Cereal supply chain waste in the context of circular economy

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Abstract. Taking into consideration the circular economy context, from cereal production and processing result by-products and residues which can be transformed into the new raw materials. Straw, husks, brans, flours, bread waste, confectionary waste, so on, can be re-used using different processes such as: extraction, fermentation, microorganism cultivation, for obtaining added value products. These new products obtained can be: biofuels, enzymes, biodegradable material food contact, single cell protein, bio-adsorbent, nanoparticles, bio alcohol, bioactive compounds like fibres, phytochemicals, minerals, so on. This paper is a short review regarding sharing knowledge and good practices in implementing circular economy within food systems, specifically, cereal supply chain.

Key words: cereal, circular economy, waste, loss, bio-technology

1 Introduction

Cereal production and processing are one of the most important sectors of agri-food industry knowing that the cereal food products cover over 20% of daily diet [30]. More, the cereal products are the basis of all Food Pyramid that were developed and proposed in different studies. Cereal products are also vectoring to increase the consumption of dietary fibre in the daily diet. By changing the eating habits, replacing white bread, pasta, biscuits so on, with wholemeal products, an improvement of food cereal-based health benefits may be achieved. In many studies, the role of dietary fibres in nutrition is pointed out, especially in prevention against chronic non-communicable diseases [25].

The increasing demand for food as a consequence of a growing global population is direct connected with an increasing of quantity of food waste. UN Sustainable Development Goals include the reducing of food waste which is one of the most serious environmental, economic and social issues [23].

One of the aims of waste management in agri-food industry is to improve resource efficiency while protecting the environment. For this purpose, management strategies and measures for the proper reduce waste or transform it into new raw materials are needed. These management strategies are included within the circular economy system which is an industrial system that is regenerative or restorative by intention and design (producing

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no waste and pollution). A circular economy is characterized by several keys characteristics and enabling factors related to efficiency of using resources, reducing of emissions, minimizing losses and residues, reusing and recycling of products [4].

Different studies for the management of food food supply chain offer opportunities to biofuels, biodegradable plastics, alcohols, antioxidants, In this respect, food waste is a source of very valuable compounds such as: macronutrients - proteins, carbohydrates and lipids, and micronutrients or bioactive compounds which can be further transformed into new added value products . Different studies for the management of food waste along the supply chain offer opportunities to biofuels, biodegradable plastics, alcohols, enzymes and nanoparticles production, so on, among many others [24].

2 Cereal supply chain waste as a new raw material resource

Huge quantities of waste are generated along the food chain during harvesting, transport, processing, storage, distribution of retailing. Baiano (2014), estimated that about 12.9% of food waste are generated from the cereal processing and manufacturing.

In medium, as well as in high income countries, wheat is the main crop for milling and baking industries [8]. Approx. 35% of the total production account cereal loss and waste in North America, Europe, and industrialized Asia. Along the cereal food chain approx. 10–12% of the total production is lost in North America and Europe, while, in industrialized Asia total loss and waste amount reaches up to 18% [8].

The cereal supply chain waste estimates show that, for example, wheat straw is produced in SUA in amount of 57,000 tonnes/year [34], rice husk in amount of 120,000 tonnes/year at the global level [14] and cereal waste, in general, in amount of 40,000-45,000 tonnes/year in Europe [8].

Each kg of pasta produces approx. 1.98 kg of loss and waste throughout its entire lifecycle is mentioned in a 2019 study of Ludovica Principato et al. This waste is consisting in 1.65 kg by inedible parts, that it means about 83.4% of the total loss and waste. To determine re-usable waste and inevitable losses and to identify the corrective actions whenever required it is needed to analyse entire process of pasta production related to the composition of waste across the stages of food chain [23].

Within the cereal chain some by-products and waste can be recovered, such as the following: sesame husk and rice bran for obtaining dietary fibre [17], oat waste for extraction of antioxidants [27] wheat bran for fructans [36], and Brewers' spent grain for ferulic acid production [16].

3 The new Circular Economy Policy Package

Published in December 2015 by the European Commission, *Closing the loop* — An EU action plan for the circular economy is a strategy with the main aims to support the transformation of linear economy in a circular one.. Earlier, in September, in the same year, 2015, the UN through, the 2030 Sustainable Development Goals, adopted a food waste target per capita at the retail and consumer levels and reducing food losses along the food chain [39]. The new Circular Economy Package consists in several documents: an EU Action Plan for the Circular Economy, a timetable for achieving the actions (in Annex to the Action Plan) and several legislative proposals: Directives on Waste including Packaging Waste or on Landfill.

In this respect, at the level of EU, calculation methods for recycling rates and definitions have been harmonized and simplified. EC is encouraging to have targets for re-use and

recycling for municipal waste by weight, to 60% by 2025 and, 65% by 2030. EC is also encouraging to increase the economic incentives for the products with better design, through provisions on extended producer responsibility schemes. At the same time, for the packaging material waste, specific targets were established for different materials – plastic, wood, glass, paper and cardboard but also general reuse and recycling targets waste to 65% by 2025 and 75% by 2030.
The ensuring the separate collection of bio-waste is needed, including biodegradable gardens waste, food and kitchen waste from caterers, restaurants, retail premises and households where it is economically and environmentally appropriate and practicable from the technically point of view [39].

4 Opportunities to meet Circular Economy

Food waste can be transformed into a raw material to be further used for different purposes.

The bio-refinery concept means to obtain from the agri-food side products, in cascade, commercial added value products and energy. This concept is seen as a sustainable option by the scientific community. The products like bio-fuels, bio-fertilizers, biomass or chemical compounds are obtained by bio-refinery process, in fact, through biotechnological transformation of agri-food waste via anaerobic digestion, fermentation and composting technologies [26].

Table 1 Examples of transforming cereal producing and processing waste into new products [38]

Food waste	Product	Country where research was developed
Bread waste	Sourdough	The Netherland
Oat husks from milling operations	Bio-diesel	Finland
Waste from the confectionery site's manufacturing processes		
Agricultural waste		
By-products from bakery and confectionary factories		
Bakery and confectionary factories	Bio-ethanol	Finland
Agricultural residues	Food and pharma ingredients	Finland
	Soil improvement and organic fertilizers	
	Microbial feed protein	Most of EU countries

For implementing the circular economy both, at the European and national levels it is needed to have an integrated approach based on the triangle: consumer-company-natural environment.

Circular economy means changing people habits, mentalities, especially of the policy decision makers at both public administration and company levels. The most important issue is that the national policy related to Circular Economy to be operational across governmental, entrepreneurial and consumers levels.

Further, some examples of products are given, that can be produced using cereal production and processing waste.

4.1 Bio-fuels production

Many favourable outcomes, coming from the recent literature showed that researches on different cereal waste, such as straw and bran, rich in simple sugars and complex carbohydrates have been demonstrated generation capacity of bio-fuel producing of such substrates. Fuel ethanol was produced from plant biomass since almost one hundred years ago. Transformed through enzymatic hydrolysis of lignocellulose, the plant biomass releases fermentable sugars which are further converted by fermentation process, into bio-ethanol.

The 'biofuel' term comprises a wide variety of products such as biodiesel, biogas, bioethanol, biobutanol, bio ether, biohydrogen and syngas [35].

Separate studies showed the biohydrogen has been produced using wheat straw or sweet sorghum. In all studies, hydrogen was produced through dark fermentation using Enterobacter, *Bacillus*, and *Clostridium* as the most used microorganisms [29]. Genetic improvements of the fermentative capacity of microorganisms resulted in better biohydrogen yields [14, 3, 12].

4.2 Bio-ethanol production

Bio-ethanol has been derived from the microbial supporting fermentation of agriculturally based carbohydrates waste. Because the similar properties and characteristics of petroleum, including high-octane number, ethanol is used as an alternative liquid fuel. Its blend can achieve the same anti-knock effect as that of petroleum.

Ethanol can also be used in the production of plastics, especially polyethylene. First-generation feedstock, derived from agricultural cereal (wheat, rice, sweet sorghum etc.) has limited applications for ethanol production mainly because of issues related to land use and food security.

By the action of commercial enzymes like amylases (α-, β-, glucoamylase etc,), carbohydrates (starch or lignocellulosic substrates like rice, potato, and sugarcane) are converted to simple sugars through "saccharification process" and further, by fermentation, involving yeast like *S. cerevisiae* and its enzymes – invertase and zymase - to ethanol production. [31, 11]. For bio-ethanol production, *S. cerevisiae* utilises only hexose sugars (Balat, 2011).

Fungi and bacteria have been also used for fermentation.

Table 2. Performance data of ethanol production from cereal processing waste.

Cereal Waste	Yeast	Glucose yield (g/100g FW)	Ethanol yield (g/g FW)	References
Rice husk	*S. cerevisiae*	49	0.98	Saha and Cotta, 2008
Rice straw	*S. cerevisiae*	60.0 g/L	12.34	Sukumaran et al. (2009)
Wheat straw	*S. cerevisiae*	54.96 g/L	25.14	Han et al. (2009)

4.3 Bioactive compounds

One of by-products milling industry is rice bran. Rice bran contains proteins,fibre, minerals,and vitamins, as well as phytochemicals such as polyphenols and tocopherols. The rice bran consumption has been reported to have health benefits by lowering cholesterol with effects on the health of cardiovascular system and antitumor effects. Fivefold increased the antioxidant activity of bread was obtained by addition of 30% rice bran to wheat flour (Irakli et al.). By this addition, the increasing of phenolic content leads to an overall acceptable bread, although the vitamin E content was reduced.

4.4 Nanoparticles

A new research area is to use food processing residues such as, wheat husk and rice bran, to obtain nanomaterials. As renewable resources, starch, cellulose, xylan or chitosan have been widely used to produce stable nanoparticles [15]. The same cereal based resource, rice husk is a very good raw material to obtain nanoparticles on the basis of silica found in its composition.

In this sense, there are several new methodologies for using rice husk in order to produce nanoparticles. Silica was extracted from rice husk and was used for anchorage of Pt and Ni nanoparticles, *in situ*. By using a non-ionic surfactant (Span 40) and a cationic surfactant (CTAB), rice husk silica (RHS) texture was tuned. The non-ionic surfactant and rice husk silica (Span 40 RHS) had been immobilised Ni particles on its surface and revealed high dehydrogenation activity and performance in acetaldehyde production [9].

4.5 Biodegradable Plastics

A perfect replacement for petroleum-derived plastics are polyhydroxyalkanoates (PHAs). The main barrier in the commercialisation of PHAs is the high operational cost of its production [22]. For the production of PHAs and poly-3-hydroxybutyrate (PHB), agri-food waste is used as substrate having the advantage of abundance of lignocellulosic materials and very low value.

The agri-food waste coming from wheat, corn, rice, barley or other cereal food chain is rich in carbohydrates which are enzymatic transformed into fermentescible sugars and further fermented by a series of bacteria and fungi such as *Lactobacillus*, *Streptococcus*, *Leuconostoc*, and *Enterococcus* or *Monilina*, *Mucor*, and *Rhizopus* to lactic acid producing [13, 5].

Some studies showed that PHB is produced by *Burkholderia sacchari*, through sugars (e.g. glucose, xylose and arabinose) metabolization. It was also tested the efficacy of wheat straw hydrolysate used as a raw material for PHB production. Some experiments demonstrated that it was a cells accumulation of 60% g PHB/g cell dry weight with a yield of 0.19 g/g when *B. sacchari* was grown on wheat straw hydrolysate as the only carbon source [2].

The microenvironment had the greatest influence on PHA production it was the conclusion of Venkata et al., 2013, after an optimisation study on PHA production when it was used mixed aerobic and anaerobic cultures.

Other studies showed the possibility to obtain PHB from rice straw hydrolysate, wheat bran and potato waste or wheat straw hydrolysate using *Bacillus firmus, Halomonas boliviensis and,* respectively, *Burkholderia sacchari* (28, 32, 2).

4.6 Bio-adsorbents development

For producing adsorbent for wastewater by-products and residues from agriculture and forest have been used, having the advantage of price and composition and being considered as a sustainable alternative for the synthesis of quality activated carbons [6, 19, 21]. Among the residues from agriculture and forest it can be mentioned: rice and wheat bran, rice and wheat husk, corn cob, maize, etc. which have been demonstrated their suitability as substrates for use as adsorbents for water treatment.

Table 3. Waste based activated carbon for wastewater treatment. Adsorption capacities. (adapted after A. Nayak, Brij Bhushan [18]).

Adsorbent	Adsorbate	Adsorption capacity mg/g	Optimum conditions, pH, time, °C	References
Rice husk (treated with H_3PO_4)	Cd(II)	102	6	Zafar et al., 2007
Rice husk (sulfuric acid)	Se(IV)	41,15	na	El-Shafey, 2007
	Cd(II)	40,92	na	
	Zn(II)	19,38	na	
	Hg(II)	384,62	-	
Rice husk	Cd(II)	73,96	6.5	Ye et al., 2010
Rice husk (alkali treated)	Cd(II)	125,94	6.5	
Rice husk ash	Pb(II)	39,74	6	Akhtar et al., 2010
	Cd(II)	39,87	6	
	Zn(II	39,17	6	
	Cu(II)	40,82	6	
Wheat bran (chem mod)	Pb(II)	62	5, 20 min.	Farajzadeh and Monji, 2004
	Cr(III)	93	5, 20min.	
	Ni(II)	12	5, 20min.	
Wheat bran	Pb(II)	87	4-7, 60 min, 60°C	Bulut and Baysal, 2006
Wheat straw (chem mod)	Cr(VI)	322,58	55°C	Chen et al., 2010
Rice husk (H_3PO_4 treated)	Cd(II)	102	pH-6	Zafar et al., 2007
Rice husk	Cd(II)	73.96	pH-6.5	Ye et al., 2010
Rice husk (alkali treated)	Cd(II)	125.94	pH-6.5	
Rice husk ash	Pb(II)	39.74	pH-6	Akhtar et al., 2010
	Cd(II)	39.87	pH-6	
	Zn(II	39.17	pH-6	
	Cu(II)	40.82	pH-6	
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	Cd(II)	40.92	na	
	Zn(II)	19.38	na	
	Hg(II)	384.62	-	
Wheat straw (chem mod)	Cr(VI)	322.58	temp-55°C	Chen et al., 2010
Wheat bran	Pb(II)	87	pH=4-7, 60 min, 60°C	Bulut and Baysal, 2006
Wheat bran (chem mod)	Pb(II)	62	pH-5, 20min.	Farajzadeh and Monji, 2004
	Cr(III)	93	pH-5, 20min.	
	Ni(II)	12	pH-5, 20min.	

5 Conclusions

Several ideas for re-using of cereal supply chain waste were presented in this study. More studies are necessary in order to optimize the additional technologies for processing waste. It is important to evaluate the entire process of biorefinery, the main process and additional ones, including all technological flows, in order to be “clean”, without any solid or liquid residues or by-products. Also, it is important to obtain the maximum added value products while optimizing other resources consumption such as water and energy.

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