

Comparative study of the smoke emissions from fine-cut tobacco blends depending on the characteristics of the used RYO/MYO cigarette materials

Silvia Peeva¹, Violeta Nikolova^{1*}, and Nikolay Nikolov¹

¹ Tobacco and Tobacco Products Institute, Agricultural Academy, Markovo village, Rodopi municipality, Bulgaria

Abstract. The European tobacco market has experienced significant changes in the last years – with the introduction of new tobacco products and the increased consumption of certain traditional products. Recent research of fine-cut tobacco blends (for RYO and MYO cigarettes) in Bulgaria is very limited, which substantiates the current comparative investigation of the smoke emissions of RYO tobaccos, accounting for the used materials (cigarette paper and filter tips). Three variants of laboratory-made cigarettes from five tobacco blends (A - E) were analyzed: variant I – with ready-to-use cigarette tubes; variant II – with gummed cigarette paper and filter tips with diameter 8 mm and length 15 mm; variant III – with the same cigarette paper and filter tips with diameter 6 mm and length 20 mm. The highest levels of smoke emissions were found for variant I and the minimal - for variant III, with no uniform trend between the blends. The smoke emissions from the analyzed RYO tobaccos exceeded the legal limits for commercial cigarettes, except for nicotine from blends B and D, and CO from blend D in variant III. In all variants, a strong correlation between the studied smoke emissions was observed - positive for nicotine/tar and tar/CO, and negative for nicotine/CO.

1 Introduction

There are over 112 million current smokers in the European Union, according to a survey conducted in 12 member states in the period 2017-2018 [1]. The prevalence of smoking varies from 18.9% in Italy to 37.0% in Bulgaria, being the highest among the population aged 25-44. The survey confirms that teenagers and younger people are the most vulnerable groups, as almost all current smokers in Europe start smoking before the age of 25. According to the authors of the survey, the main factor behind the smoking habit is the lower socio-economic status.

In recent years, the European tobacco market has experienced significant changes - new tobacco products have been introduced and the consumption of certain traditional products such as water pipe (hookah) mixes and roll-your-own (RYO) tobacco blends has increased [2-9]. The situation with RYO tobaccos is particularly interesting, as their growing popularity is not the result of technological innovation, nor is a part of the policies for reducing the harmful effects of smoking [2]. Studies by a number of researches show that the increased consumption of RYO products is mostly due to the lower price and to the conviction that they are a safer alternative to conventional cigarettes [3, 10-14]. These products are considered to be more popular among younger people, as well as among smokers with lower education and income levels [1 - 3, 15, 16]. According to [17] consumers assume that hand-rolled cigarettes are “more natural” than the commercial ones, respectively – less harmful due to the lower content of additives in their composition. Another reason for the increased consumption is found in the possibility to control the

amount of tobacco in each item by rolling slimmer cigarettes [13, 18].

RYO blends represent fine-cut tobacco that is purchased by consumers along with gummed cigarette paper and filter plugs for manual rolling of cigarettes [18]. A survey conducted in 18 European countries, including Bulgaria, confirmed that the weight of RYO cigarettes is significantly lower than that of manufactured cigarettes, with an average value of 0.75 g [9]. According to literature data, the weight of RYO cigarettes varies from 0.40 g to 0.80 g per item [14, 19]. As smokers can change the weight of their cigarettes, they can counteract price elevation by adjusting their consumption to changes in income [20].

On the other hand, it is known that cigarette manufacturers are able to regulate the content of nicotine, tar and carbon monoxide (CO) in tobacco smoke to the legally accepted maximal levels for these emissions (1 mg/cig, 10 mg/cig and 10 mg/cig, respectively), through the variation of blend components and the used filter and paper materials. The content of smoke emissions in RYO cigarettes, however, can vary up to 60% depending on the combination of filter and paper materials [21]. Comparative studies by independent research teams have documented similar or elevated levels of these emissions in the smoke of RYO tobaccos [22, 23]. A research team [24] has analyzed up to 70% of fine-cut tobacco market in Spain and have found that smoke nicotine content in 6 commercial brands varied in the range from 1.0 mg/cig to 1.7 mg/cig, tar – from 13.7 mg/cig to 18.5 mg/cig, and CO – from 13.5 mg/cig to 18.4 mg/cig. The same study concludes that the content of the regarded smoke emissions is much higher than the threshold levels for conventional cigarettes, in some cases up to 85% or more. A similar trend has been found in a study on 4 brands of RYO

* Corresponding author: nikolova.v@abv.bg

tobacco legally distributed on the Bulgarian market [25]. It has been stated that the variation ranges of the smoke emissions are far beyond the normative limits for manufactured cigarettes, nicotine – from 1.23 mg/cig to 1.35 mg/cig, tar – from 19.12 mg/cig to 20.54 mg/cig, and CO – from 12.06 mg/cig to 15.22 mg/cig. The study concludes that the increased consumption has led to an increase in the variety of paper and filter materials used, which further complicates the control of this type of smoking articles. It also states that research on the harmful substances in smoke, the used materials and their ability to modify tobacco smoke, as well as cigarette design are the basis for protecting human health.

A previous study [26] has investigated components in the main stream of 11 brands of RYO tobacco from Spain, in comparison with the 3R4F reference cigarette. They state that RYO tobaccos generally provide lower concentrations of components in the gas phase of tobacco smoke. The CO content varied from 15.4 mg/cig to 20.4 mg/cig, with no significant difference between the compared RYO tobaccos and the 3R4F reference cigarette. In most of the cases RYO tobaccos had higher nicotine content in the smoke compared to 3R4F. In conclusion, they state that RYO tobaccos are not less harmful than the reference material.

Despite the increased consumption of fine-cut (RYO) tobacco blends, recent research on this type of smoking product in Bulgaria is very limited, which justifies the need for conducting this study. *Objective:* Comparative study on the smoke emissions of RYO tobacco blends depending on the characteristics of the used cigarette (filter and paper) materials.

2 Materials and methods

For the purpose of the study, 5 brands of RYO tobacco blends, 7 brands of cigarette paper, 1 brand of cigarette tubes (for make-your-own, MYO, cigarettes), and 2 brands of filter plugs (with a diameter of 8 mm and 6

mm) were purchased from the commercial network. The RYO tobaccos in the study were designated as samples A, B, C, D and E, the cigarette paper brands - with numbers from 1 to 7, and the cigarette tubes - with number 8.

It was necessary to determine in advance the air permeability (CU) of the cigarette papers and the tubes, respectively, in order to select the cigarette paper sample with air permeability close to that of the cigarette tubes. The air permeability of the cigarette materials, $\text{cm}^3/\text{cm}^2 \text{ min dm H}_2\text{O}$ (CU), was determined according to BDS 17337:1993 [27]. On the basis of the obtained results, as shown in Table 1, cigarette paper No 6 was chosen for further experiments.

Three variants of laboratory cigarettes from each of the tobacco blends (A - E) were made and further analyzed:

- Variant I - hand-filled, using cigarette tubes with mean values of the physical parameters, as follows: length - 83.88 mm, cigarette paper permeability 53.33 CU, diameter 8.15 mm, plug wrap length - 24.60 mm, filter plug length - 20 mm;

- Variant II - hand-rolled, using cigarette paper No 6 (length - 70 mm, permeability - 50.40 CU) and filter tips with diameter 8 mm and length 15 mm;

- Variant III - hand-rolled, using cigarette paper No 6 (length - 70 mm, permeability - 50.40 CU) and filter tips with diameter 6 mm and length 20 mm.

The RYO tobaccos were analyzed in terms of the following indicators:

a) Physical parameters:

- Puff number - by automated smoking using a linear analytical smoking machine Filtrona 302, according to ISO 3308:2000 [28];

- b) Indices of smoke composition - by automated smoking using a linear automated smoking machine Filtrona 302:

- Nicotine (mg/cig) - according to ISO 10315:2000 [29];

Table 1. Air permeability of cigarette papers (No 1÷7) and cigarette tubes (No 8)

No	Air permeability, $\text{cm}^3/\text{cm}^2 \text{ min dm H}_2\text{O}$ (CU)															Mean
	12	13	13	11	11	11	19	19	18	15	14	12	16	19	13	
1.	70	89	87	65	65	65	59	72	89	84	82	88	80	66	63	74.93
3.	28	31	30	29	29	29	27	25	33	33	42	34	30	27	32	30.60
4.	18	23	21	28	21	18	20	21	21	26	31	35	31	24	28	24.40
5.	13	13	13	11	10	13	13	14	15	13	10	10	7	9	10	11.60
6.	49	50	51	51	46	43	46	50	56	49	55	60	50	50	50	50.40
7.	13	12	11	27	19	12	18	19	20	37	32	27	14	15	15	19.40
8.	49	50	51	54	53	52	51	51	51	57	55	52	56	58	60	53.33

- Crude condensate, water, tar (mg/cig) - according to ISO 4387:2000, ISO 10362-2:1994 and ISO 3308:2000 [30, 31, 28];

- Carbon monoxide (mg/cig) - according to ISO 8454:2007 [32].

All measurements were carried out on two parallel samples and the mean values were presented.

3 Results and discussion

3.1 Smoke composition of the three variants of laboratory cigarettes

Data about nicotine, tar and CO emissions in the smoke of the studied RYO tobacco blends in Variant I cigarettes (with cigarette tubes) are presented on Fig. 1.

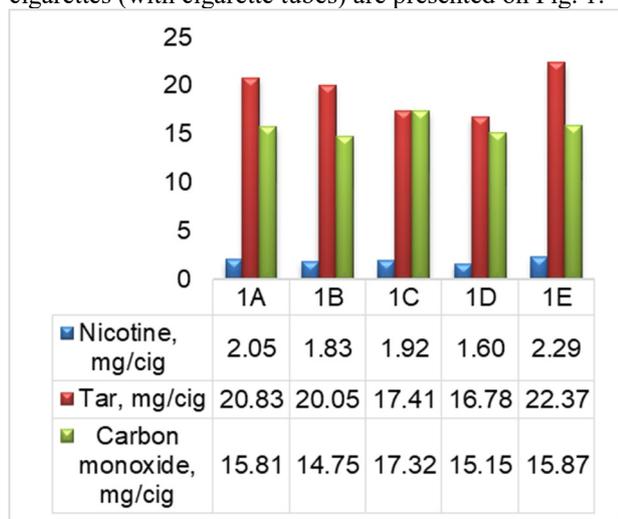


Fig. 1. Nicotine, tar and carbon monoxide (CO) in the smoke of RYO tobacco blends in Variant I cigarettes.

As seen from Fig. 1, the highest levels of nicotine and tar emissions in the smoke of the studied RYO tobacco blends were found in sample E - 2.29 mg/cig and 22.37 mg/cig, respectively, while the lowest levels were in sample D - 1.60 mg/cig and 16.78 mg/cig. The remaining samples showed intermediate values of those indicators. The CO content varied in the range from 14.75 mg/cig in sample B to 17.32 mg/cig in sample C. The other three blend samples A, D and E, had CO levels closer to the lower range value, without significant difference between them.

Fig. 2 presents the results about the smoke emissions of the studied RYO tobaccos in Variant II - manually rolled cigarettes using filter with a diameter of 8 mm.

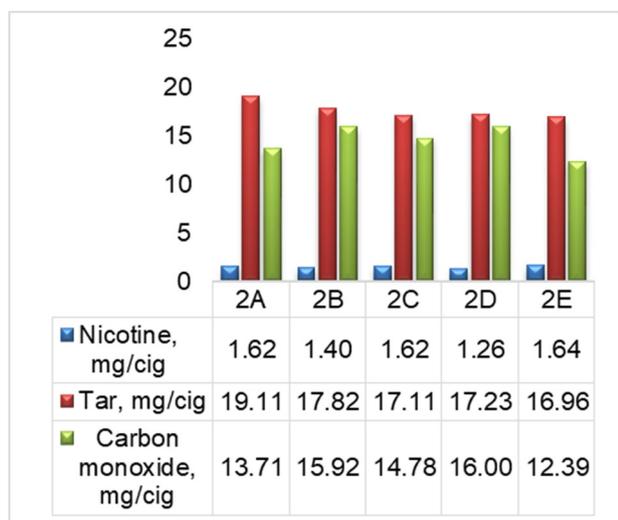


Fig. 2. Nicotine, tar and carbon monoxide (CO) in the smoke of RYO tobacco blends in Variant II cigarettes

Data on Fig. 2 revealed that nicotine content in the smoke of the studied RYO tobaccos varied from 1.26 mg/cig in sample D to 1.64 mg/cig in sample E. Samples

A and C had equal nicotine content (1.62 mg/cig), very close and insignificantly different from the registered maximal value. In turn, sample B was closer to the low in terms of the regarded indicator. Tar content varied in a relatively narrow range - from 16.96 mg/cig (sample E) to 19.11 mg/cig (sample A). No significant variations were observed in the tar content between the remaining three samples, B, C and D. The lowest CO level was found in sample E (12.39 mg/cig), and the highest - with no significant deviation between the values - in sample D (16.00 mg/cig) and sample B (15.92 mg/cig). The rest of the blends provided intermediate CO emissions. The obtained results were close to those reported in [24].

The results from the analysis of smoke emissions of RYO tobaccos in Variant III (rolled cigarettes using filter with a diameter of 6 mm) are presented on Fig. 3.

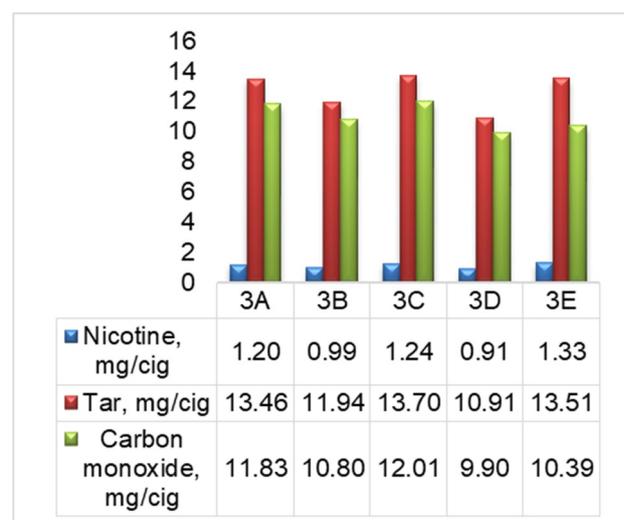


Fig. 3. Nicotine, tar and carbon monoxide (CO) in the smoke of RYO tobacco blends in Variant III cigarettes

Nicotine content in the smoke of the studied RYO tobacco, as seen from Fig. 3, varied in a very narrow range - from 0.91 mg/cig (sample D) to 1.33 mg/cig (sample E). Sample B had smoke nicotine content very close to that of sample D, while in the other two samples the registered values were closer to the high, in the absence of a significant difference between them. The variations in the tar content were also in a relatively limited range - from 10.91 mg/cig (sample D) to 13.70 mg/cig (sample C). Samples A and E were with nearly identical tar levels, insignificantly deviating from the maximal, while sample B was closer to the minimal value. Similar tendency was found for the CO emissions, and in particular - a variation in a relatively narrow range, from 9.90 mg/cig in sample D to 12.01 mg/cig in sample C. Sample A was with CO content very close to that in sample C, while the remaining two samples had intermediate, insignificantly varying CO contents. Based on the results obtained in Variant III, it was stated that sample D had the lowest level of smoke emissions, while sample C had the highest tar and CO contents, and close to the highest nicotine content.

The summarized assessment of the results about the determined smoke emissions of the studied RYO

tobacco blends revealed the same trend in terms of smoke nicotine content in all three variants of laboratory-made cigarettes - minimal in sample D and maximal in sample E. Regarding the tar and CO contents, no similar differentiation between the RYO blends could be completed. The maximal contents of smoke emissions of the studied RYO tobacco blends were found in Variant I cigarettes, followed by those in Variant II, and the minimal - in Variant III. Partial exceptions of that trend were observed in blends C and D, with regard to the tar content in Variants I and II, and in blends B and D - with regard to the CO content in the same variants.

The results showed that all experimentally determined values for the studied emissions in the smoke of RYO tobacco blends exceeded the legal limits for manufactured cigarettes, with the exception of the nicotine content in blends B and D, and the CO content in blend D (in Variant III cigarettes).

3.2 Physical parameters and indices of smoke composition

Table 2 presents the results from the determination of the puff number, the crude condensate and water contents in the smoke of the studied RYO tobacco blends, for the three variants of laboratory-made cigarettes.

In Variant I, the results showed the highest number of puffs per cigarette and close values in samples E and A (7.80 and 7.60), and respectively - the smallest values in samples B and D (6.80 and 6.90). Crude condensate and water contents were maximal in sample E (26.58 mg/cig and 1.92 mg/cig, respectively) and minimal - in sample D (19.73 mg/cig and 1.35 mg/cig). The rest of the samples showed intermediate values of those indicators, with no significant difference between the water content in samples A and B (1.60 mg/cig and 1.65 mg/cig).

In Variant II, the number of puffs was the highest in sample E (7.30) and lowest - in sample B (5.70), while the other tobacco samples set intermediate and very close values. The highest crude condensate and water levels were registered in sample A (22.78 mg/cig and 2.05 mg/cig, respectively), and the lowest - in sample D (19.64 mg/cig and 1.15 mg/cig). No significant differences with regard to those indicators were observed between the rest of RYO blends.

In Variant III, the number of puffs varied from 4.20 in sample B (minimal) to 5.60 in sample E (maximal). Crude condensate and water levels were the highest in sample A (16.78 mg/cig and 2.12 mg/cig), and the lowest - in sample D (12.94 mg/cig and 1.12 mg/cig). The rest of the blends were with intermediate indicator values, with samples C and E being practically undistinguishable.

The comparative analysis of the data revealed that in all three variants of laboratory cigarettes the number of puffs was highest in sample E and lowest - in sample B. The amount of crude condensate and water was lowest in sample D in all variants, but the highest values showed variation - in sample A in variants II and III, and in sample E in variant I. Within each of the tobacco samples, the number of puffs was maximal in Variant I, followed by Variant II, and minimal - in Variant III. The same trend was observed for crude condensate contents, with the partial exception of samples C and D in Variants I and II, which were practically identical. With regard to the water content in smoke condensates there was no clear differentiation between the three variants.

We further investigated the existence of correlation between the nicotine, tar and CO levels in the smoke of the three variants of laboratory cigarettes made with the studied RYO blends.

Linear and non-linear (quadratic) relationship between the studied smoke emissions was determined in all variants of laboratory cigarettes. Both functions

Table 2. Smoke indicators of the studied RYO tobacco blends in different variants of laboratory cigarettes.

Sample	A	B	C	D	E
Variant I					
Number of puffs	7.60	6.80	7.20	6.90	7.80
TPM*, mg/cig	24.48	23.53	20.90	19.73	26.58
Water content, mg/cig	1.60	1.65	1.57	1.35	1.92
Variant II					
Number of puffs	6.20	5.70	6.40	6.16	7.30
TPM*, mg/cig	22.78	20.52	20.19	19.64	20.00
Water content, mg/cig	2.05	1.30	1.46	1.15	1.40
Variant III					
Number of puffs	4.91	4.20	5.00	5.20	5.60
TPM ¹ , mg/cig	16.78	14.43	16.64	12.94	16.54
Water content, mg/cig	2.12	1.50	1.70	1.12	1.70

¹ TPM - total particulate matter (crude condensate), mg/cig

provided nearly identical results and the graphical presentation of the relationship varied negligibly. Due to the uniformity of the graphs for the linear dependence between nicotine, tar and CO contents in the smoke from the three cigarette variants, one figure for each of them was presented, respectively – nicotine/tar for variant I

(Fig. 4), nicotine/CO for variant II (Fig. 5), and tar/CO for variant III (Fig. 6).

The derived regression equations and linear dependency graphs between nicotine, tar and CO, presented on Fig. 4, Fig. 5 and Fig. 6, where R^2 is equal to the square of the correlation coefficient (r), show what

part of the dispersion of one variable can be considered related to the dispersion of the other variable. The correlation coefficients in the linear function were as follows: $r_1 = 0.854$ (nicotine/tar), $r_2 = -0.826$ (nicotine/CO), and $r_3 = 0.730$ (tar/CO).

The respective regression equations and the graphs of the quadratic correlations between nicotine/tar (Variant I), nicotine/CO (Variant II) and tar/CO (Variant III) are presented on Fig. 7, Fig. 8 and Fig. 9.

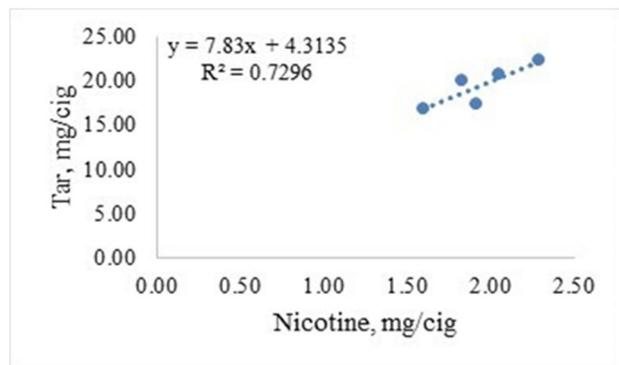


Fig. 4. Linear relationship between nicotine and tar in the smoke of laboratory-made cigarettes with RYO tobacco blends in Variant I.

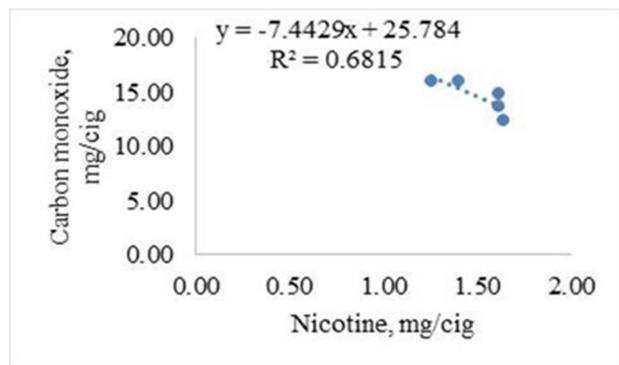


Fig. 5. Linear relationship between nicotine and CO in the smoke of laboratory-made cigarettes with RYO tobacco blends in Variant II.

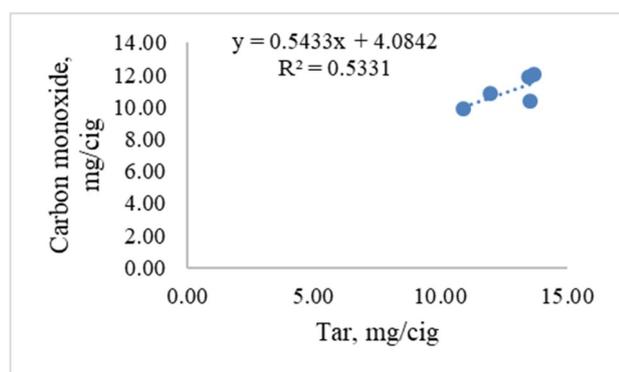


Fig. 6. Linear relationship between tar and CO in the smoke of laboratory-made cigarettes with RYO tobacco blends in Variant III.

The correlation coefficients in the non-linear (quadratic) function were as follows: $r_1 = 0.856$

(nicotine/tar), $r_2 = -0.883$ (nicotine/CO), and $r_3 = 0.733$ (tar/CO).

The coefficients in both cases (in linear and non-linear dependence) were sufficiently high, which showed a clear correlation between nicotine, tar and CO smoke emissions.

From the dependences presented above it is evident that:

- The correlation between nicotine and tar is positive, i.e. with the increase of nicotine, tar also increases;
- Nicotine is in a negative correlation with CO;
- The correlation between tar and CO is positive.

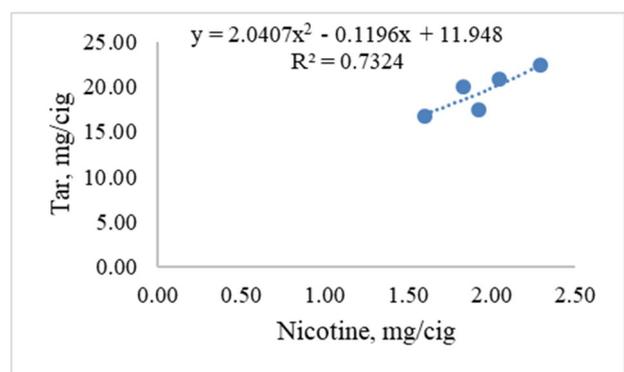


Fig. 7. Non-linear relationship between nicotine and tar in the smoke of laboratory-made cigarettes with RYO tobacco blends in Variant I.

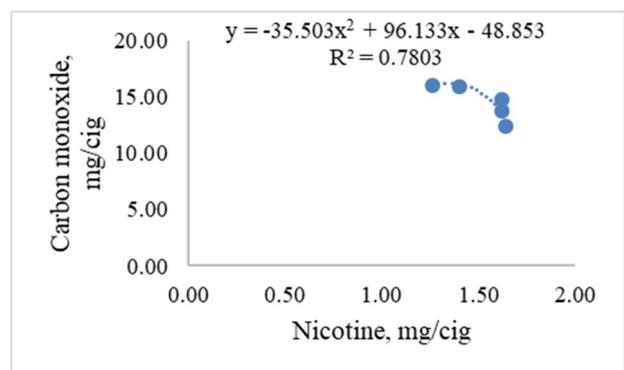


Fig. 8. Non-linear relationship between nicotine and CO in the smoke of laboratory-made cigarettes with RYO tobacco blends in Variant II.

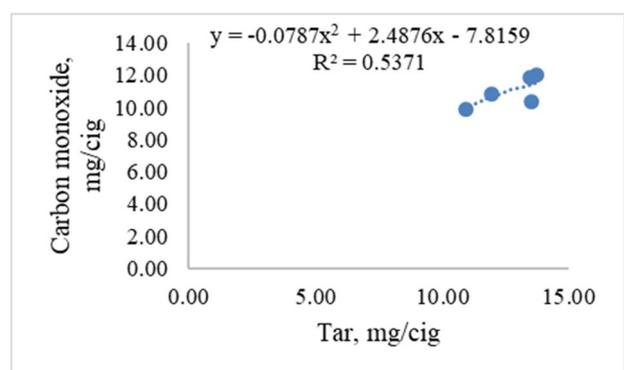


Fig. 9. Non-linear relationship between tar and CO in the smoke of laboratory-made cigarettes with RYO tobacco blends in Variant III.

4 Conclusions

The comparative investigation on the smoke emissions of RYO tobacco blends, depending on the characteristics of the used cigarette materials allows drawing the following conclusions:

- The experimentally determined values for the studied emissions in the smoke of RYO blends exceeded the legal limits for manufactured cigarettes, with the exception of the nicotine content in blends B and D, and the CO content in blend D (in Variant III cigarettes).

- A positive correlation between nicotine/tar, tar/CO and a negative correlation between nicotine/CO existed in all three variants of laboratory cigarettes. There was a strong, clearly expressed correlation between the respective emissions in the smoke of the studied RYO tobacco blends.

- It has been found that the same RYO tobacco blend produces different levels of nicotine, tar and CO in smoke depending of the used materials (cigarette paper and filter tips), which logically determines different levels of consumer exposure.

- The obtained results give grounds to recommend that such information will be provided to consumers, as it is directly related to the health effects and the degree of risk in consumption.

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