Alternative valorisation pathways for orange peel waste

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Introduction

Orange juice industries produce the juice but also orange peels as their main solid waste. From an industrial point of view, an orange can be considered as a composite of 43% juice and 57% peel and pulp. Thus, for single-strength juice 1,33 kg peels are produced per litre of juice, while the respective value for concentrated juice is over 2,85 kg/L. According to latest FAO statistical data (2019), the geographical distribution of juice production and the respective peels production are presented in Figure 1. Therefore, the potential of peels production is over 8 million tons globally and nearly 600000 tons in Europe. In the context of circular economy, the valorisation of orange peels is of high priority given their high availability and composition. Within this work, alternative valorisation pathways such as animal feedstuff, ethanol and/or biogas production are studied.

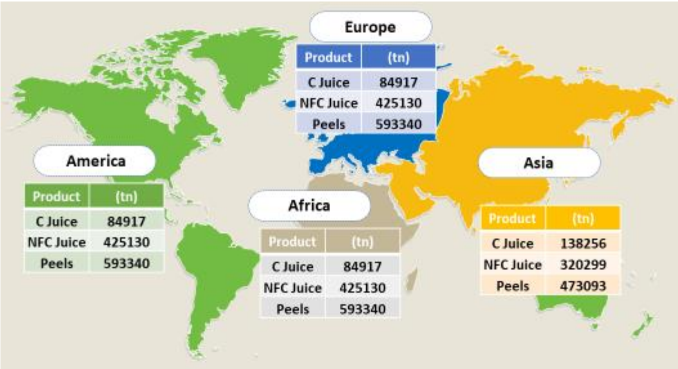

Figure 1. Geographical distribution of annual production of orange juice production and resulting orange peels (2019).

Materials and Methods

Raw materials: Orange industrial waste utilized in the present study was provided by the industrial facility of Hellenic Fruit Juices Industry, Lakonia, Greece. The orange waste was transferred to the Unit of Environmental Science and Technology (UEST), School of Chemical Engineering, National Technical University of Athens.

Physicochemical Characterisation: Cellulose, hemicellulose, acid-soluble lignin, acid-insoluble residue, ash and moisture were measured following the analytical procedures of NREL laboratory analytical protocols (Sluiter *et al*, 2012). Glucose was estimated following the Glucose Oxidase–Peroxidase method via a commercial kit (Biosis SA). The concentration of ethanol in the liquor was estimated by the 2019.11 technique (AOAC, 1995). Samples were also analyzed for crude protein (CP), crude fat, neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL). Crude fat was extracted for 6 h with petroleum ether, whereas the Kjeldahl method was used to determine nitrogen (N) (AOAC, 1995). CP was calculated as N × 6.25. NDF, ADF and ADL were determined according to the methods of Van Soest et al. (1991).

Animal Feedstuff production: In order to investigate the potential of using orange peels for animal feed, the feedstock was dried in a commercial food waste dryer (GAIA-100) to remove moisture and maintain its physicochemical and organoleptic characteristics.

Ethanol Production: Enzymatic hydrolysis of orange peels was performed in 250 mL autoclavable bottles. Enzymatic saccharification of cellulose was performed at 50^{o}C by the addition of a cellulolytic formulation; Cellic CTec2 (Novozymes, Denmark) for 24h in an Incubator Shaker (IKA-KS 3000i). Dosages of 0, 50, 150, 300 and 450 μL enzyme/g cellulose were adopted. Bioconversion of the glucose produced to bioethanol via ethanolic fermentation was achieved by the addition of Saccharomyces cerevisiae (2% w/w) in the same autoclavable bottles, at 30°C for 24h. After the 24-hour fermentation period, the solid and liquid phases were separated by centrifugation (3500rpm for 10min) and were physicochemically characterized.

Biogas Production: Biogas potential tests (BP) were carried out according to Kavalopoulos *et al* (2021) in order to estimate the biodegradability of the raw orange peels and the stillages. The BP tests were performed in 0.5 L autoclavable bottles, half-filled with feedstock and inoculum (1:2 Volatile Solids ratio) at 35 °C and 150rpm. For more reliable results, at least two dilutions and 3 replicates were tested.

Results and Discussion

The physicochemical characteristics and nutritional value of the dried unprocessed orange peels on dry basis (%w/w) are the following: moisture 90,74%, volatile solids 96,03%, cellulose 20,58%, hemicellulose 24,62%, acid insoluble residue 12,98%, oil 2,71%, ether extract 3,57%, crude protein 7,18%, NDF 72,0%, ADF 40,4% and ADL 26,6%. For a balanced ruminants' diet, NDF and ADF should be over 28% and 19% respectively, while Non-fibrous Carbohydrate (NFC) should be below 38%. Thus, from the nutritional analysis, it can be concluded that the feedstock could stand as a secondary component for a balanced ruminants' diet.
As far as ethanol production is concerned, Table 1 presents the saccharification and ethanol yields for all trials.

Table 1. Saccharification and ethanol yields of enzymatic hydrolysis and ethanolic fermentation performed with CellicTec2, along with biogas potential (BP) of stillages.

A/A	Cellic CTec2 (μL enzyme/g cellulose)	Saccharification Yield (%)	Ethanol Yield (%)	Ethanol Yield (mg ethanol/g wet feedstock)	BP (mL/g VS)
1	0	37,1	66,9	9,62	443
2	50	52,7	89,7	12,33	243
3	150	78,6	58,4	8,03	507
4	300	83,6	55,0	7,56	530
5	450	52,7	27,3	3,75	159

The biogas potential of the unprocessed orange peels was equal to 655.37 mL/g VS.

Figure 2 summarizes the alternative valorisation routes of 1000kg orange peels waste feedstock. Apart from the products on mass basis, their energy content is also presented. Additionally, the products index (PI) is calculated as the input to products efficiency in terms of mass.

Figure 2. Alternative valorisation routes of orange peels.

It can be concluded that the production of animal feedstuff is the valorisation route with the highest product index (10,29%). From an energy viewpoint, 1632 MJ energy (biogas) are obtained from the anaerobic bioconversion of one ton of orange peels to biogas. Nearly the same energy content is achieved in the optimum scenario of bioethanol production followed by the production of biogas. At this point, it should also be noted that bioethanol as liquid biofuel is preferable to biogas for numerous reasons (storage, transportation, existing network etc.).

Thus, it was made evident that orange peels can stand as a suitable feedstock for high quality biobased products, which could contribute substantially to bioeconomy.

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