MAINSTREAM SMOKE EMISSIONS FROM 'ROLL-YOUR-OWN' LOOSE-LEAF TOBACCO SOLD IN NEW ZEALAND

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J Fowles (PhD)

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Science Programme Manager

Dr Bruce Adlam

Project Leader
Dr Jeff Fowles

Peer Reviewers
Dr Rod Lea and Dr Penny Truman

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SUMMARY

A comparative study of mainstream smoke emissions from loose-leaf, "roll your own" (RYO) cigarettes using International Organisation for Standardisation (ISO) machine testing conditions for nicotine, tar, carbon monoxide, volatile organics, and tobacco-specific nitrosamines (TSNAs) was carried out on five top selling RYO tobacco brands in New Zealand. Groups of 50 manually-rolled cigarettes were tested for each brand, each cigarette containing the (ISO) specification of 0.4 g tobacco and a single source of commercially available tobacco wrapping paper. Each brand also included a separate group of 50 cigarettes containing filters obtained at the point of sale, making a total of 10 RYO brand variants for comparison. The Holiday Special Filter manufactured cigarette, since renamed Holiday Red, was included in the testing as a reference cigarette as a) it has been included in similar studies and b) this brand has the largest share of the manufactured cigarette market in New Zealand. Samples were sent to two different international laboratories for testing: Labstat International and the U.S. Center for Disease Control and Prevention. For the volatile and TSNA tests conducted by the US CDC, the Kentucky 2R4F reference cigarette was used.

Results showed that the 0.4 g RYO cigarettes tested, compared with the commercially manufactured cigarette tested, produced relatively high nicotine yields, and also 27.5% higher tar:nicotine (T:N) ratios, on average, when tested under this ISO condition. All RYOs tested had higher T:N ratios than the commercially manufactured brand. The RYO cigarettes had significantly greater puff counts, which explained the greater nicotine yields (1.4-fold), but not the higher tar yields (1.8-fold).

As the specification tested (0.4 g) was the lower of the two recommended ISO testing standard tobacco weights, it can be surmised that test results at the higher tobacco weight per cigarette would produce even higher nicotine and tar yields than the current results suggest. It remains unknown what quantity of tobacco typical New Zealand RYO users employ in their hand-rolled cigarettes.

There was significant variation, with a range of nearly four-fold, among the 10 brand variants in terms of combined carcinogenic risk as a ratio to nicotine yield, and there was also a similar range of differences in acrolein yields when expressed as per mg nicotine yield. The Drum brand displayed much higher TSNA yields, and was speculated by experts at the U.S. CDC to probably consist of a blended form of tobacco, which included high nitrosamine Burley tobacco. The high TSNA content of the Drum cigarette smoke, combined with the relatively low nicotine delivery, resulted in the overall highest cancer risk index (CRI)/ nicotine ratio. This was almost 4-fold higher than the lowest cancer risk index / nicotine ratio from Holiday RYO smoke.

No general statement could be made regarding the relationship of the "mild" label to any reduction in carcinogens. In the case of Drum regular vs Drum Mild, a significantly lower TSNA yield was found in the Mild brand, whereas no difference in TSNA content was observed between Park Drive and Park Drive Mild. Park Drive Mild imparted no real reduction in exposure to TSNAs, volatile organic carcinogens, CO, or acrolein. Except for a slight 3% reduction in TSNA yields, the Park Drive Mild brand had higher yields for toxicants. Since nicotine yields were reduced in both the mild brands, the CRI:nicotine ratio was consequently higher for Park Drive Mild. In contrast, Drum Mild had a significantly lower level of TSNAs than Drum regular, due to the very high starting level in Drum regular.

In this case, the mild version of the tobacco had significantly lower yields of nitrosamines, a slight reduction in volatile carcinogens, and an overall 21% reduced CRI:nicotine ratio compared to Drum regular. Therefore, while mild tobaccos had lower smoke nicotine yields, any comparison to the regular brand depended on the manufacturer and the level of nitrosamines in the regular brand. The very high TSNA concentrations in the Drum regular brand figured prominently in all comparisons and relationships.

The five carcinogens tested do not represent a comprehensive testing of all major carcinogenic components of tobacco smoke, but are intended to serve as a preliminary indication of the magnitude of variation expected in smoke yields and CRIs for the selected RYO tobaccos and how these compare with the manufactured cigarette tested. It is clear from the current study that significant differences exist between RYO brands in terms of exposure to several important carcinogens. This finding provides enough evidence to suggest that regular testing and reporting of yields could usefully identify technologically reducible hazards from different products. Whether such reductions would translate into real, measurable differences in health outcome to smokers, is uncertain and remains highly controversial.

To answer this question, it would be necessary to establish the range of smoking behaviour for RYOs to establish whether or not different brands are smoked similarly, and then to measure a full suite of known or suspected human carcinogens under standardised conditions to determine a cancer hazard index rating.

In conclusion, the New Zealand RYO tobacco cigarettes tested present a significant risk of exposure by smokers to known and suspected human carcinogens and other toxicants. Nicotine and tar yields in smoke from these RYOs were generally higher than the commercial reference cigarette, Holiday Special Filter. The T:N ratios were also higher in the RYOs than the commercial cigarette. The relative magnitude of exposures to five major carcinogens and acrolein are comparable to manufactured cigarettes, with a four-fold range of variability between the brand variants tested for TSNAs. Overall, four brand-variants (Drum regular, Drum mild, Drum w/filter, and Drum mild w/filter) had equal or higher CRI:nicotine concentrations, and six other brand variants had lower CRI:nicotine ratio than the reference commercial cigarette, Holiday Special Filter. The term “mild” had no general relationship to exposure to toxicants in the RYO cigarettes tested. Similarly, the presence of filters in RYOs provided no significant reduction in volatile toxicant yields.

Key conclusions from this study:

- The RYO cigarettes tested in this study were not safer alternatives to manufactured cigarettes
- Some RYO brands may impart significantly greater carcinogen exposures per mg nicotine delivered, and per cigarette, than manufactured cigarettes
- The filters tested in this study, which were sold with RYO tobacco, provide no protection from volatile organic carcinogens in tobacco smoke
- There was no consistent relationship between the mild and regular brand variants tested in terms of their associated hazard or risk.

1. INTRODUCTION

Loose-leaf roll-your-own cigarettes represent a significant and growing segment of the tobacco market. In New Zealand, "Roll-Your-Owns" (RYOs) account for about 30% of the tobacco smoked, and over a third of all smokers reportedly smoke RYOs on a regular basis (New Zealand Ministry of Health 2002). A trend for increasing use of RYOs is also seen in other countries (e.g. Germany, Norway, United States) (USDA 2001; New Zealand Ministry of Health 2005; Norwegian Department of Health 2004). The reasons for the increase in use of RYO tobacco are not well known but are likely to be a combination of economic and societal factors. Kaiserman and Rickert concluded that pricing was a significant factor influencing the shift to cheaper alternatives to conventional cigarettes (Kaiserman and Rickert, 1992).

While an International Organisation for Standardisation (ISO) standard exists for the testing of loose leaf cigarettes, basic data on emissions of these products is severely lacking internationally, and reliable data on smoking topography for these products is not generally available. Kaiserman and Rickert (1992) reported that tar, nicotine, and CO emissions from 31 Canadian RYO brands did not differ significantly from each other except when the paper tube and filter combinations were altered. Norwegian data suggest that RYOs have similar or higher levels of nicotine and tar compared to conventional cigarettes. Nicotine and tar delivery in Norwegian roll-your-own cigarettes was measured in 1994 in 6 brands covering almost the total Norwegian market. The levels were 1.9-3.0 mg nicotine per cigarette and 31.6-35.9 mg tar per cigarette (Norwegian Dept of Health, 2004).

While reports of standard yields of nicotine and tar may not accurately reflect an internal dose for any particular chemical or smoker, the relative ratios of key compounds to one another warrant examination, as such ratios have potential to reveal qualitative differences in health risk between tobacco products. Pankow and associates (2007) reported a refinement of cancer risk assessment methods to provide descriptions of tobacco product risks in relation to nicotine yield.

The purpose of this research was primarily to see if reliable smoke constituent data could be obtained on some top selling NZ RYO tobaccos for the standard chemical measurements (nicotine, CO, and tar) as well as a number of important volatile compounds. Secondarily, the project aimed to find out if obvious differences could be seen between “mild” vs ‘regular’ tobaccos from the same brand, and if filters provided at point of sale imparted any reduction in chemical exposure. This in turn would start to establish some preliminary baseline data for RYO smoke emission yields for nicotine, tar, carbon monoxide and 26 volatile compounds, including 4 volatile tobacco-specific nitrosamines, under ISO conditions, with a view to exploring the role of commercially available filters, and any differences in toxicant emission resulting from mild vs regular tobacco.

2. METHODS

Loose leaf tobacco from five brand variants (Park Drive, Park Drive Mild, Drum, Drum Mild, and Holiday) were selected based on contribution to market share, and covering the two major producers of tobacco sold in New Zealand. The equivalent brand variant ‘mild’ was included for comparison with each regular variant. Also tested was the manufactured cigarette Holiday Special Filter because it is the leading selling brand in New Zealand, it has been tested by the

same laboratory in other ESR reports, and because it was the manufactured counterpart to Holiday loose-leaf tobacco on sale.

Tobacco, 'ultraslim' filters, and rolling papers were purchased from a large commercial supermarket in Wellington in October 2004. The filters were provided at the point of sale by the retailer. The brand was not recorded.

Hand-rolled cigarettes were prepared using a Rizla cigarette rolling machine and water was used to wet the adhesive. Each cigarette was manufactured to contain 0.4 g tobacco, with or without filters. A total of 50 cigarettes per brand variant were sent for testing, and each numerical value for tar, CO, puff count and nicotine is the average of at least 6 replicate measurements (Labstat Laboratory), or 3 replicates for volatiles (US CDC).

Cigarettes were stored at room temperature until shipped to one of two internationally recognised laboratories: Labstat International, Inc. Canada, or to the United States Centers for Disease Control and Prevention in Atlanta for testing using smoking machines set to ISO conditions. Cigarettes were tested for a range of volatile organics and tobacco specific nitrosamines in addition to nicotine (N), tar (T) and carbon monoxide (CO):

Table 1: Chemicals measured in RYO cigarette smoke emissions

Smoke component or parameter tested	
Nicotine *	Acrolein
Tar	Acrylonitrile
Carbon monoxide	Benzene
2,3-Butanedione	Ethylbenzene
2,5-Dimethylfuran	Isobutyrolnitrile
2-Butanone	Isoprene
2-Methylfuran	Propionaldehyde
2-Pentanone	Propionitrile
3-Butene-2-one	p-Xylene
3-Ethyltoluene	Styrene
3-Pentanone	Toluene
Acetaldehyde	N-Nitrosonornicotine (NNN)
Acetone	4-(methylnitrosamino)-1-(3-
Acetonitrile	pyridyl)-1-butanone (NNK)
	N-Nitrosoanatabine (NAT)
	N-Nitrosoanabasine (NAB)

* nicotine was measured by both laboratories independently

Of principal interest in the above list of compounds were NNN, NNK, acrylonitrile, benzene, and acetaldehyde, as these represent five major carcinogens and acrolein as a critical respiratory toxicant (Pankow et al., 2007).

Mean values were compared statistically using independent samples T tests (2-tailed). A P value of <0.05 was considered statistically significant.

3. RESULTS

3.1. Tar, CO and Nicotine

Table 2 shows the results of the smoking machine testing for Tar, CO and Nicotine. Under ISO conditions tar and nicotine yields were higher in RYO cigarettes than has been reported in manufactured cigarettes (Fowles, 2002). Nicotine levels were 1.41 mg and 1.22 mg/ RYO cigarette on average for the same cigarettes as reported by Labstat and CDC, respectively. It is likely that the puff count was consistently less at CDC than at Labstat, thus accounting for the slight difference between the laboratories. Tar was found to be 22.8 mg/ RYO cigarette on average, and CO was 18.3 mg/ RYO cigarette as reported by Labstat. Puff count was on average 11.2 puffs/ RYO cigarette. The T:N ratios for all brands tested were higher than the reference commercially manufactured cigarette ($P<0.05$), with T:N ratios ranging from 13.4 to 19.5 (see Figure 1); the average across five brand variants being 16.5, approximately 35% greater than what would be expected in conventional manufactured cigarettes (Fowles, 2002). Figure 1 comprises six replicates and standard deviation. Results of the statistical comparisons for tar, nicotine and the T:N ratio are shown in Table 3.

Table 2: Results of smoking machine testing of loose-leaf tobacco under ISO conditions using 0.4 g tobacco/cigarette (data from Labstat International, Inc.)

Brand	Puff Count /cig)		CO (mg/cig)		Nicotine (mg/cig)		Tar (mg/cig)	
	Average	SD	Average	SD	Average	SD	Average	SD
Unfiltered								
Drum regular	10.7	0.5	18.0	1.6	1.35	0.09	22.3	1.2
Drum Mild	11.9	0.6	16.7	1.8	0.952♦	0.084	18.2	1.2
Park Drive regular	12.9	0.9	16.9	1.8	1.58	0.16	23.1	2.3
Park Drive Mild	11.1	0.5	17.0	1.0	1.23	0.15	24.1	1.6
Holiday	11.2	0.6	15.9	0.7	1.68	0.10	23.7	1.4
Filtered								
Drum filter	9.9	0.6	20.5	1.5	1.47	0.11	23.7	1.7
Drum Mild filter	10.4	0.9	20.4	2.0	1.11♦	0.11	20.4	2.3
Park Drive regular filter	12.2	0.5	19.9	0.8	1.67	0.13	23.9	2.3
Park Drive Mild filter	10.5	0.7	19.4	1.0	1.25	0.09	23.2	1.8
Holiday filter	11.0	0.3	18.6	1.0	1.85	0.05	24.9	0.9
Average across all brands	11.2		18.3		1.4		22.8	
Reference*	**7.6**	**0.3**	**11.3**	**0.8**	**1.03**	**0.04**	**12.3**	**0.7**

* Holiday special filter - top selling manufactured cigarette in New Zealand. ♦ All values other then these are statistically significantly different from the reference value ($p<0.05$).

The presence or absence of filters that are sold with this type of tobacco made very little difference in the yields of tar, nicotine, or carbon monoxide across five brand variants (Table 3). Filters reduced the T:N ratio of five RYO brands from an average of 16.8 to 16.2 (a 3.7% decrease) although the decrease was statistically significant only in the Holiday brand ($p < 0.05$). The puff count was clearly greater with the RYO cigarettes compared to manufactured cigarettes since they do not burn continuously when not puffed. Taking this into account, the chemical intake per puff can be calculated, as well as the intake per cigarette and the relative intake of tar per gram of nicotine.

Both the Drum and Park Drive "Mild" RYO tobacco gave statistically significantly higher T:N ratios than their corresponding "Regular" varieties ($p < 0.01$).

Figure 1: Tar:Nicotine Ratios for 10 RYO Tobacco Brand Variants in Relation to Commercially Available Reference Cigarette (data from Labstat International, Inc., Appendix A).

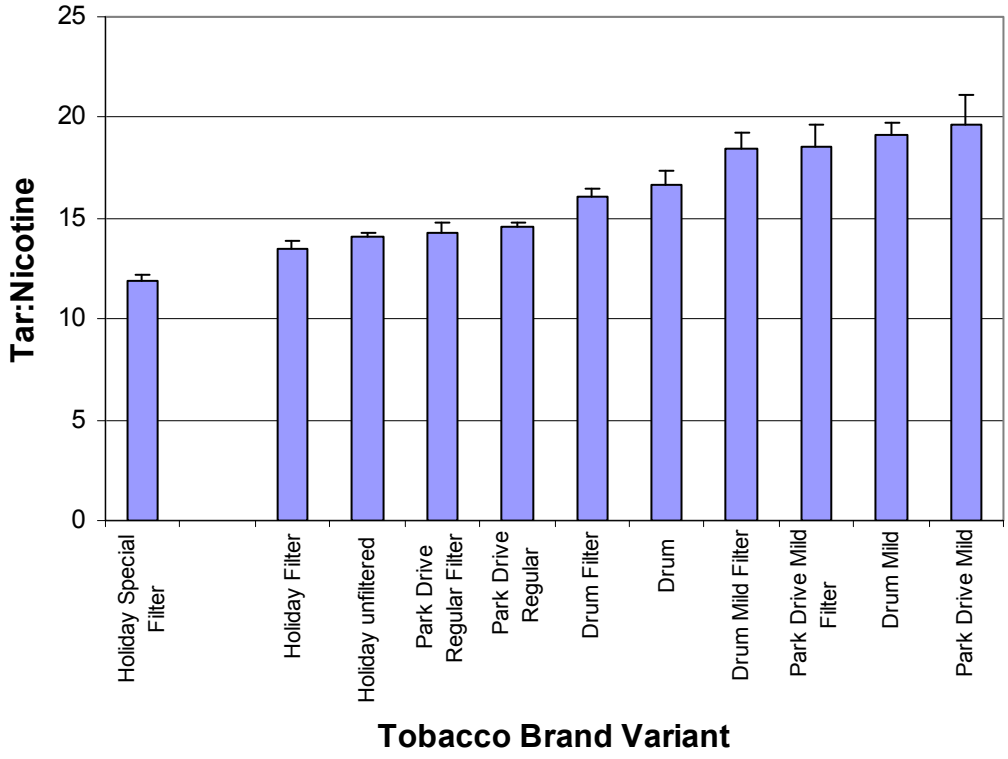


Table 3. Statistical comparisons between brand variants

Comparison	Variable		
Filtered vs Unfiltered	**Tar**	**Nicotine**	**T:N**
Drum Mild vs Drum Mild Filter	Unfiltered < filtered 11%, $p < 0.05$	Unfiltered < filtered 14%, $p < 0.05$	Filtered < Unfiltered 3%, not significant
Drum vs Drum Filter	Unfiltered < filtered 6%, not significant	Unfiltered < filtered 8%, $p < 0.05$	Filtered < Unfiltered 3%, not significant
Park Drive Mild vs Park Drive Mild Filter	Filtered < unfiltered 6%, not significant	Unfiltered < filtered 1%, not significant	Filtered < unfiltered 5%, not significant
Park Drive vs Park Drive Filter	Unfiltered < filtered 3%, not significant	Unfiltered < filtered 5%, not significant	Filtered < Unfiltered 2%, not significant
Holiday vs Holiday Filter	Unfiltered < filtered 5%, $p < 0.05$	Unfiltered < filtered 9%, $p < 0.05$	Filtered < Unfiltered 5%, $p < 0.01$
Mild vs Regular			
Drum Mild vs Drum	Drum mild < Drum 23%, $p < 0.01$	Drum mild < Drum 41%, $p < 0.01$	Drum < Drum mild 13% $p < 0.01$
Park Drive Mild vs Park Drive	Park Drive < Park Drive mild 4%, not significant	Park Drive mild < Park Drive 28%, $p < 0.01$	Park Drive < Park Drive mild, 25% $p < 0.01$

Table 4 shows the nicotine results for the two testing laboratories. Both laboratories measured nicotine in the same brand samples, and there was a strong correlation ($r = 0.82$, $p = 0.0018$) between the findings. However, the CDC nicotine values per cigarette tended to be lower by about 10-20%. A difference in puff count with the CDC and Labstat smoking machines could account for this difference.

Table 4: Nicotine yields on loose tobacco brands from Labstat and CDC analyses

Brand type	Nicotine (mg/cig)	
	Labstat	US CDC
Holiday filter	1.85	1.44
Holiday	1.68	1.53
Park Drive regular filter	1.67	1.55
Park Drive regular	1.58	1.40
Drum filter	1.47	1.04
Drum	1.35	1.11
Park Drive Mild filter	1.25	1.21
Park Drive Mild	1.23	1.09
Drum Mild filter	1.11	0.83
Drum Mild	0.952	1.02
Holiday Special Filter*	1.03	1.10

* top selling manufactured cigarette in New Zealand

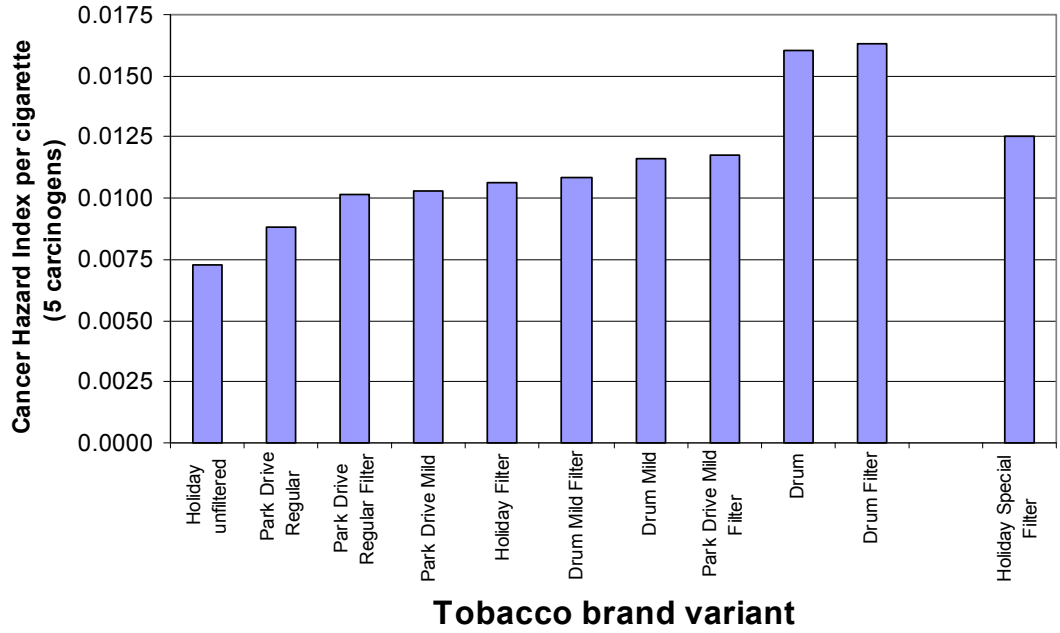
3.2. Carcinogens

The cancer risk of the five carcinogens expressed on a per cigarette basis is shown in Figure 2 below. The cancer potency values used for determining the cancer risk index of the brands are those in the public domain used by Pankow et al. 2007 (see Table 5): The results show that in relation to commercially manufactured cigarettes, the RYO cigarettes are comparable or very slightly lower than the reference cigarette (Holiday Special Filter). The exception to this was the Drum brand, which had a higher CRI per cigarette basis due to higher TSNA content. Filters had little or no impact on the CRI per cigarette basis or on a per mg nicotine yield overall. The two best performing brand variants, Holiday and Park Drive Regular, which had the lowest CRI estimates when unfiltered. The CRI values are indicative and as composite values are not amenable to statistical analysis. However, the means and standard deviations of each carcinogen can be found in Appendix B.

Table 5: Carcinogens and cancer potency factors used in this study

Carcinogen	Cancer Potency Factor $(mg/kg/day)^{-1}$
N-Nitrosonornicotine	1.4
NNK	49
Acetaldehyde	0.0077
Acrylonitrile	0.24
Benzene	0.027

Figure 2: Five Carcinogens in RYO Tobacco Expressed as a Cancer Risk (Hazard) Index, and Shown in Relationship to Commercial Reference Cigarette. (data from US CDC, Appendix B)

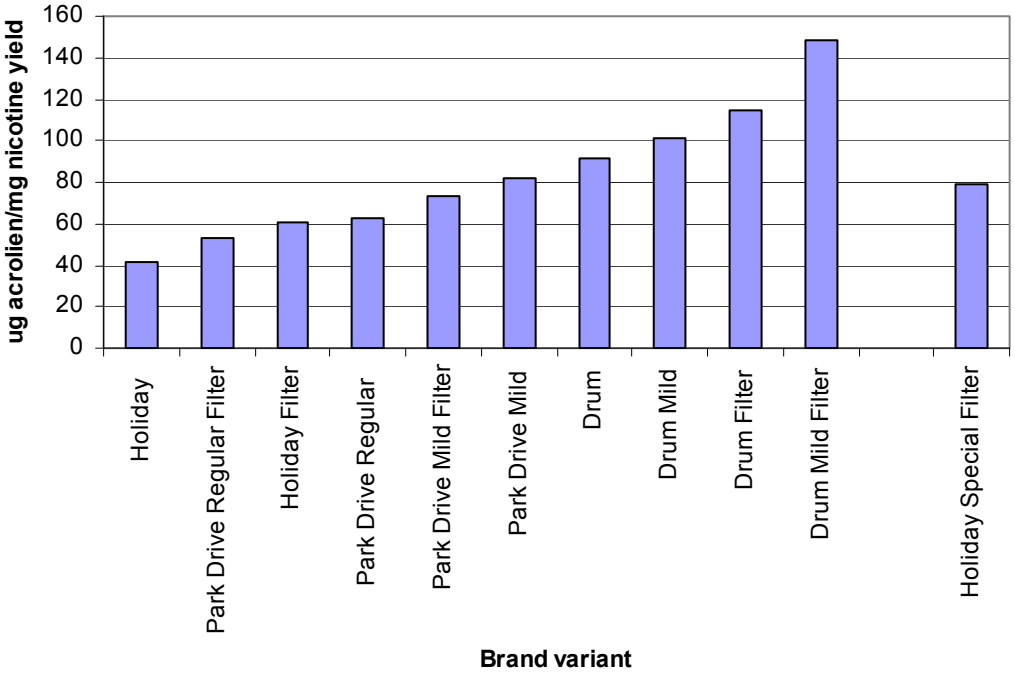


3.3. Filters

The presence of filters imparted little or no benefit in terms of reducing carcinogen exposures. Filters did reduce the T:N ratios by 3.7% on average, but the tar particulate material removed by the filters had little or no impact on removal of volatile and TSNA compounds that have known carcinogenic properties. Filters actually slightly increased the CRI:nicotine ratio for every brand variant tested, and had no impact on nicotine delivery. The U.S. CDC explanation was that under machine smoking conditions, the butt length is specified regardless of the presence of a filter in the cigarette. Therefore, for a given weight of tobacco per cigarette, more tobacco will be burned when a filter is used. To gauge the relevance of this observation under ISO machine smoking conditions to smokers' exposures, RYO smoking parameters from actual smokers would need to be collected.

Filters had either no impact, or worsened the situation with respect to acrolein yields on a per milligram of nicotine yield basis (Figure 3).

Figure 3: Acrolein as a ratio to mg nicotine yield in 10 RYO brand variants (data from US CDC, Appendix B)



4. DISCUSSION

This study has found that RYO tobacco brands smoked in New Zealand yield higher levels of nicotine, tar, T:N ratio and CO compared to a popular manufactured cigarette. One brand (Drum regular) was also shown to contain very high levels of TSNA possibly due to variation in tobacco blend. Across all brands, considerable variation was found in the yields of five important tobacco smoke carcinogens, expressed as carcinogen risk/cigarette. A nearly four-fold difference was seen between the highest and lowest brand variants in this regard.

Studies have been conducted showing clear differences in the physical nature of the wrapping paper in RYO's compared with conventional cigarettes in terms of ability to continue burning when not puffed (Laugesen et al., 2003). This results in a greater number of puffs per cigarette with RYO, as reflected in the ISO machine puff counts in this report. This implies that for a given quantity of tobacco, more nicotine can be inhaled by the smoker.

The tobacco itself may also be qualitatively different. Yet whether these differences translate into a qualitatively or quantitatively different toxicant profile in the smokestream, or in different biological activity in toxicity tests remains an untested hypothesis. Adoption of standardised, realistic testing methods, biomarkers, and regulatory schemes for all tobacco products would assist in addressing these sources of variability in toxicant delivery and estimations of health risk, and would help to ensure that appropriate messages are available to inform smokers about these products.

There is now a regularly reported group of known or probable human carcinogens in tobacco smoke which forms a useful cancer risk assessment tool when assessing emissions of different tobacco products. Using a subset of this group, representing volatile organics and TSNAs in this research reveals that:

1) Filters[1] sold with loose RYO tobacco have no significant impact on reducing exposure to volatile carcinogens. While filters reduced by a small percentage the nitrosamine yield, they increase by a significant margin the volatile organics per cigarette. This may relate to the requirement of a perfect 'connection' between filter and tobacco in the cigarette, and further studies should be done to determine if this is the case, and whether consumers understand this potential subtlety;

2) RYO cigarettes deliver an appreciable amount of nicotine considering the small quantity of tobacco used, more so per gram of tobacco present than conventional manufactured cigarettes under ISO smoking conditions;

3) Carcinogen yield per cigarette was similar to conventional cigarettes, with Drum being the only brand with a higher yield of the five carcinogens tested. The type of tobacco in Drum was reported by expert analysts as visibly different from the other RYO tobaccos that were tested in this study (a high percentage of Burley tobacco was present). It is possible that other brands not tested in this preliminary study may also have mixed tobaccos of this nature.

The current lists of known human carcinogens, using published potencies and combined with potential exposures to a smoker, do not approach the observed cancer incidence from smoking. This results in some researchers concluding that the vast majority of carcinogens have yet to be identified in tobacco smoke. However, another explanation is that the majority of carcinogens have been identified, but that the complexity of the tobacco smoke mixture, including numerous membrane irritants, inducers of inflammation and local cell division, results in a rich tumour initiator and promoter cocktail, effectively enhancing the carcinogenic potency so that the whole exceeds the sum of its parts. It is implausible that no tumour promotion activity occurs with high concentrations of inhaled smoke. Particulate matter alone can induce inflammation and lead to cell proliferation locally. Therefore, the characterised carcinogens may indeed represent a significant proportion of the carcinogens in tobacco smoke, and their reduction would be expected to impart a less hazardous outcome to chronic exposure.

This study indicates that the RYO cigarettes tested yielded a third more tar than the most popular manufactured cigarette (Holiday). Considering the fact that tobacco excise rate per gram is currently the same for both cigarette types and that RYO cigarettes containing much less tobacco, their lower price could encourage increasing numbers of smokers towards RYO smoking and consequently higher tar yields.

Key conclusions from this study:

- The RYO cigarettes tested in this study were not safer alternatives to manufactured cigarettes
- Some RYO brands may impart significantly greater carcinogen exposures per mg nicotine delivered, and per cigarette, than manufactured cigarettes
- The filters tested in this study, which were sold with RYO tobacco, provide no protection from volatile organic carcinogens in tobacco smoke
- There was no consistent relationship between the mild and regular brand variants tested in terms of their associated hazard or risk.

[1] General statements about filters assume that the filters used in this study are representative of all brands

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APPENDIX A

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APPENDIX B

Polzin GM, Zhang L, Tavakoli AD, Ashley D, and Watson C. 2006. New Zealand Roll-Your-Own (RYO) Cigarette Mainstream Smoke Analyses. A report by the U.S. Centers for Disease Control and Prevention for the New Zealand Ministry of Health.