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CHARACTERIZATION OF WASTES AND WASTEWATERS GENERATED FROM DIFFERENT PROCESSES

DELIVERABLE 6.2

PulpIng

Developing of **Pu**mpkin Pu**lp** Formulation using a Sustainable **Int**egrated Strategy

Index

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1. Executive Summary

This document is deliverable 6.2 of Work Package 6 of the PulpIng project. In this report, the characterization of waste and wastewater generated by the different processes evaluated within the scope of this project is described, for all life cycle stages of the pumpkin pulp, at short and long-term.

The PulpIng project aims to ensure a more sustainable strategy for waste management of pumpkin sub products. By analysing the entire life cycle of the pumpkin pulp product, the life cycle assessment of before and after scenarios (i.e. without and with the use of a preservative formulated from pumpkin by-products) will allow to verify and quantify environmental sustainability. The specific analysis of generated wastes and wastewaters will also allow for the identification of the best treatment options and possible valorisation routes.

2. Description of work

Within the scope of the PulpIng project, a new preservative obtained from pumpkin by-products was developed for incorporation in the packaged pumpkin pulp product from the Portuguese company Decorgel. To ensure the environmental sustainability of the different processes involved in this pumpkin-based product value chain, the system has been analysed throughout its entire life cycle for the identification of generated solid waste and wastewater. For that, it was necessary to understand the entire value chain recurring to the literature and PulpIng partners.

In this deliverable (6.2), only the life cycle of the packaged pumpkin pulp, when the production is carried out in the traditional manner, i.e. without the use of extracts from pumpkin by-products, is considered, as the extract production constitutes a waste valorisation process; hence, it is reflected upon later deliverables. When possible, real data obtained specifically throughout the PulpIng project in straight contact with the project partners was used. Lack of data was addressed through bibliographic research and will be identified accordingly.

2.1. Goal

To identify, quantify and characterize solid waste streams and wastewater effluents within the pumpkin pulp product value chain, for further analysis of valorisation/treatment strategies (Deliverable 6.3).

3. Results

To facilitate interpretation, the analysis of the solid waste and wastewater generated will be carried out per life cycle stage: pumpkin cultivation (the main constituent of the product);

packaged pumpkin pulp production; packaged pumpkin pulp distribution, consumption, and end-of-life of the product.

3.1. Pumpkin cultivation

MORE conducted meetings with PulpIng partners in order to obtain information regarding the waste and wastewater produced in this phase. Since it was not possible to acquire data specifically from the producer of the pumpkin used by Decorgel, data regarding the pumpkin cultivation phase is based on the work carried out by the project partner UTH – University of Thessaly in Velestino, central Greece, at the experimental field, and was obtained through direct contact over the past 2 calendar years. In summary, UTH cultivated 10 different varieties of pumpkin from the genetic background of the *Cucurbita* species, in Greece. The type of pumpkin used by Decorgel is the Butternut squash – *Cucurbita moschata*.

According to UTH, the average cultivation time was of 5 to 6 months in a 1280 m^2 open field, yielding 320 pumpkins weighing from 5.33 to 11.98 kg each (2796 kg of pumpkins in total, excluding stems and leaves). Soil preparation and planting were carried out using tractors. Irrigation is automatic, and the water applied during irrigation, sourced from a well (applied without any prior physical or chemical treatment), is not collected, remaining in the soil/plants. The irrigation system consists of tubes with filters, irrigation pipes, and a water pump. Throughout the cultivation phase, fertilizers are stored in a tank and applied through fertigation (except for the first application, which is manual using a rototiller); pesticides are applied manually using a backsprayer. Pumpkin harvesting is manual, including the manual separation of the pumpkin into its different parts.

3.1.1. Wastewater

Considering the provided description, no wastewater requiring physical or chemical treatment is generated in the current life cycle phase, as it is taken by the soil/plants. However, short and long-term generation of various solid wastes can be identified.

3.1.2. Solid Waste

At **short-term**, the solid waste from the pumpkin cultivation phase results mainly from the packaging of the required materials, namely, of equipment/infrastructure, fertilizers and plant protection products.

The plant protection products used to yield the above described amount (2796 kg of pumpkins, excluding stems and leaves, from 10 different varieties of the *Cucurbita* species), totalled a pesticide use of 874.8 g (432.0 mL of liquid and 422.4 g of solid pesticides). Given that the packaging can vary with different locations and cultivation practices, an average market amount for the packaging will be considered, based on the total quantity of pesticides used by UTH.

Considering the amounts of liquid and solid pesticides mentioned and recurring to data from the ecoinvent database [1] on the average global **packaging material for pesticides or fertilisers** in liquid and solid form, approximately 0.026 kg of high density polyethylene (HDPE) packaging are estimated to be required and will constitute solid waste at their end-of-life. This estimation is within the range of the waste pesticide plastic containers generation rate estimated by Garbounis and Komilis [2] for Greece farmers, of 0.028 ± 0.028 kg farmer $^{-1}$ y $^{-1}$ 1000 m $^{-2}$.

Applying the same strategy for the fertilisers, and considering that UTH reported the use of a total of 64.3 kg of solid fertilizers (for a yield of 2796 kg of pumpkins, excluding stems and leaves, from 10 different varieties of the *Cucurbita* species), 0.13 kg of HDPE are estimated for the packaging that will constitute solid waste at its end-of-life.

Regarding the **packaging of the equipment and remainder infrastructure**, there is not enough information for its estimation. Further, in comparison with the packaging of fertilisers and pesticides, which are continuously acquired during the life cycle, it is not expected to be of relevance as it occurs likely only a few, perhaps one point in time; plus, some of the agricultural equipment may not be delivered with packaging due its size.

At **long-term**, the very system used for cultivation will constitute waste as it reaches its end-of-life – the tractors, the rototiller, the tank, the system of tubes and filters, irrigation pipes, the pump, and the backsprayer; it may also require repairs which generate waste. From the information provided by UTH, the **tank** is made of 15 kg of steel and 0.05 kg of polyvinyl chloride (PVC); the system of **tubes** of 27 kg of HDPE, with **filters** of 0.96 kg polypropylene carbonate (PPC) and 0.03 kg stainless steel; and **irrigation pipes**, of 65.4 kg of aluminium and 0.96 kg of PVC. The PPC filters have to be changed periodically. Due to a lack of more specific information, the filter lifetime was considered to be of 6 months, as per a Greek producer (i.e. the filter is changed with then end of a cultivation phase) [3].

From the information provided by UTH, two **tractors** were used, Tractor 1 (55.95 kW) and Tractor 2 (22.38 kW), both operating on gasoline. Tractor 1 has a field cultivator and a disk harrow, whereas Tractor 2 has a row crop cultivator (for weeds) and a boom sprayer. Due to the higher variety of material composition of tractors, more specific information is not as easily available. According to Nemecek and Kägi [4], which is the basis on the data used on the ecoinvent database [1] for agricultural production systems, most of the weight of a tractor is typically steel, followed by rubber (mainly from tyres), other metals, and lastly glass, plastics and varnish; respectively, approx. 76 %, 10 %, 9 % and 5 % (estimated from Figure 6.1 of Nemecek and Kägi [4]). Nemecek and Kägi [4] also mention average weights of 3300 kg for tractors between 30-64 kW (Tractor 1) and of 1900 kg for tractors up to 29 kW (Tractor 2), and that an average of 38 % from the waste incurred from its lifetime results from maintenance and repair. Based on this information, the above materials were considered to be only 62 % of the waste generated during the tractors lifetime, and the total amounts throughout a lifetime amount to the 100 %.

UTH reported the use of a 12.1 kW **water pump** with a volumetric capacity of 35 m^3/h. In similarity to the tractors, more specific information is not as easily available. Nemecek and Kägi [4] take as representation of generic irrigation water pumps an electric-powered 22 kW pump with a volumetric capacity of 30 m^3/h, with a weight of 300 kg mainly made of cast iron. The **rotary tiller**, which in the case of UTH is manual, and the **backsprayer** (16 L backsprayer Viopsec Elettra Primavera, Viopsec, Greece), are simpler and smaller equipment, but, due to a lack of more specific information, could not be considered independently. It must be noted however that its contribution to the total solid waste is much smaller than e.g. the tractors, due to its size.

Table 1 lists the relevant type and quantities of solid waste expected at short and long term from the pumpkin cultivation processes, which consists of inorganic fractions composed of primarily plastics and metals. Values are reported per cultivation season, i.e. for the 5-6 months resulting in a total of 2796 kg of pumpkin (excluding stems and leaves), except for the machinery/equipment. In this case, the solid waste frequency of occurrence is specified considering their expected lifetime; for a more comprehensive understanding of the frequency of occurrence, this lifetime as reported in the literature is also included. Naturally, these are indicative values which will vary depending on the context, frequency and care of use, among other variables.

Table 1. Most relevant solid waste streams resulting from the pumpkin cultivation processes and expected frequency of occurrence, based on values from literature.

Expected frequency of occurrence (indicative)	Type	Quantity (kg)
Over each cultivation period, approx. 5-6 months	HDPE	0.15
After each cultivation period, every 6 months	PPC	0.96
Over the span of 12 years	Steel [1]	2422
	Rubber [1]	319
	Metals (unspecified) [1]	287
	Glass, plastic, varnish (unspecified) [1]	159
After 12 years	Steel [2]	3952
	Rubber [2]	520
	Metals (unspecified) [2]	468
	Glass, plastic, varnish (unspecified) [2]	260
After 15 years	HDPE [3]	27
	Stainless steel [4]	0.03
	Aluminium [5]	65.4
	PVC [5]	0.96
After 20 years	Cast iron [6]	300
After 25 years	Steel [7]	15
	PVC [7]	0.05

[1] For the maintenance and repair of a 30-64 kW tractor and a tractor up to 29 kW, from Nemecek, Bengoa [5]

[2] Lifetime for a 30-64 kW tractor and a tractor up to 29 kW, from Nemecek, Bengoa [5]
[3] Lifetime based on PE pipes from various sizes as reported by Gazzarin and Albisser [6]
[4] As a part of the system of HDPE tubes, it was assumed to have the same lifetime
[5] Lifetime based on the lifetime of an irrigation system reported by Gazzarin and Albisser [6]
[6] Based on the lifetime of an electric irrigation pump reported by Gazzarin and Albisser [6]
[7] Lifetime based on a steel tank from various sizes for e.g. winemaking, as reported by Gazzarin and Albisser [6]

3.2. Packaged pumpkin pulp production

The following data was obtained through direct contact with the project partner and pumpkin pulp producer Decorgel, in the last 2 calendar years. The production of packaged pumpkin pulp begins with the reception of its main constituent, the pumpkin. In the case of Decorgel, only the pumpkin flesh is received (frozen), implying that previous **washing** and **separation of the pumpkin into its different components** is performed by the Spanish provider. It is kept refrigerated until processing begins. The first processing step consists on the transformation of the pumpkin flesh in a dicing machine, followed by the pulp production in a pulp making machine. The resulting pulp is mixed and homogenised with the technical ingredients (such as sugar, preservatives, etc.) in a mixer and tilting jacketed steam kettle with agitator. Once prepared, the pumpkin pulp is packaged in a packaging system with a metal detector recurring to **polypropylene (PP) plastic buckets**, **paper labels**, **pallets** and **film**. After each production stage, yielding 688 kg of pumpkin pulp (packaging excluded), the machines are **washed manually**.

3.2.1. Wastewater

Water is used for the washing of the pumpkins, before pulp production, and for the washing of equipment once every 688 kg are produced.

This wastewater could not be characterized, as it is not a process performed by a PulpIng partner, and it was not possible to acquire data specifically from the producer of the pumpkin used by Decorgel. It must however be noted that this wastewater from the washing of the fruit may contain, particularly of relevance, e.g. pesticides used during the cultivation phase, as reported in the literature [7, 8], or, even from application during fruit preservation until use [8-10]. In, e.g., a study by Vass, Korpics [11] that tested five washing techniques, up to 30 % of imazalil was removed from the surface of lemon samples.

The specific substances and respective quantities depend on the types of pesticides applied, which vary with cultivation practices. As an example, in the cultivation performed by the project partner UTH, penconazole, acetamiprid, myclobutanil, etoxazole, tebuconazole, trifloxystrobin and sulphur, out of which 3 – acetamiprid, penconazole and tebuconazole – have been identified as contaminants of emerging concern in Decision 2015/495/EU of March of 2015 [12]and Decision 2020/1161 of 4 August 2020 [13], respectively, for being substances that could also pose a significant risk to or via the aquatic environment. **Table 2** lists the ecotoxicity and potential human health effects for these substances as per the Pesticide Properties Database (PPDB) by the University of Hertfordshire [14].

Table 2. Ecotoxicity and Human toxicity of pesticides that may be present in wastewaters from pumpkin washing, based on UTH cultivation practices.

Pesticide	CAS nº	Ecotoxicity	Human Health	Reference
Penconazole	66246-88-6	Moderate alert	High alert (Endocrine disruptor)	[15]
Acetamiprid	135410-20-7	High alert	Moderate alert (Reproduction/development effects)	[16]
Myclobutanyl	88671-89-0	Moderate alert	High alert (Endocrine disruptor)	[17]
Etoxazole	153233-91-1	High alert	Moderate alert (Reproduction/development effects)	[18]
Tebuconazole	107534-96-3	High alert	High alert (Endocrine disruptor)	[19]
Trifloxystrobin	141517-21-7	High alert	High alert (Reproduction/development effects)	[20]
Sulphur	7704-34-9	High alert	Low alert	[21]

As for the wastewater from the washing of the equipment, it will possibly contain organic matter, and particularly, remains of the washing products. Although the wastewater was not characterized, by direct contact with Decorgel a total of 2 m^3 of water were identified as spent during washing of the equipment after every 688 kg of pumpkin pulp production. The cleaning products have been identified in as Endurosafe (used at 3 %) and 4Plus (used at 1 %).

Endurosafe is a detergent containing disodium/dipotassium metasilicate (3-10 %), sodium hypochlorite (3-10 %), sodium xylenesulfonate (1-3 %) and n,n-dimethyltetradecylamine n-oxide (1-3 %) based on the Divosan EnduroSafe VS64 safety datasheet [22].

4Plus contains sodium hydroxide (30-50 %) and ethoxylated alkyl alcohol (0.1-1 %) based on the Quattro Plus VC74 safety datasheet [23].

3.2.2. Solid Waste

Following the description above, both short and long-term solid waste generation can be identified.

At short-term, the pumpkin pulp had to be separated into its different parts, namely stems, leaves, seeds, rinds, fibres, and the pulp itself. In the current system, the pulp is the part used in the production of packaged pumpkin pulp. The remaining components can be considered co-products or organic waste that will need to undergo treatment. Their use as co-products includes, for example, use of seeds for subsequent crops, and/or for animal and human consumption. The valorisation of these components is the ideal situation, as explored in the PulpIng project, particularly as these contain compounds with important properties, such as anti-oxidant, anti-microbial, among others, however these are still currently underexplored [24]. As of nowadays, it is not uncommon for these components to constitute discarded solid waste in industries focused on the utilization of the pulp [24].

As mentioned in section 3.1, it was not possible to acquire data specifically from the producer of the pumpkin used by Decorgel and, hence, the data resulting from the pumpkin cultivation carried out by the project partner UTH was considered. In the experiments from UTH, from the aforementioned cultivated varieties, which result in a total of 2796 kg of pumpkin (excluding stems and leaves), 736 kg are rinds, 142 kg fibres, 52 kg seeds, and 1867 kg flesh. Additionally, up to 1775 kg of stems and 613 kg of leaves are obtained. This means that, to obtain 1867 kg flesh, **3316 kg of organic waste** may be generated, mainly stems, rinds and leaves.

Within the scope of the PulpIng project, CRAPC (Centre de Recherche Scientifique et Technique en Analyses Physico-Chimique) determined the composition of common pumpkin cultivars, per fruit part (seeds, peels, fibrous strands, and flesh). These analysis are within one of the first to understand biomass suitability for a variety of waste treatments, e.g., for the estimation of biogas production potential during anaerobic digestion, as per Raposo, Borja [25]. Hence, this characterization is summarized in **Table 3**, for the seeds, peels and fibrous strands – which are the fractions that may constitute waste, as the flesh is used for pulp production – as average, maximum and minimum percentages, for cultivars from Algeria and Tunisia.

Table 3. Dry matter, ash, protein, fat, fibres, protein content and energy as reported by CRAPC for Algerian and Tunisian cultivars, %.

Parameter ([a])		Peel	Fibrous strand	Seeds
Dry matter (3)	MIN	71.2	70.4	84.9
	AVERAGE	73.1	73.0	85.8
	MAX	75.0	75.5	86.5
Crude Protein (6)	MIN	2.4	7.12	23.6
	AVERAGE	7.1	11.3	28.9
	MAX	19.8	15.9	32.6
Ash (6)	MIN	6.6	4.1	11.0
	AVERAGE	8.8	6.4	15.5
	MAX	10.6	9.3	20.9
Total Carbohydrates (3)	MIN	55.3	46.9	35.1
	AVERAGE	59.0	56.5	37.7
	MAX	61.7	63.7	42.1
Fat (6)	MIN	0.3	0.3	1.0
	AVERAGE	0.5	0.5	2.1
	MAX	1.0	0.7	4.1
Fibres (6)	MIN	9.8	10.1	14.1
	AVERAGE	13.3	14.5	22.6
	MAX	18.4	18.2	28.4
Energy (3)	MIN	246.0	257.3	274.2
	AVERAGE	256.5	273.6	288.5
	MAX	263.4	289.1	298.2

[a] The value within parenthesis represents the number of varieties considered. 3 – Algerian varieties: *Cucurbita maxima* (Gold nugget pumpkin), *Cucurbita moschata* (butternut squash), *Cucurbita moschata* (musquée de provence squash); 6 – Algerian varieties + Tunisian varieties: "Kharoubi", "Batati", "Bajaoui".

Decorgel reported that mass losses during the remainder of the pulp production were irrelevant. Thus, no further **short-term** solid waste generation of relevance is expected in this stage. At **long-term** and in similarity to the pumpkin cultivation system, all of the equipment and infrastructure will constitute waste as it reaches its end-of-life. The composition of these wastes depends on the type of equipment used by the pulp production company. Although Decorgel has reported the use of a dicing machine, a pulp making machine, a mixer and tilting jacketed steam kettle with agitator, and a packaging system with metal detector, this information is not detailed enough for an estimation of its composition and waste amounts and types after dismantling at the end-of-life. On Nemecek and Kägi [4] on the inventory for agricultural production systems, unknown infrastructure is sometimes approximated by the inventory for a chemical plant producing organic compounds in Europe with a lifetime of 50 years. Based on this, as well as on the inventory for the disposal of facilities for chemical production report by Althaus, Chudacoff [26], per kg, **Table 4** includes estimated waste streams for the dismantling of the pulp production infrastructure, which produces approx. 1000 ton/year, as reported by Decorgel.

Table 4. Estimation for the waste streams resulting from the dismantling of the pulp production infrastructure, based on [26].

Type	Quantity (ton)	Expected frequency of occurrence (indicative)
Concrete, non-reinforced	13900	After 50 years [a]
Steel	22400	
Electronics for control units	2150	
Mineral wool	412	

[a] Based on Nemecek and Kägi [4] for a chemical plant producing organic compounds in Europe

3.3. Packaged pumpkin pulp distribution, use and end-of-life

3.3.1. Wastewater

No relevant amounts of wastewater are expected to be generated during these phases.

3.3.2. Solid Waste

During the distribution and use phase, it is possible for some of the products to go to waste. This stage of the life cycle was not directly analysed in the PulpIng project. Food waste during distribution and use is highly variable, depending on the product, location, distribution cycle and the user.

The Food and Agriculture Organization of the United Nations has reported that, for fruits and vegetables, in Europe, food losses can be of over 45 % along the value chain: approx. 20 % from agricultural production; 5 % from postharvest handling and storage; 2 % from processing and packaging; 10 % from distribution (supermarket/retail) and 19 % from consumption [27]. It must however be mentioned that: i) in the PulpIng project, a packaged product, with preservatives, and fully consumable (i.e. seeds and other parts that the consumer may opt to discard have already been removed) is being analysed and, for this reason, the food waste could be expected to be lower; ii) the data is significantly variable; iii) the product under assessment is of a higher use – 5.5 kg – possibly used in the food industry/bakeries/among others and not in households; iv) the waste from the agricultural phase, which appears to have the highest contribution to food losses along the value chain, was considered. Hence, food waste during distribution and use will not be considered in this deliverable.

At the end-of-life, the packaging materials mentioned in section 3.2 may constitute waste. Some of these may be collected for reused or recycling, e.g. the polypropylene buckets and pallets. The buckets are from polypropylene (180 g / 5.5 kg of pumpkin pulp), the labels are made of paper (printed with color; 1.7 g / 5.5 kg of pumpkin pulp), the film is of polyester (PE) with polyvinylidene chloride (PVDC), glue and polypropylene (PP) cast (0.008 kg / 5.5 kg of pumpkin pulp). The pallets are made of wood, and one 100x120cm pallet carries 125 units of buckets with 5.5 kg of pumpkin pulp each, i.e., approx. 688 kg of pumpkin pulp (one production phase). Table 5 summarizes possible waste types and quantities generated in this phase.

Table 5 Solid waste streams resulting from the end-of-life of the pumpkin pulp product per production phase (i.e. with every 688 kg of pumpkin pulp).

Type	Quantity (kg)
PP	22.5
Plastic film (PE+PVDC+glue+PP)	0.001
Wood pallet	17 [a]

[a] Based on a 100×120 standard wood euro pallet [28].

4. Prospection

The definition and characterization of waste and wastewater resulting from the different stages of the life cycle of pumpkin pulp present in this report (Deliverable 6.2) will allow for estimations regarding the most suitable treatments.

The information of the present deliverable (Deliverable 6.2) will also be relevant to help establish a baseline for the environmental impacts of the current production process regarding water and wastewater treatment, for comparison of the traditional method with any new processes or improvements. Further, hotspots, i.e. the key stages in the value chain where the most waste and wastewater are generated, can be identified and consequently, so can optimization opportunities.

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