A viewpoint on the use of microalgae as an alternative feedstuff in the context of pig and poultry feeding - a special emphasis on tropical regions

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Abstract

With the current increase in meat and animal products consumption, there is a need to make production systems more sustainable. The use of microalgae in monogastric feeds, replacing widely used conventional feedstuffs such corn and soybean, can be a solution to overcome this problem. Several studies have shown promising results in the use of microalgae in feeding of both pigs and poultry. However, there are several important constraints associated to the production of microalgae. Such constraints are particularly limiting in the context of tropical regions. Research and scientific development on microalgae production systems are thus essential so that may be widely used in monogastric feeding. Herein, we conduct an overview of the major findings in the use of microalgae in the context of monogastric feeding and analyse the major constraints associated to its production and use, particularly in the specific context of tropical regions.

Keywords: Microalgae, alternative ingredient, monogastric feed, swine, poultry, challenges.

Introduction

The continuous increase of world population, estimated to be over 10 billion people by 2100 (UN, 2019) presents a huge challenge for worldwide food security (FAO, 2018). Additionally, the increase in income and standards of living, particularly in developing countries will consequently generate an increase in the consumption of animal products in many regions of the world, leading in turn to a higher demand for meat products. Indeed, the growth of revenues in emerging economies will necessarily lead to higher purchasing power by local populations and, consequently, consumer choices will tend to be more selective and less dependent on prices, generating an increase in consumption of animal products, notably meat, dairy products or eggs (EU, 2019). This increase in demand for animal products creates a need for greater production, particularly poultry and pigs as these are the more affordable types of meat (FAO, 2011). Finally, it must be said that such an increase in both population and demand for animal origin products is, and will be particularly important in developing countries, located mostly in tropical regions.

The production of monogastric and consequently of their feed, requires obtaining large quantities of two ingredients: corn and soybeans, as these are the major feedstuffs provided to these animals being essential sources of energy, lipids, proteins and amino acids. However, these two ingredients are also very important for human nutrition. This creates a problem regarding human food security and food-feed competition. Such competition is especially important in developing countries that often do not have strong currencies reserves to ensure the purchase of these conventional feedstuffs in international markets.

The production of conventional feedstuffs requires large areas of land. This leads in turn to habitat destruction, deforestation, and use large amounts of water, with serious consequences for the environment (Gibbs *et al.*, 2015). As such, and if the current pattern for the growth of corn and soybean production for animal and human use continues, it will, in a near future, lead to severe environmental degradation and raise sustainability issues.

In order to mitigate this problem, it is urgent to find novel solutions leading to higher sustainability and productive efficiency in monogastric feeding and production. The use of new ingredients that can be more economically and environmentally sustainable alternatives in monogastric diets is therefore the solution to overcome this problem (Tacon and Metian, 2015).

In such a context, microalgae are often suggested as interesting alternative feedstuffs, more sustainable and interesting from the technological point of view, being able to fulfil the high protein, amino acid and energy of pigs and poultry in a more sustainable way.

The objective of this article is to make a short and critical review on the importance of microalgae in the context of monogastric feeding, namely what are their main advantages and limitations in order to determine their importance and future relevance. This analysis finally provides a perspective related to the importance of microalgae in the context of monogastric feeding in tropical regions.

Microalgae as a sustainable feedstuff with high nutritional value

Microalgae are a group of microorganisms, predominantly aquatic and microscopic, uni- or multicellular, with a wide genetic heterogeneity and with numerous physiological and biochemical varieties. This group can include almost 100,000 different species (Madeira *et al.*, 2017), of which only about 30% have been studied so far (Richmond, 2004).

These microorganisms are divided into 4 main types, depending on their pigmentation, life cycle and cell structure. They include Diatoms (*Bacillariophyceae*) which includes over 10,000 species; Green algae (*Chlorophyceae*) that are found mainly in the marine environment and make up about 17,000 species. They include also Blue-green algae (*Cyanophyceae*), which comprise about 2,000 species and are responsible for fixating oxygen in the atmosphere and, finally, Golden Algae (*Chrysophyceae*) with about 1,000 species that are predominantly found in fresh waters (Schmitz *et al.*, 2012).

Their composition can vary significantly, depending on factors such as species, production methodology, the use of enzymes, among others, but normally microalgae have interesting levels of proteins, carbohydrates, lipids, vitamins, minerals and particularly bioactive compounds, such as carotenoids (Valente *et al.*, 2020). Interestingly, these microorganisms have levels of protein, carbohydrates and lipids comparable or even higher than those of conventional feedstuffs, with crude protein content up to 71% of dry matter (Becker, 1994). Indeed and according to Valente et al. (2020), microalgae such as Spirulina may have average protein contents of 62-72% in dry matter content whereas for *Chlorella vulgaris* and *Nannochloropsis oceanica* protein contents may be of respectively 67% and 34%. Regarding the lipid content, in Spirulina, *Chlorella vulgaris* and *Nannochloropsis oceanica*, levels may be of respectively 11, 14 and 10%. Another interesting characteristic is the mineral content that may be as high as 35% for instance in *Nannochloropsis oceanica*. Another interesting characteristic are the PUFA (Polyunsaturated fatty acids) concentrations that can be as high as 44% of total fatty acids in Spirulina (Valente et al., 2020).

Depending on how they obtain the necessary energy to survive, microalgae can be separated into two groups: autotrophic species that use sunlight and Carbon dioxide as a source of energy and carbon, respectively, and heterotrophic species that use organic carbon as an energy source (Madeira *et al.*, 2017; Valente *et al.*, 2020). This capacity and its ubiquitous presence in ecosystems make them very important for Carbon fixation reducing Carbon dioxide in the atmosphere. In fact, they are able to produce more oxygen than all plants existing on the planet, representing at least 60% of Earth's Oxygen production (Chisti, 2004). Their ability to fixate Carbon present in the atmosphere consequently lowering the greenhouse gases (GHG) balance emitted by several industries is one of the interests in these species. By fixating Carbon dioxide in the atmosphere, they can thus be a very useful tool for industries to reduce their ecological footprints. As such, industries producing these microorganisms will simultaneously reduce the balances of GHG emissions into the atmosphere and create a product (the microalgae) that can be used for instance by the food, feed or cosmetic industries, in addition to other putative uses. It has been estimated that 30% of global microalgae production is used in feed manufacture (Guill-Guerrero, 2004).

All these characteristics have led the use of microalgae in animal feed to be strongly encouraged in the last decade. Their uses include for instance the supplementation of nutrients (Valente *et al.*, 2019; Tibaldi *et al.*, 2015; Cardinaletti *et al.*, 2018; Qiao *et al.*, 2014 ; Kiron *et al.*, 2016 ; Sørensen *et al.*, 2017; Lum *et al.*, 2013 ; Lamminen *et al.*, 2017; Lamminen *et al.*, 2019; Hopkins *et al.*, 2014; Wang *et al.*, 2017). However, in recent years, microalgae's interest as an important source of compounds like fatty acids, pigments, vitamins and minerals has also been highlighted (Hemaiswarya *et al.*, 2011; Tibbetts, 2018; Valente *et al.*, 2020).

In conclusion, microalgae, in addition to being an interesting nutritional alternative to corn and soy in monogastric feeding, may also represent an interesting solution to address sustainability concerns. Indeed, by reducing the production of ingredients such as corn and soybeans, we will contribute to lower resource consumption in agriculture.

Furthermore, by using microalgae to fixate Carbon dioxide originating from human activities, we will significantly contribute to increase the sustainability of monogastric production systems.

Microalgae in swine and poultry nutrition

Based on the above, it is of the utmost importance for the animal production sectors to improve the sustainability associated with the different production systems. The use microalgae as alternative feedstuffs is thus growing in importance. As a specific practical example, we show in figure 1, the effect of the inclusion of microalgae Tetraselmis sp. in piglet feeding at 0, 5, 10 and 15% inclusion rates. It is noteworthy to highlight the differences in pigmentation of the different feeds according to the different levels of inclusion.

As such, and based on worldwide *per capita* meat consumption patterns, their competitive costs and relatively fast production cycles, the most prominent monogastric species are undoubtedly pigs and poultry (Ritchie *et al.*, 2017). Recently, this topic has been thoroughly reviewed by us (Valente *et al.*, 2020). Readers are directed to such publication for further details.

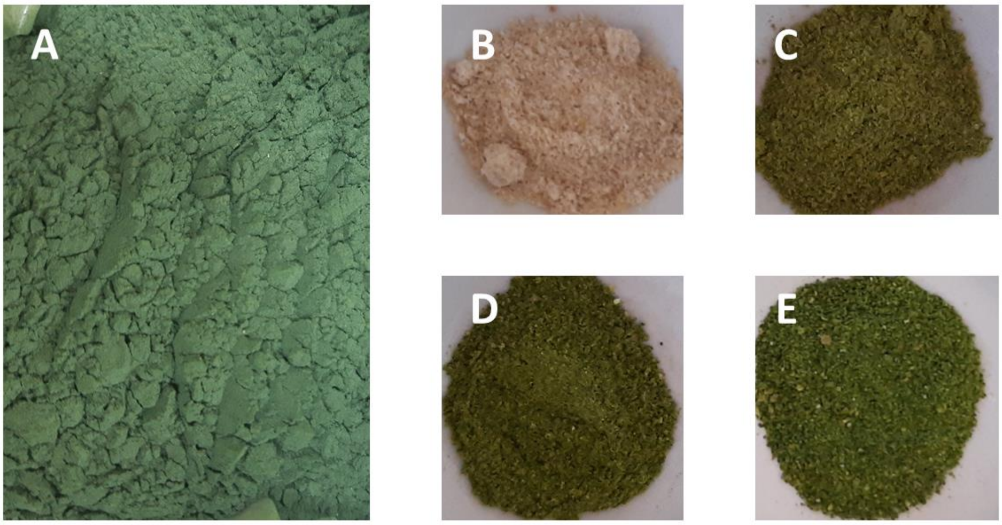


Figure 1 – An example of the use of the microalga *Tetraselmis* sp. in a swine feeding experiment. A – Spray-dried *Tetraselmis* sp.; B – Control diet with 0% level of inclusion of *Tetraselmis* sp.; C – Diet with 5% level of inclusion of *Tetraselmis* sp.; D - Diet with

10% level of inclusion of *Tetraselmis* sp. and E - Diet with 15% level of inclusion of *Tetraselmis* sp.

Briefly, numerous studies on the incorporation of different dried microalgae in poultry and swine feeds have been conducted over the years (Lum *et al.*, 2013). In the case of pigs, this research is often divided according to the stage of the life cycle, clearly separating three distinct phases: post-weaning piglets, growing/ fattening pigs and breeders. In table 1, we present an overview of the main effects of the inclusion of microalgae in the different stages of pig production and in table 2, the same information for the use of microalgae in the context of poultry feeding.

Table 1 – Major effects of microalgae incorporation in swine feeding (adapted from Valente et al., 2020).

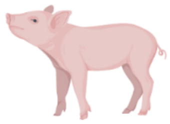
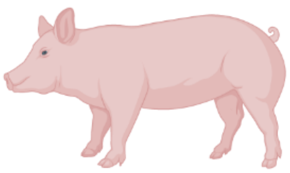
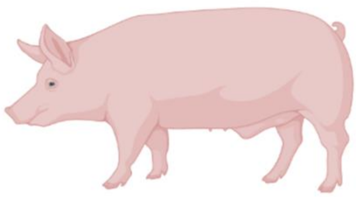
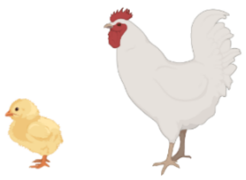
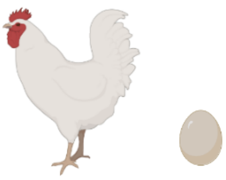
Physiological phases	Function	Main effects
 Post-weaning piglets	Additive	- Improvement of feed conversion ration ratio and weight gain. - Increase of villus height in the jejunum. - Increase of dry matter, N apparent total tract and ileal digestibility. - Variation of effects in feces consistency. - Reduce of feed intake without affecting the performance.
 Growing/ Fattening pigs	Additive	- Increase of EPA, DHA and n-3/n-6 ration in muscle. - Increase of dry matter digestibility. - Improvement of lactobacillus intestinal population. - No negative effects on animal performances. - No effects in carcass characteristics and quality.
	Ingredient	- Increase of EPA concentrations in muscle. - No effects on performances. - Increase of back fat thickness.
 Breeders	Additive	- Increase of ovarian development. - Increase of volume and count in sperm ejaculate. - Increase of sperm mobility. - Improvement of immune system of foetuses

Table 2 – Major effects of microalgae incorporation in poultry, laying hens and duck feeding (adapted from Valente et al., 2020).

Physiological phases	**Function**	**Major effects**
 Broilers	Additive	- Increase of omega-3 in meat. - Improvement of growth rate, performance and body weight. - Increase of lactobacillus intestinal population. - Improvement of immune characteristics. - Improvement of fatty acids in meat. - Increase of digestible methionine value. - Changes in muscle color (more pigmentation).
 Laying hens	Additive	- DHA enriched eggs. - Change of color of yolk color (darker, orange-red, intense). - Decrease of cholesterol levels in yolk. - Layer performance and egg quality not affected. - Enrichment of fatty acids (n-3) in eggs.
 Ducks	Additive	- Improvement in body weight. - No differences in performances. - DHA increase in breast meat.

In weaned piglets, the main concern is to guarantee intestinal health during post-weaning stress, by briefly avoiding diarrhoea or any factors that may delay the development and weight gain of such young animals. This phase is one of the most critical due to the stress and drastic environmental and nutritional changes associated with weaning. It is also the stage when the animal will be most susceptible to stress factors. Several studies have been conducted using microalgae, mostly with a prebiotic function (alone or in combination with enzymes) in order to promote intestinal health and decrease antibiotics use or use them as a feedstuff (Heo *et al.*, 2013; Martins, *et al.*, 2020).

In growing and fattening pigs, studies on the use of microalgae have a different role and researchers frequently target them as an alternative source of proteins and carbohydrates (Valente *et al.*, 2020). Indeed and as these are older animals, their susceptibility to infections is lower, for that reason the use of microalgae is more frequent than in piglets. Several authors have developed works using microalgae as an adequate protein source (Hintz *et al.*, 1967; Neuman *et al.*, 2018) describing its use as generally beneficial. Other effects have been reported: increased linoleic acids in subcutaneous fat (Altman *et al.*, 2019), increased thickness of body fat, without negatively influencing the animal's performance (Hintz *et al.*, 1967), improved nutritional properties of meat, namely the fatty acid profile in pork (Marriott *et al.*, 2002; Moran *et al.*, 2018; Sardi *et al.*, 2006; Tonnac *et al.*, 2018). In addition, the use as a prebiotic has been studied at this stage. Yan *et al.* (2012) for instance reported an improvement in the microbiological profile of animal faeces with microalgae incorporation.

In the case of breeding boars and sows, the use of microalgae is directed mostly to the latter aspect. However, few studies have been done yet and the results have to be further explored in order to have more sound data (Valente *et al.*, 2020). However, the incorporation of microalgae in the feed provided to boars showed significant improvements both in the mobility and quantity of sperm, as well as in the increase in the ejaculate volume (Andriola *et al.*, 2018; Murphy *et al.*, 2017). The way the reproductive cycle of gilts is affected by the incorporation of microalgae is still largely unexplored. However, some studies show that the incorporation of microalgae in feeds during pregnancy and lactation leads to improvements in the immune system of foetuses (Valente *et al.*, 2020).

Concerning poultry, the incorporation of several species of microalgae in feeds has been widely studied. In general, results indicate that when microalgae are incorporated at levels below 15% have the potential to be used in several species of birds for meat production, overall improving meat quality, without decreasing animal productive performance (Valente *et al.*, 2020).

Studies carried out in poultry have shown that relatively small incorporations of microalgae (less than 15%) generally lead to positive effects in several productive aspects. They include using them as a replacer for conventional protein sources. In such cases, animal performance parameters, digestibility, gastrointestinal development and growthtract or traits of meat quality has generally improved (Evans *et al.*, 2015; Kang *et al.*, 2013; Park *et al.*, 2018; Shanmugapriya *et al.*, 2015; Venkataraman *et al.*, 1994; Choi *et al.*, 2017; Yan and Kim, 2013; Mirzaie *et al.*, 2018).

Studies involving the incorporation of microalgae in diets supplied to laying hens have also shown promising results, mainly in egg quality. The fatty acid profile of both yolk and egg white showed improvements without harming animals and even improving zootechnical indexes (Manor *et al.*, 2019; Ao *et al.*, 2015; Kralik *et al.*, 2020; Ginzberg *et al.*, 2000). There was a decrease in the yolk cholesterol contents (Park *et al.*, 2015) and an intensification of its colour (Anderson *et al.*, 1991). Improvements in eggshell hardness was also reported, decreasing the number of broken eggs in laying hens (Saeid *et al.*, 2016).

Other species of poultry, such as Japanese quails or ducks, have also been used in studies involving the improvement of animal performance, changes in skin colour, improvement of meat quality and fatty acid profiles of meat (Valente *et al.*, 2020).

Considering what was stated above, the studies carried out so far on the use of microalgae as a feedstuff for swine and poultry, are a clear indication of their interest and usefulness. However, with the increase in microalgae use, a very important drawback persists. Indeed, the production of microalgae still has a very high cost, both in the creation of structures and in the technological means necessary for their production, drying, conservation, storage and transport. All of these factors will condition the interest of microalgae as a feedstuff of commercial use.

Major limitations about the use of microalgae in pig and poultry nutrition

Even with the high potential of microalgae use as in carbon fixation, production on a commercial scale is still incipient (FAO, 2009). This is due several drawbacks associated with the production systems of these organisms.

The first limitation is the high investment required in the installation of structures for the production of microalgae. The costs of implementing infrastructures such as closed photobioreactors are extremely high, representing an increased initial investment that not all industries and countries are currently able to support. Despite this, these reactors are undoubtedly those with the highest production efficiency and with a lower energy and water use (Amin *et al.*, 2009; Nogueira, 2010). In order to reduce these costs, more economical structures such as open reservoirs can be used. They lead however to a decrease in microalgae production due mainly to the variable environmental conditions to which they are subjected to. These several contaminations and the loss of water due to evaporation (Amin *et al.*, 2009; Schenk *et al.*, 2008; Demirbas, 2011).

The second limitation are the inputs necessary for the cultivation of these microorganisms and the high price associated to them. Indeed, the photosynthetic growth of microalgae requires sunlight, carbon dioxide, water and essential elements. These essential elements include mainly nitrogen, phosphorus, potassium, iron, magnesium and, in some cases, silicon. Additionally, the water used as a culture medium (usually seawater) must be enriched by adding, for example, nitrates or fertilizers with phosphate and other micronutrients. In addition, the optimal growth temperatures should vary between 20 and 30ºC (Molina-grima *et al.*, 1999; Iira *et al.*, 2012) leads to the need for energy and technology to heat cultures.

Thirdly, the biomass produced has a reduced concentration (1 to 5 g / L). Indeed, and although microalgae have a fast growth rate, a good adaptive capacity to extreme environmental factors namely poor quality water, the fact of having a reduced biomass concentration leads to high prices associated to the harvest. As such, the production rate is often lower than desired (Benemann, 1997; Li, 2008).

Finally, the production of microalgae involves large energy costs in drying and conditioning the biomass produced. However, these are dependent on the efficiency of the harvest, an aspect that can easily be improved (Matos *et al.*, 2013).

All of these factors mean that the large-scale commercial production of microalgae is still a long way from being available for animal production needs. Interestingly, the energy and transport sectors may be two of the biggest promoters of microalgae increased production. Indeed, the increasing need to find alternatives to fossil fuels has led to major interests in the production of biodiesel using microalgae for that purpose (Barata, 2016). This may provide a stimulus towards increased production and, consequently, availability for other uses, namely in animal feed. Nevertheless, it is a double-edged sword, as it will also lead to competition between the two sectors.

As such, it is essential to carry out research envisaging to lowering production costs, increasing productivity, recycling nutrients and water, using by-products and the reusing effluents treated as carbon sources for these crops (FAO, 2010). Furthermore and in the developing countries perspective, efficient and solid translation of research results and commercial implementation of such solutions will be a dire necessity for the use of microalgae in animal feeding.

Conclusions and future prospects

As mentioned above, the difficulties inherent to the use of microalgae in the context of monogastric feeding are still very significant. To some extent, such technical difficulties and their commercial price that is still very high may hamper their regular use in the context of animal feeding, particularly in pigs given the fact that higher amounts are needed to feed this animals by comparison to poultry. Furthermore, these difficulties are a particularly important challenge in developing countries, mainly located in tropical regions, due to technical and investment difficulties. Indeed, the technology required for the production of microalgae on a large scale is relatively complex from a technical point of view and expensive regarding the costs of construction, maintenance and operation of such production units. In addition, their operating energy costs and especially the high microalgae drying and transport costs also raise questions on their viability, in both developed and developing countries. However, in the latter and given some weaknesses in terms of infrastructure and its functioning, the problem can be particularly serious.

To conclude, it is essential to invest in research so that novel, more economical and energetically sustainable, techniques can be used in the manufacture, drying and transportation of microalgae ultimately targeting their use in monogastric feeding. Concerning tropical developing countries, it is clear that these solutions will have to be particularly adapted to several local constraints such as the use of simple reactors, furthermore easy to maintain and operate that should be produced at low costs. Additionally, the use of equally technically simple, produced at low cost and using renewable energy sources and not fossil fuels dryers is also a top priority. Ultimately, and from the point of view of animal feed research, it is also important that the use of microalgae moves from reduced inclusions (which has been the bulk of the research carried out so far) to higher inclusion percentages, making microalgae a possible technical alternative to corn and soybeans in monogastric diet formulations.

Declarations

Author's contribution: AMA and JPBF conceptualized this review; AAMC, CFM, DMR, DFPC and ML conducted the literature search, data analysis and interpretation. AAMC, JPBF and AMA wrote the manuscript. All authors agreed on the final version of the manuscript.

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