Comparative study of the design and chemical composition of heated tobacco products

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Abstract. Heated tobacco products (HTPs) are marketed as alternatives to conventional cigarettes and as products with potentially reduced harm. Despite the growing consumption of HTPs worldwide, their chemical composition and physical properties remain insufficiently explored. This study aims to examine the design and the physical and chemical characteristics of HTPs sold on the Bulgarian market. The physical dimensions and weight of the sticks and their structural components were determined, as well as the main chemical indicators of the incorporated tobacco material and the aerosol produced, respectively - ash, total reducing sugars, nicotine, cellulose; total and dry particulate matter, etc. The results indicate high cellulose levels in the tobacco material (13.10–18.39%) and relatively higher total particulate matter (26.63–39.86 mg/stick) compared to conventional cigarettes. The obtained results expand the knowledge about the structure and composition of HTPs and contribute to a deeper understanding of their physical and chemical characteristics.

1 Introduction

Heated tobacco products (HTPs) are appearing on the market as an alternative to conventional cigarettes. They are promoted as products with "potentially reduced harm", "modified risk", "smokeless products".

HTPs first appeared on the market in the 1980s, but failed to gain traction. In the 21st century, leading tobacco companies have again attempted to introduce this type of product, and this time they have been successful, with the market share of heated products expected to grow by 12.2% by 2027 [1]. To date, the heated product market is mainly operated by three companies: Philip Morris International (PMI), British American Tobacco (BAT), and Japan Tobacco International (JTI) [2]. Modern HTPs were first introduced in 2014 in Japan, Italy, and Switzerland.

The consumption of HTPs is growing significantly worldwide. Japan is the largest consumer of heated tobacco products, accounting for 85% of the smoking product market. According to a 2020 EC study, seven of the top 10 countries in terms of consumption of heated tobacco products are in Europe (Turkey, Slovakia, Portugal, Poland, Germany, Sweden, Italy). According to the study, around 6% of respondents have tried such products (up from around 2% in 2017). Heated products have been introduced in some countries in South America, but their market penetration and consumer acceptance can vary [3]. At the same time, there has been a decline in the consumption of these products in Australia [4] and a ban on their use in countries such as India, Saudi Arabia, Singapore and the USA.

In Bulgaria, heated tobacco products are gaining more and more popularity among smokers and are in second place in consumption after cigarettes. According to the EC report, in Bulgaria 12% of the survey participants have tried heated products (the second highest value in the EU after the Czech Republic with 14.6%), and 1.7% use them every day (with an average value for the EU of 0.7%) [3].

The main reasons cited for the use of heated products in the EU include: belief that they are less harmful than smoking tobacco products, use by friends, desire to quit/reduce smoking, attractiveness of the aroma, possibility of using them in places where smoking is prohibited, etc. [3].

Each of the HTPs uses a different heating method, characterized by differences in the heating device, different heating conditions – temperature rise rate, maximum temperature and duration of heating, and last but not least differences in the technologies for obtaining the tobacco material, which is specially processed to be susceptible to low to moderate heating temperatures [5]. The tobacco part is a reconstituted tobacco leaf (RTL) obtained by mixing tobacco powder with water, glycerin, guar gum and cellulose fibers [6]. Depending on the product, the RTL may be pleated [6] or cutted [7]. In the production of heated tobacco products, various flavor compositions are used – menthol, lime, bubblegum, ginger, cherry, grape, etc. [8].

The temperature at which tobacco is heated is about 300 °C. When the tobacco part is heated, no smoke is released, but only a vapor (aerosol) saturated with nicotine, which is inhaled by the smoker. When heating tobacco, there is a reduction in the levels of toxic substances in the aerosol, compared to those obtained when burning cigarettes. In addition, it has been shown that heating tobacco at temperatures lower than those when burning cigarettes leads to lower levels of mutagenicity of the aerosol [5]. Between the puffs, the

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tobacco in the THPs does not heat up and no sidestream smoke is released into the environment [6].

Despite the increased interest of scientists in this type of products, studies on the chemical composition of the tobacco part and their aerosol are still very scarce. The amount of nicotine in the tobacco material in two types of IQOS sticks has been found to be comparable to that in conventional cigarettes [9, 10]. Liu et al. [11] reported nicotine content in the material ranging from 1.9 to 4.6 mg/stick in three different heated tobacco products. The nicotine content in the total particulate matter (TPM) has also been studied and found to vary depending on the product, from 510 μg/stick (for the BAT product) to 1200 μg/stick (for the PMI product) [12]. The amount of condensate is twice as high as in cigarette smoke. This is due to the higher water and humectant content. However, it has been found that the substances in the aerosol from heated tobacco products are lower than those in the smoke from conventional cigarettes. The content of nitrosamines in the aerosol is reduced by up to 90% compared to that in cigarettes [13]. The content of carbonyl compounds is lower than in cigarette smoke. The highest amounts are formaldehyde, acetaldehyde and acrolein, which are products obtained by heating propylene glycol and glycerol [14]. Studies by manufacturers show low levels of polycyclic aromatic hydrocarbons. Their content in the aerosol represents less than 4% of all substances [15]. Some studies have reported 97 to 99% lower levels of volatile hydrocarbons compared to cigarette smoke [16]. On the other hand, the high content of moisture, propylene glycol, glycerol and acetone is striking. Moisture accounts for 75–85% of the total amount, while the moisture in cigarette condensate is 17–27% [12]. Humectants have the greatest influence on the amount of TPM. The glycerol content in the TPM of HTPs is higher than that in cigarette smoke [17], as is the amount of propylene glycol – 240–850 μg/stick and 11–28 μg/cigarette [12]. HTPs also generate higher amounts of acetone (140–260 μg/stick) compared to traditional cigarettes (50–110 μg/cigarette) [12].

Information about the design and chemical performance of heating products in Bulgaria is very scarce. Therefore, the aim of the study was to determine the main physical and chemical characteristics of HTPs sold on the Bulgarian market

2 Materials and methods

The analyses were conducted on five samples of HTPs sold on Bulgarian market, in particular: disposable tobacco sticks HEETS “Teak selection”, HEETS “Dimensions Ammil”, Fiit “Marine” (PMI), Dunhil “Scarlet click” and Dunhil “Blue tobacco” (BAT).

The analyzed samples were characterized in terms of the following indices:

Physical parameters. The length and diameter of the entire stick, the length of the tobacco part and the individual filter segments were determined using an electronic caliper, mm, as well as the mass of the entire stick, the tobacco part and the filter segments, g.

Chemical composition of the tobacco part of the tested samples. For the chemical analyses, the samples were ground to a particle size smaller than 0.25 mm. The amounts of all analyzed substances were calculated relative to the absolutely dry mass, for which the moisture content of the samples was determined by drying at a temperature of 103 ± 2 °C for 1 hour. The main chemical indicators influencing the quality of the tobacco were determined: ash - by burning at 550 °C, %; total alkaloids (as nicotine) – by a spectrophotometric method for the determination of total alkaloids as nicotine, %; total reducing sugars – by Schoorl method, %, proteins - by Lowry method, %; cellulose - by burning with acetic and nitric acid, %; hexane extracts – by double extraction with n-hexane lasting 1 hour and 30 minutes at a temperature of 40°C, % [18].

Amounts of total particulate matter (TPM) and dry particulate matter (DPM) in the aerosol. The amount of TPM was determined by puffing with an analytical laboratory puffing machine, using the intensive Canadian method. The TPM from three sticks was collected on a Cambridge filter. The puffing parameters were: 55 ml puff volume, 2 s puffing and 30 s pause between puffs. [19]. Moisture in the TPM was determined by drying for 72 hours over silica gel [18].

3 Results and discussion

3.1 Design of HTPs

Tobacco sticks are sold in consumer packs containing 20 tobacco sticks, with an excise stamp. The arrangement of HEETS sticks is in three rows, configuration 7-6-7, and Dunhill sticks are in two rows of 10. Information about the harm of smoking is available on all packages. The products are classified as new tobacco products, which are prohibited for sale to minors. Tobacco sticks resemble a cigarette in design and are made of a tobacco part (made of RTL), a filtering part (made of mono acetate filter, hollow cardboard filter/polymer filter and hollow acetate filter), all placed in a cylinder made of paper.

In HEET sticks, the tobacco part is a folded sheet of RTL, and in Dunhill sticks, the RTL is cut with width of 0.5 to 0.6 mm.

In the Dunhill "Scarlet click" sample, the hollow acetate filter is on the mouth end of the stick, and a capsule is placed in the mono acetate filter. The capsule contains a flavor and can be broken when pressure is applied. After breaking, a flavor is released, which is inhaled by the consumer when smoking.

HTPs change during use. The tobacco part is charred due to heating. The cigarette paper wrapping the tobacco becomes soaked, most likely from the additives in it. The filter elements change color due to retention of material released during smoking. The tobacco part that is in direct contact with the heated plate is charred.

3.2 Physical characteristics of HTPs

The results from the measurements of the physical indices of the studied HTPs were presented in Table 1.

As can be seen from the results, the tested sticks have identical physical indices for the respective product (HEETS and Dunhill). The total mass of tobacco in the consumer packages is very close to the specified limits. For Dunhil about 6-6.2 g with available information on the box 6.1 g and for HEETS 4.8-5.2 g with information announced on the boxes by the manufacturer 5.1 g, for 20 pieces in a pack. When comparing the determined physical indices of the two groups of tobacco sticks (HEETS, Dunhill), it is seen that the design elements were selected by the manufacturers in accordance with the preferences of consumers for the two main forms of conventional cigarettes – Dunhill in length, diameter and mass are an analogue, evoking similar tactile and visual perceptions of slim cigarettes, while HEETS in mass and diameter are an analogue of king size cigarettes, but with a significantly shorter length. Regardless of the differences in the length of the tobacco part, both groups of tobacco sticks contain a similar amount of tobacco in one product.

Table 1. Physical indices of five brands of HTPs

Index	Brands				
	Dunhill Scarlet click	**Dunhill Blue tobacco**	**HEETS Ammil**	**HEETS Teak Selection**	**Fiit Marine**
Stick length, mm	75.65	75.59	45.14	45.16	45.21
Tobacco part lenght, mm	34.12	34.43	11.91	12.02	12.05
hollow cardboard filter*/polymer filter length, mm**	25.49*	25.29*	18.15**	18.14**	18.06**
Hollow acetate filter length, mm	6.03	5.78	8.04	8.00	8.00
Mono acetate filter length, mm	10.01	10.09	7.04	7.00	7.10
Stick diameter, mm	6.58	6.58	7.16	7.18	7.20
Stick mass, g	0.61	0.60	0.73	0.73	0.74
Tobacco part mass, g	0.30	0.31	0.24	0.26	0.26
Filters mass, g	0.20	0.18	0.40	0.40	0.42

3.3 Chemical composition of HTPs

The results of chemical composition of the studied HTPs are presented in Table 2.

The highest ash content is in HEETS Teak selection – 15.67%, followed by HEETS Ammil - 14.57%. Of the samples studied, the lowest ash content is the Dunhil Scarlet click sample – 11.07%. There is no data in the literature on the amount of ash in HTPs

The nicotine content in the tested samples varies within narrow limits from 1.58 to 1.75%. The highest nicotine content is the Scarlet click sample with 1.75%, followed by the Teak Selection sample with 1.74%, and the lowest nicotine content is the Blue tobacco sample with 1.58%. The obtained values are comparable to the nicotine content in conventional cigarettes and are confirmed by the data in the literature [11].

The content of total reducing sugars in all tobacco samples is relatively high, over 17%. The Dunhill sticks - Scarlet click and Blue tobacco, have a lower content of total reducing sugars, 18.29% and 17.57% respectively. The HEETS sticks have a higher content of sugars, with the Fiit Marine sample having the highest content of 23.29%, followed by the Teak Selection sample with 22.07% and Ammil - 20.83%. The higher values of total reducing sugars are most likely due to the technology for obtaining the tobacco material and the use of additives to the tobacco powder.

Based on the analysis of the content of ash, nicotine and total reducing sugars, it can be assumed that for obtaining the RTL was used Virginia flue-cured tobacco as the main raw material, which is characterized by a low ash content and a high content of total reducing sugars.

Table 2. Chemical composition of five brands of HTPs

Index	Brands				
	Dunhill Scarlet click	**Dunhill Blue tobacco**	**HEETS Ammil**	**HEETS Teak Selection**	**Fiit Marine**
Ash, %	11.07	12.41	14.57	15.67	13.64
Nicotine, %	1.75	1.58	1.69	1.74	1.71
Total reducing sugars, %	18.29	17.57	20.83	22.07	23.29
Proteins, %	17.42	16.76	21.33	21.87	26.29
Hexane extract, %	6.36	1.84	3.32	3.17	3.49
Cellulose, %	17.70	18.39	17.00	14.04	13.10

After analyzing the results, it was found that the protein content was higher in the representatives of the HEETS samples. The highest protein content was Fiit Marine with 26.29%, followed by Teak selection with 21.87%, and Ammil with 21.33% protein content. From Dunhil, the highest content was Scarlet click with 17.42%, followed by Blue tobacco with 16.76%. There is no data in the literature on the protein content of HTPs. However, the results obtained are much higher than the values for protein in different types of tobacco – from 4 to 16%.

Significant differences in the amount of extract are observed between the Dunhill and HEETS samples. The highest amount of hexane extract is in the Scarlet click sample – 6.36%, which is most likely explained by the larger amount of aromatic components used in the production of the tobacco material. On the other hand, the extract content in the Blue tobacco sample is logically the lowest, since the manufacturer declares the absence of non-tobacco aromas. In the HEETS sticks, the results are statistically indistinguishable from 3.17-3.49%.

The cellulose content is relatively high in all the samples tested. The amount in the Dunhil samples is higher. The highest content is the Blue tobacco sample - 18.39%, followed by the Scarlet click sample - 17.70%. From HEETS, the Ammil sample with a significantly higher cellulose content is 17.80%. The high cellulose content in the tested samples is explained by the use of cellulose fibers in the production of the RTL, which makes up the tobacco part of the sticks.

3.3 Amounts of total particulate matter and dry particulate matter.

The amounts of TPM and DPM are presented in Table 3.

The comparative characteristics between the amounts of TPM and the DPM show significant differences between the two indices. The amount of TPM is many times more than the DPM, which is due to the high moisture content and the use of humectants in the production of RTL. The results obtained are also confirmed by the data in the literature, where it is indicated that moisture constitutes about 75-85% of the total mass of the condensate [12].

Table 3. Amounts of TPM and DPM

Brands	Index	
	TPM, mg/stick	**DPM, mg/stick**
Dunhill Scarlet click	6.83	1.2
Dunhill Scarlet click with a burst capsule	6.16	0.43
Dunhill Blue tobacco	8.40	0.37
HEETS Ammil	29.93	6.2
HEETS Teak selection	39.86	7.97
Fiit Marine	26.63	8.16

The TPM content in the HEETS samples, over 26%, is higher than the TPM content in cigarette smoke. The highest TPM content is in the Teak Selection sticks - 39.86 mg/stick, and the highest DPM content is in the Fiit Marine 8.16 mg/stick. The lowest TPM content is in the Dunhill Scarlet click with a burst capsule - 6.16 mg/stick, and the lowest DPM content is in the Dunhill Blue tobacco - 0.37mg/stick. This is most likely due to the differences in the design of the sticks and the method of obtaining the tobacco material. During the smoking, a comparative analysis was also made of the amount of condensate in the aerosol for the Scarlet click sample with and without capsule bursting during the study. The data shows that the aromatic composition released when the capsule bursts does not significantly affect the amount of condensate.

4 CONCLUSION

The study provides a comprehensive overview of the design, physical parameters and chemical composition of heated tobacco products (HTPs) sold on the Bulgarian market. The results show that despite

differences in design, all analyzed sticks contain similar amounts of tobacco. They are characterized by high levels of cellulose and total reducing sugars, as a result of the technology for obtaining the reconstituted tobacco leaf. The determined amounts of nicotine are comparable to those in traditional cigarettes.

Aerosol analysis reveals significantly higher values of TPM in HEETS products compared to Dunhill and conventional cigarettes. The differences between TPM and DPM confirm that the main part of TPM is moisture.

The obtained data contribute to a better understanding of the physicochemical characteristics of HTPs and emphasize that despite the lack of combustion, these products have a complex chemical profile that deserves more in-depth scientific investigation in order to assess their health risk.

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