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In order to feed the growing world population and achieve a more sustainable society and a "zero waste economy", it is necessary that organic products and waste are reprocessed and used. The current scenario encompasses an increasing demand for energy and animal-derived protein and, at the same time, the global requirement of a balanced and adequate intake of trace nutrients. The animal feed industry currently uses a vast amount of human edible diet ingredients (e.g. corn, soy) which could be upgraded to human food products. Less valuable by-products and organic wastes are more difficult to use because, for instance, lignin limits the use of cellulose and hemicellulose, which might be a source of glucose and other sugars for ruminants. Nowadays, the majority of organic waste materials, containing valuable sugars, starch, protein, fat, cellulose and hemicelluloses, is discarded, composted or just burned, In the meanwhile, intensive animal farming makes use of feed materials that could be used, in a more sustainable way, as human foods such as corn, soy and, in the case of aquaculture, fish. By upgrading the waste materials to animal feed, more food would be made available for the human consumption.

In spite of the increased public awareness about the environmental impact of food waste and the consequent benefits (also for global food and water security) of reducing such waste at source, households remain the major contributor of food waste in developed countries. The determinants of household food waste have been investigated (e.g., EU countries with a better economic status do waste on average more food than those with a relatively lower status), but research on the efficacy of reduction measures is still lacking. Together with reducing food waste, a consistent effort is needed to recycle and reuse (avoidable and unavoidable) food waste. Reusing food waste as feedingstuff might be one of the main measures to be encouraged. Major cases of food waste can be envisaged: kitchen (households or restaurant/hotels/catering) waste, supermarket waste, fruits/vegetables waste (it is estimated that 25% of the high-value food is wasted at these stages), agricultural and food industry waste.

At the moment in EU it is estimated that just 20% of the generated food waste is separately collected and treated by composting and digestion. Most of the food waste still ends up in mixed municipal waste that is sent to incineration or landfills. A cost-effective, transparent and safe “food waste transformation chain” from collection to use as feedstock, and production of bio-based products for the feed and chemical industry is highly recommended. Food waste from households, restaurants, retail, farms and food industry contains many valuable organic and mineral components that are lost (and even contribute to airborne pollution) if they end up in incinerators. By composting and anaerobic digestion, food waste can be recycled so turning the waste into organic fertilisers and bioenergy. However, this process does not recover the full value of the food waste. The recover capacityof the whole food system should be improved including the feed system in the circle. Nevertheless, present conversion technologies are not fully and directly applicable for several reasons: 1. As food waste often contains impurities such as paper and plastics, they cannot be used directly as animal feed. Indeed, direct use of food waste as animal feed is regulated by EU legislations, e.g. the Animal By-product Regulation, and in some cases restricted; 2. Food waste can be transformed via biotechnological routes to valuable chemical products such as fatty acids and ethanol, even though the costs to separate these valuable compounds from the food waste matrix are usually very high. In addition, the residue of the food to feed transformation process can be further recycled and upgraded to become an organic fertilizer or soil improver, thus recovering the minerals and humus and closing the cycles of nutrients and organic matter. This results in a reduction of the use of chemical fertilizers and fosters healthy and resilient soils. With that said, a further use of waste that could contribute to improve the food chain system efficiency as well as the sustainability of food and feed production is to use agri-food by-products as feed ingredients. This approach could also help to raise small farm’s income (at least 60% of the total cost of livestock farming is due to feeding) and to ameliorate the quality of animal products.

The use of dried stoned olive pomace in buffalo and dairy cows feeding can be cited as a good example of the use of an agri-food by-product as feed. The fresh pomace, resulting from the conversion process in the olive oil production, is actually under-exploited and represents a problem from an economic and environmental perspective. On the contrary, it may represent an interesting source of new, alternative and low environmental impact feeds that are also affordable and capable to enhance the quality and healthiness of food. A study conducted by Terramoccia et al., (2013) shows dried stoned olive pomace resulted not to interfere neither with productive performances nor with milk composition nor milk clotting properties of Mediterranean Italian Buffalo. The same result was achieved by Meo Zilio et al. (2015) on lactating dairy cows. Besides, the nutritional characteristics of buffalo milk improved for fatty acid composition and for the higher presence of antioxidants (tocopherols, retinol, and polyphenols). In order to further reduce the costs for stabilization of the pomace, ensiling could be considered to replace drying. Indeed, lactic acid deriving from anaerobic fermentation of silage and the concomitant increase of hydrogen ions can hamper the growth of bacteria (e.g. Clostridium spp) and moulds. A further example of efficient recycling of food industry by-products is represented by the use of milk whey from dairies for animal feeding. This practice is well known for monogastrics (e.g. pigs) and unweaned calves. The inclusion of whey in ruminants, particularly dairy cattle, feeding schemes would represent an interesting opportunity in order to recover a not negligible portion of energy for livestock production. Indeed, milk whey contains about 3.500

kcal of digestible energy per kg of dry matter, represented in particular by lactose (practically equal to the raw milk), as well as protein, minerals vitamins and to a lesser extent fat. From the processing of 100 kg of milk one can get on average 80 kg of whey, which are often discarded or delivered to biogas plants as fermentation substrate. An important challenge in order to feed whey to animal is to stabilize the mass low input way, in particular avoiding approaches that are resource-intensive such as refrigeration, chemical stabilization, sanitization etc. A possible solution is to exploit and to promote the natural acidification provided by lactic bacteria. In this sense some preliminary studies are promising and prompt to further developments.

Another example of waste stream is the separation of sugars and proteins from tons of unsold or rotten fruits and vegetables and their use as ruminants feed. This waste stream can be collected from producers, auctions, trade companies and shops and it might be fed to ruminants and other animals as such. Because fruits and vegetable wastes are high in water, proper storage procedures and facilities are necessary to ensure an adequate shelf-life. This type of waste contains a lot of valuable components (e.g., vitamins, bioactive polyphenols) which can be extracted and used as an upgraded component in the nutrition of monogastric livestock animals (pigs, poultry) for which a direct use is unsuitable. The remaining part, after extraction, will be the more fibrous part of the waste stream that is an excellent component in the nutrition of ruminants (cows, sheep, and goats). However, to prevent spoilage on the farm and to create strategic solutions for these products, these fibrous residues have to be stored in order to allow a continuous use in feedingstuffs over time. Extraction techniques/procedures and their order are decisive for the remaining product; all processing procedures will be especially relevant in establishing the proportion of the more purified products (e.g. sugars) or of residual fibrous components for animal feeding purposes. The on-farm ensiling storage of fibrous components should be considered as a further valuable, as well as challenging, solution. Processing conditions should aim to retain the nutritional value for ruminants during a prolonged storage time, to avoid oxygen- or heat-induced damage of the ensiled feed and to establish a rapid rate of acidification, which is more important than a final low pH; conditions should also prevent or minimize the contamination with pathogenic microorganisms and fungal or bacterial toxins These novel feeds have to be assed for their digestibility and the amount and composition of fatty acids, which have an effect on the quality of animal products, especially milk.

The safety of novel feeds has been recently considered by a joint FAO-WHO working as a critical issue in the context of updating criteria and methods to ensure safe animal feeds (FAO-WHO, 2015). In the case of novel feed ingredients derived from food waste, main safety issues encompass the whole flow from raw materials (provenance, quality) through to the end-products, the transfer of chemical and biological contaminants, as well as natural substances (e.g., too little or too much vitamins or trace elements, exposure to undesirable components such as glucosinolates), and the liability to contamination during the process. The main biological, chemical and nutritional hazards related to the raw materials (e.g. E. coli, nitrate, pesticide residues, mycotoxins) should be identified and targeted by an HACCP strategy. Criteria for provenance, quality, traceability and processing conditions of raw materials should be set up. European regulatory requirements should cope with issues posed by novel feeds.

The implementation of food waste reduction, reuse and recycle measures depends exclusively on the costs and benefits for the different operators in food supply chains (farmers, processors, retailers, food service industry, consumers, disposal industry). Besides costs and benefits considered by the different operators, there are additional external (environmental and social) impacts of rational food waste recycling, including a drop in the use of energy, hydric and chemical inputs, the reduction of carbon footprint and the decrease of social costs as well as, on the other hand, an increase of food availability for the general population and of profit for the small farmers. There is also the need to develop effective strategies to prevent and monitor hazards for farm animals, consumer and the environment; if science-based safety considerations are incorporated in the development of the process from its very start, it will result in a gain in terms of prevention of alarms and crises and increased confidence by farmers and the general public. From a societal perspective all these aspects need to be considered in order to enable policy makers to make informed decisions about food waste reduction, reuse and recycling.

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