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(Organizadores)

Investigación, tecnología e innovación EN CIENCIAS AGRÍCOLAS 4

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APRESENTAÇÃO

A agronomia desde os tempos remotos atua como uma área de conhecimento que além de ampla, é necessária para o desenvolvimento econômico e social. Desse modo, a pesquisa e inovação nos segmentos que fazem parte do setor agrário são indispensáveis para promover um melhor desempenho no futuro.

Nos últimos anos, a inclusão da tecnologia tem impulsionado a grade de estudo no campo das ciências agrárias. Tal avanço, evidentemente, permitiu que novas técnicas e melhorias chegassem até produtores, de forma a garantir um novo cenário, a fim de aliar produtividade e rendimento econômico.

As ciências agrárias, em sua totalidade, agrupam um conjunto de conhecimentos que permitem uma melhor utilização dos recursos naturais. Assim, este livro intitulado "ORGANIZACIÓN, INVESTIGACIÓN, TECNOLOGÍA Y INNOVACIÓN EM CIENCIAS AGRÍCOLAS 4" tem como finalidade abranger uma série de estudos focados em apresentar métodos e tecnologias para impulsionar os processos agrícolas já existentes, desde técnicas no campo e laboratório.

Os temas aqui abordados refletem estudos de artigos científicos e revisões bibliográficas, de maneira a reunir informações precisas e fundamentais para uma estratégia de aproveitamento dos recursos naturais. Nesse sentido, ao longo da obra são apresentados 10 trabalhos que objetivam imergir o (a) leitor (a) dentro de um panorama agronômico.

Espera-se que este estudo permita ao presente leitor (a) a possibilidade de conhecer novos mecanismos de pesquisa para fins agropecuários, além de agregar mais conhecimento e um novo olhar sobre a importância da tecnologia no meio agrário.

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SUMÁRIO

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CAPÍTULO 10

TOTAL REPLACEMENT OF FISHMEAL BY SOYBEAN, RAPESEED AND LUPINE MEALS IN CHILEAN SOUTHERN RIVER CRAYFISH JUVENILES, *Samastacus spinifrons*

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ABSTRACT: One of the concerns for maintaining the growth rate of aquaculture is the availability of inputs for the preparation of feed. As is well known, the most commonly used ingredient is fishmeal, an input which in the near future will no longer be sufficient for maintaining this growth rate. In this context, a proposal was made to establish the effects caused by a total replacement of fishmeal with vegetable ingredients such as soybean, rapeseed and lupin meals on the growth and survival rates of Chilean southern river crayfish juveniles, *Samastacus spinifrons*. To this end, 12 tanks (length 0.4 m; width 0.23 m; height 0.17 m) were prepared with customised PVC and mosquito net structures. The water flow rate was 0.132 L min^{-1}. 20 juveniles were allocated to each tank, and isoproteic feed (30%) was administered once a day. After 100 days, no significant differences were found in the growth parameters between the fish meal-based diet and the diets made from soybean, rapeseed and lupin meal. In terms of survival rates, rapeseed and lupin significantly out-performed soybean and fishmeal. No difference was observed between the latter two.

KEYWORDS: S. spinifrons, fishmeal, soybean, raps, lupin, replacement

1 I INTRODUCTION

In the culture of aquatic organisms, fishmeal is a high quality protein input for diet preparation. This is due to the fact that it contains suitable components, has good palatability and has been relatively abundant. Its use in aquaculture is 73% of the 6 to 7 million tonnes that are produced annually, and it has been increasing in other similar industries such as poultry farming, pig farming and others (Jackson & Aldon, 2012). The continued rapid expansion, which the aquaculture industry is experiencing, cannot be sustained based on the use of fishmeal as the main ingredient in diet formulation. As such, it is imperative that the use of fishmeal in feeds be reduced and replaced with plant-based sources of protein.

The replacement of fishmeal with vegetable proteins has its limitations due to the generally lower quality and concentration of proteins in vegetable sources compared with fishmeal, along with the fact that the palatability of the majority of vegetables is relatively low. However, vegetable protein offers lower costs and greater availability compared with fishmeal. Given this cost advantage, the quality of the protein from these vegetables could be improved during the production phase (Drew, Borgeson, & Thiessen, 2007).

Among the vegetables used as fishmeal substitutes in aquatic organism diets are soybean, canola/rapeseed, lupin, pea and flax meal (Table 1). Some of the characteristics that should be highlighted are the lower crude protein content of vegetables compared with fishmeal, as well as the presence of heat-labile and heat-stable compounds that negatively affect their usability. Global production of the three primary inputs (soya, rapeseed and lupin) has increased from 286 (2009) to 386 (2016) million tonnes per year (Table 2).

1.1 Characteristics of the vegetable ingredients used

1.1.1 Global production volumes of soybean, rapeseed and lupin

a) Soybean meal

Soybean meal is the vegetable most used as a source of proteins in animal diets. It has the advantages of high yields and high crude protein and lysine content, as well as being supply and cost stable. However, it has a relatively low protein efficiency ratio (PER) (1.60) and contains heat-labile and heat-stable compounds (Table 1). Its low PER is due essentially to its low methionine content (Sarwar, 1985).

There are a good number of studies which show that a high level of soybean in their diets leads to reduced growth and lower feed efficiency in aquatic organisms (Tacon, 1983); (Kaushik et al., 1995). High soybean meal content causes pathological changes to the intestinal mucosa of Atlantic salmon, and it is suggested that this is due to a reduction of intestinal villi and a thickening and infiltration of the mucosa with inflammatory cells (Baeverfjord & Krogdahl, 1996), and changes in bacterial flora (Drew et al., 2007), possibly leading to levels of necrosis in parts of the intestine as caused by *Clostridium perfringens* in birds (Drew et al., 2007).

Soybeans also contain heat-labile compounds which are trypsin inhibitors but, fortunately, these can be removed during soybean meal processing (Arndt, 1999). They also contain heat-stable compounds like saponins, phytates, phytoestrogens and protein antigens which must be removed by other methods, such as aqueous or solvent extraction, fractionation or use of exogenous enzymes (Bureau, Harris, & Cho, 1998; Refstie, Storebakken, & Roem, 1998).

The main producers of soybeans (in millions of tonnes) are: USA (106.9), Brazil (100), Argentina (57), China (12), Paraguay (8.8), India (8) and Canada (6.2) (Soja, 2016). In January 2016, the U.S. Department of Agriculture (USDA) estimated that 2015/2016 global soybean production would be 319.01 million tonnes (Table 2). Last year's global production was 318.8 million tonnes, meaning an increase of 0.21 million tonnes or 0.07% in global soybean production.

b) Rapeseed

Rapeseed is the protein ingredient with the second highest production after soybeans. It is also known as colza or canola. The cost per amount of protein is almost half that of fishmeal, and its PER value is high (3.29) (Sarwar et al., 1984). However, it contains heat-labile and heat-stable compounds, which limit its use in aquaculture diets (Table 1).

This ingredient has been studied alongside a variety of aquatic species: trout, *Oncorhynchus mykiss* (Hilton & Slinger, 1986), Chinook salmon, *Oncorhynchus tsawytscha* (Satoh et al., 1998), and Nile tilapia, *Oreochromis niloticus* (Soares, Hayashi, de Faria, & Furuya, 2001). Its high fibre and low protein content, combined with low total tract digestibility coefficients of protein, dry matter and energy are restrictive to its commercial use in aquaculture diets. Inclusion of rapeseed in the order of 200 g kg^{-1} in diets for trout juveniles does not affect growth (R. Hardy & Sullivan, 1983). However, Hilton and Slinger (1986) demonstrate that levels of 135 g kg^{-1} reduce growth rate in young trout. There are also studies of crustacean species: *Litopenaeus vannamei* (Cruz-Suarez, 2001; Lim et al., 1997) and *Marsupenaeus japonicus* (Bulbul, Kader, Koshio, Ishikawa, & Yokoyama, 2014).

Heat treatment is beneficial for its use in fish diets. There is a reduction in glucosinolates, although there is always concern about the effect that this has on thyroid function, feed acceptance, renal and hepatic function, and growth in fish (R. Hardy & Sullivan, 1983; R. S. Hardy, C, 1983). In the case of chickens, glucosinolate has no effect, whereas in the case of fish like the Chinook salmon, growth was reduced when fishmeal was replaced by rapeseed (Satoh et al., 1998). However, when rapeseed which has been extruded at 90 or 150°C is used, no growth rate differences were observed.

In addition to glucosinolates, rapeseed contains a relatively low level of protein and high levels of fibre and phytates. Clearly, this reduces its value for aquaculture diets (Drew et al., 2007). The value of rapeseed can be boosted by grinding at 60 mesh; this breaks down the structure of the fibre and increases the protein content (Thiessen, Campbell, & Adelizi, 2003). Under these conditions the levels of fibre and phytates can be reduced even further by aqueous extraction of the protein (Thiessen, Maenz, Newkirk, Classen, & Drew, 2004) in order to produce rapeseed protein concentrate.

The main global producers of rapeseed (in millions of tonnes) are: European Union (21.8), Canada (17.2), China (14.1), India (6) and Japan (2). Last year's global production was 72.2 million tonnes. The current season's estimated 67.72 million tonnes could mean a decrease of 4.4 million tonnes, or 6.1% less rapeseed production around the world (Colza, 2016).

c) Lupin

This general term encompasses various species of lupin, with high protein content (350-500 g kg^{-1} on the basis of dry matter) and lipid content (80-100g/kg^{-1}). The white lupin variety (*Lupinus albus*) represents the "sweet lupins" for their low alkaloid content (Roemer, 1993). The lupin's protein has a good balance of amino acids and a PER of 2.32 (Table 1). However, sweet lupins contain some heat-labile compounds (protease inhibitors) and heat-stable compounds (non-starch polysaccharides, saponins, protein antigens and phytoestrogens). These varieties of lupins have some drawbacks compared with soybean meal, such as lower protein levels and high levels of fibre, non-starch polysaccharides and alkaloids (Francis, 2001). However, they have several advantages over soybeans in that sweet lupins do not require thermal treatment in order to be used in aquaculture diets, due to the absence of lectins and low levels of protease inhibitors (Higuera et al., 1988).

In terms of the digestibility of unprocessed sweet lupin meal, studies have been done with various species of fish (Table 3). The total tract digestibility coefficient for crude protein was greater than 0.90 in trout (B. Glencross et al., 2004), Nile tilapia (Fontainhas-Fernandes, Gomes, Reis-Henriques, & Coimbra, 1999) and Australian yellowtail (Booth, Allan, Frances, & Parkinson, 2001), as well as in crustaceans*: Penaeus monodon* (Sudaryono, Tsvetnenko, & Evans, 1999) and *L. vannamei* (Molina-Poveda, Lucas, & Jover, 2013). Gross dry matter and energy digestibility is low due to the presence of indigestible fibre and non-starch polysaccharides (Brett D. Glencross, Boujard, & Kaushik, 2003). Extrusion at 145°C increases the gross dry matter and energy digestibility in rainbow trout, offering better yields in growth, intake and feed efficiency (Bangoula, 1993).

1.2 The organism under investigation

The Chilean southern river crayfish, *Samastacus spinifrons*, is a species which can be found from the Aconcagua river all the way to the Taitao peninsula. It reaches a good size and has a good tail proportion (35% of the total weight), and offers good flavour and versatility for human consumption. (Salgado & Tacon, 2015).

There are many studies of fishmeal replacement in aquaculture diets, which have been carried out with species of crustaceans, and results have been varied. The majority of these studies involve partial replacement of fishmeal. Based on these foundations and having determined the protein requirements (30%) with fish meal-based diets in *S. spinifrons* juveniles (Salgado & Tacon, 2015), a study was proposed into total replacement of fish meal with soybean, rapeseed and lupin meal (individually) in order to observe the effects on growth and survival of those juveniles.

2 | MATERIALS AND METHODS

The pilot experiment was carried out in the laboratory of the School of Aquaculture at the Universidad Católica de Temuco (UCT), Chile, in an open flow water system (Q=0.132 L min^{-1}). 12 experimental units were used, consisting of plastic containers of area 0.092 m^2 (length: 0.40 m x width: 0.23 m) and volume 0.016 m^3 (height: 0.17 m). These were equipped with 20 individual numbered pens of 45 cm^2 which would each be occupied by one specimen in order to observe growth individually and avoid cannibalism. The individual pens were made from sheets of PVC and 3mm mesh mosquito netting to allow for water and air circulation between them.

The juveniles all came from the same birth cohort of the breeding stock kept in the School of Aquaculture's laboratories, and had an average individual weight of 0.477 g. The experiment design was simple and completely random, involving four applications (rapeseed, lupin, soybean and control), with three replications each. 12 experimental units were used, meaning a total of 240 individuals.

The formulated diets were isoproteic (Table 4). The formulation was calculated in an Excel spreadsheet, maintaining ingredient proportions which would result in protein content of 30% and lipid levels of between 6 and 7.5%, in line with the content of the control diet (Ackefors, Castell, Boston, Raty, & Svensson, 1992). All of the diets had a vitamin and mineral supplement added to them. Each of the experimental diets was then produced according to the formulations generated. The component ingredients were each ground to a size of 300 microns. Then the correct weight of each ingredient was measured out according to the generated formulations. Subsequently the principal dry ingredients were mixed. The other ingredients were mixed separately. The wheat meal was added to cold water and cooked to form a gelatin, then added to each mixture. The oil and the secondary mixture were then mixed and added to the larger mixture. This process was carried out in a model K5SS KitchenAid mixer over a period of 20 minutes. To make the pellets, the mixture was passed through an RCA meat grinder with a sieve of 1.5 mm holes, and formed into continuous ribbons of moist feed. These were then moved to the kiln (55 °C) for 24 hours. Once dehydrated, the feed was broken up into 2mm lengths. As with the ingredients, the diets were then analysed in the nutrition laboratory of the School of Aquaculture (UCT) using the AOAC Official Methods of Analysis (AOAC, 2006).

The experiment ran for a period of 100 days. The juveniles were fed until they appeared to be satisfied, once a day. Before the next feeding, the uneaten feed was removed from each pen using a syphon and stored in individual plastic bags. These were kept refrigerated. Every 20 days, the leftovers were dried in the kiln and weighed. This figure was removed from the total feed figure for each pen and in this way, the quantity of feed consumed could be established. Additionally, the water temperature and dissolved oxygen levels were measured using a WPW OXI 330 digital oxygen meter with a sensitivity of 0.01 mg/L^{-1}.

Measurements were taken of each specimen every 20 days. On each occasion, a measurement was taken of the total length using a millimetre ruler, and of the individual weight using a LAK analytical balance with a limit of 217 g and an accuracy of 0.0001 g. Survival was recorded daily at feeding time. Dead individuals were removed, identified by pen number and weighed.

2.1 Growth parameters

The following growth parameters were used:

- Absolute individual weight increase = Final individual weight – Initial individual weight
- Relative increase in individual weight = [(Final individual weight – Initial individual weight) / Initial weight] * 100
- Specific growth rate (SGR) = [(Final individual weight – Initial individual weight) / T (days)] * 100
- Gross biomass increase = (Final biomass – Initial biomass) + Biomass increase of dead individuals

2.2 Nutritional parameters

Feed conversion ratio = Feed consumed / Gross biomass increase

Protein efficiency ratio = Gross biomass increase / Quantity of protein consumed*

*Quantity of protein consumed = Feed consumed x % of protein in the diet

2.3 Survival

(Final number of individuals / Initial number of individuals) * 100

2.4 Statistical analysis

In the first instance, normality, homoscedasticity and independence of variance were verified.

The data obtained were ordered and evaluated using a one-way analysis of variance (ANOVA), with a confidence interval of 95% ($p<0.05$). Mean comparison was done using Tukey's test. The Minitab v.17 programme was used for all of these analyses.

3 | RESULTS

In Table 5, the results suggest that a total replacement of fishmeal by vegetable ingredients in diets achieves the following increases in biomass: the greatest increase is with soybean (35.54%), followed by the control (33.38%), then with lupin (25%) and finally with rapeseed (22.84%). There are no significant differences between these new diets, nor compared to fishmeal.

Rapeseed, lupin and soybean do not affect the growth of *S. spinifrons* juveniles. This can be concluded from the fact that no significant differences were observed in the production variables between these different diets. The survival variable is the one exception: the soybean-based diet (32.5%) does not differ from the lupin-based diet (37.5%) nor from the control (17.5%). By contrast, all of these differ from the rapeseed-based diet (75%). It can be seen that vegetable diets improve the survival of organisms compared with fishmeal diets.

Despite the results of the statistical tests, in practical terms, the soybean-based diet produced the best results in biomass gain (35.54%), in conversion factor (1.75) and in protein efficiency ratio (1.99).

4 | DISCUSSION

This study demonstrates that total replacement of fishmeal in diets by vegetable ingredients such as soybean, rapeseed and lupin has similar effects in terms of growth parameters in *S. spinifrons* juveniles. This is evidenced by the lack of statistical difference in the individual weight increase, SGR, biomass gain, feed conversion ratio and protein efficiency ratio variables.

4.1 With soybean meal

Of all the vegetable ingredients, soybean meal has been the most studied and utilised in aquaculture diet preparation (Akiyama, 1991).

In the species of crustaceans that have been studied, the replacement of fishmeal by soybean meal seems to have different tolerance levels to diets where fat-free soybean meal is used. (Fuertes, Celada, Carral, Saez-Royuela, & Gonzalez-Rodriguez, 2012). For example, in studies with *L. vannamei*, replacing up to 40% of the animal protein in their diets with soybean meal protein does not affect growth or feed efficiency (Lim & Dominy, 1990).

In *Cherax quadricarinatus*, it was observed that a replacement in the order of 25% can reduce their growth (Garcia-Ulloa, Lopez-Chavarin, Rodriguez-Gonzalez, & Villarreal-Colmenares, 2003).

In *Macrobrachium rosenbergii*, their growth and feed efficiency was reduced when the replacement level was as low as 20% (Du & Niu, 2003). This will depend on the feeding behaviour of the animal.

In *Pascifastacus leniusculus*, it was demonstrated that in diets with 50% protein content, up to 25% of the protein derived from fishmeal can be replaced by soybean for juveniles. Greater levels of replacement affect survival and growth (Fuertes et al., 2012).

Similar results were observed in *Ch. quadricarinatus* (Garza, Davis, Rouse, Ghanawi, & Saoud, 2012), working with soybean meal-based diets (350 g kg^{-1} crude protein, 71 g kg^{-1} lipids) combined with fish meal, by-products of the chicken industry, pea meal or dry grain distillates as sources of protein. No significant differences in growth or feed conversion ratio (FCR) were found. Similarly, Muzinic et al. (2004) obtained the same results by replacing fishmeal with soybean meal and grains and yeast from the brewing industry. In the same way, Saoud et al. (2008) studied the reactions of *Ch. quadricarinatus* juveniles to six diets (260 g kg^{-1} crude protein, 70 g kg^{-1} raw lipid) in which fish meal was replaced to various degrees with by-products of the chicken rearing industry. Yuniari et al., 2011 (Saoud, Garza, & Ghanawi, 2012) used snail (*Pomacea canaliculata*) meal to replace fish meal, finding the same results. Thompson et al. (2005) demonstrated that in closed circulatory systems, red claw juveniles can be offered a diet with 350 g kg^{-1} of crude protein without the inclusion of fishmeal, but with a combination of vegetable ingredients such as soybean meal, wheat and brewing grains with yeast, without affecting their growth. In the case of raising juveniles in earthen ponds, fishmeal can be replaced with soybean meal, brewing grain distillates and maize, maintaining growth rate (Thompson, Metts, Muzinic, Dasgupta, & Webster, 2006).

In other species of crustaceans, (Roy et al., 2009)) obtained identical results in *L. vannamei* using the same diets and at lower levels of salinity than Garza et al. (2012). This can be explained by the omnivorous nature of the majority of crustaceans, which gives them the capacity to digest and absorb nutrients not only from fish meal but also from vegetable ingredients (Campana-Torres, Martinez-Cordova, Villarreal-Colmenares, & Civera-Cerecedo, 2005).

With *Macrobrachium tenellum*, replacing fish meal with different levels of soybean meal resulted in no significant differences in growth and survival rate (Gomez, Lopez-Aceves, Ponce-Palafox, Rodriguez-Gonzalez, & Arredondo-Figueroa, 2008).

Procambarus clarkii juveniles exhibited similar growth behaviour compared with commercial diet (McClain & Romaire, 2009).

With *Macrobrachium nipponense*, total replacement of fishmeal with fermented soybean meal did not affect either growth or survival, just like in this study. The best results were achieved with a 25% replacement (Ding, Zhang, Ye, Du, & Kong, 2015).

On the other hand, there are studies which have resulted in different marginal growths in red claw (*Ch. quadricarinatus*) juveniles when fishmeal has been replaced with soybean meal at different levels. In these experiments, diets with fishmeal offered better growth and more frequent shedding than those diets with varying levels of soybean meal (Garcia-Ulloa et al., 2003).

Better yields from soybean than from lupin and rapeseed could be due to their high lignin content, and therefore reduced digestibility (Pavasovic, Anderson, Mather, & Richardson, 2007).

The nutritional limitations of soybean meal as a diet ingredient for aquatic organisms are well known. Compared to fishmeal, soybean meal is deficient in lysine, methionine, threonine and arginine (Akiyama, 1991). There are in addition to this antinutritional factors present such as trypsin inhibitors, lectins, saponins and protein antigens (Brown, Brown, Hart, Curry, & Hittle-Hutson, 2008). Although the transformation of soybeans into meal, or submitting them to the extrusion process reduces the presence of antinutritional factors, these compounds, together with essential amino acid deficiencies, limit the quantity of soybean meal in aquaculture feeds (Brown et al., 2008).

In this study, none of the growth parameters were affected by total replacement of fish meal with soybean meal.

b) With rapeseed meal

In the case of rapeseed, the same tendencies are seen as before. That is to say, as their use increases, growth and feed consumption are affected. Lim et al. (1997) suggests that rapeseed could constitute up to 30% of the protein source for *L. vannamei* without significantly affecting growth, feed consumption or survival rate. At this level they demonstrate that the moisture, protein and mineral content of the organism is not significantly altered when compared with fish meal-based diets. However, the stability of the pellet in water is reduced, as is the survival rate. For this reason, it is stated that the replacement content should be kept to 150 g kg^{-1}. Suppression of feed ingestion is attributed to the presence of antinutritional factors in rapeseed, such as sinapine, a phenolic compound responsible for the bitter flavour which this ingredient can exhibit. In the case of this species, it is demonstrated that it consumes its feed based on organoleptic conditions, and therefore feed consumption is affected by diets where a higher level of fish meal is replaced by rapeseed meal (Davis, 1993).

In case of *S. spinifrons* juveniles, all of these constraints were overcome.

c)With lupin meal

Lupin (L. albus) meal can replace fishmeal by up to 75% without affecting growth parameters and survival rate of *P. monodon* (Sudaryono et al., 1999). With higher replacement percentages, growth is significantly affected compared to the results obtained with *S. spinifrons*. The authors consider that, given that the diets are isoproteic, this reduction in growth must be down to the lower quality of lupin protein. In effect, lupin has a low content of lysine and other sulfur-containing amino acids: methionine and cysteine. However it has more arginine than soybeans, and a reasonable balance of essential amino acids. (B. D. Glencross, 2001). Consequently, Sudaryono et al. (1999) considered that the low levels of lysine, methionine and cysteine relative to the requirements of *P. monodon* is a consideration for the lower yield of lupin-based diets. In the case of this study, this consideration would not be a limiting factor. That is to say that, as with soybean and rapeseed, lupin would satisfy the essential amino acid requirements of *S. spinifrons*, as no growth rate differences were exhibited.

Lupin can be used to replace 40% of the fishmeal protein in *P. monodon* diets without causing an affect on growth rate (Smith, Tabrett, & Glencross, 2007).

One of the concerns about lupin is the alkaloid content, specifically of gramine. Smith et al. (2007) experimented with different content levels of this alkaloid, concluding that content levels of up to 500 g kg^{-1} do not compromise the growth of *P. monodon*.

Lupin can be used to replace fishmeal by up to 50% in *L. vannamei*, but above 75% replacement, weight gain and SGR are affected. This coincides with the findings of Sudaryono et al. (1999) described in the previous paragraph.

At all tested replacement levels, the digestibility of the diet reduces. This could be explained by the fact that they are marine organisms being given ingredients of terrestrial origin (Molina-Poveda et al., 2013). Drew et al. (2007) looked into the extrusion process for soybean, lupin and rapeseed as a means of improving the suitability of these ingredients in diets.

To summarise, the reduction in growth which is observed in experiments where fishmeal is replaced with proteins from various vegetable sources has been attributed to antinutritional factors and to an inadequate balance of amino acids in these sources (Lim & Dominy, 1990). Other contributing factors are a reduction in ingestion and a lowering of digestibility, which impact the SGR achieved (Molina-Poveda et al., 2013).

As has been observed, there are groups of crustaceans whose growth is affected by the replacement of fishmeal with vegetable ingredients. However, *S. spinifrons* belongs to the group whose growth is unaffected by this replacement, presenting the potential for dispensing entirely with fishmeal in the manufacture of their diets, at least at the juvenile phase.

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	Crude protein (g/kg)	Protein efficiency ratio	Heat-labile secondary compounds	Heat-stable secondary compounds
Fishmeal	500-720	3.1-3.7		
Soybean meal	480	1.60	Trypsin inhibitor, lectins	Saponins, non-starch polysaccharides, phytate, phytoestrogens, protein antigens
Canola/rapeseed meal	380	3.29	Myrosinase	Glucosinolates, phytate, tannins, sinapine, fibre, phenolic compounds
Peas	230	1.56	Protease inhibitors, lectins, cyanogens	Saponins, starch, phytic acid, protein antigens.
Lupins	350	2.32		Non-starch polysaccharides, saponins, protein antigens, phytoestrogens
Flax	260	2.88	Cyanogenics glycosides, linatine	Mucilage and non-starch polysaccharides

Table 1. Nutritional properties of fishmeal and vegetable proteins commonly used in aquaculture diets.

Taken from Drew et al., 2007

Ingredient	2009	2010	2011	2012	2013	2014	2015
Soybean	223.411	264.914	261.596	241.580	278.092	318. 8	319.01
Rapeseed	62.594	60.091	62.731	64.627	72.844	72.12	67.72
Lupin	0.883	1.032	1.107	1.29	0.785	n.i.	n.i.
Total	286.888	326.037	325.434	307.497	351.721	390.92	386.73

Table 2. Global production of soybean, rapeseed and lupin 2009 - 2015 (millions of tonnes)

Source: FAOSTAT, 2016

Compiled by the author

Type of product	Trout[a]	Nile tilapia[b]	Australian yellowtail[c]
Lupin meal			
-Crude protein	0.97	0.90	0.97
-Dry matter	0.65	0.72	0.52
-Energy	0.71	0.72	0.51
Lupin meal without husks			
-Crude protein	n.i.	n.i.	1.00
-Dry matter	n.i.	n.i.	0.70
-Energy	n.i.	n.i.	0.70
Lupin protein concentrate			
-Crude protein	1.01	n.i.	0.95
-Dry matter	0.77	n.i.	0.81
-Energy	0.87	n.i.	0.81

a Glencross et al., 2004

b Fontainhas-Fernandes et al., 1999

c Booth et al., 2001

Table 3. Digestibility of different forms of lupin meal in three fish species

Taken from Drew et al., 2007

Ingredient	Soybean diet	Rapeseed diet	Lupin diet	Fish meal diet (control)*
Soybean meal	50.0	0	0	0
Rapeseed meal	0	71.0	0	0
Lupin meal	0	0	81.0	2.1
Fish meal	0	0	0	23.0
Blood meal	0	0	0	14.0
Lupin fibre	0	0	0	36.0
Carrot meal	5.0	5.0	5.0	5.0
Wheat meal	2.6	2.6	2.6	2.6
Kelp meal	4.0	4.0	4.0	4.0
Sunflower oil	3.5	3.5	3.5	0
Fish oil	0	0	0	4.7
Vitamins and minerals	1.5	1.5	1.5	1.5
Inert material	33.4	12.4	2.4	7.1
Protein	29.17	30.07	30.83	30.5
Ether extract	5.95	6.52	7.49	9.5
Nitrogen-free extract	17.95	33.11	36.70	22.2
Fibre	1.72	4.17	5.51	19.8
Ash	35.54	16.73	8.80	14.2
Moisture	10.45	9.42	10.86	3.8

*(Salgado and Tacon, 2015)

Table 4. Ingredient and nutritional composition of the experimental diets and the control diet (%)

Variable	Diets			
	Rapeseed	Lupin	Soybean	Control
Individual weight gain (%)	13.98±9.22	12.38±3.05	20.46±13.21	35.89±0.73
SGR (%)	0.13±0.08	0.12±0.03	0.18±0.10	0.31±0.00
Biomass increase (%)	22.84±2.35	25.00±1.2	35.54±7.38	33.38±8.97
Survival (%)	75[a]±7.07	37.5[b]±3.54	32.5[b,c]±3.54	17.5[c]±3.54
Conversion factor	4.09±0.88	2.95±0.19	1.75±0.39	2.36±0.8
Protein efficiency ratio	0.85±0.18	1.16±0.08	1.99±0.45	1.45±0.48

Table 5. Production variables in S. spinifrons juveniles, according to diets

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