Seaweeds in Pig Nutrition

Subjects: Agriculture, Dairy & Animal Science

Submitted by: Raffaella Rossi

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Definition

In order to reduce the antimicrobials used in livestock, it's important to find natural and sustainable molecules that boost animal performance and health. Brown seaweeds seem to be a promising dietary intervention in pigs in order to boost the immune system, antioxidant status and gut health.

1. Introduction

Marine-derived bioactive compounds are valuable as food and feed ingredients due to their biological activities [1]. The term "algae" includes photosynthetic organisms that are usually divided into microscopic unicellular organisms, identified as microalgae, and multicellular large-size organisms defined as macroalgae or seaweed.

Microalgae usually grow in seawater and freshwater environments and can be prokaryotic, similar to cyanobacteria (Chloroxybacteria), or eukaryotic, similar to green algae (Chlorophyta). Diatoms (Bacillariophyceae), green algae (Chlorophyceae) and golden algae (Chrysophyceae) are the most abundant but blue-green algae (Cyanophyceae) are also defined as microalgae [2]. The bioactive molecules of microalgae are used as food and feed supplements [3].

Seaweeds are marine organisms and comprise thousands of species, which are classified on the basis of their pigmentation: brown seaweeds (Phaeophyceae), red seaweeds (Rhodophyceae) and green seaweeds (Chlorophyceae).

There are around 1800 species of brown seaweeds include, only 1% of which are recognized from freshwater and the size range varies from 20 m to 30 cm long. The brown color of these algae is related to the main content of carotenoid fucoxanthin, which masks β-carotene, violaxanthin, diatoxanthin, and chlorophyll. The main polysaccharides are laminarin, fucoidans and alginates, and the cell walls are composed of cellulose and alginic acid [4].

There are around 2200 species of green seaweeds. They are of similar size to red seaweeds, only 10% are marine, and their color is related to the presence of chlorophyll. The reserves are composed of starch, and the cells wall are made up of polysaccharide ulvan [5].

Of the brown seaweeds, common species such as Ascophyllum, Laminaria, Saccharina, Macrocystis, Fucus, and Sargassum was considered [6]. Brown seaweed shows a highly variable composition but presented a low protein (7.6–12.6% dry matter, DM) and fat content (0.8–6% DM). The Fucus species presents the highest protein content (12.9% DM), followed by Sargassum (10% DM), Laminaria (9.4% DM) and the Ascophillum nodosum (7.4% DM), as observed by Fleurence et al. [7]. The fat content of brown seaweeds is generally lower with an average value of 3.2% DM, and high values are observed in Fucus spp. and Ascophillum nodosum [8][9].

Red seaweeds contain a higher protein content (16.9% DM) and fat content (8.9% DM) than brown seaweeds [10].

The green seaweed Ulva lactuca has a protein content (16.2% DM) compared to red seaweeds and a comparable fat content (1.3% DM) with brown seaweeds [11]. The fat content of the studied seaweeds varies between 0.8 to 8.9% which is a similar range reported for other seaweeds species [12].

All seaweeds are characterized by a higher ash content (19.3–27.8% DM) than those observed in edible plants, in fact they are a considerable rich source of minerals for livestock nutrition [9][10].

Seaweeds are rich in potassium, sodium and calcium. Although there is a high variability, in general, the sodium and potassium contents in Ulva spp. are lower than those reported for red and brown seaweeds. A higher content of potassium has been observed in Palmaria palmata, Macrocystis pyrifera, and Laminaria spp. [10]. All seaweeds present higher levels of calcium than phosphorous, and thus may be a possible natural source of calcium in livestock. Seaweeds are also a source of essential trace elements such as iron, manganese, copper, zinc, cobalt, selenium and iodine. In particular, iron is abundant in all the species considered, and the iodine content is higher in brown than in red and green seaweeds (Laminaria spp., with a range 833–5100 mg/kg DM), and a higher zinc content has been observed in red and brown than in green seaweed.

The bioavailability of minerals is related to the fiber content of seaweeds. In addition, the interactions with several polysaccharides, such as alginates and agar or carrageenan, lead to the formation insoluble complexes with minerals, decreasing their bioavailability [13]. The mineral content in the insoluble indigestible fraction residues was higher in brown than in red seaweeds with a range of 150–260 g/kg [14]. Some studies in vitro and in rats have been performed on the bioavailability of minerals [13]. In an in vitro study of 13 seaweed species, only Palmaria palmata and Ulva lactuca showed higher Fe bioavailability than spinach, although six species had a higher Fe content. The apparent absorption values of Na and K were significantly higher in rats supplemented with Laminaria spp., while Mg absorption was not affected. It has also been reported that Laminaria spp. is rich in alginates, which probably hampers the bioavailability of Ca. The absorption of inorganic I, which is the predominant form in brown seaweeds, was observed to be moderate (20–70%). Therefore, the low bioavailability may be related to the iodine interaction with other compounds in the seaweed matrix.

The vitamin content showed that seaweeds are a source of water-soluble vitamins (B1, B2, B3 and C) and fat-soluble vitamins (E and provitamins carotenoids, with vitamin A activity). Seasonal effects have a great influence on vitamin content. Most of the red seaweeds, such as Palmaria palmata contained a considerable amount of provitamin A and vitamins B1 and B2. The brown seaweeds Laminaria spp., Ascophillum nodosum and Fucus spp. showed a high content of vitamins E and C [15].

The amino acid composition of different seaweeds species is reported in **Table 2**. Red seaweeds have a higher quality of protein than brown and green seaweeds [16], however there is a considerable difference in the amino acidic content among seaweeds, in relation to the different seasons. It has been reported that seaweeds have a low content of methionine and histidine [17][18]. Leucine was the most abundant amino acid, ranging from 2.43 g/kg DM to 6.63 g/kg DM for Palmaria palmata. and Ascophillum nodosum respectively, followed by lysine (1.42–7.60 g/kg DM), threonine (1.26–5.17 g/kg DM) and valine (2.25–5.87 g/kg DM). Glutamic and aspartic acids are the most common amino acids found in the non-essential fraction which are responsible for the flavor and taste of seaweeds [19].

2. Influence on Growth Performance

Brown seaweeds have a generally positive effect on growth, as presented in **Table 1**. Some interactions between seaweeds bioactive molecules and dietary components should be probable, but considering the heterogeneity of seaweeds species, the effects on growth performances have to be firstly analyzed in relation to seaweed supplement, and bioactive molecules content. With dietary integration in sows at the end of gestation and during lactation, an increase in average daily gain (ADG) of suckling piglets has been observed (from +11.8 to +32.3% compared to the control group). Most of the studies we reviewed involve the dietary supplementation of brown seaweeds in weaned piglets. In weaned piglets, improvements of ADG are observed. The ADG of piglets fed brown seaweeds is higher than the ADG of piglets fed a control diet with an increase of between +4.6 and +40.8%.

Table 1. Effect of seaweed supplement on average daily gain (ADG) in pigs.

Algae Supplement	Dose	Animal	Control	Supplemented	Diff. %	Ref.
A. nodosum	Dried seaweed 2.5–5–10 g/kg	Weaning to 28 d	0.220	0.209	−5.0	[20]
				0.198	−10.0	
				0.213	−3.18	
A. nodosum	Dried seaweed 10–20 g/kg	Weaning to 11 d	0.027	0.054	+100	[21]
				0.040	+48.14	
Brown seaweed	Alginic acid oligosaccharides (50–100–200 mg/kg)	Weaning to 14 d	0.216	0.248 (50)	+14.81	[22]
				0.304 * (100)	+40.78	
				0.301 * (200)	+39.35	
Brown seaweed	Alginates oligosaccharides (100 mg/kg)	Weaning to 21 d	0.441	0.516	+17.01	[23]
Ecklonia cava	FUC = 0.05 – 0.10 – 0.156 g/kg	Weaning to 28 d	0.344	0.347	+0.87	[24]
				0.368 *	+6.98	
				0.360 *	+4.65	
Laminaria digitata	LAM + FUC (0.314 – 0.250 g/kg) – lactose 15 or 25%)	Weaning to 25 d	0.275 0.287	0.293 (15% lact.)	+6.55	[25]
				0.350 ** (25% lact.)	+21.95	
Laminaria spp.	LAM (1 g/day)—sows, 109 d until weaning at 20 d	20 d lactation Weaning to 26 d Challenge Salmonella Typhimurium at 10 d post weaning	0.340	0.450 **	+32.35	[26]
	LAM (0.3 g/kg)—piglets		0.410	0.370	−16.13	
Laminaria spp.	LAM + FUC (0.18 + 0.34 g/kg)	30.9 kg pigs for 28 d Challenge Salmonella Typhimurium at 10d	0.620	0.720 ***	+16.13	[27]
Laminaria spp.	LAM (0.112 g/kg) [y] FUC (0.089 g/kg) [z]	Weaning to 25 d	0.281	0.322 **	+14.59	[28]
Laminaria spp.	LAM + FUC (1 g + 0.8 g day) − sows LAM + FUC (0.3 + 0.24 g/kg) − piglets	Weaning to 126 d	0.760	0.850 ** (lactation effect)	+11.84	[29]
			0.800	0.810 (weaning effect)	+1.23	
Laminaria spp.	Extract (1–2–4 g/kg) [x] LAM = 0.11–0.22–0.44 FUC = 0.09–0.18–0.36	Weaning to 21 d	0.249	0.274 ***(1 g/kg)	+10.04	[30]
				0.313 *** (2 g/kg)	+25.70	
				0.303 ***(4 g/kg)	+21.69	
Laminaria spp.	LAM (0.30 g/kg)	Weaning to 32 d	0.280	0.353 *	+26.07	[31]
Laminaria spp.	LAM + FUC (0.30 + 0.24 g/kg)	Weaning to 40 d	0.356	0.374	+5.06	[32]

Algae Supplement	Dose	Animal	Control	Supplemented	Diff. %	Ref.
Laminaria spp.	LAM (0.3 g/kg) FUC (0.36 g/kg) LAM + FUC (0.3 + 0.36 g/kg)	Weaning to 21 d	0.288	0.319 * LAM 0.3	+10.7	[33]
				0.302 FUC 0.36	+4.86	
				0.328 LAM + FUC	+13.89	
Laminaria spp.	LAM + FUC (0.30 + 0.24 g/kg) [k]	Weaning to 21 d	0.235	0.239	+1.70	[34]
		21–40 d	0.489	0.523	+6.25	
Laminaria spp.	LAM (0.15–0.30 g/kg) FUC (0.24 g/kg) LAM + FUC (0.15 + 0.24 and 0.30 + 0.24 g/kg)	Weaning to 35 d	0.340	0.351 FUC 0.24	+3.24	[35]
				0.334 LAM 0.15	–1.76	
				0.347 FUC 0.24 LAM 0.15	+2.06	
				0.390* LAM 300	+14.71	
				0.358 FUC 0.24 LAM 0.3	+5.29	
OceanFeedSwine	Seaweeed extract (5 g/kg)	21 to 56 d	0.401	0.380	−5.24	[36]
		56–160 d	0.798	0.824 *	+3.26	

Draper et al. [29] and Ruiz et al. [36] appear to be the only two authors to report the effects of long–term dietary supplementation with brown seaweed from weaning to slaughter on ADG. In this case, the influence on ADG was limited but statistically significant, and ranged from +1.2 to +3.3%. Bouwhuis et al. [26][27] evaluated the effects of brown seaweed supplementation on pigs' growth performance after being challenged with Salmonella Typhimurium. When the challenge occurred in post–weaning, no significant effect was observed; in pigs with a live weight of 30 kg, the seaweed supplement led to a significant increase in growth (+16%). It is possible that the bioactive compounds of seaweeds are not able to positively modulate the immune system of the post–weaning piglet which is still immature.

Positive effects on growth are related to the improvement in digestibility and overall health conditions of piglets due to the prebiotic effects of seaweed polysaccharides, as described in the following sections. The effects of seaweed dietary supplementation on the improvement in antioxidant status and the decrease in inflammatory condition may contribute to reduce energy and amino acidic expenditure.

3. Influence on Digestibility

Many authors have evaluated the effects of algae supplementation on the digestibility of the diet in pigs, as presented in **Table 2**.

Table 2. Influence of seaweed on digestibility in swine.

Algae Supplement	Dose g/kg	Animal	Effects on Digestibility	Treatment vs. Control, %	Ref.
A. nodosum	Dried intact (2.5 g/kg)	Male Pigs, 45 kg LW	NS	–	[37]
A. nodosum	Dried intact (10–20 g/kg)	Weaned piglets (35 d age)	NS	–	[21]
			Improved digestibility of		

Algae Supplement	Dose g/kg	Animal	Effects on Digestibility	Treatment vs. Control, %	Ref.
Brown seaweed	Alginates olisaccharides (100 mg/kg)	Weaned piglets, 6.2 kg LW	N, fat, ash GE	+6.7% +10.8% +25.9% +4.0%	[23]
Ecklonia cava	Seaweed (0.5–1—1.5 g/kg) [s]	Weaned piglets 7.8 kg LW	Improved digestibility of GE	+3.3% (1g/kg)	[24]
Laminaria digitata	LAM + FUC (0.314–0.250 g/kg)	Weaned piglets, 7.2 kg LW	Improved digestibility of OM, N, NDF, GE	+4.5% +7.3% +73.3% +5.9%	[25]
Laminaria spp.	Extract (1–2–4 g/kg) [x]	Weaned piglets (24 d age)	NS		[30]
Laminaria spp.	Seaweed extract LAM (0.112 g/kg) [y] FUC (0.089 g/kg) [z]	Weaned piglets, (24 d age)	Improved digestibility of N, GE	+6.7% +5.2%	[28]
Laminaria spp.	LAM + FUC (0.30 + 0.24 g/kg)	Weaned piglets (22 d age)	Improved digestibility of DM, N, NDF	+8.8% +8.9% +57.5%	[32]
Laminaria spp.	LAM (0,15–0,30 g/kg) FUC (0,24 g/kg) LAM + FUC (0,15 + 0.24 and 0.30 + 0.24 g/kg)	Weaned piglets (24 d age)	improved digestibility of DM, LAM and LAM + FUC OM, LAM and LAM + FUC N, LAM NDF, LAM and LAM + FUC GE, LAM and LAM + FUC	+7.0% – +4.5% +5.9% – +3.5% +5.1% 54.5% – 39.7% +7.3% – +4.3%	[35]
Laminaria spp.	LAM (0.30 g/kg) FUC (0.24 g/kg) LAM + FUC (0.30 + 0.24 g/kg)	Weaned piglets (24 d age)	Improved digestibility of DM, LAM and LAM + FUC N, LAM Ash, LAM and LAM + FUC GE, LAM and LAM + FUC	+7.9% – +4.5% +6.6% 58.0% – 42.6% +8.5% – +4.3%	[31]
Laminaria spp.	Extract (0.66 g/kg) [k]	Weaned piglets (24 d age)	Improved digestibility of OM, N, Ash, NDF, GE	+8.8% +8.9% +82.4% +57.5% +10.9%	[34]

All digestibility trials were conducted in weaned piglets, except for the study by Gardiner et al. [38] which investigated male pigs with a 45 kg live weight. The Ascophyllum nodosum does not appear to have a significant influence on diet digestibility [21][38]. On the other hand, Laminaria digitata, Laminaria spp., Ecklonia cava and brown seaweed, titrated in alginates, showed positive effects on the digestibility of nitrogen (N), gross energy (GE), fiber (NDF) and ash in various experiments. Significant improvements from +5.1 and +8% in N digestibility are reported. Also for GE, dietary integration with seaweed improved the digestibility, with an increase of between +3.3 and +10%.

Some authors have also observed that introducing laminarin and fucoidans in the formula increases the digestibility of the fibrous fraction (NDF). The animals fed seaweed showed a higher digestibility of NDF (+39 to +73%) compared to the control group. Finally, ash digestibility presented values that in the seaweed group were 25.9–82.4% higher than in the control.

The improvement in nutrient digestibility is related to the influence of the seaweed constituents, in particular carbohydrates and antioxidants, on microbiota and on the villous architecture with an increase in absorptive capacity and nutrient transporters [37]. These effects are also related to the trophic effect on the intestinal mucosal cells of volatile fatty acid production.

4. Prebiotic Function

Seaweeds are rich in carboxylated and sulfated polysaccharides, such as alginates, ulvans and fucoidans which all act as prebiotics with positive effects on gut health. According to FAO [39] a prebiotic is a 'non–viable food component that confers a health benefit on the host associated with the modulation of microbiota'. The health benefit is associated with the stimulated activity/growth of beneficial bacteria and the higher production of short chain fatty acids (SCFAs) with direct impact on gut health and also an immunomodulatory effect, as reported below.

Several papers have analyzed the prebiotic effects of algae [40][41][37][42][43][44][45][46]. In swine, 24 studies have been published in the last 10 years on the effects of supplementation with brown seaweeds, or their extracts, on gut health: Ascophyllum nodosum [21][20][38], Ecklonia cava [24], Laminaria digitata [25][47][48], Laminaria hyperborea [49][50], Laminaria digitata and Laminaria hyperborea association [51], Laminaria spp. [26][27][28][31][33][34][35][52][53][54][55][56][57]. Brown seaweeds titrated in alginic acid polysaccharides have also been studied [24]. Most of the studies were carried out on weaned piglets (14 trials), considering that the weaning phase is a critical period with a high incidence of enteric pathologies. Some studies were carried out on growing pigs ranging between 14 and 65 kg LW, and some others on gestating and lactating sows.

In general the compounds present in the brown seaweeds (in 20 trials the supplement was titrated in laminarin and/or fucoidans) stimulated the growth of Lactobacilli [22][25][28][34][35][38][48][49][50][51], and reduced the enterobacteria population or Escherichia coli [21][26][22][24][25][33][35][38][50][51][52][54]. Brown seaweed supplements supported the growth of Bifidobacteria species in the ileum in piglets [22][47][48]. Gut health is modulated by laminarin and/or fucoidans, with the microbial production of short–chain fatty acids (SCFAs), in particular butyrate [48][51][53]. Glucose are the main energy source for small intestinal epithelial cells, and SCFAs are the main energy source for caecum and colon cells, stimulating cell growth [58]. Several studies have reported that brown seaweeds have a positive influence on gut morphology [24][54][55][59]. Supplementation with Ecklonia cava (0.05 and 0.15% of dietary inclusion), linearly improved villi height in the ileum [24]. In weaning piglets, maternal dietary supplementation with laminarin and fucoidans (1 and 0.8 g/day) after 83 days of gestation and during lactation increased villi height in the jejunum and ileum (+43 and +88% respectively) [54]. According to Heim et al. [55], maternal dietary treatment with fucoidans (0.8 g/day) had no influence on the small intestine morphology, while laminarin increased the villus height in the ileum (+13%) at day 8 post–weaning. In vitro and in vivo experiments carried out by Dierick et al. [21] revealed that native seaweeds Ascophyllum nodosum suppressed in vitro the gut flora counts and metabolic activity (production of organic acids), while in vivo, a significant better lactobacilli/E. coli ratio was found in the small intestine. Michiels et al. [20] on the other hand observed no significant effects on gut health with the use of the same seaweed in weaned piglets, most probably due to the already high digestible basal diet, including lactose. To probiotic activity algae associate bacteriostatic and antibacterial activities recently reviewed by Perez et al. [60]. In particular potential applications in aquaculture [61] and in the pharmaceutical and food industry [62], have been evaluated.

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Keywords

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