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EXPOSURE TO DUST AND ITS PARTICLE SIZE DISTRIBUTION IN SHOE MANUFACTURE AND REPAIR WORKPLACES MEASURED WITH GRIMM LASER DUST MONITOR

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Abstract

Objectives: Owing to a diversified technological process and a great variety of products and materials used in shoe manufacture, workers may be exposed to dusts that contain different chemicals and particles of various shapes and sizes. The aim of this study was to assess the dust exposure, taking account of concentration of particular size fractions according to the European Standard Norm, and to analyze particle size distribution in inhalable dust at selected workplaces in a modern shoe manufacture plant and in a small shoe repair workshop in comparison with other industrial branches. **Materials and Methods:** In these two workplaces, the concentrations of dust, representing the inhalable, thoracic, and respirable fractions, were measured with the GRIMM 1.105 laser dust monitor. **Results:** The particle size distribution in inhaled dust in the most characteristic workposts was analyzed. In the shoe manufacture plant, the concentrations ranged from 124 µg/m^3 (leather cutting out) to 724 µg/m^3 (scouring and milling of soles); concentrations of the thoracic and respirable fractions in the same workposts ranged from 74 µg/m^3 to 412 µg/m^3 and from 24 µg/m^3 to 120 µg/m^3, respectively. In the shoe repair workshop, the recorded concentrations were higher: the values ranged from 521 µg/m^3 (gluing of shoes and soles, zipper exchange and heel abrasion) to 916 µg/m^3 (uppers sewing and heel scouring) for the inhaled fraction; from 335 µg/m^3 to 499 µg/m^3 for the thoracic fraction; and from 88 µg/m^3 to 120 µg/m^3 for the respirable fraction. The mass median aerodynamic diameters of inhalable dust particles fell within the limits of 6.2–25.0 mm. Dust with the smallest particles (MMAD = 6.2 mm) was observed in shoe brushing and polishing, and with the largest particles (MMAD = 25.0 mm) in uppers sewing. **Conclusions:** The modern process of shoe manufacture is characterized by very low concentrations of inhalable dust and its fractions, they are considerably lower than occupational exposure limits in Poland for inhaled (4000 µg/m^3) and respirable (2000 µg/m^3) dust. In the workplaces under study, a relatively high proportion of extrathoracic fraction of leather dust was found, which supports a hypothesis on a potential etiologic role of this factor in the development of pathologies in the upper airways region.

Key words:
Exposure to leather dust, Inhalable, thoracic and respirable dust concentration, Particle size distribution of inhalable dust, Shoe manufacture and repair, GRIMM laser dust monitor

INTRODUCTION

Owing to a diversified technological process as well as to a great variety of products and materials used in shoe manufacture and repair, the composition of dust pollutants emitted in the shoe industry workplaces is also greatly diversified. They may represent a mixture of dusts emitted

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by natural leather, leather-like materials, fibers, natural (cotton, wool, linen, silk) and synthetic fabrics, paper, wood, caoutchouc and rubber.

At present, the shoe industry has at its disposal a stock of machines, which are continuously modernized, and manufactured shoes are made of varied materials with a growing tendency towards automation of all production processes.

In the technological process of shoe production, four major stages can be distinguished:

- the preparation of shoe components (development and cutting out of outer elements, production of soles, insoles and heels);
- sewing and finishing of outer elements;
- shoe assembling (putting together outer and inner parts);
- finishing, brushing and polishing.

At each stage of the process, workers may be exposed to various chemicals and dusts of different composition. The category of air pollutants depends on the kind of raw materials (e.g., glues, dissolvents, lacquers, dyestuffs). Airborne dust emissions usually take place during such operations as cutting out of individual shoe elements, thinning of edges, scouring, abrasing, milling, sewing, brushing and polishing. Dusts may contain particles of different shapes and sizes.

The world epidemiological studies show that employment in shoe manufacture and repair plants is mostly associated with an increased risk of malignant neoplasms, cancer of the nose and paranasal sinuses in particular, which, according to their authors, result especially from exposure to tanned leather dust. It is also known that leather dust particles may contain various chemicals (chromium salts, extracts of plant dyestuffs, mineral oils) spread during processes of leather tanning and finishing. Some of these compounds are carcinogenic [1–8].

The dust particle size distribution plays a vital role in the localization of pathological changes in the respiratory system induced by exposure to leather dust. The magnitude of changes in the tracheobronchial and unciliated airways mostly depends on the concentration of the tracheobronchial and respirable dust fractions, whereas the risk of changes in the upper airways most likely depends on the concentration of the extrathoracic dust fraction penetrating the airways within the head.

In the literature, neither data on concentrations of specific particle size fractions of leather dust nor the characteristics of workers' exposure to these fractions are available. An attempt to fill this gap may help to explain the cause-effect relationship between occupational exposure and specific health effects.

The studies carried out in a pottery plant [9] and in man made mineral fibers (MMMF) production plants [10] showed different particles size distributions with lower percentage of extrathoracic and higher percentage of respirable fractions. The distribution found in the construction industry [11] as well as during the agricultural operations [12] and in the forest products industry [13] was characterized by the largest proportion of dust of the extrathoracic fraction.

The aim of this study was to assess the dust exposure, taking account of concentration of particular size fractions according to the European Standard Norm [14] and to analyze particle size distribution in inhalable dust at selected workplaces in a modern shoe manufacture plant and in a small shoe repair workshop in comparison with other industrial branches.

MATERIALS AND METHODS

Dust exposure was assessed in selected workposts typical of technological processes of shoe manufacture and at a small shoe repair workshop. Particle size distribution of inhalable dust and concentrations of dust inhalable fractions were measured according to the European Standard Norm (EN 481) [14]. This norm formulates the definition of inhalable fraction as a weight-proportion of total dust particles inhaled by nose and mouth. Moreover, this norm defines the extrathoracic fraction as a fraction of particles that penetrate the head airways and cannot penetrate beyond the larynx, the thoracic fraction as a fraction that penetrates the chest, the tracheobronchial fraction as a fraction of particles that penetrate beyond the thorax. but do not penetrate the unciliated airways and the respirable fraction as a fraction of particles that penetrate unciliated airways. Measurements were performed with the GRIMM laser dust monitor (model 1.105 characterized by the following parameters: size range 0.5–20 μm, mass range 0–100 mg/m^3, flow range 1,2 l/min, reproducibility ± 4 μg/m^3) adjusted to dust samples collection according to requirements laid down in EN 481 [9]. The monitor recorded every minute inhalable, thoracic and respirable dust fractions (in μg/m^3) as well as mass concentrations of particles (in μg/m^3) with diameter larger than 0.5 μm; 1.0 μm; 2.0 μm; 3.5 μm; 5.0 μm; 7.5 μm; 10 μm; and 15 μm. The measurement records were analyzed in individual workplaces at least during a half of an eight-hour shift. The monitor was placed as close as possible to the breathing zone of selected workers. The selected workposts were stationary, and workers operated machines installed in large production rooms in sitting or standing position.

On the basis of the monitor records, we estimated mass concentrations of dust particles in proportions of diameter intervals: 0.5–1; 1–2; 2–3.5; 3.5–5; 5–7.5; 7.5–10; 10–15; >15 μm and cumulative proportions of particles smaller than upper limits of these diameter categories. Having collected the data, the results of the analysis were presented in a form of lognormal probability plots on a log probability paper. From the plots (distributions) we read out their characteristic parameters: mass median aerodynamic diameter of dust particle (MMAD) and geometric standard deviation (GSD).

RESULTS AND DISCUSSION

Table 1 provides the list of selected workposts. Table 2 summarizes the results of the analysis of inhalable dust particles in the workposts under study. The results show that the mass proportion of particles with diameters smaller than 15 μm predominated in all workposts, except those of seamstresses, and ranged from 51.23% (thinning of edges, outer and inner elements) to 81.49% (shoe brushing and polishing), with relatively low mass proportion of particles smaller than 5 μm, range between 8.13% (sewing) and 17.32% (shoe brushing and polishing).

Table 1. List of workposts in the shoe manufacture plant and shoe repair workshop, selected for the dust exposure assessment

Department	Workpost
A. Shoe manufacture	
Cutting out	Hydraulic cutter operator
Uppers preparation	Thinner operator
Sewing	Uppers sewing
Insoles production	Trimming and scouring
Soles production	Scouring and milling edges
Assembling	Brushing and polishing
B. Shoe repair	
	Scouring, sewing
	Gluing of uppers, insoles and soles, zipper fastening, heel abrasing

The measures of general tendency and distribution characterizing the size of particles are given in Table 3. The parameters were read-out from lognormal probability plots presented in Fig. 1. Mass median aerodynamic diameters (MMAD) of inhalable dust particles in workposts fell within the range of 6.2–25.0 μm. Dust with the smallest particles (MMAD = 6.2 μm) was observed in the shoe brushing and polishing workplace and that with the largest particles (MMAD = 25.0 μm) was found during uppers sewing. At the other workposts, the particle diameters of inhalable dust were similar. MMAD of dust particles ranged from 10.0 μm (operation of cutting out machine and sole milling) to 13.0 μm (thinner operator and scouring).

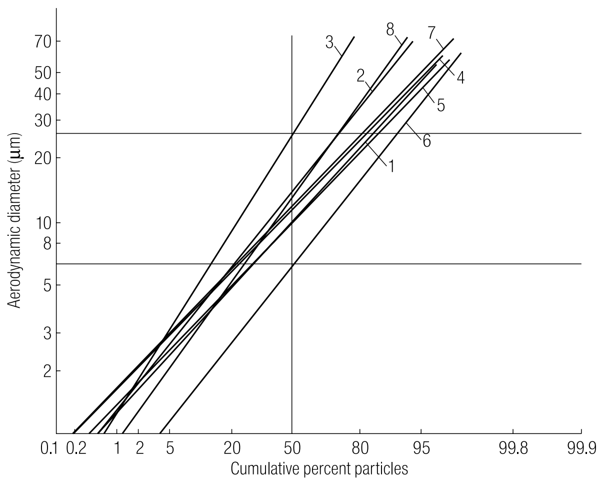

Fig. 1. Cumulative lognormal particle size distribution on workposts 1–8, according to Table 3.

Table 2. The analysis of inhaled dust particle size in workposts of the shoe manufacture plant and shoe repair workshop according to mass levels

Department/Workplace		Inhalable dust particles in diameter intervals (µm): mass levels (µg/m³), proportion (%), cumulative percentage (Σ%)							
		0.5–1	1–2	2–3.5	3.5–5	5–7.5	7.5–10	10–15	>15
A. Shoe manufacture									
Cutting out		1	3	7	20	17	15	21	40
– hydraulic cutter operator	%	0.81	2.42	5.64	16.13	13.71	12.10	16.93	32.26
	Σ%	0.81	3.23	8.87	25	38.71	50.81	67.74	100
Uppers preparation		2	7	19	48	43	39	67	214
– thinner operator	%	0.45	1.59	4.33	10.93	9.79	8.88	15.26	48.75
	Σ%	0.45	2.04	6.37	17.3	27.09	35.97	51.23	99.98
Sewing		2	3	7	17	12	10	16	142
– uppers sewing	%	0.96	1.43	3.35	8.13	5.74	4.78	7.65	67.9
	Σ%	0.96	2.39	5.74	13.87	19.61	24.39	32.04	99.94
Insoles production		4	12	45	158	165	160	235	388
– trimming and scouring	%	0.34	1.03	3.86	13.54	14.14	13.71	20.14	33.25
	Σ%	0.34	1.37	5.23	18.77	32.91	46.62	66.76	100
Soles production		2	6	14	42	38	35	53	87
– scouring and milling of edges	%	0.72	2.16	5.03	15.11	13.67	12.59	19.06	31.29
	Σ%	0.72	2.88	7.91	23.02	36.69	49.28	68.34	96.63
Assembling		13	24	32	44	31	27	36	47
– brushing and polishing	%	5.12	9.45	12.60	17.32	12.20	10.63	14.17	18.50
	Σ%	5.12	14.57	27.17	44.49	56.69	67.32	81.49	99.99
B. Shoe repair									
– scouring, sewing		6	9	30	102	108	130	236	290
	%	0.66	0.99	3.30	11.21	11.87	14.28	25.93	31.87
	Σ%	0.66	1.65	4.95	16.16	28.03	42.31	68.24	100
– gluing of uppers, insoles and soles, zipper fastening, heel abrasing		8	19	31	56	52	60	110	229
	%	1.4	3.36	5.49	9.91	9.20	10.62	19.47	40.53
	Σ%	1.4	4.76	10.25	20.16	29.36	39.98	59.45	99.98

Table 3. Statistical parameters (geometric mean, geometric standard deviation) of lognormal distribution dust particles for inhalable fraction in workposts of the shoe manufacture plant and shoe repair workshop

Number of workpost	Department/Workpost	Mass median aerodynamic diameter (MMAD) (µm)	
		Geometric mean	Geometric standard deviation
	A. Shoe manufacture		
1	Cutting out – hydraulic cutter operator	10.0	2.40
2	Upper preparation – thinner operator	13.0	2.85
3	Sewing – uppers sewing	25.0	3.60
4	Insoles production – trimming and scouring	11.5	2.26
5	Soles production – scouring and milling of edges	10.0	4.00
6	Assembling – brushing and polishing	6.2	2.74
	B. Shoe repair		
7	– scouring, sewing	12.0	2.25
8	– gluing of uppers, insoles and soles, zipper fastening, heel grinding	13.0	3.08

Table 4. Concentration of inhalable, thoracic and respirable fractions in the workposts of the shoe manufacture plant and shoe repair workshop

Department/Workpost	Dust concentration (µg/m³)		
	Inhalable fraction	Thoracic fraction	Respirable fraction
A. Shoe manufacture			
Cutting out – hydraulic cutter operator	124	74	24
Upper preparation – thinner operator	220	105	30
Sewing – uppers sewing	173	85	28
Insoles production – trimming and scouring	498	263	68
Soles production – scouring and milling of edges	724	412	110
Assembling – brushing and polishing	424	247	103
B. Shoe repair			
– scouring, sewing	916	499	120
– gluing of uppers, insoles and soles, zipper fastening, heel grinding	521	335	88

Table 4 summarizes the inhalable, thoracic and respirable dust fractions, measured in all workposts. Inhalable dust concentrations in the shoe manufacture plant ranged between 124 µg/m³ (cutting out) and 724 µg/m³ (sole milling and scouring). The range of the thoracic and respirable fractions concentrations was 74–412 µg/m³ and 24–120 µg/m³, respectively in the same workposts. In the shoe repair workshop, concentrations of inhalable dust and its fractions were higher: the inhalable fraction ranged from 521 µg/m³ (gluing of soles, zipper exchange, heel abrasing) to 916 µg/m³ (uppers sewing and heel scouring); the thoracic fraction – from 335 to 499 µg/m³; and the respirable fraction from 88 to 120 µg/m³. The highest concentrations of inhalable dust and its fractions were found in workposts of sole and heel-tap scouring both in the shoe manufacture plant and shoe repair workshop.

Table 5. Mean concentrations of inhalable dust and percentage content of dust fraction in inhalable dust in workposts of the shoe manufacture plant and shoe repair workshop

Department/Workpost	Mean concentration of inhalable dust (µg/m³)	Percentage content of dust fraction in the inhalable dust			
		Extrathoracic fraction	Thoracic fraction		
			Tracheobronchial fraction		Respirable fraction
A. Shoe manufacture					
Cutting out – hydraulic cutter operator	124	40.3	40.4	59.7	19.3
Uppers preparation – thinner operator	220	52.3	34.2	47.7	13.6
Sewing – uppers sewing	173	33.5	50.3	66.5	16.2
Insoles production – trimming and scouring	498	47.2	39.2	52.8	13.6
Soles production – scouring and milling of edges	724	43.1	41.7	56.9	15.2
Assembling – brushing and polishing	424	41.7	34,0	58.3	24.3
B. Shoe repair					
– scouring, sewing	916	45.5	41.4	54.5	13.1
– gluing of uppers, insoles and soles, zipper fastening, heel grinding	521	35.7	47.5	64.3	16.8

Table 5 illustrates the proportion of inhalable dust fractions (according to EN 481) [14]. In all workposts, the great majority of inhalable dust (halted in the rhino-pharyngeal airways) belonged to the extrathoracic fraction and ranged from 33.5% (uppers sewing) to 52.3% (thinner operation); the thoracic fraction was a predominating fraction of inhalable dust in the majority of workposts, ranging from 47.7% (thinner operation) to 66.5% (sewing); the respirable fraction was in small proportion in inhalable dust and fell within the limits from 13.1% (uppers sewing and heel-taps scouring) to 24.2% (shoe brushing and polishing).

An analysis of one-minute concentration recorded by a GRIMM 1.105 monitor disclosed vast fluctuations in workpost dust concentrations during one shift. Particularly wide ranges were noted in workposts with the highest dust exposure.

Table 6 illustrates the variation in one-minute concentrations in workplaces with the highest exposure to respirable dust. In a sewing room, the highest one-minute concentration during uppers sewing reached 6912 µg/m³ with the mean concentration of 172 µg/m³; during sole scouring and milling, the highest concentrations reached 6433 µg/m³ with the mean concentration of 724 µg/m³. More extensive variations were observed during shoe repair; the highest one-minute concentration of 14 571 µg/m³ was recorded during heel-tap scouring. Lower variations in concentrations were observed in thoracic fractions, and relatively low in respirable fractions.

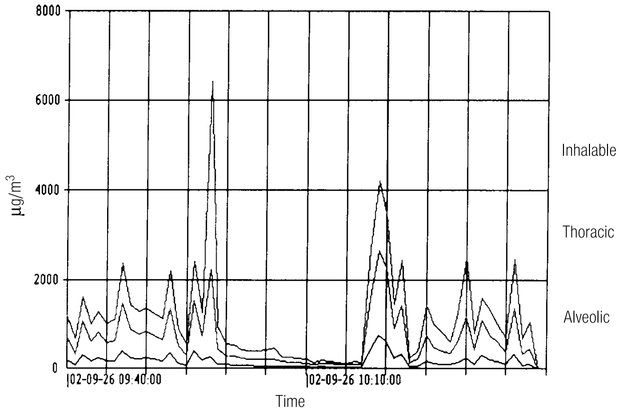

Fig. 2. Graphical record (GRIMM) of the dust concentration in the scouring workpost.

Figures 2 and 3 present examples of diagrams of dust fractions during scouring of heel edges in the shoe manufacture plant and during gluing of uppers and soles, zipper fastening and uppers sewing in the shoe-repair workshop. The diagram records help to link individual operations with the magnitude of the dust emission into the air of workers' breathing zone.

A study carried out in a pottery plant showed the following ranges of values in individual workposts: 33.1–42.3% ($\bar{x}$ = 38.8%) for the extrathoracic fraction; 57.7–67.2%

Table 6. Variation in short-term concentrations of inhalable dust and its fraction in workposts with the highest dust exposure

Department/Workplace	N	Dust concentration (µg/m³)								
		Inhalable			Thoracic			Respirable		
		Range	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD
A. Shoe manufacture										
Sewing										
– uppers sewing	187	48–6912	172	400	39–1276	85	73	18–53	28	4
Insoles production										
– trimming and scouring	146	118–6433	724	595	90–2642	411	304	30–745	110	76
B. Shoe repair										
– scouring, sewing	301	107–14571	916	1919	77–7905	499	933	31–1658	120	174
– gluing of uppers, insoles and soles, zipper fastening, heel grinding	314	17–10373	521	1235	16–10373	335	1047	10–3804	883	323

N – Number of dust concentration measurements.
Range – Minimum and maximum dust concentrations.
$\bar{x}$ – arithmetic mean of the dust concentration.
SD – standard deviation.

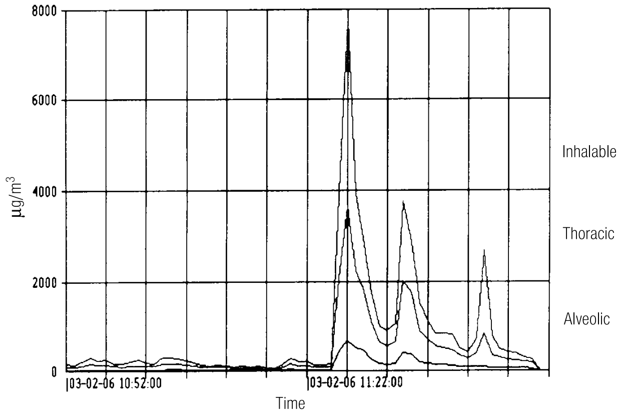

Fig. 3. Graphical record (GRIMM) of the dust concentration during shoes repairing.

($\bar{x}$ = 61.2%) for the thoracic fraction and 11.8–21.6% ($\bar{x}$ = 16%) for the respirable fraction [9]. In MMMF production plant, dust concentrations also measured with a GRIMM laser dust monitor ranged: 27.0–56.1% ($\bar{x}$ = 35.0%); 43.9–73.0% ($\bar{x}$ = 65.0%); and 9.8–22.7% ($\bar{x}$ = 18.6%) for extrathoracic, thoracic and respirable fractions, respectively. In plants producing MMMF-based heat-insulating and sealing products, the following values were recorded: 10.8–56.9% for the extrathoracic fraction; 43.1–89.2% for the thoracic fraction and 9.1–47.4% for the respirable fraction [10].

Nieuwenhuijsen et al. [12] investigated exposure to dust and its particle size distribution in California agriculture. The measurements of individual exposure performed with four-stage cascade impactors showed rather large particles of inhalable dust; the average MMAD estimate for all measurements taken together was 49 μm (range 22–150 μm). The largest proportion of dust belonged to the extrathoracic fraction, and the levels of thoracic fraction for dust particles with median value of 9.8 μm fell within the range of 3.6–26.5% of total dust in different agricultural operations. The author suggests that the percentage of these particles in total dust increases with an increase in dust exposure.

Bello et al. [11] investigated exposure to quartz dust in the construction industry. The exposure measurements were performed with personal impactor samplers. The proportion of the thoracic fraction in respirable dust during various construction operations ranged from 16.3 to 29.8%, and of the respirable fraction from 2.5 to 10.6%. The extrathoracic fraction predominated. The data showed that the quartz level in the thoracic fraction exceed 4.5 times its level in the respirable fraction. Exposure to quartz contained in the inhalable fraction was 25.6 times higher than that to quartz in the respirable fraction.

The measurements in the forest products industry with a multistage virtual impactor RespiCon, performed by Tatum et al. [13], evidenced that concentrations of respirable dust in workplaces ranged from 30 to 1160 μg/m³ and made 37.5–14.8% of inhalable dust. Concentrations of the thoracic fraction ranged from 40 to 1840 μg/m³ and made 50–23.5% of inhalable dust. Concentrations of inhalable dust ranged from 80– 7830 μg/m³.

To sum up, the studies carried out in a pottery industry [9] and in a man made mineral fibers production plants [10] showed different particles size distributions with lower percentage of extrathoracic and higher percentage of respirable fraction. The distribution similar to that in the shoe manufacture was found in the construction industry [11], during the agricultural operations [12], and in the forest products industry [13].

CONCLUSIONS

1. Nowadays, the concentrations of respirable dust and its particle size distribution fractions in the shoe manufacture process are very low, well beyond the occupational exposure limits for dust in Poland (4000 μg/m³ for inhalable, 2000 μg/m³ for respirable dust). Slightly higher concentrations, but also below standard norms, are observed in shoe repair workplaces.

2. Analyses of particle size distribution of inhalable dust showed that the medians of particle aerodynamic diameters were well above 10 μm in the majority of workposts, thus inhalable dust shows a medium level of distribution and contains high percentage of particles with diameters above 15 μm.

3. The results were confirmed by estimating fractions for inhalable dust according to EN 481. In the workposts under study, a high percentage of thoracic and a low percentage of respirable fractions were found as compared

with those of dusts emitted in plants of some industrial sectors.

4. The analyses of particle size distribution of leather dust indicating a relatively high proportion of the extrathoracic fraction support a hypothesis on a potential etiologic role of this factor in the development of pathologies in the upper airways.

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ERRATUM

Re: the paper entitled "Nasal lavage fluid examination in diagnostics of occupational allergy to chloramine" by Cezary Pałczyński, Jolanta Walusiak, Anna Krakowiak, Wojciech Szymczak, Tomasz Wittczak, Urszula Ruta and Paweł Górski published in the *International Journal of Occupational Medicine and Environmental Health*, 2003; 3: 231–40.

On behalf of the Editorial Office and the co-authors, we offer the apology for giving incorrect first name of one of the co-authors of the aforesaid paper. The proper name of the co-author is Wiesław Szymczak.