VALORISING SIDE STREAMS IN CIRCULAR ANIMAL FEED AND ADDITIVES: OPPORTUNITIES AND CHALLENGES

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ABSTRACT:
Because of a growing world population there is an increasing need for protein production, in addition to traditional agriculture and fisheries. Several new crops such as microalgae, macro algae, aquatic higher plants, aquatic and terrestrial invertebrates (insects and worms) have received growing scientific attention, because of potential high biomass yields for protein production on small surface areas. Several side streams (flue gas, residual heat, biogas slurry and solid wastes) can be valorised in their cultivation. Combining bioenergy production and its side streams with cultivation of these circular crops, improves economy and sustainability of both.
At the ACRRES site, Wageningen University runs pilot facilities together with several SMEs. The research is aimed at innovating and improving economics of alternative crop production and energy use efficiency. The main focus is on utilization of microalgae and other novel crops to benchmark this with conventional feeds. Data on their value as feed ingredient and from optimized production systems are used as input for legislation matters with regard to nutrient use and feed safety. In addition to their suitable macro composition research indicates that some circular feed components have added value to improve animal health and final quality of the animal end products.

Keywords: agroindustrial residues, microalgae, circular economy, agricultural biogas plant, pilot plant, novel crops

1 INTRODUCTION

With an increasing world population (estimated to be 9.1 billion people by 2050) there is an increasing need for food and feed sources. Combined with elevated income levels, there will be a 70 % higher demand for food. Meat production will increase from 229 to 465 Mtonnes and milk production from 580 to 1043 Mtonnes [1]. The aquaculture and livestock sectors will have to keep up the pace of this increase. With regard to aquaculture wild fish capture is stagnating (Fig. 1) and the increase in fish yield during the last decennia is purely based on farmed fish. As feed for the farmed fish, fish meal is an important component as well as in poultry and pig feeds. The supply of fish meal is however limited and wild fish stocks should not decrease any further. Wild fish stocks are not only relevant from a nutritional viewpoint but also for storing CO_2 in the oceans and benthic production [2;3].. The fish meal price has roughly tripled over the last two decades, while that of soybean meal has doubled (Fig. 1). Soybean meal is partly used as an alternative for fish meal in some feeds.

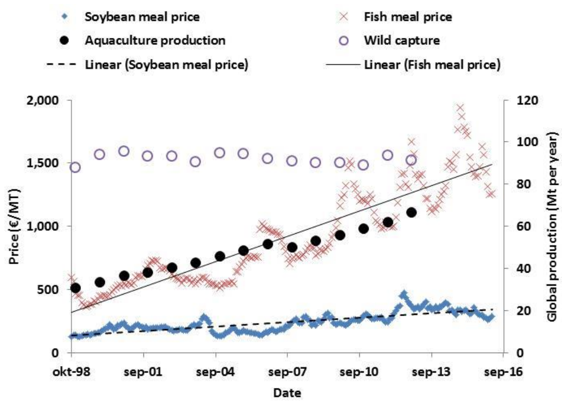

Figure 1: Prices of fish meal and soybean meal in time (1998-2016) and global wild fish capture and aquaculture production (From: FAO, IndexMundi)

Although soy bean has high protein yields and is widely used as a feed ingredient, there is limited agricultural area, even though crop yields are still increasing (70 % of the world arable land is in use). Additionally, there is a shortage of fresh water and an increase in CO_2 levels. At the same time nutrient cycles are out of balance (feed is imported, which leads to depletion of nutrients in some continents but manure surplus on other continents). New sources for feed and food are thus needed that tap into alternative, efficient and local nutrient, land and energy uses. One of the possibilities is to cultivate new or novel ‘crops’ in combination with bioenergy production, making efficient use of each other’s side streams. It is expected that by 2054 33 % of food proteins originate from alternative sources such as algae, insects and novel food crops (1). Also, the goal for 2020 is to diminish the net import of protein rich feed ingredients into the EU from 70 % of total feed ingredients used to 35 % [4].

Novel crops include microalgae, macroalgae, aquatic plants, aquatic and terrestrial invertebrates. The water footprint of these crops is low compared to traditional livestock production and organic waste streams can be used. In order to be used as animal feed ingredient several factors are important: protein and lipid content, amino and fatty acid profile and other nutrients, good digestibility, palatability, absence of anti-nutritional components and other risks, added value for animal health and final quality of the animal end products. Alternative sources such as algae can yield up to 15 times higher protein yields per surface area than soybeans [5].

The research question is whether animal feed (ingredients) can be produced economically and sustainably by valorizing local waste streams from bioenergy production.

2 APPROACH

At the open public-private pilot site of ACRRES (Application Centre for Renewable Resources) (2, 3), an innovative pilot-scale biorefinery concept is being constructed and tested, with the aim of small scale local maximisation of biomass valorisation for food, feed and non-food purposes. The concept is directed at transporting high value products (end-products and semi-manufactured products), resulting in minimised transport of water and maximised local re-use of nutrients and organic matter [6]. This type of small-scale biorefinery can be a step in the development and implementation of a biobased economy. The valorisation of side streams and associated processes plays a key role in enhancing the economic efficiency and sustainability of production of green gas, electricity and basic components for feed, food or fuels based on (co)fermentation and biorefinery (Figs. 2, 3).

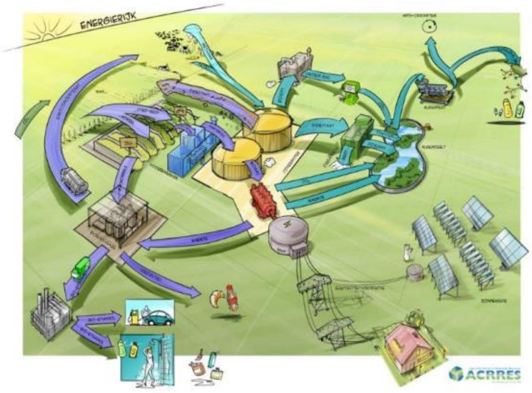

Figure 2. Schematic presentation of the ACRRES pilot site

Figure 3: Aerial photo of ACRRES site in Lelystad, the Netherlands

In order to research and test new production methods, nutrient recycling and soil quality issues, the pilot project currently comprises:

- A pilot digester, CHP (123 kWh) and associated storage for co-products and digestate
- A bio-ethanol plant with a capacity of 150 000 L per year
- An installation for hydrolysis of recalcitrant biomass for fermentation processes and other follow-up processes
- Open production systems for algae situated in a greenhouse or in open field raceway ponds of both 250 m^2 and 100-200 m^3 depending on culture depth, and open LED-light supported bioreactors ranging in size from 1 to 60 m^3
- A pilot for aquatic plant cultivation (six temperature controlled open ponds of 2 m^3) (Fig. 4)
- An installation to upgrade biogas to green gas (4),
- Arable land and grassland available to produce biomass and cattle (dairy farm) to produce manure.

In addition, the possibility of decentralised processing of (aqueous) side streams that occur locally on farms, and within landscape and water management organisations and processing industries is being explored. The ACRRES concept being tested is not a fixed solution, but keeps evolving with new developments in technology and environmental research. At the moment, the addition of a refinery process for manure or digestate using invertebrates is being considered. In a broader perspective, ACRRES is open to new and innovative technologies that can help to maximise local utilisation of available resources.

At the ACRRES pilot site, the algae culturing and harvesting technology of the company Algae Food & Fuel (AF&F) (5) is being tested. The raceway ponds are used to grow algae fed by minerals from biogas slurry or artificial fertilisers and CO_2 from the flue gases of the nearby digester and the CHP engine. The growth rate of algae is further increased by using excess heat from the CHP engine to support algae productivity. The algae are harvested three to five times a week year round. The temperature, optical density, nutrient content, algae biomass and species composition are monitored. At present, the algae biomass produced is mostly used for high value feed applications (feed additive). The algae production site of ACRRES was one of the pilots in the Interreg project Energetic Algae (Enalgae) (6). Within that project a bio economic model in Excel is being developed based on the open algae ponds built at ACRRES, Lelystad [7].

Figure 4: System with aquatic plants growing on the diluted fraction of biogas slurry

Research is conducted to improve and innovate the production, and energy use efficiency, finally aiming to improve economics of production. Furthermore, research focuses on the utilization of, in the first place, microalgae, to benchmark this with other feeds. The produced new alternative circular products are tested for their value as feed ingredient and production systems are monitored in order to generate data needed for legislation matters with regard to nutrient use and feed safety.

4 RESULTS

Experimental and literature results show that different categories of alternative feed crops can be produced on specific residual resources (Table I).

Table I: Overview of promising combinations of alternative feed crops and residual resources

	Residual heat	Flue gas	Dissolved nutrients	Slurries	Solid wastes	Infertile soils	Sea
Microalgae (*Chlorella*, *Spirulina*, *Nannochloropsis*)	+	+	+			+	+
Macroalgae (*Ulva*, *Sargassum*)	+	+	+			+	+
Aquatic higher plants (water hyacinth, duckweed)	+	+	+			+	
Aquatic invertebrates (aquatic worms, mosquito larvae)	+			+		+	
Terrestrial invertebrates (fly larvae, mealworms, earthworms)	+				+	+	

In the following paragraphs the combinations for each crop are described.

3.1 Microalgae

Algae have received growing scientific attention, mostly because of potential high biomass yields for production of proteins on a small surface area. Besides, algae contain valuable lipids and/or chemicals. Moreover, side streams (flue gas and residual heat) can be valorized in algae cultivation, whereas algae are able to recover nutrients from remaining process water or biogas waste water (liquid digestate).

Many studies on the possibilities of utilising microalgae biomass in human and animal nutrition have been published [see reviews by 8; 9;10; 11 and 32]. Kent [12] describe the biochemical composition of well-known microalgal species *Scenedesmus* sp., *Nannochloropsis* sp., and *Dunaliella* sp.. Algae often contain many valuable proteins, which can be safely digested by several species of farm animals as part of their diet [8]. Algae also contain valuable vitamins and pigments (e.g. carotenoids) and varying types and concentrations of antioxidants. They are the main producers of the omega-3 and -6 fatty acids in the food chain [10;11]. Claims that they can be a useful additive to improve the health of animals and humans have been supported, at least partly, by research [8; 9; 10; 32]. Positive effects reported to result from algae consumption include: a low mortality rate in young turkeys, lower microbial infection in chickens, increased milk production in cows, lower feed-based cholesterol concentration in the blood of cows, higher feed conversion efficiency in pigs, decreased intensity of pain in humans suffering from fibromyalgia syndrome, lower levels of toxins in human breast milk, and improvement of IQ and serological blood parameters in humans. However, these effects are species-specific and dependent on algae growing conditions and they also differ between studies, so more research is needed [8]. Applications of algal biomass for generating value-added animal products is also seen as a great potential [9].

3.2 Macroalgae

As with microalgae, production of macroalgae does not compete with food production and they can use CO_2 from industrial emissions as carbon source and nutrients from waste water [13].

Lehahn [14] have shown the potential for offshore farming of the green marine macroalga *Ulva*. Brockmann [13] did an LCA analysis of onshore production of this species on seawater in raceway ponds.

Garcia-Vaquero and Hayes [15] evaluated the use of red and green macroalgae for fish and animal feed and human functional food development. The macroalgae contain essential amino acids and other bioactive components, such as taurine, lipids, carotenoids, and pigments. In addition, macroalgal proteins are a substrate for bioactive peptides generation.

3.3 Aquatic higher plants (e.g. waterhyacinth, duckweed).

Water hyacinth can be used for phytoremediation of wastewaters: the plants remove dissolved solids, nitrogen and phosphorous [e.g. 16]. When grown on non-polluted sources they can be used as cattle or fish feed. Duckweed can be grown on different kinds of wastewater, for example anaerobically treated swine wastewater and used as cattle and fish feed [e.g. 17].

3.4 Aquatic invertebrates (e.g. aquatic worms and mosquito larvae production).

Aquatic worms (e.g. *L. variegatus* or *T. tubifex*) and other invertebrates (e.g. mosquito larvae *Chironomus* sp.) feed on particles in slurries. Examples are activated sludges from industrial and municipal wastewater treatment plants or different manures [e.g. 18; 19]. Optimum growth rates are achieved at higher temperatures of around 15-25°C [e.g. 20; 21], which makes combinations with residual heat profitable in colder periods.

The produced invertebrates are excellent feeds for ornamental fish or juvenile farmed fish due to their high protein content, omega-3 fatty acid content and soft structure [e.g. 22].

3.4 Terrestrial invertebrates (Fly larvae, mealworms, earthworms).

Earthworms (e.g. *Eisenia fetida*) can be used to process organic wastes [23]. The produced worm biomass in turn can be used as fish or poultry feed. Agrifood waste, fibrous materials and the solid fraction of biogas slurry are examples of suitable substrates [e.g. 24]. The processed substrates (vermicompost) can be used as biofertilizers for improved plant growth [25].

Global warming potential, energy use and land use of for example larvae meal are in between those of fishmeal and soybean meal [26; 27]. Veldkamp [26] give an overview of waste streams that can be used for production of BSF, housefly and mealworms.

Several insect species have a good amino acid composition to be used as fish feed [28]. Safety aspects of feeding insects as well as consumer perception should be evaluated. Black soldier fly is for example used to decrease *Salmonella* and *E. coli* infections. Chicken meat fed on crickets contain less cholesterol and moisture, more antioxidants and protein, extends shelf life and is tastier and more expensive [29]. Some researches show improved immune responses in poultry and fish fed on insects or chitin [30].

Tzompa-Sosa [31] found that the omega-3 fatty acids constituted at most 2.5 % of the total fatty acids in four insect species (two types of mealworms, crickets and cockroaches). This is low in comparison to microalgae. The C/P ratio is beneficial in some species as well as the presence of some micronutrients [29].

5 OPPORTUNITIES AND CHALLENGES

Novel crops like microalgae, macroalgae, aquatic plants, aquatic and terrestrial invertebrates (worm, insects and larvae) can be cultivated using waste streams of agricultural biogas plants like flue gas, residual heat, solid and liquid fractions of the biogas plant slurry and also several other waste streams in other processes. These novel crops can be used as high value protein sources for animal feed, needed in the nearby future. Their composition can be altered to a certain extent by varying the input source. Nutrient cycles can be closed and CO_2 and residual heat can be valorized. Economics and sustainability improve by combining bioenergy production processes and the cultivation of alternative novel crops using waste streams and vice versa. Greenhouse emissions and emissions of nutrients in wastewaters can be reduced, land use and protein yield can be improved.

The costs of producing these alternative protein sources are at this moment still too high for replacing fish meal and soy bean protein. Some of these novel crops will however have a higher value as a feed additive. Additional effects can include higher feed conversion, improved immunity and general health and weight increase and improvement of the quality of the produced animal products (omega increased egg, milk, meat or better taste) [32].

The main challenges are increasing economic viability by:

- decreasing production and processing costs and energy use for cultivating, harvesting and processing these novel crops,
- further innovation in the machinery, tools, processes and efficiency using waste streams,
- generation of data to prove additional value as feed additive and to prove feed safety (legislation),
- more knowledge on (scaling up) production (e.g. on waste streams), pilot and demonstration results,
- economic and societal acceptance, evaluation and communication.

Legislation is an important aspect. EU feed legislation changed recently. For example, in the past, algae biomass was not permitted to be sold as a feed additive if manure or digestate had been used as the nutrient source. Since 2013, the GMP+ rules have changed (7). Now, algae biomass can be used as a feed additive if a risk analysis has been conducted on the production method and the products which will be sold have been analysed to ensure that they contain acceptable levels of certain compounds and pathogens.

Because of the expected shortages in the world protein production (already demonstrated by the rising of fish meal prices), the limitations in phosphate and non renewable energy reserves, the degradation of fertile soil area and the increase of climate problems, companies, governments and research institutes should cooperate in taking steps to overcome these challenges. The production of alternative proteins using waste streams of bioenergy production and other processes in a circular economy, can be an important stepping stone to solve the problems.

7 NOTES

(1) Lux Research, 2016. Lux Research website. http://www.luxresearchinc.com/news-and-events/press-releases/read/alternative-proteins-claim-third-market-2054
(2) Short company movie about ACRRES at http://www.youtube.com/watch?v=vSYgjIqWA8I
(3) Short movie about closing the loop with algae at ACRRES at http://www.omroepflevoland.nl/Nieuws/95170/nieuwe-algenkas-officieel-geopend (in Dutch)
(4) More information of the pilot to test the upgrade of biogas to green gas on http://www.dirkse-milieutechniek.com/dmt/do/webPages/202356/Biogasupgrading_small_size.html
(5) More information about the company producing LED lamps and cultivation systems for algae at http://www.algaefoodfuel.com/english/home/
(6) More information at www.enalgae.eu
(7) Relevant regulations GMP+: https://www.gmpplus.org/pagina/2241/gmp-fsa-certification.aspx, https://www.gmpplus.org/bestand/4224/gmp-b6---en-20130301.pdf.ashx, , https://www.gmpplus.org/pagina/9/standards.aspx

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9 LOGO SPACE