three to four times. Measurement of the nicotine, NNN, NNK, and total reducing sugars in tobacco filler blend were replicated twice.

Data analysis

Mean, standard deviation, and CV of the constituents in smoke and tobacco filler blend and cigarette design parameters were calculated with five averaged data points from each sampling. Pearson's correlation coefficients were calculated using five averaged data points from each sampling to understand the degree of linear relationships between two parameters. Coefficient of determination is the percentage of the response variable variation that is explained by a linear model. When the value of Pearson's correlation coefficient is 0.7, then, the value of coefficient of determination is 0.49, almost 0.5. Pearson's correlation coefficient of 0.7, which a parameter explains about 50% of the variation of constituent yields, was used in this study. Variance associated with cigarette manufacturing over the ten months in this study and repeatability variance from CRMs was combined to understand the variation associated with cigarette manufacturing and measurement between laboratories. Reproducibility standard deviations for the brands in this study were estimated from simple linear regressions of the mean and reproducibility standard deviation of test samples in CRMs. Mean and reproducibility standard deviation were used as explanatory and independent variables, respectively. Reproducibility standard deviations for brands in this study were calculated from the relevant simple linear regression using the mean value from

five averaged data points from each sampling by constituents and smoking regimes.

RESULTS

Since two brands for 1,3-butadiene (No. 2, 3), three brands for benzene (No. 2, 3, 8), three brands for formaldehyde (No. 2, 4, 5), and two brands for acrolein (No. 2, 3) included yields were below the limit of detection or limit of quantification under the ISO smoking regime, they were excluded from the data analysis.

Mean, standard deviation, and CV by brands, constituents under ISO and HCI smoking regimes are shown in Tables 2-1 and 2-2, respectively. Mean, standard deviation, and CV for physical properties and constituents found in the tobacco filler blends are shown in Table 2-3. CV values varied largely by brands, constituents, and smoking regimes. In particular, CV values of the yields of NNN and NNK in smoke and tobacco filler blend showed the highest variation among all the constituents in this study. CV values of the yield of NNN in tobacco filler blend were beyond 20% for ten out of nineteen brands.

Pearson's correlation coefficients between cigarette design parameters and the yields of TPM, "tar", and nicotine are shown in Tables 3-1, 3-2, and 3-3, respectively. The number of brands with Pearson's correlation coefficients below -0.7 between filter ventilation and the yield of TPM, "tar", and nicotine were twelve, twelve, and eight, respectively, under the ISO smoking regime. Only two brands had Pearson's correlation coefficients above 0.7 between the yield of nicotine in the tobacco filler blend and the smoke under the ISO smoking regime and three under the HCI smoking regime as shown in Table 3-3. Pearson's correlation coefficients relating the constituents in the smoke for the nineteen brands and brand No. 20 are shown in Table 4. Cigarettes from brand No. 20 were the monitor cigarettes used to check the stability of the measurement. The number of brands with Pearson's correlation coefficients above 0.7 was thirteen under the ISO smoking regime and eleven under the HCI smoking regime for benzo[*a*]pyrene. The number of brands with Pearson's correlation coefficients above 0.7 was nine under the HCI smoking regime for 1,3-butadiene. Pearson's correlation coefficients between constituents in the tobacco filler blend and in the smoke are shown in Table 5-1 and 5-2. The number of brands with Pearson's correlation coefficients above 0.7 between NNN and NNK in tobacco filler blend and in smoke was thirteen and nine, respectively, under the ISO and HCI smoking regimes as shown in Table 5-1. On the other hand, only a limited number of brands showed Pearson's correlation coefficients above 0.7 between total reducing sugar levels in the tobacco filler blend and the yield of formaldehyde in the smoke as shown in Table 5-2; additionally, the trends were largely different between the two smoking regimes. Pearson's correlation coefficients between the amount of charcoal in the filter and yields of constituents, namely 1,3-butadiene, benzene, formaldehyde, acetaldehyde, and acrolein, are shown in Table 6. Brand No. 13 was the only brand that showed Pearson's correlation coefficients above 0.7 for five constituents under the ISO smoking regime.

Table 2-1. Mean, standard deviation, and CV by brands, constituents under ISO smoking regime.

Brand No.	Manu- facturer	TPM (mg/cig)		"Tar" (mg/cig)		Nicotine (mg/cig)		Carbon monoxide (mg/cig)		Puff number (per cig)		Benzo[<i>a</i>]- pyrene (ng/cig)		1,3-Butadiene (μ g/cig)		Benzene (μ g/cig)		Formaldehyde (μ g/cig)		Acetaldehyde (μ g/cig)		Acrolein (μ g/cig)		NNN (ng/cig)		NNK (ng/cig)	
		Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)
1	JT	1.5	5.2	1.27	6.2	0.14	5.3	2.0	10.7	6.5	2.8	1.73	12.4	6.87	10.6	5.88	13.7	2.63	8.9	101.0	13.3	7.35	15.1	13.0	28.1	6.37	29.6
2	non-JT	1.3	12.9	1.07	13.2	0.11	18.1	1.7	11.9	8.2	2.5	1.49	17.6	NA	NA	NA	NA	NA	NA	47.5	20.5	NA	NA	13.1	30.8	6.67	5.3
3	non-JT	1.4	14.7	1.15	15.6	0.13	13.5	1.4	16.2	6.9	0.9	1.31	15.6	NA	NA	NA	NA	1.76	14.4	46.0	17.9	NA	NA	20.5	9.4	8.55	5.7
4	JT	1.2	19.9	1.03	19.2	0.08	17.2	1.7	26.1	7.4	4.8	1.45	27.2	5.68	20.6	5.41	23.8	NA	NA	65.1	20.7	4.04	27.1	11.3	36.1	8.22	39.5
5	JT	1.5	16.3	1.24	16.5	0.13	13.6	2.1	12.3	7.8	3.2	1.79	13.3	6.80	12.8	5.74	14.7	NA	NA	92.5	23.6	6.07	30.0	14.1	28.4	7.00	25.5
6	JT	4.2	10.1	3.52	10.5	0.35	9.5	4.9	12.2	6.9	1.2	3.58	9.7	16.12	11.8	14.34	9.4	9.02	26.7	264.6	16.8	22.08	22.3	20.2	5.3	10.09	8.6
7	non-JT	3.5	10.3	3.04	10.0	0.28	9.5	3.6	9.3	7.2	1.9	3.55	18.5	11.68	16.0	6.79	27.6	6.64	13.6	161.8	14.7	9.69	21.4	19.7	21.1	15.50	25.0
8	non-JT	3.8	7.8	3.24	7.9	0.34	4.1	3.3	8.4	6.9	3.1	3.19	12.7	10.13	17.8	NA	NA	5.36	15.8	119.1	17.3	5.29	36.3	42.2	3.7	20.74	13.9
9	JT	3.1	9.3	2.71	8.5	0.21	9.3	4.6	12.8	7.0	1.1	3.03	22.6	10.70	11.7	11.37	12.2	4.85	16.6	167.4	9.8	11.86	15.1	23.3	25.6	18.67	20.5
10	JT	4.0	7.5	3.40	8.3	0.33	6.6	4.8	7.4	8.0	1.7	3.65	8.6	14.24	14.7	13.26	17.4	7.02	10.9	233.2	6.9	17.56	13.0	21.9	12.0	10.96	5.4
11	JT	7.3	6.1	6.14	5.6	0.54	5.1	7.4	9.2	7.4	1.2	5.86	8.8	22.20	3.7	16.34	2.7	17.02	16.1	342.8	10.3	26.64	14.4	31.7	9.0	18.79	7.6
12	non-JT	7.9	7.9	6.73	7.1	0.57	9.8	7.3	5.8	7.3	2.4	6.20	25.9	26.06	12.3	17.74	16.0	19.10	10.4	375.8	3.2	28.44	7.1	41.2	22.5	32.77	26.9
13	non-JT	7.5	5.5	6.24	5.6	0.61	5.0	6.9	5.5	6.4	1.7	4.53	15.2	23.80	5.0	13.30	18.5	13.38	4.9	277.2	3.6	17.26	8.4	65.8	7.8	31.47	15.2
14	JT	5.9	7.9	5.26	7.8	0.35	8.4	7.8	5.6	6.1	1.8	4.66	13.2	21.46	9.1	21.56	4.2	19.60	16.5	388.0	6.6	30.92	9.1	30.4	12.3	20.45	6.3
15	JT	6.9	4.5	5.85	4.2	0.52	4.4	7.4	3.5	8.5	2.5	5.57	7.3	20.08	13.9	16.92	14.7	12.56	16.5	329.2	12.4	24.64	17.8	34.4	19.7	20.59	21.4
16	non-JT	7.5	4.8	6.40	5.1	0.55	4.4	6.9	5.7	7.7	1.8	5.79	10.5	22.56	6.5	15.48	9.1	17.08	15.8	321.2	9.1	24.28	18.4	31.9	14.5	26.81	17.3
17	JT	12.8	5.6	10.44	4.3	0.88	6.3	11.5	4.9	7.2	1.3	8.43	7.2	35.40	5.1	25.16	4.6	36.60	13.5	519.6	9.0	42.40	15.3	40.4	8.4	25.82	8.4
18	non-JT	14.5	3.4	12.03	3.5	0.97	2.2	12.0	4.4	8.5	1.3	9.10	5.7	43.02	10.6	32.04	7.5	33.10	5.8	609.6	2.4	49.66	4.7	123.6	46.1	77.25	39.3
19	JT	19.1	2.5	14.97	2.5	1.28	2.3	14.3	3.9	7.7	2.0	13.19	9.5	48.48	8.5	31.32	6.6	82.94	3.0	669.6	6.7	64.30	7.6	25.6	9.0	23.99	13.1
20	JT	6.9	1.3	5.87	0.8	0.57	2.1	7.0	1.9	7.3	1.7	5.56	12.9	27.94	4.3	28.20	3.9	16.80	12.3	390.2	5.1	34.88	8.1	27.1	4.5	17.10	6.7

NA: Not applicable. The constituent in this brand included yields below the limit of detection or limit of quantification.

Table 2-2. Mean, standard deviation, and CV by brands, constituents under HCl smoking regime.

Brand No.	Manu- facturer	TPM (mg/cig)		"Tar" (mg/cig)		Nicotine (mg/cig)		Carbon monoxide (mg/cig)		Puff number (per cig)		Benzo[a]- pyrene (ng/cig)		1,3-Butadiene (µg/cig)		Benzene (µg/cig)		Formaldehyde (µg/cig)		Acetaldehyde (µg/cig)		Acrolein (µg/cig)		NNN (ng/cig)		NNK (ng/cig)	
		Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)
1	JT	26.5	2.4	15.0	1.3	1.08	1.8	21.9	1.7	6.6	0.2	9.24	9.1	84.18	4.3	63.64	3.6	88.50	6.5	1215.8	4.3	137.00	2.4	76.9	24.3	47.05	10.5
2	non-JT	28.5	1.3	16.9	1.6	1.26	4.3	22.4	1.3	8.4	1.5	10.03	12.6	85.02	3.1	65.88	3.4	56.72	6.0	1264.6	3.2	126.80	5.2	85.5	30.2	55.25	21.2
3	non-JT	28.4	4.2	16.1	4.2	1.34	5.1	21.2	2.6	6.8	2.4	8.05	10.3	87.12	3.9	54.68	4.6	41.20	2.6	1102.8	3.1	99.62	4.5	156.0	9.4	69.32	12.6
4	JT	25.2	15.4	16.0	8.6	0.85	7.4	35.4	3.0	7.2	5.4	10.31	20.7	92.04	4.0	72.36	2.5	91.70	10.8	1582.8	4.7	159.60	4.4	73.9	25.6	65.81	11.9
5	JT	25.2	3.1	16.1	2.0	1.20	4.4	25.6	3.7	8.0	1.9	9.88	11.3	95.70	5.5	76.90	3.7	70.34	7.8	1298.4	2.6	140.60	3.4	80.4	16.4	52.13	7.1
6	JT	33.6	2.1	19.0	2.7	1.48	4.7	23.8	1.8	7.7	3.7	11.68	8.7	88.70	4.6	71.14	3.8	92.70	5.5	1274.8	2.0	137.40	2.6	70.7	8.7	40.91	8.5
7	non-JT	28.3	1.7	17.7	1.6	1.29	6.1	21.5	2.5	8.1	1.8	11.92	8.9	79.86	4.8	63.84	5.4	79.72	11.2	1238.6	3.1	117.80	6.1	70.5	26.3	57.16	22.2
8	non-JT	35.0	3.9	19.8	2.0	1.62	2.2	22.7	3.3	7.4	4.1	10.67	9.9	86.46	4.5	55.50	6.5	62.04	10.0	1177.8	3.4	108.20	5.7	168.7	7.2	81.16	12.6
9	JT	28.3	20.4	17.9	13.9	0.98	11.6	35.3	4.9	7.1	4.4	12.34	16.4	89.96	6.1	70.74	3.2	106.90	7.2	1571.4	0.8	159.80	4.0	85.1	24.1	75.59	9.6
10	JT	31.6	1.9	20.3	1.1	1.58	0.9	27.0	1.7	8.8	1.8	12.81	10.1	95.60	6.4	79.52	5.5	84.06	3.6	1376.6	1.0	144.40	2.8	74.4	10.9	42.79	5.7
11	JT	41.6	4.4	23.3	2.9	1.69	2.6	26.2	2.1	8.6	1.9	14.15	9.6	93.22	4.9	72.34	4.5	109.60	3.5	1398.6	3.6	139.40	3.9	83.8	10.3	58.54	7.2
12	non-JT	36.3	2.1	22.0	2.5	1.64	5.6	23.8	2.9	8.4	3.7	13.43	14.4	89.16	6.6	69.56	4.7	95.40	7.2	1306.0	4.5	125.40	5.2	105.7	25.2	83.53	29.3
13	non-JT	38.0	2.5	21.5	1.7	1.75	3.1	22.7	1.7	7.5	2.1	11.53	8.6	90.62	8.1	59.78	9.6	68.10	9.5	1187.2	3.4	111.40	4.5	182.0	2.8	77.34	9.6
14	JT	43.8	4.4	24.1	3.1	1.25	6.0	31.9	2.0	5.8	3.4	12.68	10.5	110.00	4.2	80.80	3.6	138.20	7.8	1626.0	2.7	166.40	3.3	88.8	9.9	64.76	13.2
15	JT	37.9	2.9	23.9	2.6	1.82	4.5	28.8	2.2	9.9	2.4	16.33	10.7	97.96	6.2	82.88	6.5	100.12	5.5	1511.2	3.6	149.60	5.0	97.0	16.9	64.81	21.6
16	non-JT	40.4	2.1	24.0	1.8	1.75	1.9	24.6	2.5	8.7	0.8	14.83	9.5	94.76	5.7	73.66	4.9	110.80	4.7	1326.2	2.2	136.00	3.4	86.8	17.5	77.39	16.2
17	JT	48.3	5.2	27.5	4.0	2.15	5.0	26.8	2.2	9.1	2.7	16.98	8.4	91.44	3.6	70.48	4.6	121.80	4.5	1410.6	2.9	136.00	3.3	85.4	4.7	57.85	7.6
18	non-JT	54.8	5.5	32.2	4.0	2.37	2.9	29.0	4.5	10.3	2.0	19.86	13.6	108.60	4.8	90.44	4.3	119.20	7.3	1656.2	3.4	161.40	5.3	276.1	45.9	169.99	38.6
19	JT	54.6	0.5	31.9	1.1	2.82	1.7	27.9	2.0	10.4	1.1	23.49	7.5	99.18	9.0	76.92	7.4	194.60	4.7	1340.6	4.4	150.20	5.2	47.4	9.4	44.03	10.4
20	JT	36.4	2.1	21.6	1.9	1.68	1.6	24.7	2.6	8.6	1.9	13.11	17.0	93.92	5.9	84.08	4.7	88.80	7.7	1309.6	4.0	131.40	4.7	67.3	4.0	46.75	7.7

Table 2-3. Mean, standard deviation, and CV for physical properties and constituents in tobacco filler blend.

Brand No.	Manu- facturer	Filter ventilation ^a (%)		Draw resistance (mmH ₂ O)		Circumference (mm)		Cigarette weight (g/cig)		Tobacco weight (g/cig)		Charcoal in filter ^b (mg/cig)		Tobacco nicotine (% dwb)		NNN (µg/g dwb)		NNK (µg/g dwb)		Total reducing sugars (% dwb)	
		Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
1	JT	70.9	2.2	99.7	4.4	24.93	0.1	0.803	0.4	0.504	0.51	20.5	3.7	1.91	2.7	1.64	38.6	0.45	17.5	11.5	4.8
2	non-JT	76.7	1.7	88.3	2.8	24.76	0.4	0.932	0.9	0.602	0.68	47.2	3.8	1.86	5.1	1.41	39.7	0.41	27.7	11.2	3.6
3	non-JT	77.0	2.6	99.4	1.7	24.89	0.1	0.872	0.6	0.536	0.62	56.1	3.7	2.38	3.1	2.32	13.0	0.68	8.3	7.8	5.6
4	JT	81.1	2.7	94.2	5.3	22.59	0.3	0.818	1.1	0.501	1.42	NA	NA	1.72	0.8	1.99	23.3	0.76	9.1	8.4	1.1
5	JT	72.1	3.2	98.2	3.6	24.90	0.3	0.939	0.3	0.610	0.55	21.5	4.4	1.91	3.0	1.52	20.9	0.46	13.4	11.1	4.7
6	JT	53.5	6.0	98.7	3.9	24.98	0.2	0.869	0.5	0.575	0.18	24.2	4.8	1.98	2.2	1.02	8.0	0.26	18.1	12.0	2.3
7	non-JT	59.6	3.6	100.9	2.8	24.76	0.3	0.927	1.2	0.598	1.82	47.0	4.7	1.68	2.7	0.86	34.3	0.36	18.3	10.0	4.2
8	non-JT	64.0	1.5	93.7	0.9	24.92	0.1	0.921	0.4	0.587	0.90	56.3	7.1	2.19	2.5	2.19	15.0	0.85	21.6	8.4	3.3
9	JT	67.4	2.2	101.2	3.5	22.67	0.3	0.816	0.5	0.499	1.29	NA	NA	1.71	1.7	1.98	24.9	0.77	11.3	8.5	3.4
10	JT	56.4	2.6	95.8	1.9	24.95	0.3	1.003	0.4	0.679	0.25	26.3	1.4	1.98	1.7	1.07	18.0	0.26	8.3	11.9	4.5
11	JT	40.8	6.5	99.9	3.9	25.03	0.3	0.917	0.4	0.644	0.45	29.3	3.0	1.80	1.6	0.92	6.9	0.27	14.7	11.8	2.8
12	non-JT	36.7	6.5	111.7	2.1	24.76	0.3	0.939	0.7	0.619	0.63	47.5	3.4	1.78	2.1	1.22	38.1	0.43	28.0	11.2	7.8
13	non-JT	41.1	3.6	102.7	1.7	24.90	0.1	0.915	0.2	0.586	0.18	56.5	3.8	2.21	2.6	2.10	6.2	0.73	7.2	8.5	2.5
14	JT	53.1	2.4	90.7	3.5	22.69	0.4	0.847	0.3	0.507	0.44	NA	NA	1.96	1.5	1.52	21.1	0.52	15.5	8.4	1.8
15	JT	45.3	5.9	95.9	4.5	24.98	0.3	1.062	0.8	0.745	1.00	31.5	4.8	1.79	1.1	0.93	13.4	0.29	29.8	11.7	3.5
16	non-JT	45.3	5.3	91.3	2.4	24.85	0.2	0.927	0.4	0.612	0.86	49.5	3.7	1.76	3.4	1.00	21.0	0.40	19.1	11.9	4.7
17	JT	16.6	10.0	108.4	3.5	24.94	0.2	0.946	0.4	0.666	0.36	34.2	3.4	1.89	1.6	0.85	5.8	0.26	9.5	12.2	2.9
18	non-JT	27.0	4.7	99.7	1.9	24.86	0.2	0.981	0.9	0.712	0.69	48.2	4.0	1.83	0.8	2.72	56.7	0.57	40.1	10.7	3.2
19	JT	NA	NA	108.6	1.4	24.94	0.1	0.997	0.3	0.706	0.50	35.1	2.4	1.99	1.6	0.41	9.0	0.20	2.8	16.4	3.6
20	JT	40.9	0.9	105.9	0.5	25.04	0.0	0.866	0.2	0.623	0.32	NA	NA	2.06	0.9	0.81	6.8	0.39	7.7	11.6	1.4

^a Filter ventilation: Brand No. 19 did not have filter ventilation holes.

^b Charcoal in filter: Brand No. 4, 9, 14, and 20 did not include charcoal in filter.

Table 3-1. Pearson's correlation coefficients between TPM yields and cigarette design parameters.

Brand No.	Manu- facturer	ISO smoking regime						HCl smoking regime					
		Filter ventilation	Draw resistance	Circum- ference	Cigarette weight	Tobacco weight	Tobacco nicotine	Total reducing sugars	Circum- ference	Cigarette weight	Tobacco weight	Tobacco nicotine	Total reducing sugars
1	JT	0.04	-0.07	-0.14	-0.22	-0.64	-0.27	0.39	-0.99	0.38	0.51	-0.07	-0.65
2	non-JT	-0.61	0.17	-0.11	0.04	-0.75	0.12	-0.66	-0.36	0.16	-0.34	0.42	-0.43
3	non-JT	-0.59	0.77	-0.63	-0.59	-0.79	-0.77	-0.40	0.28	0.55	0.98	0.44	-0.30
4	JT	-0.78	0.67	-0.81	0.02	0.05	0.14	0.05	-0.79	-0.21	-0.83	0.37	0.17
5	JT	-0.81	0.67	0.11	-0.25	-0.26	0.52	-0.14	0.55	0.36	0.34	0.84	0.37
6	JT	-0.82	0.71	0.59	0.04	0.58	0.11	-0.63	0.84	-0.04	-0.07	0.18	0.12
7	non-JT	-0.91	0.69	-0.11	-0.45	-0.74	0.45	-0.09	-0.53	-0.82	-0.94	0.67	-0.43
8	non-JT	-0.83	0.47	-0.75	-0.37	-0.65	-0.18	-0.18	-0.53	-0.59	-0.29	0.42	-0.28
9	JT	-0.90	0.42	-0.08	0.06	-0.22	-0.11	0.35	-0.62	-0.36	0.62	0.52	0.10
10	JT	-0.93	0.94	0.39	0.33	0.03	-0.52	0.38	0.55	0.87	0.91	-0.80	0.46
11	JT	-0.99	0.87	-0.77	0.72	0.42	-0.53	0.57	0.25	-0.43	-0.54	-0.51	-0.32
12	non-JT	-0.65	0.76	-0.91	-0.62	-0.50	0.32	0.35	-0.88	-0.65	-0.68	0.16	0.39
13	non-JT	-0.47	0.86	0.83	0.85	0.68	0.32	0.81	0.17	0.32	0.13	0.73	0.39
14	JT	-0.97	-0.33	-0.47	0.20	0.22	0.12	-0.39	0.07	-0.03	-0.02	0.57	-0.51
15	JT	-0.74	-0.08	0.86	-0.59	-0.36	0.66	0.00	0.50	0.00	-0.15	-0.45	-0.26
16	non-JT	-0.90	0.81	-0.63	0.64	0.81	0.27	0.43	-0.59	0.14	-0.42	0.13	0.29
17	JT	-0.80	-0.67	-0.01	0.10	0.07	-0.21	0.52	0.01	-0.02	-0.15	-0.04	0.16
18	non-JT	0.04	0.41	-0.17	0.45	0.95	0.26	0.11	-0.28	0.33	0.92	0.08	0.07
19	JT	NA ^a	-0.50	-0.80	-0.01	-0.83	0.59	0.31	0.19	0.04	-0.30	-0.56	0.25
20	JT	0.42	-0.62	0.56	0.40	0.32	-0.62	0.37	0.01	-0.09	-0.11	-0.17	0.50

^a Brand No. 19 did not have filter ventilation holes.

Table 3-2. Pearson's correlation coefficients between “tar” yields and cigarette design parameters.

Brand No.	Manu- facturer	ISO smoking regime							HCI smoking regime				
		Filter venti- lation	Draw resis- tance	Circum- ference	Cigarette weight	Tobacco weight	Tobacco nicotine	Total reducing sugars	Circum- ference	Cigarette weight	Tobacco weight	Tobacco nicotine	Total reducing sugars
1	JT	0.30	-0.13	-0.43	0.26	-0.09	-0.59	0.19	-0.44	0.30	0.09	-0.70	-0.12
2	non-JT	-0.63	0.20	-0.19	-0.02	-0.77	0.11	-0.62	0.11	0.23	-0.68	0.19	-0.74
3	non-JT	-0.41	0.61	-0.72	-0.52	-0.70	-0.69	-0.51	0.28	0.58	0.97	0.56	-0.21
4	JT	-0.73	0.57	-0.84	0.11	0.14	0.06	0.14	-0.70	-0.29	-0.88	0.37	0.17
5	JT	-0.84	0.72	0.06	-0.29	-0.30	0.45	-0.18	0.63	0.64	0.73	0.67	0.34
6	JT	-0.85	0.76	0.54	0.06	0.65	0.09	-0.69	0.79	-0.13	-0.26	0.28	0.35
7	non-JT	-0.93	0.75	-0.02	-0.42	-0.76	0.51	0.00	-0.92	-0.62	-0.74	0.01	-0.84
8	non-JT	-0.87	0.59	-0.82	-0.38	-0.68	-0.26	-0.25	-0.33	-0.20	0.28	0.32	-0.47
9	JT	-0.84	0.42	-0.14	-0.09	-0.32	-0.06	0.22	-0.63	-0.45	0.54	0.51	0.00
10	JT	-0.96	0.91	0.33	0.27	0.03	-0.48	0.33	0.19	0.53	0.69	-0.76	0.16
11	JT	-0.99	0.93	-0.76	0.77	0.52	-0.60	0.46	0.24	-0.45	-0.22	-0.22	-0.69
12	non-JT	-0.69	0.73	-0.95	-0.67	-0.52	0.23	0.24	-0.90	-0.69	-0.51	0.27	0.19
13	non-JT	-0.49	0.88	0.85	0.79	0.64	0.23	0.74	0.36	0.68	0.35	0.80	0.65
14	JT	-0.97	-0.25	-0.52	0.16	0.23	0.06	-0.29	-0.35	0.20	0.08	0.25	-0.63
15	JT	-0.78	-0.02	0.80	-0.69	-0.49	0.72	-0.10	0.83	-0.10	-0.02	-0.11	-0.01
16	non-JT	-0.91	0.79	-0.67	0.65	0.81	0.27	0.47	-0.77	0.25	0.35	0.73	0.66
17	JT	-0.84	-0.67	0.03	0.07	0.07	-0.28	0.57	0.17	-0.25	-0.40	-0.26	0.40
18	non-JT	0.00	0.50	-0.23	0.41	0.97	0.17	0.17	-0.17	0.46	0.94	0.04	0.09
19	JT	NA ^a	-0.34	-0.89	0.29	-0.99	0.59	-0.06	-0.33	0.47	-0.46	-0.01	-0.07
20	JT	0.17	-0.53	0.47	0.17	0.05	-0.52	0.38	0.27	-0.11	-0.16	-0.09	0.68

^a Brand No. 19 did not have filter ventilation holes.

Table 3-3. Pearson's correlation coefficients between nicotine yields and cigarette design parameters.

Brand No.	Manu- facturer	ISO smoking regime							HCI smoking regime				
		Filter Venti- lation	Draw Resis- tance	Circum- ference	Cigarette weight	Tobacco weight	Tobacco nicotine	Total reducing sugars	Circum- ference	Cigarette weight	Tobacco weight	Tobacco nicotine	Total reducing sugars
1	JT	-0.65	0.42	-0.14	-0.66	-0.74	0.57	0.22	0.92	-0.38	-0.35	0.03	0.29
2	non-JT	-0.67	0.38	-0.20	-0.05	-0.92	0.23	-0.69	0.01	0.31	-0.76	0.61	-0.81
3	non-JT	-0.39	0.54	-0.70	-0.46	-0.79	-0.53	-0.36	0.10	0.54	0.73	0.67	-0.14
4	JT	-0.66	0.45	-0.92	0.07	0.07	-0.07	0.36	-0.63	-0.10	-0.84	0.35	0.19
5	JT	-0.67	0.53	0.21	-0.15	-0.22	0.70	-0.16	0.79	0.74	0.77	0.66	0.76
6	JT	-0.79	0.60	0.63	-0.13	0.43	0.33	-0.50	0.71	-0.23	-0.29	0.45	0.42
7	non-JT	-0.75	0.44	-0.47	-0.56	-0.69	0.23	-0.45	-0.56	-0.36	-0.45	-0.08	-0.54
8	non-JT	-0.71	0.32	-0.62	-0.44	-0.69	-0.07	-0.01	-0.03	0.70	0.85	-0.03	-0.78
9	JT	-0.96	0.56	0.17	0.09	-0.24	-0.35	0.37	-0.60	-0.49	0.60	0.49	-0.03
10	JT	-0.95	0.75	0.27	0.02	-0.02	-0.21	0.34	0.61	0.02	-0.41	0.20	0.64
11	JT	-0.91	0.71	-0.67	0.69	0.50	-0.18	0.63	0.34	-0.12	0.53	0.17	-0.98
12	non-JT	-0.69	0.54	-0.95	-0.76	-0.55	0.01	-0.10	-0.97	-0.81	-0.63	0.00	-0.06
13	non-JT	-0.29	0.71	0.68	0.83	0.52	0.45	0.74	0.06	0.59	0.03	0.79	0.42
14	JT	-0.94	-0.50	-0.30	0.31	0.29	0.30	-0.49	0.02	0.57	0.59	0.56	-0.40
15	JT	-0.44	-0.38	0.83	-0.62	-0.49	0.40	-0.36	0.95	-0.16	0.07	0.21	0.24
16	non-JT	-0.93	0.83	-0.71	0.66	0.82	0.31	0.54	-0.21	-0.08	0.27	0.79	-0.06
17	JT	-0.53	-0.70	-0.17	0.04	-0.10	-0.04	0.67	0.14	-0.16	-0.30	-0.17	0.21
18	non-JT	-0.10	-0.14	-0.06	0.25	0.57	0.68	-0.32	0.24	0.38	0.38	0.52	-0.65
19	JT	NA ^a	-0.53	-0.90	0.37	-0.75	0.72	-0.01	-0.95	0.56	-0.35	0.97	-0.41
20	JT	0.74	-0.79	-0.02	0.78	0.98	-0.85	-0.22	0.56	0.65	0.64	-0.44	0.11

^a Brand No. 19 did not have filter ventilation holes.

Table 4. Pearson's correlation coefficients relating the constituents in the smoke for the nineteen brands with brand No. 20.

Brand No.	Manu- facturer	ISO smoking regime							HCl smoking regime								
		Benzo-[a]- pyrene	1,3- Butadiene	Benzene	Form- aldehyde	Acet- aldehyde	Acrolein	NNN	NNK	Benzo-[a]- pyrene	1,3- Butadiene	Benzene	Form- aldehyde	Acet- aldehyde	Acrolein	NNN	NNK
1	JT	0.90	-0.14	-0.33	-0.06	-0.13	-0.06	-0.97	-0.19	0.80	0.86	0.06	0.28	0.64	0.64	0.67	0.64
2	non-JT	0.95	NA	NA	NA	0.20	NA	0.47	-0.13	0.62	0.83	-0.50	0.27	-0.10	-0.14	-0.58	-0.28
3	non-JT	0.72	NA	NA	0.13	0.06	NA	0.40	-0.05	0.52	0.39	0.96	-0.30	0.32	0.54	-0.21	-0.40
4	JT	0.70	-0.04	0.44	NA	0.33	-0.07	-0.71	0.41	0.99	0.79	-0.16	0.69	-0.82	-0.10	0.44	0.90
5	JT	-0.43	0.92	0.31	NA	0.93	0.94	-0.67	-0.45	0.77	0.80	0.35	0.24	0.42	0.27	0.27	0.56
6	JT	0.79	0.61	-0.91	-0.49	-0.08	-0.28	-0.86	0.04	0.77	0.79	0.74	0.07	0.11	0.20	0.21	-0.30
7	non-JT	0.75	0.31	0.82	0.29	0.31	0.47	0.19	0.04	0.76	0.19	-0.20	0.61	0.60	0.31	-0.55	-0.42
8	non-JT	0.87	-0.52	NA	-0.12	-0.77	-0.35	0.30	0.38	0.82	0.73	0.18	0.46	-0.77	-0.24	0.04	0.31
9	JT	0.89	0.11	0.34	0.27	0.60	-0.02	-0.71	0.50	0.86	0.56	0.64	-0.31	0.15	0.78	0.43	0.57
10	JT	0.16	0.91	-0.01	0.62	0.92	1.00	-0.81	0.43	0.74	0.85	-0.56	-0.43	-0.64	-0.75	0.83	0.82
11	JT	0.68	-0.73	-0.50	0.65	0.36	0.48	-0.25	0.19	0.77	-0.37	0.22	-0.56	0.30	0.22	0.54	-0.40
12	non-JT	0.97	0.11	-0.01	-0.25	-0.36	0.10	0.09	0.50	0.87	0.68	0.93	0.21	-0.04	-0.01	0.08	0.10
13	non-JT	0.81	-0.82	0.73	0.57	-0.16	-0.10	0.16	0.22	0.60	0.67	0.93	0.28	-0.37	0.15	-0.66	-0.71
14	JT	0.71	0.45	-0.29	0.39	-0.49	0.28	-0.78	-0.40	0.89	0.76	0.75	-0.04	0.70	0.35	0.46	0.72
15	JT	0.80	0.89	0.53	0.89	0.60	0.62	-0.66	0.08	0.50	0.28	0.03	0.01	-0.86	-0.54	0.72	0.13
16	non-JT	0.90	-0.03	0.96	0.06	0.15	0.39	0.77	0.34	0.46	0.75	0.25	-0.38	-0.14	-0.16	-0.20	-0.40
17	JT	0.52	0.75	0.18	0.80	0.24	0.28	-0.83	-0.29	0.21	0.20	0.45	0.48	0.56	0.36	0.40	0.05
18	non-JT	0.84	0.92	0.45	-0.38	0.39	0.66	0.65	0.06	0.33	0.25	-0.20	0.70	0.13	0.31	-0.62	-0.20
19	JT	-0.44	0.15	-0.21	-0.09	-0.71	-0.59	-0.37	0.40	0.53	0.18	0.18	0.09	0.20	0.12	0.17	0.40

NA: Not applicable. The constituent in this brand included yields below the limit of detection or limit of quantification.

Table 5-1. Pearson's correlation coefficients between NNN and NNK in tobacco filler blend and those in smoke.

Brand No.	Manu- facturer	ISO smoking regime		HCI smoking regime	
		NNN	NNK	NNN	NNK
1	JT	0.92	0.85	0.98	0.76
2	non-JT	0.92	0.98	0.99	0.98
3	non-JT	0.90	0.29	0.84	0.76
4	JT	0.82	0.00	0.96	0.26
5	JT	0.99	0.73	0.96	0.73
6	JT	0.58	-0.23	0.48	-0.10
7	non-JT	0.83	0.25	0.97	0.51
8	non-JT	0.71	0.76	0.87	0.93
9	JT	0.87	0.01	0.92	0.81
10	JT	0.25	-0.49	-0.05	-0.79
11	JT	0.66	0.03	0.62	0.57
12	non-JT	0.91	0.96	0.91	0.97
13	non-JT	0.42	0.75	0.74	0.65
14	JT	0.93	0.50	0.72	0.67
15	JT	0.84	0.82	0.93	0.92
16	non-JT	0.91	0.76	0.93	0.86
17	JT	0.19	0.27	-0.21	0.51
18	non-JT	0.98	0.97	0.97	0.93
19	JT	0.53	0.27	-0.11	0.24
20	JT	0.59	-0.59	-0.66	-0.97

The number of brands with Pearson's correlation coefficients below -0.7 for the relationship between the yield of charcoal in the filter and the yields of constituents were three to four, regardless of the constituents, under the ISO smoking regime. The number of brands was lower under the HCI smoking regime. Mean, maximum, and minimum CV values associated with both cigarette manufacturing over ten months and measurements at different laboratories are shown in Table 7. Coefficient of determinations for regression models of 1,3-butadiene, benzene, acetaldehyde, and acrolein under the HCI smoking regime were 0.0727, 0.461, 0.1734, and 0.0596, respectively. Therefore, CV values were not calculated for four constituents under the HCI smoking regime. Coefficient of determinations was higher than 0.9, except for formaldehyde, under the HCI smoking regime. The coefficient of determination for formaldehyde under the HCI smoking regime was 0.7092. The grand mean of CV values of the yield of formaldehyde showed the highest values among the constituents.

DISCUSSION

Cigarette manufacturing

The difference between the average yields of "tar" and nicotine in each brand in this study and their levels displayed on the package were compared with the confidence intervals over a period of time in ISO 8243 (16). The differences were within the range of confidence intervals except for the yields of nicotine in brand No. 13. Physical properties of JT brands were within the range of cigarette specification allowances. Therefore, this study provides information regarding normal cigarette manufacturing.

The influence of measurement over the 10-month period variations in the yields of the constituents in smoke

Variation associated with measurement, out of the total variation, was evaluated by calculating Pearson's correlation coefficients by constituents and smoking regimes between monitor cigarette brand No. 20 and nineteen commercial cigarette brands. Thirteen brands had Pearson's correlation coefficients above 0.7 under the ISO smoking regime and eleven under the HCI smoking regime for benzo[*a*]pyrene. This means that the variation in the yields of benzo[*a*]pyrene in smoke was largely influenced by the measurement. When benzo[*a*]pyrene was measured with HPLC-FLD, the difference in peak integration between laboratories affected the yields and reproducibility of the measurements (28). Peak integration in the measurement of benzo[*a*]pyrene in smoke might be one factor causing the variation. The number of brands with Pearson's correlation coefficients above 0.7 was nine under the HCI smoking regime for 1,3-butadiene. On the other hand, the number of brands was lower under the ISO smoking regime. In addition, benzene, which was measured with 1,3-butadiene using the same method, did not show the same trend. Therefore, measurement of the yields of 1,3-butadiene in smoke had some issues that have to be improved, as reported by ELDRIDGE *et al.* (7). Variation associated with measurement was not the main source of variation for the yields of the constituents in smoke, except benzo[*a*]pyrene and 1,3-butadiene because Pearson's correlation coefficients were not high. Monitoring the variation in the yields of the constituents in smoke over time, evaluates the variation

Table 5-2. Pearson's correlation coefficients between total reducing sugar levels in tobacco filler blend and the yield of formaldehyde in smoke.

Brand No.	Manu- facturer	ISO smoking regime	HCI smoking regime
		Formaldehyde	Formaldehyde
1	JT	0.56	0.73
2	non-JT	NA	0.18
3	non-JT	0.80	-0.20
4	JT	NA	0.30
5	JT	NA	0.93
6	JT	-0.64	0.82
7	non-JT	0.53	0.82
8	non-JT	-0.27	-0.54
9	JT	0.52	0.14
10	JT	0.80	-0.56
11	JT	0.32	-0.54
12	non-JT	0.05	0.29
13	non-JT	-0.33	-0.41
14	JT	0.05	-0.57
15	JT	0.09	-0.43
16	non-JT	0.17	0.18
17	JT	-0.12	0.94
18	non-JT	-0.21	-0.35
19	JT	0.11	0.90
20	JT	-0.54	-0.66

NA: Not applicable. The constituent in this brand included yields below the limit of detection or limit of quantification.

Table 6. Pearson's correlation coefficients between the amount of charcoal in the filter and yields of constituents in the vapor phase. In addition, brand No 4, 9, 14, and 20 did not include charcoal in the filter.

Brand No.	Manu- facturer	ISO smoking regime					HCl smoking regime				
		1,3- Butadiene	Benzene	Form- aldehyde	Acet- aldehyde	Acrolein	1,3- Butadiene	Benzene	Form- aldehyde	Acet- aldehyde	Acrolein
1	JT	-0.62	-0.94	-0.30	-0.62	-0.91	0.32	-0.37	0.17	0.22	0.76
2	non-JT	NA	NA	NA	0.57	NA	-0.09	0.79	-0.52	-0.68	0.07
3	non-JT	NA	NA	0.03	0.11	NA	-0.82	0.00	0.88	0.60	0.56
4	JT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	JT	0.59	0.12	NA	0.36	0.37	0.21	-0.04	0.00	0.08	-0.15
6	JT	0.36	-0.28	-0.23	-0.18	-0.21	-0.12	-0.43	-0.46	-0.97	-0.69
7	non-JT	-0.72	-0.80	-0.41	-0.81	-0.87	0.70	0.34	-0.60	-0.46	-0.81
8	non-JT	0.48	NA	0.49	0.19	0.42	-0.58	0.72	0.96	0.22	0.58
9	JT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	JT	-0.22	-0.22	0.59	0.11	0.04	-0.15	-0.48	-0.50	-0.56	-0.51
11	JT	0.43	-0.29	0.98	0.79	0.86	0.00	-0.21	-0.17	0.92	0.93
12	non-JT	-0.71	-0.33	-0.81	-0.97	-0.60	-0.44	-0.56	0.25	0.14	0.38
13	non-JT	-0.80	-0.85	-0.85	-0.95	-0.84	0.30	-0.12	-0.74	-0.73	-0.96
14	JT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	JT	-0.28	-0.35	-0.27	-0.10	-0.03	0.12	0.04	-0.11	-0.21	-0.07
16	non-JT	0.28	-0.67	-0.71	-0.47	-0.51	0.34	0.00	-0.60	-0.73	-0.24
17	JT	0.73	-0.57	0.12	-0.41	-0.40	-0.79	-0.82	0.05	0.00	-0.48
18	non-JT	0.25	0.74	-0.08	0.75	0.80	-0.26	0.70	0.59	0.37	0.92
19	JT	0.53	0.63	-0.91	0.21	-0.11	0.24	-0.40	-0.27	-0.59	-0.63
20	JT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA: Not applicable. The constituent in this brand included yields below the limit of detection or limit of quantification.

associated with cigarette manufacturing and measurement simultaneously. Therefore, it is important to measure monitor cigarettes along with commercial cigarette brands to understand the stability of the measurement.

Variation of NNN and NNK yields in smoke

CV values for the yields of NNN and NNK in smoke and tobacco filler blend showed the highest variation among the constituents in this study. In addition, NNN and NNK yields in smoke correlated well with those in the tobacco filler blend. Other studies also report these relationships (7, 9, and 12). MOLDOVEANU and BORGERDING have studied the formation of NNN and NNK in detail (29). As typical examples, brands No. 18 and No. 1 are shown in Figure 1 and Figure 2, respectively. For brand No. 18, the first to third batches and fourth to fifth batches apparently contained different yields in both smoke and tobacco filler blend. In contrast, it seemed that the data for brand No. 1 showed random variations which might come from normal manufacturing without a major blend composition change. The example of brand No. 18 indicates the importance of understanding the variation in the yields of smoke constituents over a period of time, rather than at one point in time.

Variation in formaldehyde yields in smoke

PARRISH and HARWARD have shown that tobaccos with high levels of total reducing sugars tend to give high yields of formaldehyde in smoke (30). Only limited brands showed Pearson's correlation coefficients above 0.7 between total reducing sugar levels in tobacco filler blend

and the yields of formaldehyde in smoke, and this tendency was largely different between the two smoking regimes. For brand No. 1, the yields of NNN in tobacco filler blend ranged from 1.1 to 2.6 µg/g, which is a 2.4-fold change between batches. On the other hand, the total reducing sugar levels in tobacco filler blend ranged from 10.8 to 12.2%, only a 1.1-fold change. This small range within a given brand may not be adequate to demonstrate the relationship. Thus, variation of levels of total reducing sugar in tobacco filler blend were not the main factor for the variation for the yields of formaldehyde in smoke. The variation for the yields of formaldehyde in smoke might be

Table 7. Mean, maximum, and minimum CV values associated with both cigarette manufacturing over ten months and measurements at different laboratories. Values are given in percent (%). Due to low coefficient of determinations for regression models of 1,3-butadiene, benzene, acetaldehyde, and acrolein under the HCl smoking regime, CV values were not calculated for these four constituents.

Constituent	ISO smoking regime			HCl smoking regime		
	Min	Mean	Max	Min	Mean	Max
1,3-Butadiene	17.9	20.4	24.7	NA	NA	NA
Benzene	17.4	25.6	40.8	NA	NA	NA
Formaldehyde	16.3	28.4	57.1	21.9	22.9	24.5
Acetaldehyde	10.6	21.4	44.1	NA	NA	NA
Acrolein	13.7	27.2	55.2	NA	NA	NA
NNN	12.5	23.8	47.1	13.9	23.7	47.7
NNK	15.2	24.4	44.0	17.8	22.4	41.6

NA: Not Applicable. The constituent in this brand included yields below the limit of detection or limit of quantification.

Figure 1. Trend of NNN in smoke and tobacco filler blend for brand No. 18.

-○-: NNN in smoke for brand No. 18 under HCl smoking regime;
 —: NNN in tobacco filler blend for brand No. 18;
 -△-: NNN in smoke for brand No. 20 under HCl smoking regime.

Figure 2. Trend of NNN in smoke and tobacco filler blend for brand No. 1.

-○-: NNN in smoke for brand No. 1 under HCl smoking regime;
 —: NNN in tobacco filler blend for brand No. 1;
 -△-: NNN in smoke for brand No. 20 under HCl smoking regime.

explained by another factor or the combination of various factors.

Charcoal filter and smoke constituents in vapor phase

Activated charcoal is well known to have the potential to selectively adsorb many vapor phase constituents from mainstream smoke (31, 32). Brand No. 13 was the only brand which showed Pearson's correlation coefficients below -0.7 for all five constituents namely 1,3-butadiene, benzene, formaldehyde, acetaldehyde, and acrolein. The average amount of charcoal in the filter of this brand was 56.5 mg/cig. Some brands also had included nearly the same amount of charcoal in filters, but they did not always show the same higher correlation seen with brand No. 13. The effect of carbon in the filter can be influenced by many factors such as the weight of the carbon, surface area, and activity (33). Since average CV value for the amount of charcoal amount was 3.9%, this small variation within a single brand may not be adequate to demonstrate the relationship. The effect of carbon in the filter has been reported by comparing two linear regressions which were established from a wide range of cigarette brands with and without charcoal in the filter on the Japanese market (34). By contrast, variation of the amount of charcoal in the filter within a given brand was not the main factor for the variation of five constituents in this study.

Variation in the yields of constituents in smoke over time associated with cigarette manufacturing and measurement at different laboratories

The cigarette itself and the laboratory measurements are two major sources of statistical variation. Both of them result in short and long-term fluctuations over time, while measurements also vary between laboratories, even for matched cigarette samples (16). Confidence intervals have not been set for the yields of constituents other than "tar", nicotine, and carbon monoxide under the ISO smoking regime. Thus, standard deviations associated with both cigarette manufacturing over ten months and measurements at different laboratories were calculated in this study. Since the yield of benzo[a]pyrene in smoke was not measured with CRM58, benzo[a]pyrene was excluded from this calculation. Since coefficient of determinations for regression models of 1,3-butadiene, benzene, acetaldehyde, and acrolein under the HCl smoking regime were 0.0727, 0.461, 0.1734, and 0.0596, respectively, they were also excluded from this calculation. One of the reasons for the lower coefficient of determinations of constituents in the vapor phase is vent blocking of cigarettes, and it narrowed the range of yields of constituents for the cigarette brands in this study. For example, acetaldehyde yields ranged from 99.96 µg/cig to 694.21 µg/cig under the ISO smoking regime, and 836.47 µg/cig to 1605.8 µg/cig under the HCl smoking regime. The ratios of maximum yields to minimum yields under ISO and HCl smoking regimes were 6.9 and 1.9, respectively. The grand mean of CV values for NNN and formaldehyde associated with both cigarette manufacturing over ten months and measurement at different laboratories under the ISO smoking regimes were 23.8% and 28.4% respectively. The grand mean of CV

values for NNN and formaldehyde associated with both cigarette manufacturing over ten months and measurement at different laboratories under the HCI smoking regimes were 23.7% and 22.9% respectively. The grand mean of CV values for NNN and formaldehyde associated with cigarette manufacturing over ten months and measurement at the JT laboratory under the ISO smoking regimes were 18.4% and 13.1% respectively. The grand mean of CV values for NNN and formaldehyde associated with cigarette manufacturing over ten months and measurement at the JT laboratory under the HCI smoking regimes were 17.1% and 6.6% respectively. The grand mean of CV values of the yield of formaldehyde showed the highest increase among the constituents when the standard deviation associated with measurement between laboratories was added. This is based on the fact that formaldehyde showed the highest CV values for reproducibility among the constituents. This study used the yields of constituents in smoke from cigarette brands during 2009 to 2010 that were on the Japanese market. Caution must prevail when information from this study is compared to similar information from cigarette brands of other markets which have been produced at different times. In order to set realistic and robust confidence intervals for constituents, it is important to take into account variations over time associated with cigarette manufacturing and variation associated with measurement within and between laboratories. Generating enough data through the global cooperation is also important to set confidence intervals.

CONCLUSIONS

This study provided the variation in the yields of constituents in smoke from commercial cigarette brands on the Japanese market under normal cigarette manufacturing. The nineteen commercial cigarette brands were sampled five times every two months from 2009 to 2010. Target constituents were benzo[*a*]pyrene, 1,3-butadiene, benzene, formaldehyde, acetaldehyde, acrolein, NNN, NNK, "tar", nicotine, and carbon monoxide. Results showed that CV values highly varied by brands, constituents, and smoking regimes. The constituents which showed the most variable were NNN and NNK, both in the tobacco filler blend and in the smoke.

NNN and NNK yields in tobacco filler blend affected NNN and NNK yields in smoke. In addition, measurement affected benzo[*a*]pyrene and 1,3-butadiene yields in smoke. However, variation of levels of total reducing sugar in tobacco filler blend was not the main factor for the variation for the yields of formaldehyde in smoke. Variation of the amount of charcoal in the filter was not the main factor for the variation of the yields of 1,3-butadiene, benzene, formaldehyde, acetaldehyde, and acrolein constituents. It was shown that factor for variation were highly varied among constituents.

The standard deviation associated with measurement between laboratories was added to the one associated with cigarette manufacturing over ten months and measurement at the JT laboratory in this study. The grand mean of CV values of the yield of formaldehyde showed the highest increase among the constituents. This is due to the fact that

formaldehyde showed the highest CV values for reproducibility among the constituents. In order to set realistic and robust confidence intervals for constituents, it is important to take into account variations associated with cigarette manufacturing and those associated with measurement within and between laboratories.

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