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EXPERTISE OF PYRAMID TEA BAGS BY OPTICAL MICROSCOPY AND FTIR-SPECTROSCOPY METHODS. MICROPLASTICS FORMATION IN BREWED TEA

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Abstract. Eight brands of pyramid tea bags on the Ukrainian market were studied: Sun Gardens (1), Lovare (2), Curtis for Mc Donalds (3), Curtis (4), Lipton (5), Premiya (6), Sonnet (7) and Loyd (8). Using FTIR spectroscopy, it was found that the pyramids of the bags are made of thermoplastic polymers polyethylene terephthalate (samples 1-7) and polylactic acid (sample 8). The threads attached to the pyramids are made of thermoplastic polymers polypropylene (samples 1,2,4-7), polyethylene terephthalate (sample 4) and polylactic acid (sample 8). The specific optical rotation of polylactic acid $[\alpha]_D^{25}$ is about -150° (c=1, $CHCl_3$), which refers to poly(L-lactic acid). Using optical microscopy, it was established that the structure of the pyramids are divided into those made of plain woven fabrics (samples 1-3) and heat-bonded nonwoven fabrics (samples 4-8). The tea bags (samples 1-3) exhibit a well patterned net structure (mesh) with the pores perceived to be uniform and regular. The tea bags made of nonwoven materials have an irregular network consisting of compact and random arrangement of fibers. The fibers are pleated randomly, generating irregular pores. Nonwoven fabrics are made from fibers with a diameter of 12-18 μm, woven fabrics are made from fibers with a diameter of 48-54 μm. The area density of nonwoven fabrics is 18.5-20.3 g/m^2, the area density of woven fabrics is 22.0-22.7 g/m^2. The threads are made by twisting several single-twisted yarns. The structure of threads are a cabled yarn from three 2-ply yarns (samples 1,8), 4-ply yarn (samples 2-4,6,7) and 4-ply multyfilament yarn (samples 5). The final twist of the plied yarn/cord is S-twist. The primary structural element of threads in the case of samples 1-4, 6-8 are staple fibers, of sample 5 are multyfilament fibers. Each empty pyramids and thread was steeped at 95°C for 5 min in 10 mL of water. It has been established that the shape of microplastic particles formed in beverages during tea brewing is determined by the primary structure of tea bags. Both pyramids and threads release irregularly shaped microplastic particles.

Key words: microplastics, plastic tea bag, optical microscopy, FTIR-spectroscopy.

Introduction. Formulation of the problem

The negative impact of plastic pollution on the environment (air, land and water) is now beyond doubt. Plastic pollution is a global problem. According to recent estimates, plastic waste that pollutes the aquatic environment (oceans, seas, lakes, and rivers) amounts to 10 to 20 million tons per year, while the global production of synthetic plastic is about 300 million tons per year [1]. Part of the plastic pollution is in the form of microplastics (particle size from 0.1 to 5000 μm) and nanoplastics (plastic particle size from 0.001 to 0.1 μm) [2]. In recent years, nano- and microplastics have been detected in food products (fish, seafood, honey, sea salt, water, etc.) [1-4].

When consuming plastic-contaminated food products, micro- and nanoplastics enter the human body and the annual consumption of microplastics ranged from 39000 to 52000 particles per person [5]. The presence of micro- and nanoplastics in human tissues has recently been established, which is a risk factor for health [6-10].

Recent studies by scanning electron microscopy (SEM) and Nanoparticle Tracking Analysis (NTA) have shown that steeping a single nylon or polyethylene terephthalate (PET) plastic tea bag at brewing temperature (95°C) for 5 min released about

11.6 billion microplastics and 3.1 billion nanoplastics into a single cup of the beverage [11]. That is, in this case, the source of micro- and nanoplastic is not the environment, but the packaging of the food product, which contaminates the tea during its preparation. Given this abnormally large amount of nano- and microplastics, it is relevant to study the plastic tea bags.

Using μ-Raman spectroscopy between 5800 and 20400 microplastic particles >1 μm were found in released by one tea bag of nylon plaine fabric with attached string/thread of polypropylene (PP) [12]. The formation of micro- and nanoplastic was observed in the case of nylon tea bags [13-15], nonwoven PET/polyethylene (PE), nonwoven PP with PET/PE string/thread, woven nylon with PP string/thread tea bags [16]. The release of plastic from tea bags made of PET/PE, polylactic acid (PLA) and PET has been shown [17,18]. Therefore, it is of interest to study the tea bags on the Ukrainian market.

The **purpose** of the work is to study pyramid tea bags intended for brewing tea using FT-IR spectroscopy and optical microscopy in order to identify polymeric materials and the structure of tea bags as a source of microplastics.

Objectives of the research:

1) to identify the type of polymer of the tea bags by FTIRspectroscopy;

2) to examine the parameters, structure and morphology of the tea bags samples using optical microscopy.

Research materials and methods

Eight brands of tea packaged in pyramid-shaped bags from the Odessa retail network were selected for examination (Tablt 1): Sample 1 – Sun Gardens, Sample 2 – Lovare, Sample 3 – Curtis for Mc Donalds, Sample 4 – Curtis, Sample 5 – Lipton, Sample 6 - Premiya, Sample 7 - Sonnet, Sample 8 - Loyd.

Packaging material with tea in the form of bags, which consists of such structural elements as a tetrahedron / triangular pyramid (hereinafter pyramid), thread and tag (label), is presented in Figure 1.

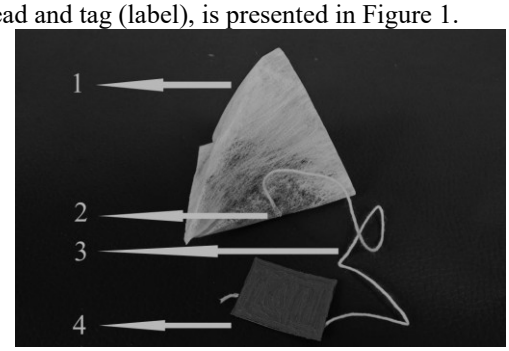


Fig.1. Packing material with tea in the form of a tea bag: 1 – pyramid bag with tea, 2 – place of termal bonding of the pyramid with thread, 3 – thread/string, 4 – tag (label)

FTIR spectra of samles were recorded using a Spectrum One spectrometer (Perkin-Elmer). The spectral resolution is 4 cm^{-1}, the number of scans is 16.

The specific rotation in the case of the Loyd tea bag (sample 8) was determined at a polymer concentration of 0.01 g/cm^3 using a P1000 polarimeter (A.KRÜSS Optronic) with a sodium lamp (wavelength D line 589.3 nm) at a cuvette length of 10 cm and a temperature of 25°C. The polymer for these mesurements was purified by precipitation with methanol from a chloroform solution.

The linear dimensions of the structural elements of the bags were measured according to DSTU EN 1773:2009 (EN 1773:1996, IDT). The area density of textile materials in units of mass per unit area (g/m^2) was determined using an electronic balance as the average value for measurements of five bags according to DSTU ISO 7211-6:2007 (ISO 7211-6:1984, IDT), DSTU ISO 9073-1:2008 (ISO 9073-1:1989, IDT), DSTU EN 12127:2009 (EN 12127:1997, IDT).

Table 1 – Description of the tea bags used in this study

No.	Brand	EAN-13 barcode	Batch number	Production date	Best before date	Recomented method of tea brewing
1	Sun Gardens	4 820082 707446	917585609	08/19	08/21	put into a cup and pour water (95°C), brew for 3-5 min
2	Lovare	4 820198 874612	3	-	12/10/21	put into a cup with boiled water, brew for 3-5 min
3	Curtis for Mc Donalds	-	10/2019	10/2019	10/2021	put into a cup with water (≥75°C), brew for 5 min
4	Curtis	4 823063 703093	07/2019-2	07/2019	07/2021	put into a cup and pour water (95°C), brew for 5 min
5	Lipton	4 823084 201073	192412D	10/06/19	10/06/21	put into a cup and pour water (75-85°C), brew for 3 min
6	Premiya	4 823096 410654	2	19/04/19	19/04/21	put into a cup and pour boiled water, brew for 5-7 min
7	Sonnet	4 820082 706036	907590638	09/19	09/21	put into a cup and pour boiled water, brew for 3-5 min
8	Loyd	5 900396 023056	L24051935 A	24/05/19	05/21	put into a cup and pour water (100°C), brew for 5 min

The morphology and structure of tea bags were determined by optical microscopy using microscopes. The fiber diameter was determined using the optical microscopy method as the cross-sectional distance of fiber.

The final twist of the plied yarns and the original twist of the single yarn before plying were determined by the procedure given in ISO 2061:2015.

The formation of microplastics was investigated for structural elements of tea bags that come into contact with water during tea brewing. Each pyramid and each thread was steeped at 95°C for 5 min in 10 mL of distilled water. Tea were removed before proceeding. Tags (labels) were not examined due to the fact that they do not come into contact with water during tea brewing.

Results of the research and their discussion

The FTIR spectra were used to identify the tea bag material. Figure 2 shows the FTIR spectra of the pyramids, and Figure 3 shows the FTIR spectra of the threads. The absorption bands in the FTIR spectra were compared with the known spectra of polymers. The FTIR spectra of the pyramids (samples 1-7) as well as the threads (sample 3) show the corresponding infrared absorption bands of PET.

It is known that the FTIR spectrum of PET has the main absorbance bands at 3431 cm^{-1} (C=O overtone, 2 x ν(C=O)), 3102, 3081 and 3054 cm^{-1} (sp^2 C-H aromatic stretch vibrations), 2960 cm^{-1} (CH_2 asymmetric stretching band, $\nu_{as}(CH_2)$), 2892 cm^{-1} (symmetric stretching band, $\nu_s(CH_2)$), 1733 cm^{-1} (C=O stretching vibrations, ν(C=O)), 1615 cm^{-1} (aromatic ring vibration, $\nu_{8B}(B_1)$), 1578 та 1505 cm^{-1} (C=C aromatic stretching vibrations, $\nu_{8A}(A_1)$ and $\nu_{19A}(B_{2u})$ respectively), 1457 cm^{-1} (CH_2 bending vibrations, $\delta(CH_2)$), 1370 and 1340 cm^{-1} (the bands correspond to the wagging vibrations of the glycol units in gauche and trans conformations respectively, $\gamma_w(CH_2)$), 1263 and 1120 cm^{-1} (C - O stretching vibrations, ν(C-O)), 973 cm^{-1} (the B_u type C-O stretching vibration of the trans form of ethylene glycol, $\nu_{12}(B_{2u})$), 846 cm^{-1} (CH_2 rocking vibrations of the ethylene groups, $\gamma_r(CH_2)$), 727 cm^{-1} (aromatic ring wagging vibrations, $\nu_{11}(B_{1u})$) [19-23].

The FTIR spectra of threads (samples 1-7) show the corresponding infrared absorption bands of PP. The FTIR spectrum of PP exhibits large peaks in the wavenumber range 3000–2800 cm^{-1}: the peaks at 2955 and 2873 cm^{-1} can be attributed to CH_3 asymmetric and symmetric stretching vibrations, $\nu_{as}(CH_3)$ та $\nu_s(CH_3)$, respectively, while the peaks at 2922 and 2843 cm^{-1} are due to CH_2 asymmetric and symmetric stretching vibrations $\nu_{as}(CH_2)$ та $\nu_s(CH_2)$, respectively. The FTIR spectrum also shows two intense peaks at 1460 and 1378 cm^{-1}: the peak at 1460 cm^{-1} is caused by CH_3 asymmetric deformation vibrations, $\delta_{as}(CH_3)$, while the peak at 1378 cm^{-1} refers to CH_3 symmetric deformation vibrations, $\delta_s(CH_3)$. The FTIR spectrum of PP also exhibits numerous less intense absorption bands in the wavenumber range 1370–700 cm^{-1}: in the region 1370-1200 cm^{-1} there are wagging and twisting vibrations of CH_2 groups) and deformation vibrations of CH_2 and CH groups, which strongly interact with each other; absorption bands in the region of 1200-700 cm^{-1} are caused by the interaction of rocking vibrations of CH_3 and CH_2 groups with stretching vibrations of the carbon skeleton, ν(CC)) [19,24,25].

In the case of sample 8, the FTIR spectra of the pyramid as well as the thread show the corresponding polylactide (PLA) infrared absorption bands.

According to the literature data, the following main absorption bands are observed in the IR spectrum of PLA with maxima at 2997 cm^{-1} (CH_2 asymmetric stretching vibration, $\nu_{as}(CH_2)$), 2947 cm^{-1} (CH_3 symmetric stretching vibration, $\nu_s(CH_3)$), 2882 cm^{-1} (CH stretching vibration, ν(CH)), 1760 cm^{-1} (C=O stretching vibration, ν(C=O)), 1452 cm^{-1} (CH_3 asymmetric bending vibration, $\delta_{as}(CH_3)$), 1388 cm^{-1} (CH symmetric bending vibration, $\delta_2(CH)$), 1368-1360 cm^{-1} (CH and CH_3 bending vibrations, δ(CH) and $\delta_s(CH_3)$ respectivelly), 1315-1300 cm^{-1} (CH bending vibration, $\delta_2(CH)$), 1270 cm^{-1} (CH bending vibration, δ(CH) and C-O-C stretching vibration, ν(C-O-C)), 1215 та 1185 cm^{-1} (C-O-C asymmetric stretching vibration, ν_{as}(C-O-C)), 1130 cm^{-1} (CH_3 rocking, $\gamma_r(CH_3)$), 1090 cm^{-1} (C-O-C symmetric stretching vibration ν_s(C-O-C)), 1045 cm^{-1} (C-CH_3 stretching vibration, νC-CH_3)), 960 cm^{-1} (CH_3 rocking, $\gamma_r(CH_3)$ and C-C stretching vibrations, ν(C-C)), 875-860 cm^{-1} (C–COO stretching vibration, νC–COO)), 760–740 cm^{-1} (C=O in-plane bending vibration, δ(C=O)) [26-29].

Thus, it was established that the pyramids are made of PET (samples 1-7) and PLA (sample 8). Threads are made of PET (sample 4), PLA (sample 8) and PP (samples 1,2,4-7).

PLA is a thermoplastic aliphatic polyester derived from lactic acid, which is optically active and has two optical isomers, namely L- and D-lactic acid. In this regard, there are optically active isomers of PLA: the L-isomer of PLA, if the polymer is obtained from L-lactic acids, and the D-isomer of PLA, if the polymer is obtained from D-lactic acids [30,31].

The measured value of the specific optical rotation $[\alpha]_D^{25}$ for the polymer of sample 8 is near -150° (c=1, $CHCl_3$), which is in accordance with the literature data for poly(L-lactic acid) [32-36].

The structure and composition of plastic tea packages were determined by optical microscopy. The material of the pyramids of samples is shown in the following photomicrographs (see Figure 4). The materials are used to separate tea from a moving fluid passing through the media. From the given microphotographs, it can be seen that the samples are divided into two groups by structure: pyramids made of plain weave fabrics (samples 1-3) and made of nonwoven fabrics with random fiber structures in sheet form (samples 4-8). Plain weave is a weave in which

each weft thread passes alternately over and under the warp thread, and each warp thread alternately passes over and under the weft thread [37]. Nonwoven fabrics are fabrics that are produced by mechanical, thermal or chemical processes, but without being woven and without the need to convert fibers into yarn, since the fiber webs are bonded together as a result of the inherent friction (entanglement) from one fiber to another thanks to these non-conventional processes [37-40].

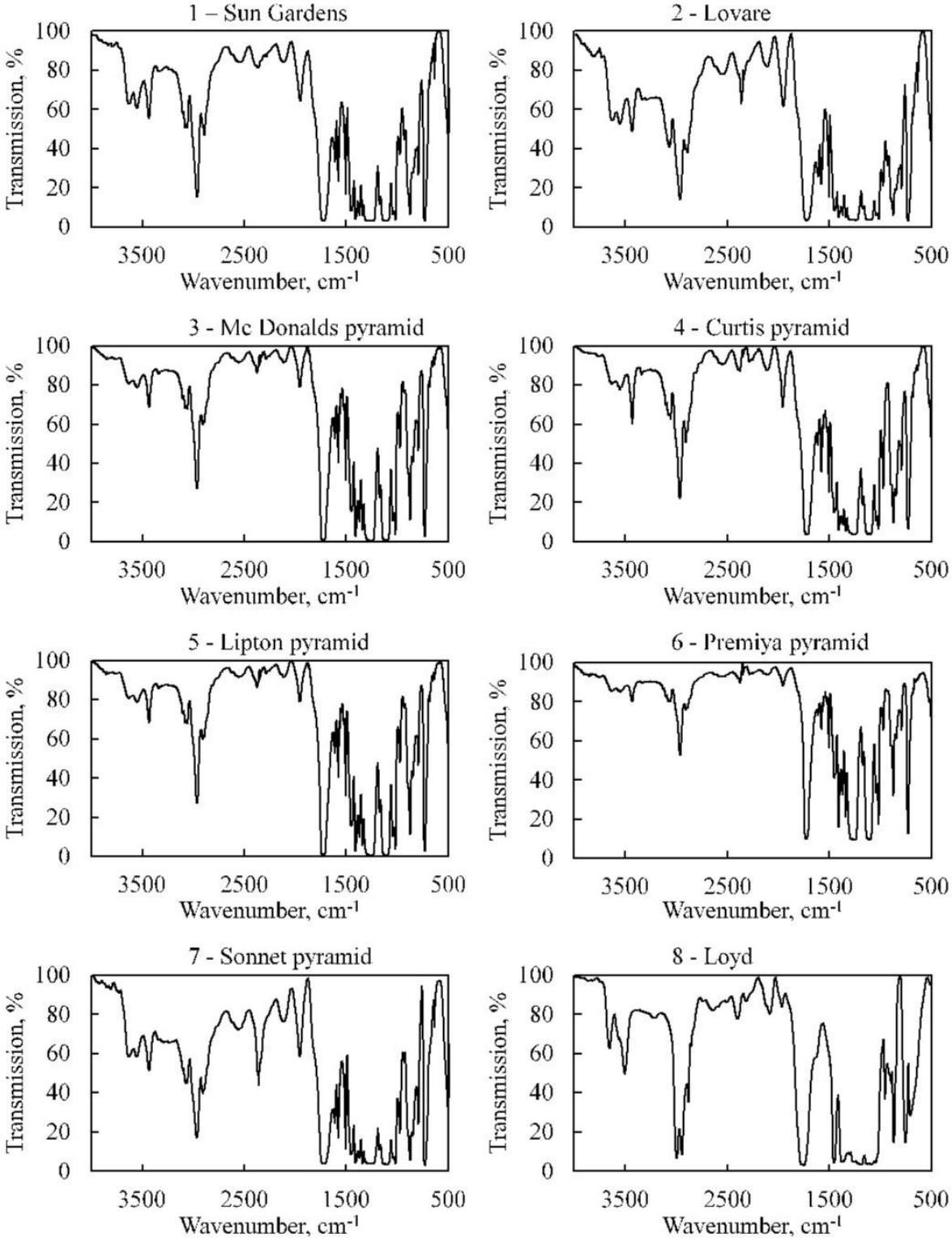


Fig.2. FTIR spectra of pyramids.

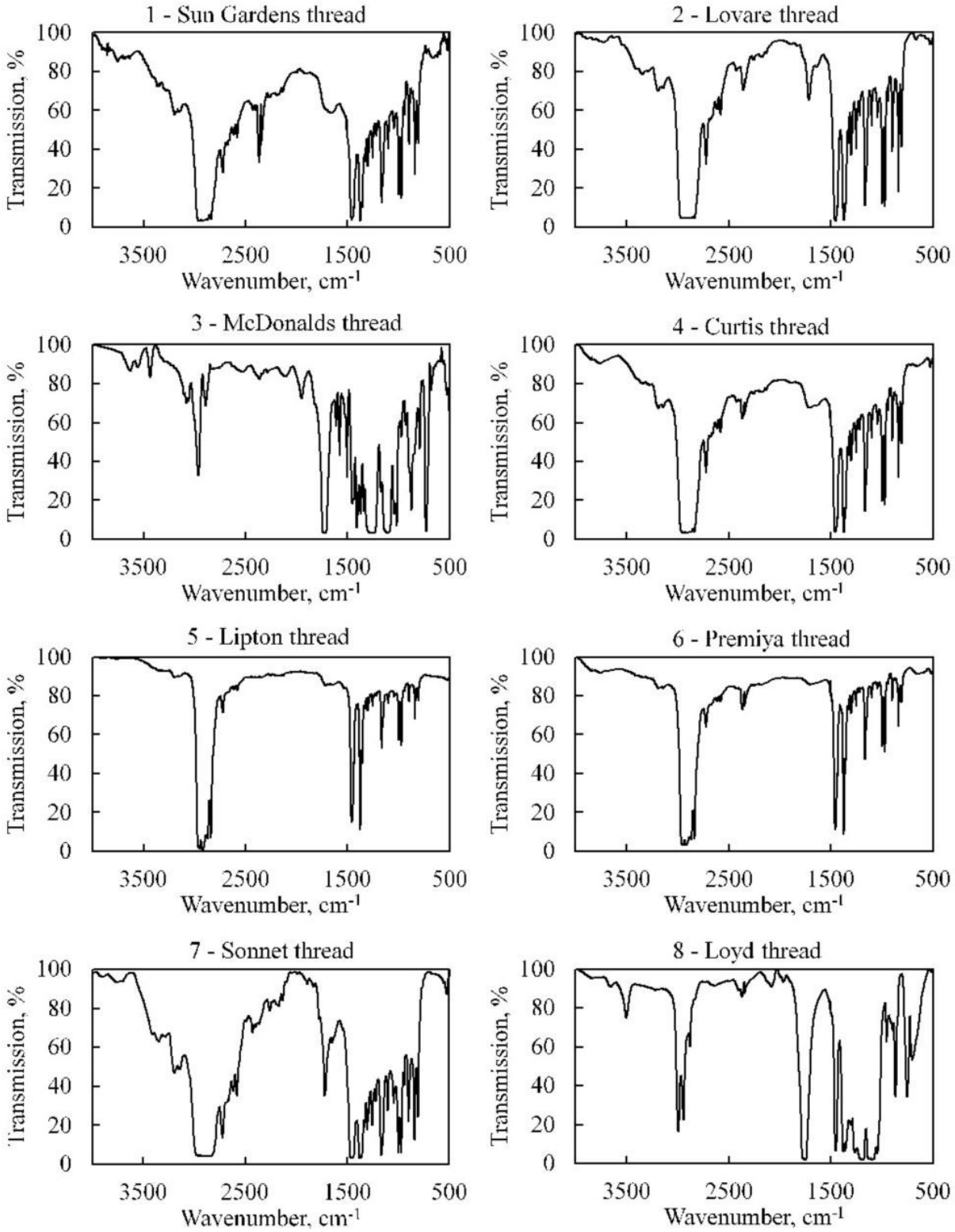


Fig.3. FTIR spectra of threads

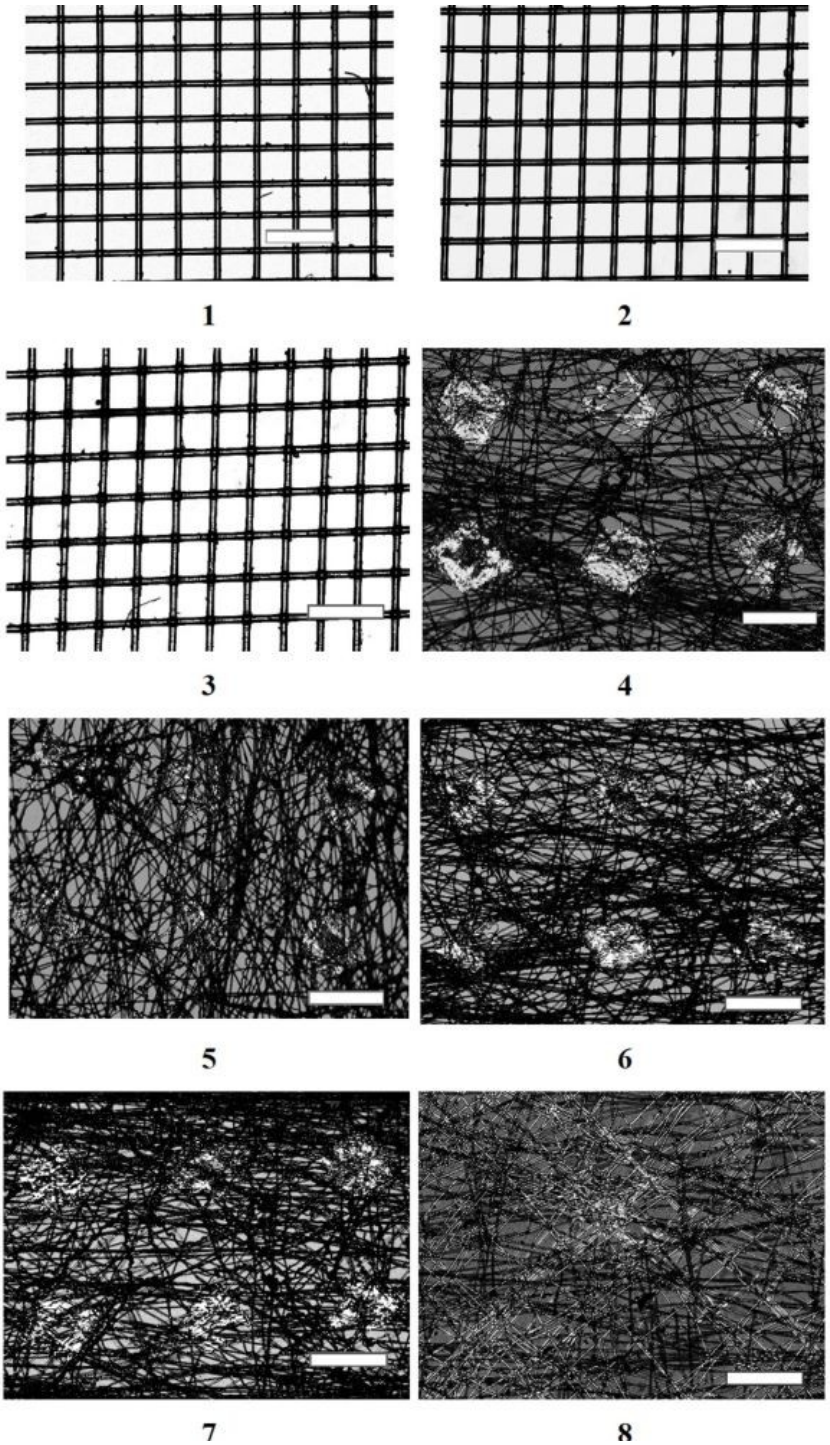


Fig.4. Photomicrographs of pyramid materials, magnification 50^x, bar 500 µm. 1 – Sun Gardens, 2 – Lovare, 3 - Curtis for Mc Donalds, 4 – Curtis, 5 – Lipton, 6 – Premiya, 7 – Sonnet, 8 – Loyd

The weft and warp threads of samples 1-3 are monofilaments which, as a result of interweaving, form a well patterned net structure (mesh) with the pores perceived to be uniform and regular.

The nonwoven material of the pyramids with the pore structure is formed by point thermal bonding of fibers on a calender. A point-bonded nonwoven material consists of randomly interwoven fibers joined together at discrete points, forming sections of thermal contact bonding uniformly distributed throughout nonwoven fabric. Other bridging fibers that connect the junctions retain their structural properties. The partial thermal contact connection of samples 4-7 has a rhombic shape, while in the case of sample 8 it has a round ones [40]. There is no complete melting of the fibers at the bonding points, which is characteristic of commercial nonwoven materials that are obtained under conditions of insufficient pressure in the inter-

roller gap, high speed of rotation of the rollers, or insufficiently high temperature, which does not ensure complete melting of the fibers at the bonding points. of contact (usually about 10 ms) [39]. Areas of partial thermal contact bonding of the studied samples have a rhombic shape with a diagonal length of about 500 μm.

Textile fabric parameters of samples 1-8 presented in table 2. The area density of nonwoven materials is 18.0–19.4 g/m^2, the area density of plain fabrics is 21.8–22.3 g/m^2. Nonwoven and plain weave fabric structures are composed of fibers. The fiber diameter of nonwovens is 13-16 μm, while mesh-type woven fabrics are made from fibers with a diameter of 50–52 μm. It must be noted that reducing fiber diameter is the dominant way of increasing filtration efficiency of a nonwoven filter medium [40].

The tea bag threads/strings are shown in Figure 5. The threads to the pyramids of all tested samples are attached using the thermal bonding method. The pyramids of samples 1,2,4-7 made of PET are connected to threads of another plastic, namely PP. It can be assumed that this is due to the fact that PP is more low melting thermoplastic material than PET. The melting point of PP is about 165°C, and the melting point of PET is 260°C [40].

The characteristics of the threads are given in Table 3. Threads made of multiple structures such as ply yarns (samples 2-7) and cabled yarns (samples 1,8) [41-43]. The primary structural element of the threads in the case of samples 1-4, 6-8 are staple fibers (elementary fibers of limited length), of sample 5 – filament fibers (elementary fibers of unlimited length).

Thus, the primary structural element of tea bags (pyramids and threads) are fibers, which are produced from thermoplastic polymers. Figures 6 and 7 shows the longitudinal morphology of PET, PP and PLA fibres. Obvious randomly distributed micro-sized defects in the form of irregularly shaped particles and fibrils (Figure 7 5b) can be observed on the surface of the fibers. Microparticle size is usually smaller or comparable to the diameter of the fibers. These particles on the surface of the fibers are potential microplastic, which is formed during tea brewing (see figure 8). It has been established that microplastics are formed from both pyramids and threads. These results are in agreement with results of other studies [11-17].

Table 2 – Characteristics of pyramids

Parameter	Sun Gardens 1	Lovare 2	Curtis for Mc Donalds 3	Curtis 4	Lipton 5	Premiya 6	Sonnet 7	Loyd 8
Type and structure	plain woven (mesh)	plain woven (mesh)	plain woven (mesh)	termal bonded nonwoven	termal bonded nonwoven	termal bonded nonwoven	termal bonded nonwoven	termal bonded nonwoven
Size of textile material, mm	120x58,5	115x60	110x44	120x56	110x50	105x50	119x58	111x53
Area density, g/m^2	21,8	22,3	21,9	18,0	18,7	18,7	18,7	19,4
Nature of fibers	PET	PET	PET	PET	PET	PET	PET	PLA
Diameter of fibers, μm	50±2	52±1	52±1	16±2	16±2	13±1	13±1	16±1

Table 3 – Characteristics of threads

Parameter	Sun Gardens 1	Lovare 2	Curtis for Mc Donalds 3	Curtis 4	Lipton 5	Premiya 6	Sonnet 7	Loyd 8
Thread length, mm	210	210	140	190	170	190	200	150
Structure of thread (type yarn*)	cabled yarn has three 2-ply yarns	4-ply yarn	4-ply yarn	4-ply yarn	4-ply multifilament yarn	4-ply yarn	4-ply yarn	cabled yarn has three 2-ply yarns
Final twist of plied yarn or cabled yarn**	S-twist	S-twist	S-twist	S-twist	S-twist	S-twist	S-twist	S-twist
Type of fiber	staple	staple	staple	staple	filament	staple	staple	staple
Nature of fiber	PP	PP	PET	PP	PP	PP	PP	PLA
Diameter of fibers, μm	20±1	18±2	18±2	18±5	42±7	20±2	19±1	14±1

* The yarn is a continuous strand which is made by fiber twisted together. Yarns can be made either from short staple length fibers or from filament fibers. Multifilament yarn is made from multiple filament fibres. Continuous filament fibre length requires little or no twisting to hold the multifilament yarn together. A ply yarn that is formed by twisting in one direction together two or more singles yarns in one operation. Cabled yarns are produced by twisting two or more ply yarns [41-43];

** Yarns are twisted in the clockwise direction for "S"twist, and counter clockwise for "Z" twist [41-43].

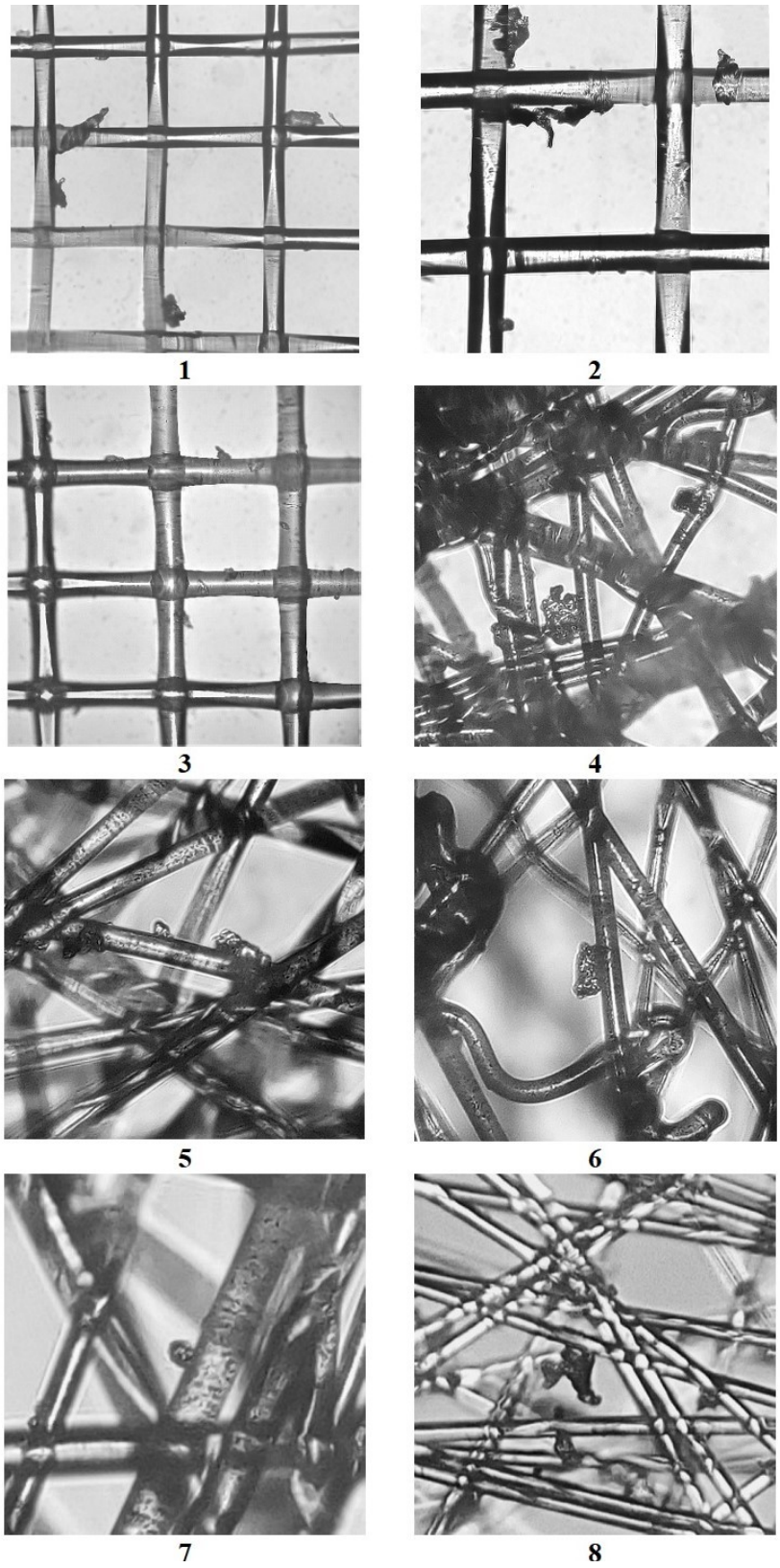


Fig.6. Photomicrographs of microplastic particles on the surface of pyramid fibers. 1 – Sun Gardens,
2 – Lovare, 3 - Curtis for Mc Donalds, 4 – Curtis, 5 – Lipton, 6 – Premiya, 7 – Sonnet, 8 – Loyd

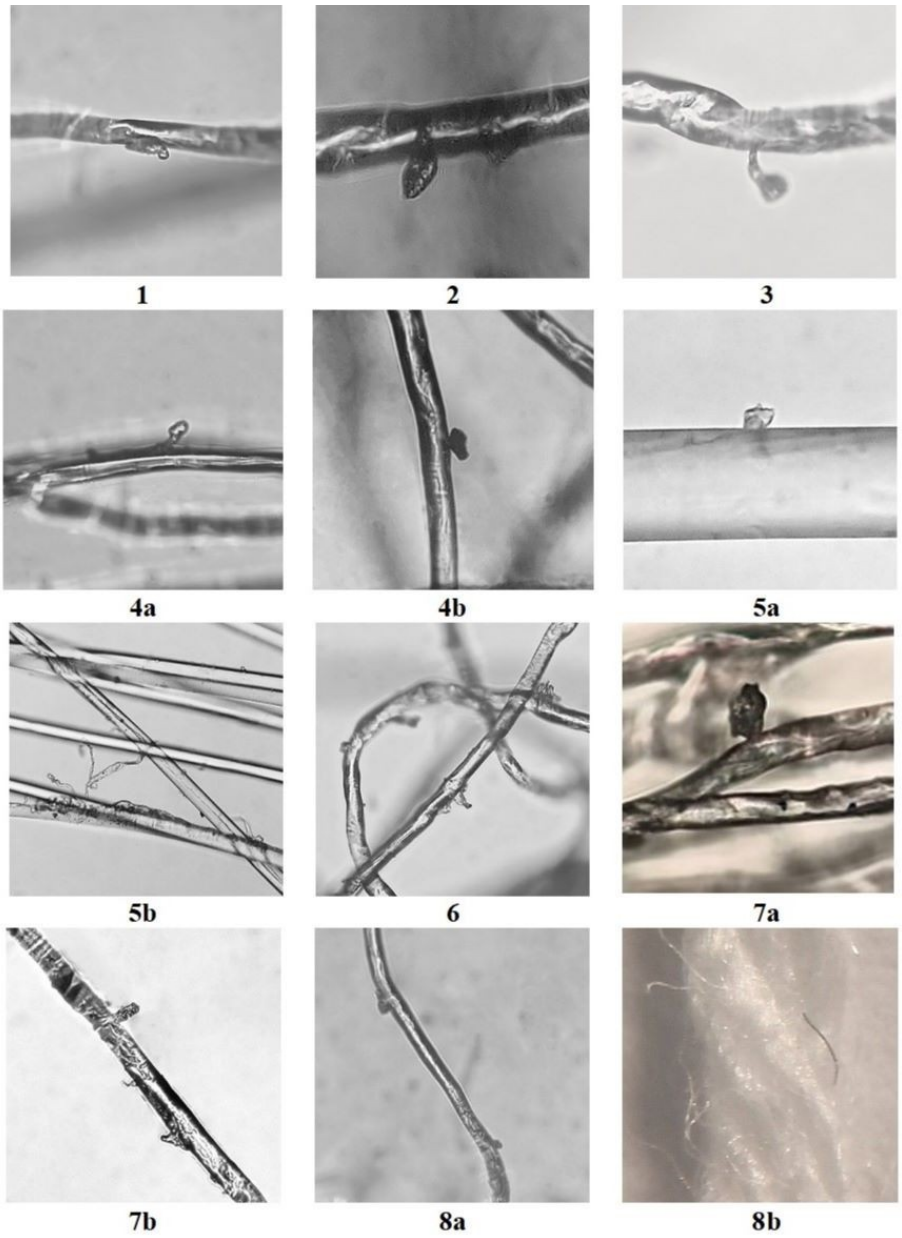
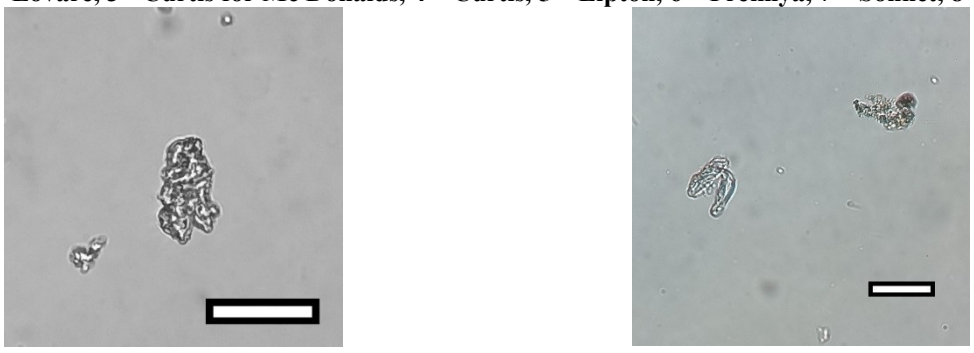


Fig.7. Photomicrographs of microplastic particles on the surface of thread fibers. 1 – Sun Gardens, 2 – Lovare, 3 - Curtis for Mc Donalds, 4 – Curtis, 5 – Lipton, 6 – Premiya, 7 – Sonnet, 8 – Loyd



a b

Fig.8. Photomicrographs of microplastics, which was formed when the pyramid of sample 4 was kept at 95°C in distilled water for 5 minutes, bar 8a 50 µm, 8b 25 µm, magnification 200^{x}

It should be noted that after steeping in hot water not all these microparticles on the fibers transfer into solution as microplastic indicating a strong interaction between the fiber surface and microparticles. On the other hand, the thread structure of samples 1-3,5-8 shows a helical arrangement of fibres with a lot of projecting ends [42]. This structure allows the threads to collect debris, including microplastic due to electrostatic and mechanical attraction by the assembly of staple fibers of the threads. Fig.8b presents black microfiber in the thread. When the threads come into contact with hot water, some of the debris gets into the tea.

Conclusion

The structure, morphology and parameters of plastic tea packages were established. The tea bags for all studied samples are made of thermoplastic materials: pyramids of PET and PLA, threads of PET, PP and PLA. No bags made of nylon were found. PET mesh filter bags of samples 1-3 have a woven structure of single filaments. Nonwoven filter bags have a nonwoven structure of single filaments which are thermofixed. Threads made of multiple structures such as ply yarns and cabled yarns. The primary structural elements of tea bags are fibers. On the surface of fibers situated particles of microplastic debris. In some cases, the presence of a small amount of microplastics, which does not belong to the materials from which the structural elements of the tea bags are made: pyramids or threads, has also been established in the composition of ready-made tea drinks.

Thus, all tea bags made of plastic textile materials (nonwoven and plain woven fabrics, yarn) are a source of microplastics. It should be noted that to date no textile plastic materials have been created that would not pollute water with microplastics [44,45]. It is therefore appropriate that information about this special characteristic of tea bags be part of the food product labeling as a tool to protect consumer health [8,9,46,47].

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ЕКСПЕРТИЗА ЧАЙНИХ ПАКЕТИКІВ-ПІРАМІДОК МЕТОДАМИ ОПТИЧНОЇ МІКРОСКОПІЇ ТА FTIR-СПЕКТРОСКОПІЇ. УТВОРЕННЯ МІКРОПЛАСТИКОВОГО ЗАБРУДНЕННЯ ПРИ ЗАВАРЮВАННІ ЧАЮ

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Анотація. Було досліджено вісім марок чайних пакетиків - пірамідок на українському ринку: Sun Gardens (1), Lovare (2), Curtis для Mc Donalds (3), Curtis (4), Lipton (5), Premiya (6), Sonnet (7) і Лойд (8). За допомогою FTIR-спектроскопії встановлено, що пірамідки пакетиків виготовлені з термопластичних полімерів поліетилентерефталату (зразки 1-7) та полімолочної кислоти (зразок 8). Нитки, що кріпляться до пірамідок, виготовлені з термопластичних полімерів поліпропілену (зразки 1,2,4-7), поліетилентерефталату (зразок 4) і полімолочної кислоти (зразок 8). Питоме оптичне обертання полімолочної кислоти $[\alpha]D^{25}$ становить біля -150° (c=1, $CHCl_3$), що відноситься до полі(L-молочної кислоти). За допомогою оптичної мікроскопії встановлено, що за структурою пірамідки поділяються на тканини полотняного переплетення (зразки 1-3) та термоскріплені неткані матеріали (зразки 4-8). Чайні пакетики (зразки 1-3) демонструють чітку сітчасту структуру (сітку) з порами, які сприймаються як однорідні та регулярні. Чайні пакетики з нетканих матеріалів мають нерегулярну сітку, що складається з компактного та безладного розташування волокон. Волокна складені безладно, утворюючи неправильні пори. Неткані полотна виготовляють з волокон діаметром 12–18 мкм, тканини полотняного переплетення – з волокон діаметром 48-54 мкм. Плотність нетканих матеріалів 18,5–20,3 г/м^2, тканих матеріалів 22,0–22,7 г/м^2. Нитки виготовляють скручуванням кількох однокручених ниток. За структурою нитки являють собою корд із трьох двокручених ниток (зразки 1,8), 4-х кручених ниток (зразки 2-4,6,7) та 4-х кручених мультифіламентних ниток (зразок 5). Останнє кручення крученої пряжі/корду є S-кручення. Основним структурним елементом ниток у зразків 1-4, 6-8 є штапельні волокна, у зразка 5 – мультифіламентні волокна. Кожну порожню пірамідку та нитку замочували при 95°С протягом 5 хвилин у 10 мл води. Встановлено, що форма мікрочастинок пластику, які утворюються в напоях під час заварювання чаю, визначається первинною структурою чайних пакетиків, при цьому і пірамідки, і нитки вивільняють частинки мікропластику неправильної форми.

Ключові слова: мікропластик, пластиковий чайний пакетик, оптична мікроскопія, FTIR – спектроскопія