COMPOSITIONAL ANALYSIS OF FOOD WASTE ENTERING THE SOURCE SEGREGATION STREAM IN FOUR EUROPEAN REGIONS AND IMPLICATIONS FOR VALORISATION VIA ANAEROBIC DIGESTION

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SUMMARY: Separate collection of food waste from households is an efficient instrument for diversion of organic material from landfill to biological treatment. There is widespread consensus that source-segregated food waste is a suitable substrate for valorisation through anaerobic digestion with biogas production. Source-segregation concepts are adopted by more and more municipalities in European countries and elsewhere. Food waste can be collected in separate food waste collection units or together with other organic materials. Based on a campaign of sorting seperatly collected materials in four European countries, along with physico-chemical analyses, the present manuscript is aimed at providing an overview of differences and similarities in food wastes enterenting the respective source segregation stream. Factors related to suitability of materials for anaerobic digestion are discussed.

1. INTRODUCTION

Aside of regulatory implications, there are strong arguments for the diversion of food waste from landfills, such as the possibility for biogas generation along with recuperation of nutrients, the general environmental benefits (Grosso et al., 2012; Takata et al., 2012), or the possibility to use

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it as a resource for high-value chemicals (Pfaltzgraff et al., 2013). Anaerobic digestion (AD) of food waste, either as mono-substate or as co-substrate, is a well studied subject (Banks et al., 2011a; Brown and Li, 2013; Cho et al. 2013; Zhang et al., 2013). Full-scale AD processes for valorisation of food waste are in general based either on the plug-flow or the CSTR (Continuous Stirred Tank Reactor) concept. It has however also been observed that alternative reactor concepts such as the Fluidized Bed Reactor might offer better stability when digesting food wastes (Kastner et al., 2012). Aside of process technology, stability problems can be linked to the composition of the food waste, which might vary in different regions and with different collection schemes. Characterisation of food waste in household composition studies is not an easy task, and results are often hardly comparable due to different classification systems (Lebersorger and Schneider, 2011).

In this study a classification system for food waste was developed under special consideration of requirements with view to valorisation of materials via anaerobic digestion. Food waste entering the source segregation stream in selected regions in the UK, Finland, Portugal and Italy was analysed for its major components. In addition to compositional analysis of organic wastes (and in particular the contained food waste), physicochemical characterisation was carried out on samples of source segregated materials. Aside of gaining knowledge of the nature and properties of food waste, and in particular of any major regional differences in composition that could impact upon its behaviour as a feedstock for anaerobic digestion, it was one aim to provide information on properties and quality to complement assessment of collection schemes. The UK has only recently introduced source segregation for domestic organic wastes, and a distinct focus was set to derive precise data for segregated UK food waste.

This presentation is based on the results compiled in the report for the the Deliverable 'Compositional analysis of food waste from study sites in geographically distinct regions of Europe' of the FP7 EU project 'Valorisation of food waste to biogas' (Valorgas Deliverable D2.1, 2011).

2. MATERIAL AND METHODS

2.1 Classification system for waste stream components

A variety of categorisation systems exists for the main components of waste streams, including the organic fraction of municipal solid waste, source segregated organic waste or food waste from households. Compositional characterisation of waste streams is often carried out under different focus and based on national guideline or generally applied procedures. In order to allow comparison of results, in a first step the variety of existing categorisation systems (including the ones applied by the Valorgas project partners) for classification of food waste stream components were adopted as a framework and mapped into a uniform system particularly suitable for the assessment of components for valorisation via the anaerobic digestion pathway.

The development of the Valorgas waste categorisation system was mainly based on four existing systems:

- The system used by the Portuguese partner Valorsul, itself based on the MODECOM system (ADEME, 1997) and on national guidelines (DGQA, 1989), which includes a wie range of materials providing a detailed breakdown of potential contamination in source segregated collection systems
- The system of UK company Greenfinch, developed in-house to provide insight into the behaviour of participants in source segregated domestic waste collection systems
- The two detailed categorisation systems applied during the major survey of food waste in England and Wales carried out by the UK government-funded Waste and Resources Action

Programme (WRAP 2008, 2009)

The extensive sorting programme of the WRAP study characterised domestic food waste into 174 types, combined into 13 major categories. In order to maximise the usefulness and comparability of the outputs of the Valorgas project, the full set of food waste types used by WRAP (2008) and revised in WRAP (2009) was considered too complex and unnecessarily detailed, but the major categories were adopted.

Certain items required special treatment in view of the purpose of the study. The WRAP (2008) categories for fruit and vegetables, which were themselves modified in the WRAP (2009) study, were simplified into two subcategories of waste (peels, rinds, uneaten residues etc) and whole fruit and vegetables, to allow the possibility of distinguishing between avoidable and unavoidable waste which was a key element in the work by WRAP. A sub-category of 'Large stones, seeds and fibrous materials' was added, as these items are sometimes rejected by automated pre-treatment systems or in manual sorting for laboratory-scale anaerobic digestion studies. A sub-category 'Bones' was added to 'Meat and fish', as bones are specifically excluded from many source segregated waste collection schemes and are often rejected in pre-treatment screening. A subcategory 'Eggshells' was added to the main category 'Dairy', because of the low biodegradability of this component. A combined category was introduced for confectionery, snacks and desserts as these items are difficult to distinguish and are present only in small quantities. Similarly, the WRAP category 'Condiments, sauces, herbs and spices' was combined with 'Mixed meals' due to the practical difficulty of distinguishing between these items in source segregated food waste.

The resulting categorisation system used in the project, and its relationship to the other systems, is shown in Table 1.

Table 1. Waste categorisation used for VALORGAS with mapping to related systems (numbers show order of categories in original source)

WRAP revised (2009)	WRAP original (2008)	VALORSUL	VALORGAS	Greenfinch
1 Fresh vegetables and salads 3 Fresh fruit 8 Processed vegetables and salad 14 Processed fruit	7 Vegetables 5 Fruit 6 Salads	1 Vegetables 13 Fruit 3 Salads	1 1a Fruit and vegetable waste 1b Fruit and vegetables (whole) 1c Large stones, seeds and fibrous materials	1 Fruit & veg peelings 2 Fruit & veg whole 17 Seeds & stones
10 Staple foods	4 Dried foods/powders	8 Dried foods/powders	2 Pasta/rice/flour/cereals	3 Pasta/rice/flour 9 Cereal
4 Bakery	1 Bakery	10 Bakery	3 Bread and bakery	4 Bread and bakery
6 Meat and fish	2 Meat and fish	9 Meat and fish 32 Special - bones	4 4a Meat and fish 4b Bones	5 Meat and fish 6 Bones
7 Dairy and eggs	3 Dairy	7 Dairy	5 5a Dairy 5b Egg shells	8 Dairy 7 Eggs
2 Drinks	9 Drinks	4 Drinks	6 Drinks	10 Tea bags & coffee
13 Confectionery and snacks 11 Cake and desserts	8 Confectionery and snacks 11 Desserts	5 Snacks	7 7a Confectionery and snacks 7b Desserts	11 Sweets & desserts
9 Condiments, sauces, herbs and spices 5 Meals (homemade and pre-prepared)	10 Condiments, sauces, herbs and spices 12 Mixed foods	12 Condiments, sauces, herbs and spices 6 Mixed meals	8 8a Condiments 8b Mixed meals	16 Mixed meals
15 Other 12 Oil and fat	13 Other	11 Other food	9 Other food	12 Other food material
			10 Biodegradable bags	14 Biodegradable bags
		2 Garden waste	11 Garden waste	13 Non food biodegradable w
		14 Paper 15 Cardboard - packaging 16 Cardboard - non packaging	12 Paper and card	
		17 Plastic - film bags 18 Plastic - bottles 19 Plastic - polystyrene 20 Plastic - other 23 Ferrous metals 24 Non ferrous metals 21 Glass - packaging 22 Glass - non packaging 25 Composites 26 Textiles 27 Sanitary textiles 28 Combustibles - wood 29 Combustibles - other 30 Incombustibles 31 Special - packaged organics 33 Special - other	13 13a Plastic containers 13b Plastic film (non-biodegradable) 13d Metals 13e Glass 13f Miscellaneous	

2.2 Compositional characterisation

2.2.1 Waste sampling procedures and overview on sampled collection schemes

Waste samples for compositional characterisation were obtained from 23 collection rounds in 15 cities across the four EU member states. The majority of the collection schemes sampled were located in the UK to ensure the evaluation included a range of collection schemes specifically targeting source segregated food waste.

A.) UK - A total of 35 waste compositional analyses were carried out for 16 different collection rounds in 12 locations as shown in Table 2. In each case, food waste is separated from dry recyclable materials, green waste and residual waste by the householder and collected by a local authority or contractor from the kerbside on a weekly basis. The collection rounds were chosen because the waste was collected in biodegradable cornstarch plastic bags, and was not mixed with waste from other sources before delivery. A total of 100 bags were randomly selected from each source: if several delivery vehicles were expected from one source, an equal number of bags was selected from each load. The date and source of collection, total weight of the delivered load (Avery Weigh-Tronix weigh bridge) and the total weight of the selected bags (EHI-B Indicator balances, model PS-102) was recorded to 0.1 kg. The waste was transferred to the characterisation area and the weight of each bag was recorded to 0.1 g (Adam Electrical, model CDW-3). Each bag was opened and visually inspected for the presence of sharps prior to sorting the contents into the defined categories. The nature of any non-food biodegradable material, other food material and contamination was recorded. The weight of material in each sorted category was determined. A core characterisation team performed all the analyses in order to maintain consistency within the project. Photographic evidence was recorded at all stages.

Table 2. Sources of waste for UK compositional analysis

	Location	Dates	Collection type	No.	Rounds
1	Ludlow [a]	4 - 7, 10 - 14, 17 - 21 & 28 May 2010	A	15	5
2	Craven Arms [a]	6 May, 12 May, 19 May 2010	A	3	1
3	Church Stretton [a]	4 & 5 May, 10 & 11 May, 17 & 18 May 2010	A	6	2
4	Flintshire [a]	25 May 2010	-	1	-
5	Presteigne	27 May & 12 July 2010	A	2	1
6	Ceredigion	4 June, 18 June 2010	B	2	1
7	Leatherhead	10 Sep 2010	C	1	1
8	Central Bedfordshire	9 Sep 2010	A	1	1
9	Ealing	9 Sep 2010	C	1	1
10	Richmond	9 Sep 2010	C	1	1
11	Surrey	9 Sep 2010	C	1	1
12	Hounslow	9 Sep 2010	C	1	1
	Total			35	16

A Small (5 or 7 litre) kitchen caddies with larger (25 litre) kerbside bins collected weekly. Cornstarch bags are supplied free of charge on request

B As above but householder must buy bags or wrap waste in newspaper; only waste in bags analysed

C As a above but householder must pay for cornstarch bags

a Categories Mixed meals and Seed and stones not used in these cases; data therefore treated separately

B.) Finland – Sorting of one sampling campaign is reported in the following (results of further sortings not yet published). The sample was taken from the Forssa waste treatment plant in south-west Finland. Envor Biotech Ltd, a waste management company, receives and treats food waste from markets, restaurants, catering services and households in the Forssa region (14 municipalities, around 2800 tonnes year^{-1}). In general, each collection scheme includes all types of food waste. All houses with five or more apartments, and stores and restaurants with more than 20 kg week^{-1} have to source-segregate food waste. Individual houses or group of houses can also source-segregate waste for municipal collection, but this is uncommon materials accepted by the scheme include food leftovers; fruit and vegetable peelings; coffee grounds, filters and teabags; eggshells and egg cartons; paper serviettes; cat faeces and litter; and garden waste (leaves, parts of plants, house plants and flowers). In the households, food waste is source segregated in biodegradable plastic bags or newspaper. If a large biodegradable plastic bag is placed inside the collection bin, this is also acceptable in the scheme. Collection is usually once per week. For compositional analyses, a load consisting of source-segregated household food waste was selected from the material arriving at the waste management plant on 03.03.2011.

C.) Portugal - Valorsul provides collection services for source segregated OFMSW (organic fraction of municipal waste) to 2547 large producers (e.g. restaurants, canteens, hotels) and 1988 households in the Lisbon area. For households the waste is collected daily from 120-litre bins serving a number of properties (e.g. apartments): each property has an individual bin, but biodegradable plastic bags are not provided. Materials accepted by the scheme include vegetables, bread, meat, fish, eggs, cakes and desserts, confectionery/snacks, tea bags, fruit peel and paper napkins. Excluded materials are liquid residues, packaging, crockery, cutlery, baking and aluminium foil papers, plastic bags, cigarette ends and textiles. The waste is transported in 15 m^3 refuse collection vehicles with compaction. For the compositional analysis, five samples of source segregated household waste only were taken from one of two collection rounds serving domestic properties. The first sample was taken in the first week of February 2011, and the remaining samples on four consecutive days in the following week. The selected load was discharged from the collection vehicle and mixed using a wheel loader. A sub-sample of ~250 kg was then taken by quartering the mixed sample which was then sorted by hand on a sorting table with individual components weighed to ±0.01 kg (ADAM scales, Milton Keynes, UK).

D.) Italy - A single sample was characterised from Treviso, Italy. The collection system in the city is based on the provision of a centralised bin serving several houses for the collection of source segregated OFMSW: waste is generally disposed of in plastic bags, although the use of biodegradable plastic bags is becoming compulsory. The waste is transported to the Treviso processing site in conventional compaction vehicles. The sample for compositional analysis was taken from bulk material entering the processing site and was obtained by the quartering method, starting from ~200 kg of waste. The initial amount of waste was divided into four parts of ~50 kg each and two opposite segments were chosen: these two segments were mixed again, divided into four parts of ~25 kg and one of these was used as the main sample.

2.2.2 Sorting

Material collected for characterisation was subject to manual sorting. Figure 1 shows an example of detailed sorted materials from Ludlow (UK), including contaminants.

Figure 1. Waste after detailed sorting (Ludlow, UK)

As two of the collection schemes are not targeting food waste only but OFMSW, the overall food waste components in the collected materials in these countries would be much lower. In each case the food waste components only were regrouped in sum in order to enable comparision of the food waste components entering the segregation schemes.

2.3 Physico-chemical analysis

In addition to compositional characterisation of the food wastes, selected samples from each of the four studied areas were analysed physico-chemical for the following parameters: pH, total solids (TS), volatile solids (VS), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), calorific value (CV), lipid, protein, total phosphorus (TP), total potassium (TK), and elemental composition (CHN).

2.3.1 Sampling

A.) UK - A sample of ~200 kg was obtained from the Eastleigh food waste collection scheme. After the material was transported to the laboratory, the food waste was taken out of biodegradable plastic bags and any contaminants and non-biodegradable components were removed. The material was then processed by passing it through a macerating grinder (S52/010 Waste Disposer, Imperial Machine Company (IMC) Limited, Hertfordshire, UK). This produced a very homogeneous material which was further blended in a single container with a drill mixer to give a mix of which any part was as representative as possible of the entire batch collected.

B.) Finland - A sub-sample from the Forssa plant was obtained as described in 2.2.1, but instead of being hand sorted it was first mechanically crushed and screened for plastics, then passed through a full-scale homogenizer at the waste treatment plant to give a particle size of ~2 mm.

C.) Portugal - Three samples were taken at the Valorsul anaerobic digestion plant, corresponding to raw waste arriving at the plant, the digester feed, and the reject stream after a pre-treatment process involving manual sorting, shredding, sieving and hydropulping as described by Vaz et al. (2008).

D.) Italy - The sample passed through the normal mechanical pre-treatment stages of the plant, including shredding, removal of ferrous iron non-ferrous metals and screening of the residual in a trommel screen (Bolzonella et al., 2006). A final shredding was then performed to reduce the substrate size and ensure homogeneity.

Representative sub-samples of 2-3 kg wet weight were packed in ice and/or frozen and sent to the laboratories of the research partners (MTT, University of Southampton, University of Venice), arriving on the day after sending. Each sample was first homogenised and then divided into two portions, one for analyses conducted on fresh material, and one for drying. The fresh samples were stored frozen until used, and the dried materials were ground and stored in sealed containers.

2.3.2 Analytical Methods

All analytical methods conformed to established standards (as one further element comparative analyses were carried out by the involved laboratories – this work and its results are not reported here). Full details for all analytical methods are documented in the reporting of the project Valorgas (Valorgas Deliverable D2.1, 2011).

3. RESULTS AND DISCUSSION

3.1 Compositional characterisation of food waste

The results of the compositional analyses are available in full detail in the respective project report of the project Valorgas (Valorgas Deliverable D2.1, 2011). The following highlights the main results in a comparative approach for the four countries.

3.1.1 Differences and similarities in the four countries

It is clear from summarizing the main results (Table 3) that there are both differences between the samples, and also an important degree of similarity. In all cases 'Fruit and vegetable wastes' form the largest proportion, making up on average from 45-70% of the total wet weight in each case. The proportion of 'Meat and fish' was similar in all countries, and this may be important as this category is likely to make a major contribution to the high protein and nitrogen content of food waste, which in turn can lead to stability problems in anaerobic digestion. The percentage of 'Bread and bakery' products was similar in Finland, Portugal and Italy and only higher in the UK; differences in the category will tend to be enhanced on a wet weight basis as these products have a high capacity to absorb any liquid present or generated as the waste begins to degrade in transport. Only waste from Italy showed a high proportion of the category Pasta/rice/flour/cereals. 'Mixed meals' and 'Drinks' showed a particularly wide range, probably reflecting both national differences (e.g. tea bags in the UK, coffee in Finland) and aspects of the waste collection system.

To understand differences in composition it would also be of interest to characterise the proportion of domestic food waste not entering the source segregated stream – a factor which could not be quantified in this study. The food waste composition found by the WRAP (2008) survey deriving data from sorting the food components from mixed waste was very similar to that of the UK samples of this study, with a slightly lower total for fruit and vegetable waste and corresponding small increases in other categories.

Table 3. Comparison of results of compositional analysis for samples from UK, Finland, Portugal and Italy (Food waste component only in source segregated organic waste stream), and overview of WRAP results for UK food waste derived from sorting the food components from mixed waste.

% wet weight	UK [a]	Finland	Portugal	Italy	Ave	WRAP [b]
Fruit and vegetable waste	60.9	44.5	59.2	69.0	58.4	46.6
Pasta/rice/flour/cereals	1.5	0.4	0.2	12.4	3.6	2.5
Bread and bakery	9.0	3.8	3.1	2.8	4.7	13.4
Meat and fish	6.7	4.3	7.3	6.2	6.1	8.4
Dairy	1.7	2.0	0.7	1.4	1.4	3.5
Drinks	7.1	27.5	0.2	0.0	8.7	8.0
Confectionery, snacks etc	0.7	3.2	0.3	0.0	1.0	1.7
Mixed meals	12.3	6.3	29.0	1.4	12.2	12.9
Other food	0.2	8.0	0.0	6.9	3.8	3.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

[a] Data from 8 sites using all food waste categories [b] Based on WRAP (2008)

The study reported here did not take into account possible seasonal variations in food waste composition: the samples analysed were from summer in the UK, however, and winter or early spring in Finland, Portugal and Italy. To study the relevant correlations in full detail it would be one main aspect to look at the variations of the individual fractions between the seasons, but also within the seasons. Based on the summarizing overview in Figure 2 it is one conclusion that in the studied four European countries variations in the fractions ‘Fruit and vegetable waste’, ‘Drinks’ and ‘Mixed meals’ are most influencial for changes in the composition of source-segregated food waste.

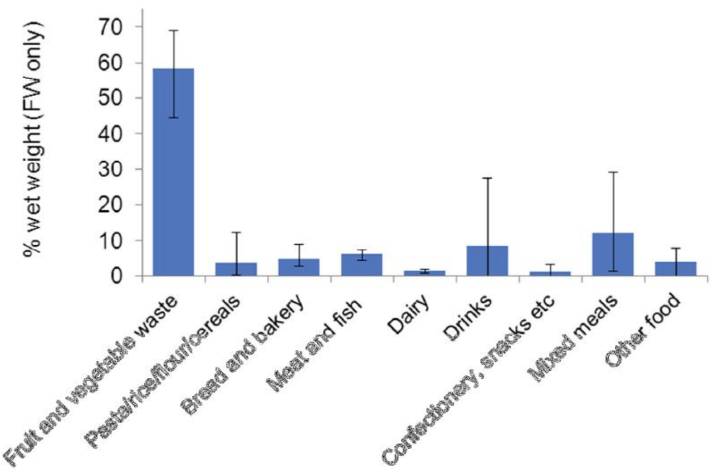

Figure 2. Comparison of results of food waste compositional analysis for samples from UK, Finland, Portugal and Italy (Error bars show range)

3.1.2 Degrees of contamination and specific aspects related to the collection schemes

Different degrees of contamination were found in the different collection schemes. The UK samples showed low or exceptionally low contamination. The samples from Portugal and Finland had low contamination levels similar to those for the UK, while the sample from Italy had a much higher proportion of contaminants. The results were as follows:

- A.) UK - The average contamination was low at < 2% of the total sample weight, although the sites could be broadly grouped as low (2-3%: Leatherhead, Central Beds, Ealing, Richmond, Surrey) and very low contamination (< 0.5%: Ludlow, Craven Arms, Church Stretton, Flintshire, Hounslow), possibly reflecting how long the scheme had been established.
- B.) Finland - The proportion of non food waste component in the sample was high at 27.5% of the total weight. The two main components categorised as contaminants were 'Paper and card' (17.5%) and 'Garden waste' (7.2%). Both of these materials are accepted for processing in the Forssa scheme, as is pet litter; the term 'contaminant' is therefore only relevant in the context of a pure food waste collection. Other types of contaminant (plastic bags and containers, glass, metals, and miscellaneous or composite items) made up < 2% of the total waste or around 2.5% of the food waste component, indicating a reasonably low degree of contamination.
- C.) Portugal - The sample included a proportion of 'Paper and card' (6.3% of total weight) and a very small amount of 'Garden waste' (0.8%). The main contaminant was plastic bags (6.0%): as biodegradable bags are not provided in this scheme, this represents a considerable input of contamination and a reduction in the potential for energy recovery from the biodegradable plastic. The remaining contaminants (plastic bottles, polystyrene foam and other plastics, glass, metals, composites, textiles, combustibles and special items) made up around 3.6% of the total weight, indicating that the degree of contamination without taking into account plastic bags was reasonably low. The sorters reported finding batteries in the collected sample on two separate occasions.
- D.) Italy - The collected material contained a large amount of 'Garden waste' and 'Paper and card', at 15.2 and 13.8% of the total waste sample respectively. It also contained 3.0% of clear contaminants including plastic containers and film, metals, and glass, and 12.8% of unclassifiable materials (mainly a mixture of organic and inert fines). With a further 3.7% being biodegradable plastic bags, the food waste made up only 51.5% of the incoming material (wet weight basis), and the contamination level is to be classified as relatively high.

These results may reflect physical and logistical aspects of the collection system (e.g. bin size, collection frequency): Arnold et al. (2010) noted that reduction in bin size led to an improvement in the proportion of food waste collected. The length of time for which source segregated collection systems have been operating may be a factor as well: the UK has only recently introduced source segregation for domestic organic wastes, and may therefore benefit from a sharper focus on food waste. The degree of contamination is a cause for concern for several reasons, including the risk of introducing potentially toxic elements (PTE) which may affect digestate quality, e.g. from the presence of batteries as reported in the sample from Loures.

3.2 Physico-chemical characteristics of the food wastes

The results of the physico-chemical characterisation of the samples are given in Table 4, with those for some closely comparable UK food waste samples carried out as part of the Defra-funded research that ran in parallel with the early stages of the VALORGAS project (Banks et al., 2011b).

Results of the physico-chemical analyses showed a strong tendency to similarity in the samples, especially from the viewpoint of key parameters in anaerobic digestion. Total and volatile solids contents were generally similar. TKN values were similar as well and as expected were relatively high on a wet weight basis, suggesting the potential for ammonia toxicity with this feedstock. Concentrations of plant nutrients (N, P and K) suggested that the digestate from this feedstock has significant potential for fertiliser replacement. The elemental analysis was in good agreement and the measured calorific value confirmed this is an energy-rich substrate.

Table 4. Results of preliminary physico-chemical characterisation of waste samples

		UK					Finland	Italy		Portugal		
		Luton [a]	Hackney [a]	Ludlow [a]	Eastleigh	Eastleigh	Forssa	Treviso	Treviso	Lisbon raw waste	Lisbon to digester	Lisbon to digester
		(Lab 2)	(Lab 2)	(Lab 2)	(Lab 2)	(Lab 1)	(Lab 1)	(Lab 1)	(Lab 3)	(Lab 3)	(Lab 1)	(Lab 3)
Fundamental characteristics for anaerobic digestion												
pH		5.12 ± 0.01	5.18 ± 0.01	4.71 ± 0.01	5.02 ± 0.01	5.70	5.34	6.16			5.93	
TS	% WW [b]	23.70 ± 0.06	25.74 ± 0.18	23.74 ± 0.08	25.89 ± 0.01	28.62 ± 0.07	27.02 ± 0.12	27.47 ± 0.03	24.43 ±4.57	33.80	6.31 ± 0.005	6.33
VS	% WW	21.84 ± 0.10	23.47 ± 0.31	21.71 ± 0.09	24.00 ± 0.03	26.83 ± 0.16	24.91 ± 0.05	23.60 ± 0.09	20.16 ± 3.75	27.60	4.93 ± 0.05	5.01
VS	%TS	91.28 ± 0.20	91.17 ± 0.91	91.44 ± 0.39	92.70 ± 0.12	94.18 ± 0.42	92.26 ± 0.26	86.60 ± 0.40	83.32 ± 5.87	81.7	78.19 ± 0.86	79.1
TOC	%TS	51.2 ± 1.2	51.3 ± 0.2	48.3 ± 1.0	48.76 ± 0.87							
TKN		3.12 ± 0.01	3.13 ± 0.03	3.42 ± 0.04	2.91 ± 0.05	2.74 ± 0.05	2.39 ± 0.04	2.55 ± 0.03	2.84 ± 0.76	1.5	6.93 ± 0.07	4.30
TKN	$g\ kg^{-1}$ WW	7.39 ± 0.02	8.06 ± 0.08	8.12 ± 0.09	7.53 ± 0.13	7.84 ± 0.16	6.45 ± 0.1	7.02 ± 0.1	7.19 ± 2.06	5.1	4.37 ± 0.05	2.72
CV	$kJ\ g^{-1}$ TS	21.43 ± 0.12	21.64 ± 0.11	20.66 ± 0.18	20.97 ± 0.02	21.32 ± 0.08	21.39 ± 0.11	20.50 ± 0.01			25.23 ± 0.26	
Biochemical composition												
Lipids	$g\ kg^{-1}$ VS	148 ± 4	157 ± 2	151 ± 1	149 ± 1	152 ± 2	156 ± 0.5	202 ± 0.5			314 ± 0.4	
Crude protein	$g\ kg^{-1}$ VS	213 ± 1	213 ± 2	235 ± 3	197 ± 4	183 ± 4	162 ± 0.4	186 ± 3			554 ± 6	
Nutrients												
TKN (N)	$g\ kg^{-1}$ TS	31.2 ± 0.1	31.3 ± 0.3	34.2 ± 0.4	29.1 ± 0.5	27.4 ± 0.5	23.9 ± 0.4	25.5 ± 0.3	28.44 ± 7.62	15	63.9 ± 0.7	43.0
TP (P)	$g\ kg^{-1}$ TS	4.87 ± 0.08	6.41 ± 0.12	5.41 ± 0.32	2.82 ± 0.13	2.94 ± 0.01	2.73 ± 0.05	3.47 ± 0.06	3.26 ± 1.54	5.0	8.92 ± 0.12	4.0
TK (K)	$g\ kg^{-1}$ TS	12.3 ± 0.1	12.9 ± 0.6	14.3 ± 0.8	8.59 ± 0.27	11.2 ± 0.2	10.0 ± 0.2	10.0 ± 0.1			29.2 ± 0.4	
Elemental analysis												
N	%TS	3.12 ± 0.01	3.13 ± 0.03	3.42 ± 0.04	2.91 ± 0.05	2.80 ± 0.02	2.46 ± 0.03	2.58 ± 0.05			5.72 ± 0	
C	%TS	51.2 ± 1.2	51.3 ± 0.2	48.3 ± 1.0	48.8 ± 0.9	50.6 ± 0.2	49.4 ± 0.04	47.2 ± 0.01			54.8 ± 0.1	
H	%TS	6.56 ± 0.04	6.67 ± 0.13	5.53 ± 0.63	6.37 ± 0.19							
S	%TS	0.21 ± 0.00	0.23 ± 0.03	0.15 ± 0.01								
O	%TS	30.7 ± 1.2	29.8 ± 0.4	34.3 ± 2.5	34.7 ± 0.9							

[a] Samples analysed as part of the Defra funded project WR1208 (Banks et al., 2011) [b] WW = wet weight

3.3 Impications for anaerobic digestion

The sorting also provided additional interesting insights into the nature and properties of source-segregated domestic food waste as a substrate for anaerobic digestion. Between 1.2-1.4% of the wet weight of food waste consisted of eggshells: these have a high total solids content, do not contribute to the organic loading rate on a volatile solids basis and normally pass through the digester almost unaffected, although they could potentially contribute to maintaining alkalinity in some cases. Bones comprised respectively 3.3, 0.5 and 2.0% of the food waste component in the UK, Finland and Italy. No bones were reported in the samples from Portugal, possibly as these are explicitly excluded from the list of acceptable materials for the Loures collection: in most schemes bones are either excluded or rejected as they are not broken down in the digestion process, can harm equipment, and may cause problems in complying with Animal By-products Regulations (EC 1774/2002 and implementing regulations in each member state). Certain types of seed and fruit stone are similar to bones with respect to their potential to cause wear and tear on equipment: as noted above, there was a considerable difference in the proportion of this material reported, from < 1% in the UK to ~9% in Italy while Finland and Portugal did not record any.

Biodegradable bags made up 4.2% (range 1.7-6.1%), 1.6% and 3.7% (wet weight basis) of the total sample weight for the UK, Finland and Italy respectively, representing an even higher proportion with respect to the food waste component. In the case of Finland biodegradable bags made up 1.6% of the total sample weight or 2.3% of the food waste component, similar to UK values. While these percentages were for wet and dirty material, the volatile solids content of the bags themselves is very high. The average biodegradable plastic bag typically weighs 6-10 g (CeDo Ltd, personal communication). In the case of UK each sort was carried out on 100 bags, and the expected dry weight of biodegradable plastic would be around 0.5-1% of the total, indicating that about 3% of the wet waste had adhered to the separated bags.

Fully degradable bags may therefore contribute a small but useful proportion of the overall biogas yield from anaerobic digestion of food waste, while nonbiodegradable bags represent a major source of contamination, equal to about 6% of the total sample weight in Portugal, and are likely to reduce the quality of the final digestate.

4. CONCLUSIONS

The results of the compositional sorting provide useful insights into the presence of specific components and therefore is to be considered a powerful technique for gaining information on the performance of a source segregated schemes in terms of the degree and nature of contamination, especially if linked to examination of the type of collection system. The results of the study allow assessment of the material as far as its suitability as a feedstock for anaerobic digestion is concerned.

Despite some variation in the waste compositions, the values for key analytical parameters showed a high degree of similarity. This is understandable in the sense that while food preferences and cuisine may vary from region to region, the fundamental requirements of human diet and therefore of domestic food waste are likely to remain similar.

The physico-chemical approach may be more powerful in terms of assessing the suitability of a material as a feedstock for anaerobic digestion; but waste categorisation and sorting can clearly provide valuable information on the degree of the success a collection scheme has in obtaining its targeted materials.

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