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Utilization of organic residues using heterotrophic microalgae and insects

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ABSTRACT

Various organic residues occur globally in the form of straw, wood, green biomass, food waste, feces, manure etc. Other utilization strategies apart from anaerobic digestion, composting and incineration are needed to make use of the whole potential of organic residues as sources of various value added compounds. This review compares the cultivation of heterotrophic microalgae and insects using organic residues as nutrient sources and illuminates their potential with regard to biomass production, productivity and yield, and utilization strategies of produced biomasses. Furthermore, cultivation processes as well as advantages and disadvantages of utilization processes are identified and discussed. It was shown that both heterotrophic algae and insects are able to reduce a sufficient amount of organic residues by converting it into biomass. The biomass composition of both organisms is similar which allows similar utilization strategies in food and feed, chemicals and materials productions. Even though insect is the more complex organism, biomass production can be carried out using simple equipment without sterilization and hydrolysis of organic residues. Contrarily, heterotrophic microalgae require a pretreatment of organic residues in form of sterilization and in most cases hydrolysis. Interestingly, the volumetric productivity of insect biomass exceeds the productivity of algal biomass. Despite legal restrictions, it is expected that microalgae and insects will find application as alternative food and feed sources in the future.

Contents

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1. Introduction

Enormous amounts of organic residues occur globally in the form of straw, wood, green biomass, food waste, feces, manure, etc. (Batidzirai et al., 2016; Bentsen et al., 2014; Gustavsson et al., 2013; Gustavsson et al., 2011; Noorollahi et al., 2015). Most of the residues are disposed of, composted, incinerated or converted into biogas, biodiesel or bioethanol (Kafle and Chen, 2016; Karmee et al., 2015; Nygaard et al., 2016; Yang et al., 2015).

Various processes have been developed and studied in order to exploit organic residues (Koutinas et al., 2014). Processes are predominantly based on hydrolysis and conversion of hydrolytic products into value added compounds using chemical and/or biological methods (Chandel et al., 2012; Shuddhodana et al., 2016). Heterotrophic microalgae, for instance, have been shown to grow efficiently on nutrients, such as glucose, amino acids and phosphate (Pleissner et al., 2011). Those nutrients can be recovered from organic residues, such as food waste, by biological hydrolysis (Pleissner et al., 2014). Heterotrophic microalgae can accumulate more than 50% (w/w dry matter) of their biomass as lipids (Li et al., 2011a). These lipids are often rich in polyunsaturated fatty acids (PUFAs) (Chen and Johns, 1991; Pleissner and Eriksen, 2012; Pleissner et al., 2013; Wen and Chen, 2003). PUFAs produced by algae, such as the ω-3 fatty acids α-linolenic acid (C18:3), docosahexaenoic acid (C22:6) and eicosapentaenoic acid (C20:5), are even essential fatty acids (Akerele and Cheema, 2016).

The utilization of algal biomass as a source of PUFAs is a profitable approach, but legal regulations need to be considered (van der Spiegel et al., 2013). Foods consisting of or derived from algae are considered novel foods. Algal products used as food additives are subjected to Regulation (EC) No 1333/2008. In the past, prior to market access of proteins derived from algae produced was obliged to apply for authorization under Directive 82/471/EEC. Furthermore, safety and nutritional value assessment was carried out in accordance to the guidelines in Directive 83/228/EEC. Nowadays, Regulation (EC) 767/2009 substituted both directives and no formal authorization and safety assessment is required. However, algae or their products used as feed should satisfy all maximum legal concentrations of contaminants mentioned in Directive 2002/32/EC (van der Spiegel et al., 2013). In addition, microalgal biomass further consists of, depending on cultivation conditions, up to 60% (w/w dry matter) carbohydrates (Pleissner et al., 2017) and 60% (w/w dry matter) proteins (Klamczynska and Mooney, 2017). It is the promising biomass composition that makes microalgae a source of high value products, such as fatty acids and nutritional proteins, and underlines its potential for the bioeconomy (Foley et al., 2011). Furthermore, the production of heterotrophic microalgal biomass has been deemed as carbon neutral and even as a positive technology (Bardhan et al., 2015). Combining the potential of algal biomass with the treatment of organic residues paves the way to the development of sustainable processes which allow even the recycling of organic matter.

Other interesting organisms in terms of biomass productivity and biomass composition are insects. Depending on insect species and feed substrate they are reared on, protein contents of up to 77% (w/w dry matter) and fat contents of up to 77% (w/w dry matter) were determined (Rumpold and Schlüter, 2013a). Omnivorous insects can grow directly on organic residues, such as manure, feces, straw hydrolysate and food waste, and convert those residue streams into carbohydrates, proteins and lipids (Banks et al., 2014; Li et al., 2011b; Sibi, 2015). Insects have been shown to more efficiently convert proteins accompanied with much lower water consumption than animals in conventional husbandry (Van Huis et al., 2013). Therefore, insects are considered a future feed source (Van Huis et al., 2013). Especially the insect species *Hermetia illucens* (black soldier fly) has attracted notice due to its potential for organic waste valorization. *H. illucens* accumulates during its larval stage more than 40% (w/w dry matter) proteins, 30% (w/w dry matter) lipids and 20% (w/w dry matter) carbohydrates (Fasakin et al., 2003; Surendra et al., 2016; Yehuda et al., 2011). *H. illucens* larvae can be reared sustainably on organic residues, in close quarters and a short time compared to conventional livestock and plants. Hurdles involved in utilizing insect proteins include first and foremost consumer acceptance and legal restrictions in Europe (Stamer, 2015). Insects will be considered "novel traditional food" according to the amended Novel Food Regulation (EU) 2015/2283 coming into effect on January first, 2018 and repealing Regulation (EC) No 258/1997. Insect and products thereof will have to be approved as food prior to marketing within the European Union (EU) for each insect species separately. In the feed sector, insect-based ingredients are also forbidden to date according to the so-called feed ban (Regulation (EC) No 999/2001) that prohibits the use of processed animal proteins in feed for farmed animals. Selected insect species were admitted as fish feed in aquaculture in 2017. In Switzerland selected insect species are admitted as food since 2017. And outside of Europe, in many countries in Asia e.g. Thailand (Hanboonsong et al., 2013), in Africa e.g. Uganda, Botswana, Namibia and Zimbabwe (van Huis et al., 2013) insects are traditionally traded. In addition, novel products such as, bars made with cricket or other insect flour, are marketed in the United States and Canada. It can thus be concluded that legal restrictions in the EU are calculable and will be overcome in the near future. The consumer acceptance of insects as feed will mostly depend on its protein and overall quality as well as its price.

Objective of this literature study was to assess the general potential and draw a comparison of insects and heterotrophic microalgae as a food and feed sources especially with regard to their bioconversion efficiency of organic residues. That information is missing and urgently needed to take grounded decisions on which organism contributes most to an effective and efficient conversion of organic residues. Furthermore, cultivation processes as well as advantages and disadvantages of utilization processes are identified and discussed.

2. Biomass production

2.1. Algal biomass

Depending on their digestibility, organic residues can be almost completely hydrolyzed and made available for algal cells. Food waste, for instance, is hydrolysable using glycolytic and proteolytic enzymes, and almost 90% of the organic matter can be degraded. The remaining 10% are made of lipids and not affected by the enzymatic treatment (Pleissner et al., 2014). However, not all organic residues are easily accessible and particularly lignocellulosic biomass needs tougher treatments using acid or base under high temperature in order to release sugars from cellulose and hemicellulose (Pleissner and Venus, 2014).

The use of organic residues as nutrient sources for heterotrophic microalgae has been investigated in various studies. Many algal strains are available which have been shown to grow in the presence of organic residues, but due to the most promising biomass compositions the focus is on the strains *Chlorella pyrenoidosa*, *Chlorella vulgaris*, *Chlorella protothecoides*, *Scenedesmus obliquus* and *Schizochytrium mangrovei*. In Table 1 yields and biomass productivities are listed. It is challenging to quantify all compounds obtainable from organic residues that can serve as nutrient source. However, since glucose serves as carbon source in many heterotrophic microalgae cultivations, the yields given are based on glucose consumption. In one example the yield is based on