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Composition and parameters of household bio-waste in four seasons

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ABSTRACT

Bio-waste makes up almost half portion of municipal solid waste. The characterization of household bio-waste is important in determining the most appropriate treatment method. The differences in composition and parameters of bio-waste derived from urban settlement (U-bio-waste) and family houses (F-bio-waste) during the four climate seasons are described in this paper. Twelve components and 20 parameters for bio-waste were evaluated. The composition of U-bio-waste was almost steady over those seasons, unlike F-bio-waste. U-bio-waste was comprised mainly (58.2%) of fruit and vegetable debris. F-bio-waste was primarily made up of seasonal garden components. The amount of variation among seasons in both type of bio-waste increased in sequence: basic parameters < macro-elements < potentially toxic elements. Spearman's correlations among proportions of individual components and parameters of bio-waste were found out. Results of this research could be utilized to support another composition and parameters of bio-waste and be suitable for establishing bio-waste processing.

1. Introduction

The environmental balance of the various options available for the management of biodegradable waste can depends on a number of local factors, inter alia collection systems, waste composition and quality, climatic conditions, the potential of use of various waste derived products such as electricity, heat, methane-rich gas or compost (European Commission, 2007).

There is much information and numerous studies on the composition and parameters of municipal solid waste (MSW). Bio-waste constitutes the highest percentage of individual components comprising MSW. It ranged from 14% to 51% in OECD countries during 2005 (OECD, 2008). The differences in waste composition were found between developed and developing countries. Asase et al. (2009) found out 30% proportion of biodegradable component in household waste of London, Canada, compared to 64% proportion in waste of Kumasi, Ghana. The composition of waste in a study from Siem Reap, Cambodia, showed largely organic origin. Kitchen wastes, yard waste, wood and coconut shells collectively account for 66% of waste by weight (Parizeau et al., 2006). These authors referred that this amount is similar to that found in residential waste in other developing countries. Iqbal et al. (2010) collected data from the area under jurisdiction in Pakistan to determine the percentage composition of solid waste in summer and winter season. The percentage (by weight) of organic waste has not shown any significant differences in those seasons. Den Boer et al. (2010) tested material composition of household waste in several towns of Poland. These tests performed in four seasons, in development areas typical for individual towns. Burnley (2007) draws together the findings of MSW compositional surveys undertaken in the United Kingdom. In the next study, Burnley et al. (2007) characterized representative samples of all the components of the MSW stream across Wales. The results from the research estimated that 28% of MSW is compostable and 62% is classed as biodegradable.

Unfortunately, studies focused on the composition and characteristics of household bio-waste itself in various seasons are rare, probably caused by labor intensive and time consuming procedures.

Feedstocks based solely on green (garden) wastes have different characteristics than those which include segregated kitchen wastes. There is evidence that socio-economic characteristics of the area from which waste is collected may affect feedstock quality, i.e. wastes collected from rural areas may differ significantly from those collected from urban areas (Krogmann, 1999). Tchobanoglous et al. (1993) reported that kitchen waste is a large fraction of municipal solid waste (20–65%). Qu et al. (2009) confirmed this fact when they found that kitchen waste constitutes 69% of household waste in Beijing, China. Thanh et al. (2010) have undertaken two-stage survey of 100 households for dry and rainy seasons in 2009. The compostable share accounted for 80%. The results show that the significant average differences between two seasons were found for grass and wood, not for food waste. Boldrin and Christensen (2010) determined seasonal fractional composition and chemical characterization of garden waste in Aarhus, Denmark, eight times during 1 year. The major fraction was "small stuff" (flowers, grass clippings, hedge cuttings and soil) making up

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more than 90% during the summer. The woody fractions (branches, wood) were more significant during the winter. Seasonal trends in waste chemical composition were recorded. Ward et al. (2005) sampled garden waste from nine different composting facilities in the UK each month for a whole year. They determined various chemical parameters whereas nitrogen and potassium showed seasonal patterns. In the study of Bary et al. (2005) yard trimmings were sampled from four composting facilities in Washington State, USA on five dates between April and August 1999. Variation among facilities was greater than variation over time. Grass clippings were the main source of variation.

Composition of the bio-waste from households may vary seasonally. This may have impact on processing facilities. There are mainly two competing types of bio-waste processing technology, aerobic digestion (composting) and anaerobic digestion (gasification). Both technologies depend on composition of wastes, in particular contents of carbon and of nutrients. Seasonal development of bio-waste composition may result in need to adjust composition of processed bio-waste by additives to reach optimum combination of nutrients and carbon or in fluctuation of process parameters that have to be taken into account in process operation. Knowledge of fluctuation of composition of bio-waste during the year may help to select appropriate processing technology.

Data about composition and parameters of household bio-waste obtained in our study could be used to: (1) develop or revise bio-waste management program for city, (2) make a decision on determining adequate treatment method, (3) predict how variation of bio-waste composition and parameters among seasons may influence both the course and results of bio-waste processing, (4) recommend as how to minimize the effects of such variation, if found, (5) assess the fluctuating quality of bio-waste in seasons, (6) determine the best strategy on the diversion of bio-waste from landfills in terms of greenhouse gases.

We conducted this study to evaluate differences in composition and parameters of bio-waste from urban settlement and family houses during four seasons. It is part of a larger project focused on evaluation of parameters of bio-wastes, suitability of their processing and use of end products.

2. Materials and methods

2.1. Characterization of city of Prague and selected neighborhoods

Prague is a capital of the Czech Republic. It has about 1.25 million inhabitants (end of 2009). Its geographical location is Central Europe, 50°4′48.031″N, 14°26′1.6″E. Production of municipal solid waste was 370 thousand tons (296 kg per capita) in 2009. There has been a 2% growth trend of municipal solid waste over the period 2002–2009. Residual household waste production was about 244 thousand tons in 2009. While residual household waste has been almost steady over the period 2002–2009, there has been twofold increase in separately collected waste types (paper, glass, plastics, tetrapack packages) and threefold increase in production of bulk municipal waste. Prague municipality supports separate collection of waste, but the focus was on recyclables over the last decade. Separate collection of paper, glass, plastics and tetrapack packages was over 50 thousand tons in 2009 and separate collection of bio-waste (including wood) was about 10 thousand tons in the same year. All recyclables and bio-waste are collected by means of either recycling bins or recycling centers. There is a large potential in increase of separate collection of bio-waste, as it forms over 20% of household waste. Further increase of separate collection of bio-waste may result in threefold increase of production of bio-waste over next 10 years. This will require new processing facilities for bio-waste. Similar situation is around the whole country.

In this study, municipal bio-waste was collected from two styles of residential densities typical of Prague living areas with existing source separation systems that have worked well over several years:

1. Apartment buildings on the edge of the city, so-called urban settlement Repy. The houses are multi storey houses. The flats have central heating. Population of this housing are belong to a middle class. Inhabitants buy all consumables including food from supermarkets and local shops. Production of bio-waste from kitchen is roughly estimated around 50 kg per capita in year. The production of garden waste is negligible. The production of kitchen waste is spread over the whole year. The bio-waste originated in this urban settlement is called as U-bio-waste in following text.
2. Housing area Dolni Chabry is a Prague quarter with prevalence of individual family houses. Majority of the houses have gas or electrical heating. Population of this housing are belong to a middle class. Inhabitants buy all consumables including food from supermarkets and local shops, with small fraction of fruits and vegetables consumption covered by their own production. The houses have usually small gardens, typically used as small orchards, flower gardens, lawn and various beds. Production of bio-waste from gardens in this type of residential area is roughly estimated around 100 kg per capita (or 1 kg per m^2 of garden area). Production of bio-waste from kitchen is roughly estimated around 50 kg per capita in year. The production of garden waste is seasonal. The production of kitchen waste is spread over the whole year. The bio-waste originated in these family houses is called as F-bio-waste in following text.

2.2. Sample collection and fractionation

The sampling strategy was designed to deliver an accurate estimate of composition and characteristics of bio-waste in individual four seasons of the year. Sampling was performed at each of the neighborhoods over the course of the 1 year. Sampling was a time consuming process which had to be carried out in a uniform manner on each sampling occasion in order to minimize sampling errors. In order to ensure that the protocol was followed to best effect, all sampling was done by the same team of 4 people led by the same leader.

In total 50 households living in 2 large apartment buildings took part in a separate collection of U-bio-waste. Basic samples (40 kg) were collected every week of the 1 year (13 sampling occasions per season) from locked boxes placed in front of apartment buildings. Nobody but people involved in the project had keys from the boxes.

In total 70 households from family houses participated in the separate collection of F-bio-waste within the project. Basic samples (170 kg) were collected almost every 2 weeks of the 1 year (6 sampling occasions per season) from thoroughly mixed outdoor bio-waste bins.

Reasons for different sampling in two neighborhoods were as follows:

1. The different numbers of households (50 and 70) were caused by the selection of the group of households with the custom to separate bio-waste several years. By the literature review, more heterogeneity of garden waste than kitchen waste was expected.
2. Higher weight of basic sample of F-bio-waste compared to U-bio-waste was caused by more numbers of households, longer sampling period, higher expecting heterogeneity and last but

not least to keep the same weight of basic sample at each sampling occasion to ensure representative sampling. Before experiment, the minimum weight of basic sample (40 and 170 kg) available at each sampling occasion was estimated especially on the basis of production of household waste and proportion of biodegradable components.

3. Two weeks sampling period in the case of family houses reflected routine collecting interval.

Basic sample from each occasion was sorted by hand. Foreign matters (plastic, glass, tetrapack, ferrous and non-ferrous metals) made up maximally 0.1% by total weight and were removed from the basic sample. Bio-waste was classified into 12 components according to origin and material similarity with the premise of its specific behavior under aerobic or anaerobic treatment. There were 12 groups of components: grass, plants, leaves, wood, citrus fruit, non-citrus fruits and vegetables, bread, bedding, soil, non-recyclable paper, non-classifiable bio-waste (e.g. teabags and compostable bags) and material improper for aerobic or anaerobic treatment.

Table 1
Yearly weighted U- and F-bio-waste average fraction composition (wet weight %).

	U-bio-waste		F-bio-waste	
	Average	SD	Average	SD
Grass	3.9	5.6	29.0	30.4
Plants	11.6	5.7	5.8	3.9
Leaves	1.6	1.6	27.6	30.8
Wood	1.1	1.0	17.5	4.7
Citrus fruit	14.0	4.3	1.5	2.3
Non-citrus fruits and vegetables	44.2	7.8	5.4	2.8
Bread	3.2	1.1	0.0	0.0
Bedding	3.9	0.7	0.3	0.6
Soil	9.3	5.7	11.5	11.1
Paper	2.7	0.8	0.4	0.5
Non-classifiable	3.8	0.8	0.3	0.3
Improper	0.8	0.6	0.5	0.3

Values given are based on 52 (U-bio-waste) and 24 (F-bio-waste) sampling occasions.
SD = Standard deviation among average values in four seasons.

Three replicate subsamples (3×250 g) were collected from components of basic sample on each sampling date. The subsample was set together by hand from sorted out individual components on based of their fresh weight proportions to avoid heterogeneity. Subsamples were dried (40 °C) to reach constant dry matter content and consequently ground.

These stored ground subsamples obtained in one season were thoroughly mixed. Three partial samples characterized one season by this way were used for analyses which were carried out in duplicate.

Bary et al. (2005) recommend one or two sampling periods representative of seasonal production as sufficient to characterize the material for majority of nutrients except total-N, ammonium-N and C:N rate.

2.3. Analytic methods

Measurements of pH were made on samples mixed with deionized water (1:10 (w/v)) by WTW pH 340 i (WTW, Germany). Volatile solids (VS) concentration was determined as ignition loss in samples kept at 550 °C for 12 h. Organic carbon was determined by dichromate oxidation in a sulfuric acid solution (Sims and Haby, 1971) and total nitrogen by the Kjeldahl method (Bremner, 1960). Concentrations of elements after microwave decomposition were determined by inductively coupled plasma optical emission spectrometry (ICP-OES, VARIAN VistaPro, Varian, Australia). The certified reference material "7004 Loam" was used for quality assurance of analytical data.

2.4. Statistical evaluation

All statistical analyses were performed using the STATISTICA 9.0 software (StatSoft, Tulsa, USA). The parameters of bio-waste in various seasons were subjected to one-way analysis of variance (ANOVA), using 95% confidence level, followed by Tukey's test. The Kruskal-Walis test (p-value < 0.05) was used to evaluate changes in proportion of the chosen components among seasons. Spearman's correlations were explored between chemical parameters and components at the probability levels 0.05, 0.01 and 0.001.

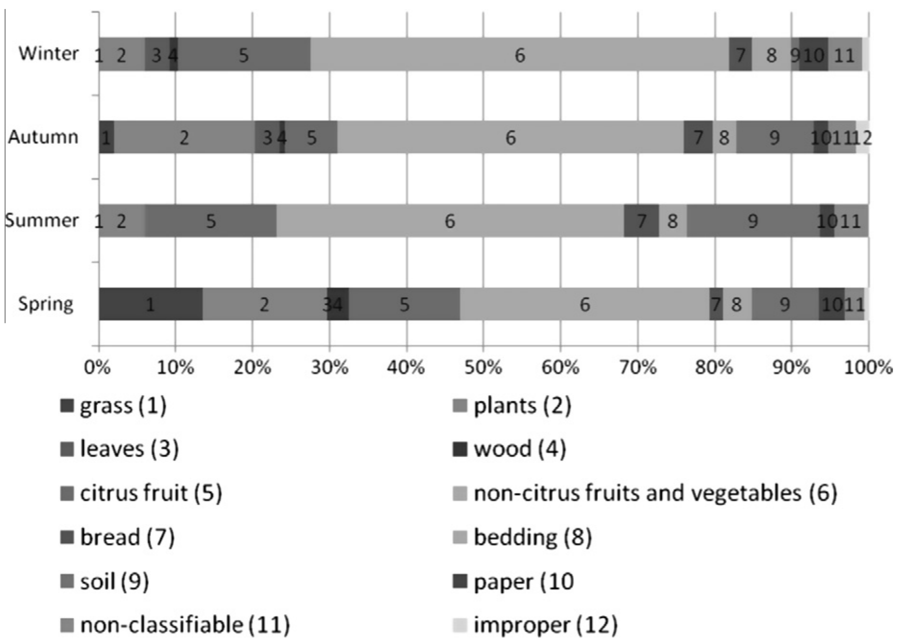


Fig. 1. Portions of individual components in bio-waste in seasons, collected from urban settlement (in % by fresh weight). Values given in each season are based on 13 sampling occasions.

3. Results and discussion

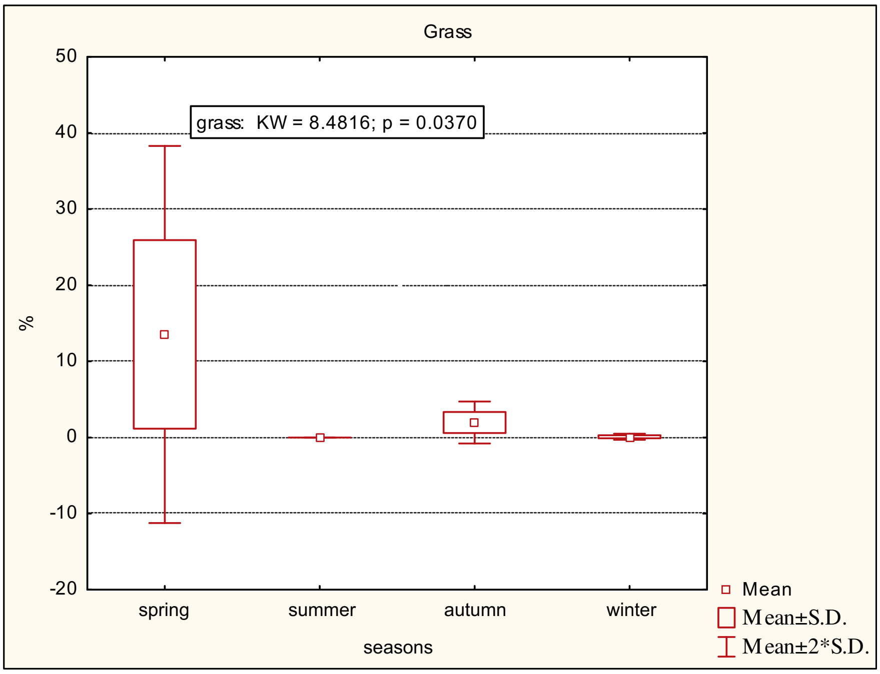
3.1. Composition of bio-waste

Yearly weighted average composition of bio-waste is presented in Table 1. Naturally, higher standard deviations were found in the case of seasonal components. Similarly, Boldrin and Christensen (2010) found 19.5% of branches, 4.5% of wood and 75.6% of the remaining biodegradable fraction in garden bio-waste collected in Aarhus, Denmark during one year.

In our study, there were no substantial differences in the life level and civic amenities between chosen neighborhoods. Gardens with trees, lawns and various beds in neighborhoods of family houses showed a significant and probably only one impact on bio-waste composition.

The distribution of individual components of U-bio-waste in seasons is illustrated in Fig. 1. Food remains from kitchens prevailed, made up of non-citrus fruits and vegetables, and citrus fruit making up 44.2% and 14.0%, respectively by total weight. The sequence of other components was as follows: plants (12.0%), soil (9.3%), grass (3.9%), pet bedding (3.9%), non-classifiable (3.8%), bread (3.2%), non-recyclable paper (2.7%), leaves (1.6%), wood (1.1%) and improper components for bio-waste processing, such as bones, leathers, etc. (0.8%).

a)



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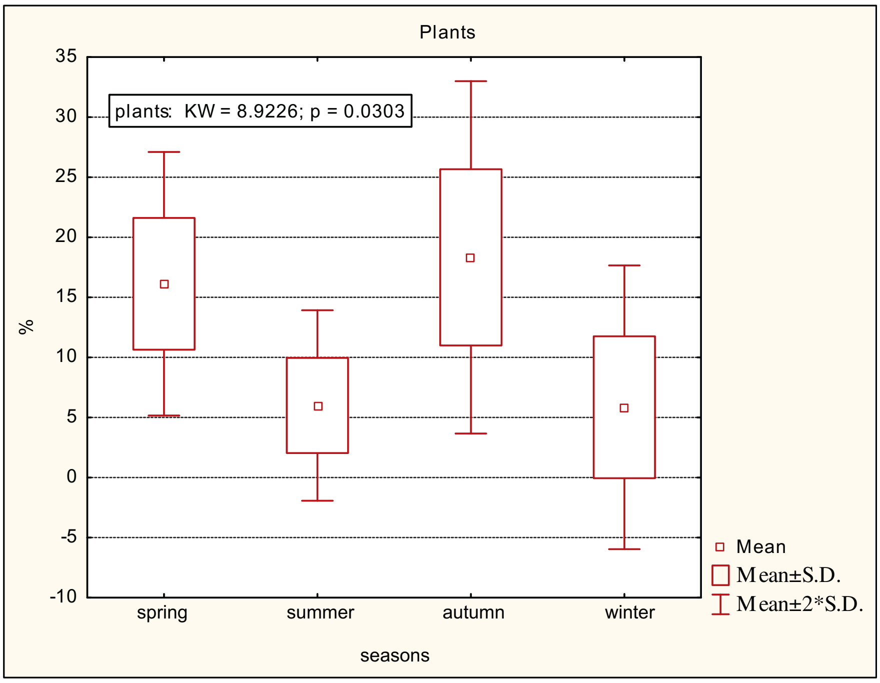

Fig. 2. Portions of components in urban settlement bio-waste showing differences among seasons (KW = Kruskal-Wallis test, p-value < 0.05).

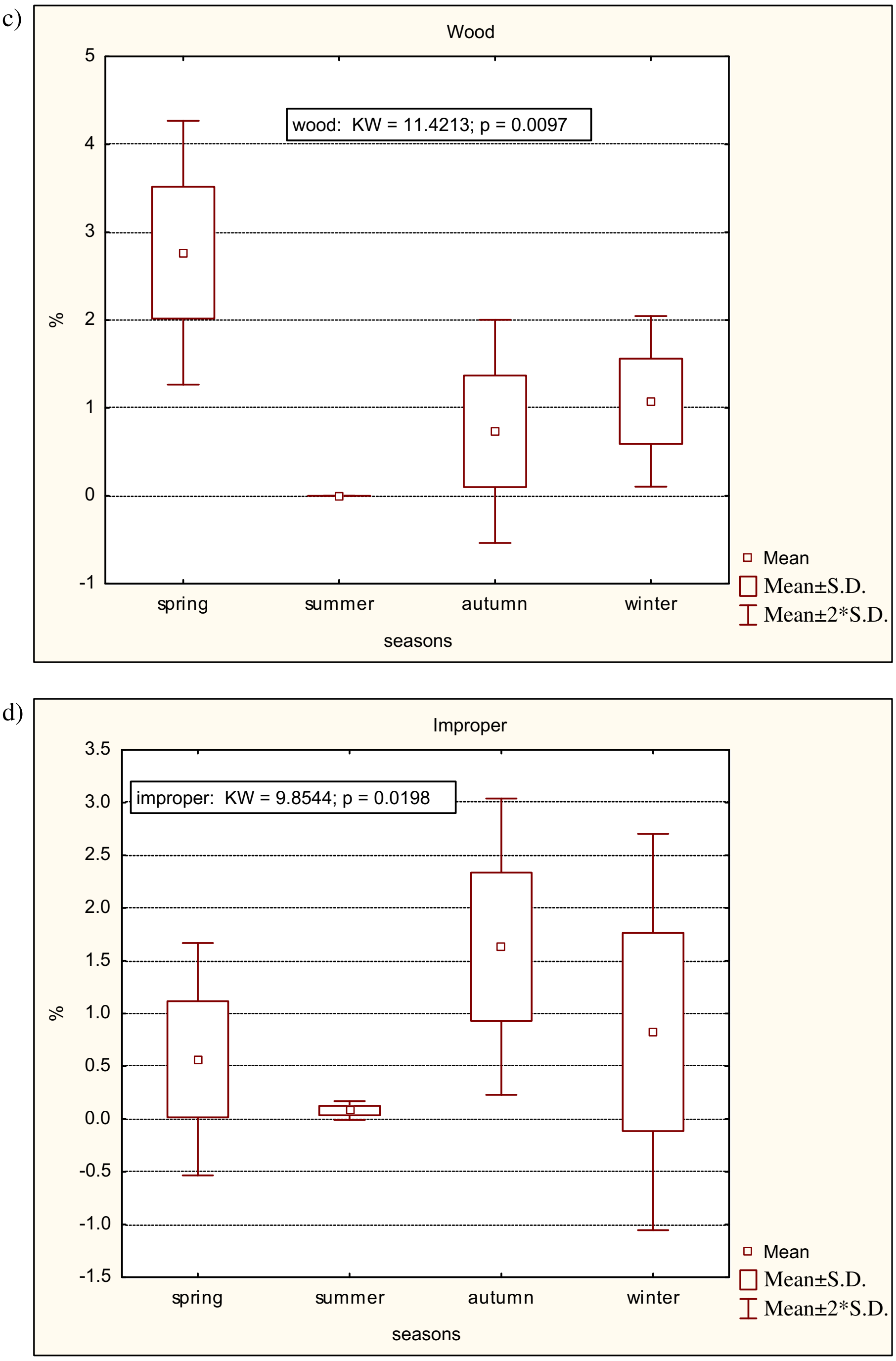

Fig. 2 (*continued*)

Detailed evaluation showed that only four components (Fig. 2) from a total of 12 differed by season. They comprised 17.5% over the average of seasons. There were no significant seasonal differences in kitchen and food debris. This is consistent with the results of Krogmann (1999), who found that the amount and composition of indoor waste are independent of the time of year and place of collection. However, kitchen waste is not homogeneous in day-to-day composition and these fluctuations may influence the anaerobic digestion process (Neves et al., 2008).

F-bio-waste was comprised mainly of garden waste (Fig. 3). The component composition varied by season according to garden activity. Grass prevailed in spring (45.2%) and summer (71.0%) connected to the periodic mowing of lawns by homeowners. It is consistent with Uhlar-Heffner et al. (1998) who found the greatest proportion of grass clippings in the yard trimmings in the Puget Sound region of western Washington State, USA from April through July. The large volumes of grass-rich materials can lead to serious odor problems at composting facilities. There are two strategies in named area: (1) encouraging residents to leave clippings on the lawn, (2) direct application of yard trimmings to agricultural land. In our study, autumn and winter collection was especially comprised of leaves from deciduous trees (74.5% and 35.8%, respectively). The third most prevalent component was wood (17.5% in an average of seasons), mainly fine branches from the pruning of trees and shrubs (Benito et al., 2006). Boldrin and Christensen (2010) found that during summer (June–August) and autumn (September–November) the predominant waste fraction was "small stuff", i.e. grass, soil, flowers, leaves, etc. in Aarhus, Denmark. In September this fraction accounts for more than 90% of the garden waste collected. In winter (December–April), garden waste contains a significant fraction of branches and wood (up to 45%). This was due to reduced activity in gardens in winter and the fact that focus was on three and bush pruning.

Typically, food waste, that is too wet and lacks the structure for composting, is treated via anaerobic digestion, whereas green waste is composted (Edelmann and Engeli, 1993; Braber, 1995). Hamzawi et al. (1998) referred to the most anaerobically biodegradable components of the organic fraction of MSW, based on their rate of biogas production, were paper and grass. In this regard, the bio-waste from spring and summer would be appropriate for anaerobic treatment. The effect of treatment on CO_2 balance should be taken into account. Kranert et al. (2010) concluded that the largest reduction of CO_2 was achieved by green waste with high wood content whenever it is used either for energy recovery or material recycling. Green waste with a high wood portion has nearly the same CO_2-saving potential as wood chips or scrap timber. Green waste with considerably lower heating values, associated to high water and high ash content suits better for composting processes or if applicable for anaerobic digestion and subsequent production of compost.

It is not the aim of this article to cover aerobic and anaerobic treatments in depth, as they have been discussed widely in the literature (Walker et al., 2009; Epstein, 1997; Mata-Alvarez et al., 2000).

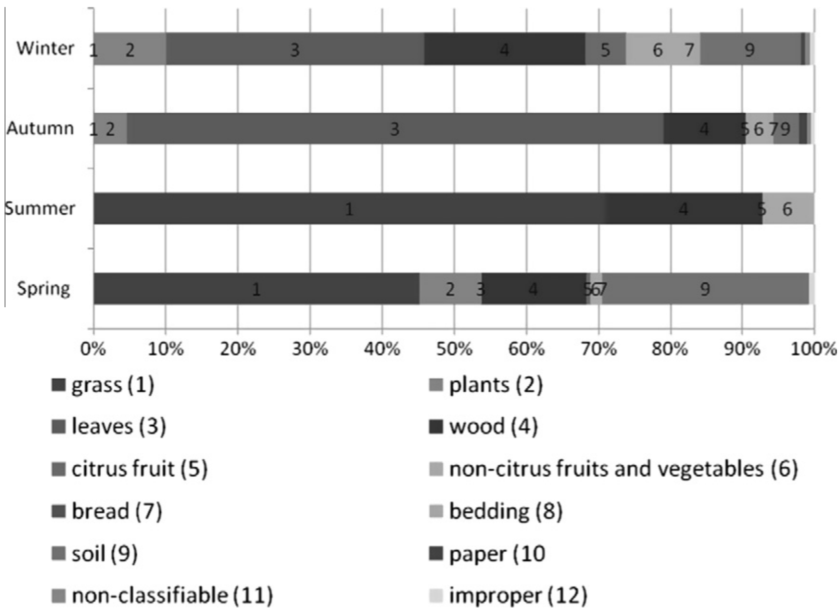

Fig. 3. Portions of individual components in bio-waste in seasons collected from family houses (in % by fresh weight). Values given in each season are based on six sampling occasions.

Table 2
Parameters of bio-waste collected from urban settlements across various seasons.

	Spring	Summer	Autumn	Winter	Mean	Min.	Max.	CV (%)
Dry matter (%)	34.2a (±0.97)	23.2b (±0.73)	27.1c (±0.32)	29.4d (±0.65)	28.5	22.3	35.4	14
pH	5.96a (±0.06)	5.42b (±0.04)	5.01c (±0.11)	6.09a (±0.11)	5.62	4.87	6.22	8
Volatile solids (%)	72a (±1.6)	62b (±1.6)	84c (±1.6)	76a (±1.6)	73	60	86	11
Nitrogen (%)	1.52a (±0.05)	1.55a (±0.05)	1.45a (±0.06)	1.76b (±0.02)	1.57	1.38	1.78	7
C:N	23.7a (±0.2)	20.0b (±0.1)	29.1c (±1.7)	21.6ab (±0.7)	23.6	19.9	31.2	15
P (%)	0.14a (±0.01)	0.19b (±0.00)	0.17 cd (±0.00)	0.16d (±0.00)	0.16	0.13	0.19	12
K (%)	1.66acd (±0.00)	1.77c (±0.05)	1.43d (±0.05)	1.07b (±0.14)	1.48	0.90	1.83	18
Ca (%)	0.72a (±0.15)	0.85a (±0.09)	1.28b (±0.00)	2.37c (±0.02)	1.31	0.54	2.39	49
Mg (%)	0.13a (±0.00)	0.14a (±0.02)	0.16a (±0.02)	0.27b (±0.04)	0.18	0.13	0.32	32
Fe (%)	0.53ac (±0.04)	0.54ac (±0.01)	0.28b (±0.00)	0.47c (±0.00)	0.45	0.27	0.57	23
Al (%)	2.16a (±0.14)	1.07b (±0.00)	0.54c (±0.02)	2.18a (±0.11)	1.49	0.51	2.35	33
Mn (ppm)	419.9a (±5.8)	263.5b (±1.9)	162.3c (±6.1)	270.6b (±12.9)	279.1	154.9	491.9	48
As (ppm)	14.63a (±0.69)	25.15b (±3.82)	14.50a (±1.07)	18.61ab (±0.80)	18.22	13.18	29.83	24
Cd (ppm)	0.40a (±0.02)	0.36a (±0.03)	0.23b (±0.00)	0.08c (±0.00)	0.27	0.07	0.43	47
Cr (ppm)	13.05a (±0.29)	14.94b (±0.26)	7.44c (±0.22)	6.14d (±0.04)	10.40	6.09	15.27	36
Cu (ppm)	18.92a (±1.03)	12.98b (±0.73)	7.44c (±0.22)	10.39d (±0.07)	12.44	7.17	20.19	34
Ni (ppm)	5.58a (±0.38)	7.61b (±0.03)	3.93c (±0.10)	3.26d (±0.13)	5.10	3.10	7.65	33
Pb (ppm)	8.46a (±0.29)	13.98b (±0.39)	5.83c (±0.27)	3.44d (±0.17)	7.93	3.23	14.47	49
V (ppm)	30.79a (±1.21)	16.71b (±0.05)	8.01c (±0.13)	10.69d (±0.25)	16.55	7.84	32.28	53
Zn (ppm)	41.2a (±5.7)	120.5b (±7.6)	58.4c (±0.7)	30.9a (±1.3)	62.8	29.4	129.8	55

Values in a line followed by different letters are significantly different ($p < 0.05$).
Values given in each season are based on 13 sampling occasions.
Coefficient of variation (CV) is calculated among seasons.

3.2. Chemical parameters of bio-waste

Parameters of U-bio-waste and F-bio-waste are shown in Tables 2 and 3, respectively. Dry matter content of bio-waste can be affected by its nature, by the rainfall that the feedstock is exposed to prior collection and by the sampling period. U-bio-waste achieved lower dry-matter values compared to F-bio-waste, caused by higher proportions of fruit and vegetable waste. Woody material from gardens tended to be drier than green material. The lower pH in the case of U-bio-waste may be caused by short-chain organic acids contained in fruits and vegetables (Beck-Friis et al., 2001). In the case of composting material with low pH, the addition of a bulking agent is a prerequisite (Iqbal et al., 2010). The content of volatile solids was similar in bio-waste from both urban and family units (on average 72%). In U-bio-waste, the lowest value among seasons was found in summer months caused high content of soil. The value of the parameter in F-bio-waste followed the seasonal sequence of spring and summer < autumn and winter, coinciding with the increase of lignin components. According Boldrin and Christensen (2010), the volatile solid content (and inversely ash content) and lower heating value (LHV) also known as net calorific value clearly link to each other. The highest heating power of F-bio-waste could be expected in winter time.

The average values for total nitrogen content were 1.57 and 1.37 for U-bio-waste and F-bio-waste, respectively. Almost no significant differences were recorded for seasonal nitrogen in U-bio-waste, unlike F-bio-waste, where a decline in that parameter was found from spring (when majority of garden bio-waste is soft and green) to winter. It might be attributed to higher portions of wood and leaves in contrast to reduced grass in late seasons. The C:N ratio varied between 19 and 36. Optimal values should range between 20 and 25 for effective composting (Diaz et al., 1993). Concentrations of plant nutrients in both types of bio-waste were lower (except potassium) than in the study of Eklind et al. (1997), who analyzed source-separated organic household waste in Uppsala, Sweden. Contents of phosphorus, potassium and calcium in dry matter were higher in F-bio-waste than U-bio-waste by 38.6%, 8.5% and 6.8%, respectively. On the contrary, Mg content was lower by 12.5%. There were differences in seasonally high contents of those elements. In the case of U-bio-waste, highest content of P and K, and Ca and Mg was found in summer and winter seasons, respectively. The highest content of P, K, Ca and Mg in F-bio-waste was found in summer, spring, winter and autumn, respectively. Higher contents of Fe and Mn were found in F-bio-waste than U-bio-waste in all seasons.

Low contents of potentially toxic elements (PTE) were found in bio-waste, indicating that source-separating systems motivate people to sort their waste more carefully. Bio-waste contained more PTE in spring and summer than in autumn and winter. Significantly higher contents of Cu, Pb and Zn were found in F-bio-waste compared to U-bio-waste. This finding is in agreement with Veeken and Hamelers (2002), who found higher contents of these elements in outdoor than indoor bio-waste. Heavy metals content in food product is low, especially for those heavy metals that are not essential plant nutrients. The natural background content of heavy metals in plant material from gardens is higher than indoor waste, because outdoor plant material is more susceptible to anthropogenic contamination. Heavy metal content in household bio-waste generally did not exceed the natural background levels of heavy metals in surface soils, as documented in Kabata-Pendias and Pendias (1985).

3.3. Correlations between composition and parameters

The correlation among proportions of individual components and parameters of bio-waste were assessed to obtain a better evaluation of mutual relationships and an origin of some elements. These could be used in the case of other compositions and parameters of bio-waste and for the suitable set-up of bio-waste processing. Non-citrus fruits and vegetables as the most dominant components of U-bio-waste (Table 4) correlated positively with nitrogen content ($R = 0.66^{*}$) and negatively with C:N ratio ($R = -0.58^{*}$). The addition of wood ($R = 0.62^{*}$), paper ($R = 0.75^{**}$), bedding ($R = 0.94^{***}$) increases the pH of bio-waste and thereby could help to solve the low pH of bio-waste in some countries (Sundberg and Jőnsson, 2008). Results showed high positive element correlations between K and Cd ($R = 0.85^{***}$), K and Cr ($R = 0.97^{***}$), Ni and Cr ($R = 0.94^{***}$), Cr and Pb ($R = 0.92^{***}$), Cu

Table 3
Parameters of bio-waste collected from family houses across various seasons.

	Spring	Summer	Autumn	Winter	Mean	Min.	Max.	CV (%)
Dry matter (%)	30.1a (±0.49)	33.6b (±1.06)	29.0a (±1.06)	37.4c (±0.65)	32.5	27.7	38.2	10
pH	6.61a (±0.03)	5.53b (±0.09)	5.82c (±0.11)	5.85c (±0.06)	5.95	5.42	6.65	7
Volatile solids (%)	64a (±2.4)	62a (±1.6)	78b (±1.6)	80b (±0.8)	71	60	81	11
Nitrogen (%)	1.63a (±0.04)	1.44b (±0.04)	1.23c (±0.02)	1.18c (±0.05)	1.37	1.12	1.68	13
C:N	19.6a (±0.2)	21.5a (±0.2)	31.7b (±0.2)	34.1b (±1.7)	26.7	19.3	36.2	23
P (%)	0.15acd (±0.00)	0.44b (±0.00)	0.14cd (±0.00)	0.16d (±0.01)	0.22	0.14	0.44	54
K (%)	2.13a (±0.04)	1.85b (±0.03)	1.41c (±0.05)	1.02d (±0.03)	1.61	0.99	2.19	26
Ca (%)	0.70a (±0.03)	0.96b (±0.01)	1.58c (±0.05)	2.34d (±0.02)	1.40	0.66	2.36	45
Mg (%)	0.10a (±0.00)	0.15b (±0.00)	0.19c (±0.01)	0.18c (±0.00)	0.16	0.10	0.20	22
Fe (%)	0.78a (±0.02)	0.60b (±0.03)	0.42c (±0.01)	0.49d (±0.02)	0.57	0.41	0.80	24
Al (%)	2.62a (±0.02)	1.23b (±0.10)	0.63c (±0.03)	0.86d (±0.02)	1.33	0.59	2.66	34
Mn (ppm)	481.8a (±8.8)	285.4b (±8.7)	178.2c (±7.3)	342.5d (±5.0)	322.0	169.1	482.9	58
As (ppm)	18.59a (±0.04)	26.10b (±2.85)	15.32a (±0.63)	16.35a (±0.43)	19.09	14.55	29.59	22
Cd (ppm)	0.39a (±0.00)	0.37a (±0.02)	0.24b (±0.01)	0.12c (±0.01)	0.28	0.12	0.40	38
Cr (ppm)	16.33a (±0.29)	17.58b (±0.40)	9.68c (±0.08)	8.34d (±0.18)	12.99	8.11	18.08	31
Cu (ppm)	42.42a (±0.97)	23.91b (±1.24)	9.68c (±0.09)	18.35d (±0.16)	23.59	9.58	43.60	51
Ni (ppm)	9.06a (±1.46)	7.84a (±0.22)	4.91b (±0.08)	4.48b (±0.06)	6.58	4.40	10.86	29
Pb (ppm)	10.12a (±0.62)	18.30b (±0.75)	8.49c (±0.05)	8.00c (±0.02)	11.23	7.99	19.23	37
V (ppm)	32.18a (±1.50)	15.99b (±0.14)	8.85c (±0.24)	12.83d (±0.19)	17.47	8.56	34.02	51
Zn (ppm)	47.2a (±1.81)	169.5b (±0.26)	74.1c (±4.13)	118.5d (±2.43)	102.4	44.9	169.9	45

Values in a line followed by different letters are significantly different ($p < 0.05$).
Values given in each season are based on six sampling occasions.
Coefficient of variation (CV) is calculated among seasons.

Table 4
Spearman correlation coefficients of chemical parameters and components of U-bio-waste (average of four seasons).

	Dry matter	pH	N	Vol. solids	C:N	P	K	Ca	Mg	Fe
(a)										
Grass	0.78**	0.06	−0.38	0.41	0.78**	−0.78**	−0.19	−0.26	−0.30	−0.17
Plants	0.00	−0.71**	−0.83***	0.41	0.78**	0.00	0.19	−0.35	−0.48	−0.35
Leaves	−0.10	−0.36	−0.17	0.91***	0.61*	0.10	−0.72**	0.72**	0.49	−0.89***
Wood	0.97***	0.62*	0.15	0.21	0.39	−0.97***	−0.39	−0.06	−0.02	0.04
Citrus fruit	0.00	−0.71**	0.83***	−0.41	−0.78**	0.00	−0.19	0.35	0.48	0.35
Fruit and vegetables	−0.39	−0.29	0.66*	−0.03	−0.58*	0.39	−0.39	0.69*	0.69*	−0.11
Bread	−0.97***	−0.62*	−0.15	−0.21	−0.39	0.97***	0.39	0.06	0.02	−0.04
Bedding	0.58*	0.94***	0.76**	−0.21	−0.39	−0.58*	−0.39	0.24	0.37	0.30
Soil	−0.78**	−0.75**	−0.51	−0.38	−0.19	0.78**	0.78**	−0.48	−0.48	0.19
Paper	0.78**	0.75**	0.51	0.38	0.19	−0.78**	−0.78**	0.48	0.48	−0.19
Non-classifiable	−0.39	0.29	0.66*	−0.03	−0.58*	0.39	−0.39	0.69*	0.69*	−0.11
Improper	0.19	−0.23	−0.19	0.96***	0.78**	−0.19	−0.78**	0.63*	0.41	−0.86***
Dry matter	1.00	0.60*	0.20	0.23	0.35	−1.00	−0.41	−0.14	−0.03	−0.03
pH	0.60*	1.00	0.64*	−0.17	−0.32	−0.60*	−0.28	0.13	0.42	0.34
Nitrogen	0.20	0.64*	1.00	−0.18	−0.65*	−0.20	−0.44	0.28	0.31	−0.01
Volatile solids	0.23	−0.17	−0.18	1.00	0.77**	−0.23	−0.74**	0.53	0.40	−0.86***
C:N	0.35	−0.32	−0.65*	0.77**	1.00	−0.35	−0.32	0.13	−0.01	−0.51
P	−1.00	−0.60*	−0.20	−0.23	−0.35	1.00	0.41	0.14	0.03	0.03
K	−0.41	−0.28	−0.44	−0.74**	−0.32	0.41	1.00	−0.75**	−0.59*	0.73**
Ca	−0.14	0.13	0.28	0.53	0.13	0.14	−0.75**	1.00	0.76**	−0.48
Mg	−0.03	0.42	0.31	0.40	−0.01	0.03	−0.59*	0.76**	1.00	−0.32
Fe	−0.03	0.34	−0.01	−0.86***	−0.51	0.03	0.73**	−0.48	−0.32	1.00
Mn	0.58*	0.75**	0.16	−0.46	−0.17	−0.58*	0.27	−0.36	−0.15	0.74**
Al	0.68*	0.88***	0.69*	−0.28	−0.35	−0.68*	−0.27	−0.06	0.19	0.27
As	−0.56	0.21	0.28	−0.59*	−0.78**	0.56	0.38	0.10	0.29	0.55
Cd	0.08	−0.09	−0.54	−0.57	0.03	−0.08	0.85***	−0.82**	−0.68*	0.72**
Cr	−0.43	−0.31	−0.38	−0.76**	−0.35	0.43	0.97***	−0.72**	−0.66*	0.70*
Cu	0.38	0.44	0.16	−0.76**	−0.41	−0.38	0.54	−0.72**	−0.48	0.74**
Ni	−0.38	−0.33	−0.41	−0.77**	−0.35	0.38	0.97***	−0.78**	−0.62*	0.69*
Pb	−0.35	−0.36	−0.34	−0.74**	−0.38	0.35	0.94***	−0.82**	−0.72**	0.64*
V	0.43	0.44	0.17	−0.71*	−0.41	−0.43	0.54	−0.79**	−0.51	0.73**
Zn	−0.78**	−0.69*	−0.61*	−0.37	−0.13	0.78**	0.81**	−0.41	−0.38	0.29
	Mn	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**V**	**Zn**
(b)										
Grass	0.32	0.17	−0.86***	0.32	−0.19	0.19	−0.19	−0.19	0.19	−0.39
Plants	−0.32	−0.60*	−0.69*	0.37	0.19	−0.19	0.19	0.19	−0.19	0.39
Leaves	−0.72**	−0.44	−0.39	−0.72**	−0.72**	−0.92***	−0.72**	−0.72**	−0.92***	−0.20
Wood	0.65*	0.67*	−0.56	0.13	−0.39	0.39	−0.39	−0.39	0.39	−0.78**
Citrus fruit	0.32	0.60*	0.69*	−0.37	−0.19	0.19	−0.19	−0.19	0.19	−0.39
Fruit and vegetables	−0.26	0.13	0.67*	−0.73**	−0.39	−0.39	−0.39	−0.39	−0.39	−0.19
Bread	−0.65*	−0.67*	0.56	−0.13	0.39	−0.39	0.39	0.39	−0.39	0.78**
Bedding	0.65*	0.89***	0.22	−0.22	−0.39	0.39	−0.39	−0.39	0.39	−0.78**
Soil	−0.39	−0.69*	0.28	0.43	0.78**	0.00	0.78**	0.78**	0.00	0.97***
Paper	0.39	0.69*	−0.28	−0.43	−0.78**	0.00	−0.78**	−0.78**	0.00	−0.97***
Non-classifiable	−0.26	0.13	0.67*	−0.73**	−0.39	−0.39	−0.39	−0.39	−0.39	−0.19
Improper	−0.52	−0.28	−0.60*	−0.60*	−0.78**	−0.78**	−0.78**	−0.78**	−0.78**	−0.39
Dry matter	0.58*	0.68*	−0.56	0.08	−0.43	0.38	−0.38	−0.35	0.43	−0.78**
pH	0.75**	0.88***	0.21	−0.09	−0.31	0.44	−0.33	−0.36	0.44	−0.69*
Nitrogen	0.16	0.69*	0.28	−0.54	−0.38	0.16	−0.41	−0.34	0.17	−0.61*
Volatile solids	−0.46	−0.28	−0.59*	−0.57	−0.76**	−0.76**	−0.77**	−0.74**	−0.71*	−0.37
C:N	−0.17	−0.35	−0.78**	0.03	−0.35	−0.41	−0.35	−0.38	−0.41	−0.13
P	−0.58*	−0.68*	0.56	−0.08	0.43	−0.38	0.38	0.35	−0.43	0.78**
K	0.27	−0.27	0.38	0.85***	0.97***	0.54	0.97***	0.94***	0.54	0.81**
Ca	−0.36	−0.06	0.10	−0.82**	−0.72**	−0.72**	−0.78**	−0.82**	−0.79**	−0.41
Mg	−0.15	0.19	0.29	−0.68*	−0.66*	−0.48	−0.62*	−0.72**	−0.51	−0.38
Fe	0.74**	0.27	0.55	0.72**	0.70*	0.74**	0.69*	0.64*	0.73**	0.29
Mn	1.00	0.66*	0.10	0.56	0.24	0.77**	0.20	0.17	0.77**	−0.30
Al	0.66*	1.00	−0.01	−0.03	−0.24	0.63*	−0.22	−0.25	0.57	−0.73**
As	0.10	−0.01	1.00	−0.01	0.31	0.07	0.35	0.32	0.11	0.36
Cd	0.56	−0.03	−0.01	1.00	0.82**	0.71*	0.82**	0.78**	0.69*	0.49
Cr	0.24	−0.24	0.31	0.82**	1.00	0.57	0.94***	0.92***	0.51	0.78**
Cu	0.77**	0.63*	0.07	0.71*	0.57	1.00	0.57	0.54	0.94***	−0.03
Ni	0.20	−0.22	0.35	0.82**	0.94***	0.57	1.00	0.97***	0.57	0.78**
Pb	0.17	−0.25	0.32	0.78**	0.92***	0.54	0.97***	1.00	0.59*	0.76**
V	0.77**	0.57	0.11	0.69*	0.51	0.94***	0.57	0.59*	1.00	−0.03
Zn	−0.30	−0.73**	0.36	0.49	0.78**	−0.03	0.78**	0.76**	−0.03	1.00

Values calculated are based on 52 sampling occasions.
* Statistically significant at the probability level 0.05.
** Statistically significant at the probability level 0.01.
*** statistically significant at the probability level 0.001.

and V ($R = 0.94^{***}$), K and Ni ($R = 0.97^{***}$), and Pb and Ni ($R = 0.97^{***}$).

Grass and leaves in F-bio-waste showed a contrary relationship to chemical parameters (Table 5). The proportion of grass

Table 5
Spearman correlation coefficients of chemical parameters and components of F-bio-waste (average of 4 seasons).

	Dry matter	pH	N	Vol. solids	C:N	P	K	Ca	Mg	Fe
(a)										
Grass	0.03	−0.31	0.72**	−0.87***	−0.72**	0.65*	0.72**	−0.72**	−0.72**	0.72**
Plants	0.35	0.6*	−0.30	0.61*	0.35	−0.39	−0.39	0.39	0.13	0.00
Leaves	−0.19	−0.01	−0.76**	0.75**	0.74**	−0.56	−0.72**	0.72**	0.85***	−0.92***
Wood	0.93***	−0.26	−0.26	0.15	0.32	0.48	−0.39	0.39	0.00	0.19
Citrus fruit	0.55	−0.49	−0.19	0.45	0.25	−0.15	−0.31	0.31	−0.03	0.20
Fruit and vegetables	0.82**	−0.56	−0.69*	0.43	0.73**	0.35	−0.78**	0.78**	0.52	−0.39
Bread	0.75**	0.03	−0.64*	0.67*	0.70*	−0.03	−0.75**	0.75**	0.42	−0.25
Bedding	0.75**	0.03	−0.64*	0.67*	0.70*	−0.03	−0.75**	0.75**	0.42	−0.25
Soil	−0.09	0.89***	0.24	0.20	−0.22	−0.45	0.19	−0.19	−0.32	0.39
Paper	−0.19	−0.01	−0.76**	0.75**	0.74**	−0.56	−0.72**	0.72**	0.85***	−0.92***
Non-classifiable	0.24	0.30	−0.73**	0.89***	0.76**	−0.52	−0.78**	0.78**	0.65*	−0.58*
Improper	0.35	0.6*	−0.30	0.61*	0.35	−0.39	−0.39	0.39	0.13	0.00
Dry matter	1.00	−0.22	−0.38	0.25	0.39	0.44	−0.51	0.44	0.08	0.14
pH	−0.22	1.00	0.18	0.11	−0.27	−0.54	0.19	−0.31	−0.36	0.35
Nitrogen	−0.38	0.18	1.00	−0.70*	−0.90***	0.22	0.95***	−0.91***	−0.78**	0.78**
Volatile solids	0.25	0.11	−0.70*	1.00	0.84***	−0.59*	−0.78**	0.82**	0.82***	−0.60*
C:N	0.39	−0.27	−0.90***	0.84***	1.00	−0.32	−0.95***	0.94***	0.90***	−0.78**
P	0.44	−0.54	0.22	−0.59*	−0.32	1.00	0.20	−0.20	−0.42	0.31
K	−0.51	0.19	0.95***	−0.78**	−0.95***	0.20	1.00	−0.92***	−0.80**	0.73**
Ca	0.44	−0.31	−0.91***	0.82**	0.94***	−0.20	−0.92***	1.00	0.87***	−0.76**
Mg	0.08	−0.36	−0.78**	0.82***	0.9***	−0.42	−0.80**	0.87***	1.00	−0.87***
Fe	0.14	0.35	0.78**	−0.60*	−0.78**	0.31	0.73**	−0.76**	−0.87***	1.00
Mn	0.33	0.64*	0.44	−0.12	−0.42	0.02	0.35	−0.38	−0.62*	0.81**
Al	0.07	0.28	0.80**	−0.70*	−0.85***	0.45	0.78**	−0.76**	−0.93***	0.94***
As	0.21	−0.32	0.61*	−0.68*	−0.57	0.59*	0,62*	−0.52	−0.62*	0.73**
Cd	−0.31	0.20	0.86***	−0.71**	−0.89***	0.21	0.88***	−0.9***	−0.75**	0.79**
Cr	−0.20	−0.27	0.66*	−0.87***	−0.76**	0.52	0,76**	−0.73**	−0.65*	0.59*
Cu	0.11	0.31	0.83***	−0.65*	−0.82**	0.41	0.76**	−0.78**	−0.90***	0.97***
Ni	−0.31	0.12	0.90***	−0.75**	−0.88***	0.31	0.86***	−0.93***	−0.76**	0.74**
Pb	−0.25	−0.28	0.69*	−0.96***	−0.78**	0.59*	0.76**	−0.78**	−0.71*	0.54
V	0.07	0.28	0.80**	−0.70*	−0.85***	0.45	0.78**	−0.76**	−0.93***	0.94***
Zn	0.59*	−0.83***	−0.36	−0.16	0.31	0.72**	−0.38	0.35	0.17	−0.22
	Mn	Al	As	Cd	Cr	Cu	Ni	Pb	V	Zn
(b)										
Grass	0.20	0.72**	0.92***	0.76**	0.92***	0.72**	0.79**	0.92***	0.72**	0.31
Plants	0.58*	0.00	−0.43	−0.48	−0.78**	0.00	−0.52	−0.78**	0.00	−0.39
Leaves	−0.61*	−0.92***	−0.9***	−0.72**	−0.72**	−0.92***	−0.72**	−0.72**	−0.92***	−0.10
Wood	0.39	0.19	0.32	−0.35	−0.19	0.19	−0.32	−0.19	0.19	0.58*
Citrus fruit	0.72**	0.20	−0.16	−0.38	−0.61*	0.20	−0.41	−0.61*	0.20	−0.20
Fruit and vegetables	−0.19	−0.39	−0.04	−0.69*	−0.39	−0.39	−0.65*	−0.39	−0.39	0.78**
Bread	0.25	−0.25	−0.31	−0.75**	−0.75**	−0.25	−0.75**	−0.75**	−0.25	0.25
Bedding	0.25	−0.25	−0.31	−0.75**	−0.75**	−0.25	−0.75**	−0.75**	−0.25	0.25
Soil	0.78**	0.39	−0.22	0.06	−0.39	0.39	0.00	−0.39	0.39	−0.78**
Paper	−0.61*	−0.92***	−0.90***	−0.72**	−0.72**	−0.92***	−0.72**	−0.72**	−0.92***	−0.10
Non-classifiable	0.00	−0.58*	−0.80**	−0.82**	−0.97***	−0.58*	−0.84***	−0.97***	−0.58*	−0.19
Improper	0.58*	0.00	−0.43	−0.48	−0.78**	0.00	−0.52	−0.78**	0.00	−0.39
Dry matter	0.33	0.07	0.21	−0.31	−0.20	0.11	−0.31	−0.25	0.07	0.59*
pH	0.64*	0.28	−0.32	0.20	−0.27	0.31	0.12	−0.28	0.28	−0.83***
Nitrogen	0.44	0.80**	0.61*	0.86***	0.66*	0.83***	0.90***	0.69*	0.80**	−0.36
Volatile solids	−0.12	−0.70*	−0.68*	−0.71**	−0.87***	−0.65*	−0.75**	−0.96***	−0.70*	−0.16
C:N	−0.42	−0.85***	−0.57	−0.89***	−0.76**	−0.82**	−0.88***	−0.78**	−0.85***	0.31
P	0.02	0.45	0.59*	0.21	0.52	0.41	0.31	0.59*	0.45	0.72**
K	0.35	0.78**	0.62*	0.88***	0.76**	0.76**	0.86***	0.76**	0.78**	−0.38
Ca	−0.38	−0.76**	−0.52	−0.90***	−0.73**	−0.78**	−0.93***	−0.78**	−0.76**	0.35
Mg	−0.62*	−0.93***	−0.62*	−0.75**	−0.65*	−0.9***	−0.76**	−0.71*	−0.93***	0.17
Fe	0.81**	0.94***	0.73**	0.79**	0.59*	0.97***	0.74**	0.54	0.94***	−0.22
Mn	1.00	0.76**	0.34	0.37	0.03	0.78**	0.30	−0.03	0.76**	−0.41
Al	0.76**	1.00	0.72**	0.72**	0.59*	0.97***	0.70*	0.59*	1.00	−0.16
As	0.34	0.72**	1.00	0.64*	0.80**	0.69*	0.59*	0.73**	0.72**	0.31
Cd	0.37	0.72**	0.64*	1.00	0.83***	0.76**	0.94***	0.75**	0.72**	−0.30
Cr	0.03	0.59*	0.80**	0.83***	1.00	0.57	0.80**	0.94***	0.59*	0.19
Cu	0.78**	0.97***	0.69*	0.76**	0.57	1.00	0.77**	0.57	0.97***	−0.19
Ni	0.30	0.7*	0.59*	0.94***	0.8**	0.77**	1.00	0.80**	0.70*	−0.21
Pb	−0.03	0.59*	0.73**	0.75**	0.94***	0.57	0.80**	1.00	0.59*	0.24
V	0.76**	1.00	0.72**	0.72**	0.59*	0.97***	0.70*	0.59*	1.00	−0.16
Zn	−0.41	−0.16	0.31	−0.30	0.19	−0.19	−0.21	0.24	−0.16	1.00

Values calculated are based on 24 sampling occasions.
* Statistically significant at the probability level 0.05.
** Statistically significant at the probability level 0.01.
*** Statistically significant at the probability level 0.001.

correlated positively with a majority of monitored elements, but presented high negative correlations with volatile solids ($R = -0.87^{***}$) and C:N ($R = -0.72^{**}$). It is contrary to grass originated in U-bio-waste. The probable reason is age of grass. Fresh short grass originated in frequent mowing of lawn in gardens has higher content of N and short C:N rate (F-bio-waste) in contrast to old grass (U-bio-waste) probably remaining as a rest after feeding of guinea pigs and other small animals kept in some flats. The behavior of leaves was contrary to grass. Unlike the content of volatile solids, C:N ratio, Ca and Mg increased and the content of other elements decreased. The higher proportion of leaves in autumn and winter caused a significantly lower content of PTE in F-bio-waste. A close positive relationship found between content of N, K, Fe and PTE probably shows the same origin of these elements. On the other hand, a high negative correlation of PTE was found with volatile solids, C:N, Ca and Mg. The negative relationship between PTE and volatile solids and on the contrary positive correlation between PTE and ash could indicate that the origin of PTE will be probably mainly in soil. Similarly Boldrin and Christensen (2010) found close positive relationship of PTE with Ca, Fe, K and Mg, and negative correlation with volatile solids and C:N. Unlike us, they used garden bio-waste itself and Pearson's correlation analysis. The relationship of Zn as a representative of PTE to the majority of chemical parameters was indifferent, with the exception of phosphorus ($R = 0.72^{**}$) and pH ($R = -0.83^{***}$). Hanc et al. (2009) found that increases of pH during composting of garden bio-waste led to a decrease of available Zn content ($R = -0.81$; $p < 0.05$).

4. Conclusion

The composition of bio-waste collected in urban settlement through four seasons was almost invariable. Fruit and vegetable waste prevailed. Bio-waste collected from family houses was affected by seasonal garden activity. Chemical parameters were influenced by the proportions of components in bio-waste. The amount of variation among seasons in both type of bio-waste increased in sequence: basic parameters < macro-elements < potentially toxic elements (PTE). It would indicate that there is need to analyze for PTE frequently than others parameters. On the other hand, the total content of PTE in four seasons complied with regulations. Majority of bio-waste was dry and addition of water would be suitable before biological processing. According to composition and parameters, U-bio-waste is preferable for anaerobic digestion and F-bio-waste for composting. It is possible to modify and combine the two processes, to get a high biogas yield and agronomically available fertilizer. In the case of composting of U-bio-waste with low pH, the addition of a bulking agent is a prerequisite. Added reason for addition of a bulking agent is requirement to achieve a more porous structure that promotes aeration. Wood chips made of wood and branches from winter F-bio-waste collection would be suitable. The problem of high C:N could be solved by this way. The analyses of dry matter content and volatile solids showed that F-bio-waste from winter period is more suitable for eventual waste to energy compared to other seasons. This suggestion could be supported by low content of recoverable N, P and K nutrients in F-bio-waste during winter. Low compost consumption and high demand for energy in winter is added reason for the use of this conception.

Characterization of bio-waste originated in other neighborhoods should be realized to compare results presented in this study. Obviously, detailed chemical analysis of individual components across seasons would be useful for specification of the results. Further research should be focused on variability of PTE which was higher than other parameters among seasons. Sequential analysis would be appropriate to carry out.

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