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A Meta-Analysis Approach toward Fish Meal Replacement with Fermented Soybean Meal: Effects on Fish Growth Performance and Feed Conversion Ratio

ROMI NOVRIADI[1,2,*]

[1]School of Fisheries, Aquaculture and Aquatic Sciences, Auburn University, 203 Swingle Hall, Auburn, AL 36849, USA
[2]Batam Mariculture Development Centre, Directorate General of Aquaculture, Ministry of Marine Affairs and Fisheries, Republic of Indonesia

Abstract

This study applied a meta-analysis approach to quantify the effect of replacing dietary fish meal (FM) with fermented soybean meal (FSBM) on the final weight and feed conversion ratio (FCR) of fishes. The impact of 14 studies was examined with 53 comparisons between fishes fed with various inclusion levels of FSBM and control treatments. The FSBM inclusion levels of 8 % to 60 % resulted in mean effect size of -3.75 [95% confidence interval (CI) -4.49 to -3.01] for final weight and 1.26 [95% CI 0.58 to 1.94] for FCR. The FSBM inclusion level greater than 40 % decreases the final weight of fish compared to the control treatment of the studies. Meanwhile, inclusion of FSBM at the level of 15 % to 44 % improves the FCR of the diet and higher than 44 % produces an inconsistent result. The present study contributes to the FM replacement debate by presenting numerical values and providing strong conclusions compared to the common narrative reviews about partial or total replacement of FM with FSBM.

Keywords: fermented soybean meal, fish meal, meta-analysis, FCR, final weight

Introduction

Partial or total replacement of dietary fish meal (FM) protein with a wide variety of plant-based dietary ingredients in fish feed formulation has been widely investigated and debated (NRC 2011; Caruso 2015; Ogello et al. 2017). So far, soybean meal (SBM) has been preferred for FM replacement due to the comparable nutritional value with FM, reasonable balance of amino acid and cost effectiveness (Gatlin et al. 2007; NRC 2011; Watanabe 2002; Qiu and Davis 2016).

* Corresponding author. E-mail: Romi_bbl@yahoo.co.id

However, the presence of anti-nutritional factors (ANFs) such as protease inhibitors, tannins, oligosaccharide and phytate; low palatability and deficiency in some amino acids is limiting its use in aquaculture diets (Fowler 1980; Guimaraes et al. 2008; Sales 2009; Phumee et al. 2011; NRC 2011). A high inclusion level of SBM may cause undesirable taste to the diet (Okubo et al. 1992; Ho et al. 2014), induce extensive damage to the intestinal mucosa of the hindgut (Bureau et al. 1998), affect the intestinal microbial communities (Heikkinen et al. 2006), and alter the hepatic morphology (Iwashita et al. 2008). Although several treatments, e.g. heating, alcohol extraction and proper processing technique could eliminate or inactivate the limiting factors in SBM (Masumoto et al. 2001; Lim and Lee 2011; NRC 2011), different sensitivities of fish to SBM inclusion level cause large data variabilities (Chou et al. 2004).

Further processing of SBM, such as fermentation, has recently been proven to prevent the SBM induced abnormalities, eliminate a variety of ANFs, increase the content of soybean peptides and improve the nutritional value of the resulting meals (Papagianni et al. 2000; Hong et al. 2004; Gatlin et al. 2007). For human foods, the fermentation technique has been widely applied in the Far East and Southeast Asia. The fermented products are commonly known as “Dou-Bian-Jiang” in China, “Miso and Natto” in Japan (Lim and Lee 2011), “Thua nao” in Thailand (Chantawannakul et al. 2002) and “Tempeh” in Indonesia (Keuth and Bisping 1994). The fermentation process, which allows microorganisms such as *Bacillus subtilis* to degrade macromolecules into water-soluble low molecular weight compounds (Kiers et al. 2000), has been utilised to destroy or decrease the ANFs present in SBM (Canella et al. 1984) and improve digestibility (Kiers et al. 2000) and shelf life of the processed foods (Skrede and Nes. 1988). Other than *Bacillus subtilis*, several other bacterial species, e.g *Aspergillus oryzae* (Kim et al. 2009), *Lactobacillus plantarum* P8 (Wang et al. 2016) and *Candida utilis* (Zhou et al. 2011) also play significant roles in fermentation processes. In addition, a commercial product of fermented soy known as PepSoyGen (PSG; Nutrafrema, North Sioux City, South Dakota, USA) manufactured via a proprietary process using *Aspergillus* spp and *Bacillus* spp is readily available as an ingredient to replace FM in fish diet formulation (Barnes et al. 2015; Trushenski et al. 2014).

Initial publication on the use of fermented soy was based on the study of Shimeno et al. (1993), who reported the effects of fermented defatted soybean meal either with *Aspergillus oryzae* or *Eurotium repens* in single moist pellet diets for juvenile yellowtail *Seriola quinqueradiata* (Temminck and Schlegel 1845). According to Shimeno et al. (1993), the feed efficiency and growth performance of yellowtail fed on fermented soybean meal (FSBM) were superior to those fed on unfermented SBM, but they were slightly inferior compared to the group of fish fed with dietary FM without any inclusion of soy-source protein. Recent studies with rainbow trout *Oncorhynchus mykiss* (Walbaum 1792) and black seabream *Acanthopagrus schlegelii* (Bleeker 1854) showed that with proper inclusion level, FSBM may improve the acceptance and utilisation of soy-based diet for carnivorous fish (Azarm and Lee 2014; Barnes et al. 2015). The good proportion of small-sized peptide contain in FSBM becomes one of the beneficial factors to induce better growth in fish, FCR and enhance the nutrient digestibility (Hong et al. 2004; Azarm and Lee 2014; Barnes et al. 2014).

Moreover, the microbial species that remain in the final fermented product could also increase the antioxidant activities and non-specific immune response of fish (Kim et al. 2010). However, several studies also suggest that the use of high inclusion level of FSBM may negatively affect the growth performance of fish (Yuan et al. 2013; Barnes et al. 2015; Wang et al. 2016; Lee et al. 2016). Therefore, this meta-analysis study was undertaken to determine the potential effect and proper inclusion level of FSBM to replace FM in practical diets without compromising the feed efficiency and growth of fish.

In this quantitative review, we employed a structured meta-analysis approach to quantify the effects of FSBM inclusion level on the growth and FCR across different fishes. Meta-analysis is a set of statistical methods combining outcomes across different data sets to examine the response patterns and heterogeneity in outcomes (Koricheva and Gurevitch 2014). Meta-analysis has had a tremendous impact on ecological studies, medicinal research and social science in synthesising particular research questions. In fact, since the 1970s, meta-analysis study has emerged in medical research and its growth has been exponential over time (Chalmers et al. 1977; Haidich 2010). However, to the best of our knowledge, only a few quantitative studies have used meta-analysis to investigate the effect of FM replacement with soy-source protein on growth performance of fish. Since the sustainable and low-cost protein source is still and always needed to improve farm productivity and efficiency, our study will serve as a catalyst for further development of food formulation and generalise the effect of FSBM inclusion level to the feed efficiency and growth performance of fish.

Materials and Methods

Search strategy and inclusion criteria

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed (Liberati et al. 2009) and a comprehensive literature search was conducted with the use of Web of Science and several publishers' websites to identify articles published between January 1960 and October 2016 investigating the dietary inclusion effects of FSBM in the growth performance and FCR of fish. The database search used multiple combinations of the following terms: fermented, soybean, fish, fish meal replacement and growth. Thorough literature searches and repeatability became two important aspects for the literature search strategy (Gates 2002; Philibert et al. 2012) to maintain the study objectivity and reduce the possibility for publication bias (Koricheva and Gurevitch 2014). In addition, unpublished results and 'grey literature' (e.g. documents such as theses and dissertations) could also be included in meta-analysis study, especially when the results were coming from reliable sources (Cook 1993; ArchMiller et al. 2015). Appropriate inclusion criteria were determined prior to the start of the database search to reduce any possible selection bias in the present study, including the clear diet preparation, experimental fish, control group, clearly defined exposure time, and clearly mentioned feeding regime.

The evaluation of growth performance as the effect of FSBM inclusion was focused on the final weight for each treatment and FCR. The crude protein level of each diet and type of feeding were also evaluated to gain better consideration for meta conclusion. In addition, studies would only be considered if the article covered the following criteria: (1) the use of pure FSBM in the food formulations without any supplementation. Thus, supplementation with any additional products, such as animal by-products and other attractants to yield a unique taste and improve the nutritional content of food was not considered; (2) isonitrogenous dietary information particularly on the crude protein ratio; (3) the reduction level of FM as the inclusion effect of FSBM in the dietary formulation; and (4) the assessment of growth performance provided sufficient details for effect size calculation (i.e., Hedges'*d* and 95 % confidence interval [CI]). The study criteria for the present quantitative assessment included:

$$\text{Feed conversion ratio } FCR = \frac{\text{Feed given (g)}}{\text{Wet weight gain (g)}}$$

Studies fulfilling the above criteria and were considered eligible to be included in this meta-analysis study are presented in Table 1.

Effect size calculations

The Hedges'*d* (Gurevitch and Hedges 2001), a metric that has been commonly used in previous meta-analysis for the mean and standard deviation available in the article, was calculated. The Hedges'*d* transforms all effect size to a common metric to estimate the effect of several FSBM inclusion levels in diet formulation on fish growth performance and FCR. The formula for the sample estimate of *d* is:

$$d = \frac{\mu 1 - \mu 2}{\text{SE}}$$

Hedges'*d* compares the effect of size of the mean of one population (μ_1) and the mean for another population (μ_2) scaled by their respective standard errors (SE), so that the differences in *d* could be attributed to different effects on the mean response variable (Preisser et al. 2005). Positive and negative values of the Hedges'*d* indicate the performance of fish in the presence of FSBM in diet formulation. For all study groups, the standardised mean difference, the 95 % confidence interval (95 % CI), and the 95 % prediction interval (95 % PI) were computed. The PI describes the distribution of true effects around the mean, whereas the CI reflects the precision of the mean effect size. The heterogeneity among studies in each group was systematically assessed by using random effect models and the I^2 and the chi-squared statistic (Q) was reported. The I^2 were calculated to assess the heterogeneity of effect sizes as a percentage of total variation, and is not affected by low statistical power (Khoury et al. 2013).

Meta-regression analysis

The determination of which study-level covariates account for the heterogeneity was performed by using meta-regression approaches and FSBM inclusion level as the predictors. From this regression, we were able to assess the relationship between one or more variables (moderators) and the pooled effect size. In this meta-analysis, meta-regressions were performed under the random effects models that allow that the true effect may vary from one study to another (Borenstein et al. 2009). All analysis was performed by computing standardised difference by using Comprehensive Meta Analysis (Borenstein et al. 2009).

Results

Data extraction

Sixty eight publications generated by Web of Science and 85 publications generated by the Google Scholar were identified, including two dissertations that discussed the use of FSBM. Preliminary searches and coding revealed 21 different fish species and one hybrid fish. The fermentation process involves a simple treatment of soaking the (non-sterile) SBM in distilled water and allowing microorganisms as a reliable source of enzyme to undergo the fermentation process (Bi et al. 2015). This fermentation process may reduce the ANFs such as phytates, protease (trypsin) inhibitors, antigens, lectins, and tannins contain in SBM that affect the growth performance, protein and mineral utilisation, and digestion of the fish (Shiu et al. 2015; Chi and Cho 2016). We carefully assessed the identified publications and applied the exclusion criteria, resulting in 30 studies consisting of 28 publication articles and two dissertations. Of the 30 studies, 14 met our eligibility criteria outlined in the Materials and Methods section. In total, there were 53 independent data sets that were investigated in our meta-analysis study for both final weight and FCR. Details of the studies are summarised in the sources of studies (Table 1).

Effect size calculations

The effect size and other statistical characteristics for each study are shown in Table 2 and 3. Studies were divided according to the response of interest, namely final weight and FCR.

Table 1. Sources of study on the meta-analysis approach consisting of 53 independent data sets in 14 published articles.

No	References	Common name	Scientific name	Fermentation type	Water type	Sample size (n)	Period (days)	Dietary CP (% DM)	FSBM (%)	FM (%)
1	Azarm & Lee 2014	Black sea bream	*Acanthopagrus schlegeli*	*Bacillus subtilis*	SW	40	56	43.7	0	60
								44.5	8	54
								44.0	16	48
								43.0	24	42
								47.1	32	36
2	Barnes et al. 2014	Rainbow trout	*Oncorhynchus mykiss*	*Bacillus subtilis*	WW	40	205	45.39	0	40
				Aspergillus oryzae				45.95	35	15
								46.96	50	0
3	Lee et al. 2016	Rockfish	*Sebastes schlegeli*	*Bacillus subtilis*	SW	50	56	51.6	0	58
								51.6	8	52
								51.6	16	46
								51.5	24	40
								51.4	32	34
4	Lin et al. 2013	Pompano	*Trachinotus ovatus*	*Bacillus subtilis*	SW	15	NA	46.4	0	65.0
								46.2	100	57.3
								47.1	200	49.6
								47.2	300	41.9
								46.6	400	34.2
5	Shiu et al. 2015	Orange spotted	*Epinephelus coioides*	*Bacillus subtilis*	SW	50	84	48.62	0	69.6
		grouper						48.82	9.8	62.6
								48.69	19.6	55.7
								48.82	29.4	48.7
								48.96	39.2	41.8
6	Storebakken et al.	Atlantic salmon	*Salmo salar*	*Bacillus* spp	FW	30	NA	42.7	0	54.48
	1998							41.9	20	34.40
7	Trushenski et al.	White seabass	*Atractoscion nobilis*	*Bacillus subtilis*	SW	15	68	51.1	0	48.0
	2014			*Aspergillus oryzae*				50.6	15	24
								50.2	25	12
								48.6	47.7	0
		Yellowtail Jack	*Seriola lalandi*		SW	15	65	50.9	0	40
								49.3	46.2	20
								49.8	52.1	0

8	Zhou et al. 2011	Black sea bream	*Acanthopagrus schlegeli*	*Candida utilis*	SW	25	56	41.4	0	60
								41.38	7.2	54
								41.3	14.4	48
								41.25	21.6	42
								41.07	28.8	36
								41.15	36	30
9	Yamamoto et al. 2012	Rainbow trout	*Oncorhynchus mykiss*	*Bacillus* spp	WW	44	70	44.2	0	46
								44.0	47.6[1]	0
								44.2	47.6[2]	0
10	Rombenso et al. 2013	Hybrid striped bass	*Morone chrysops* × *M. saxatilis*	*Bacillus subtilis* *Aspergillus oryzae*	FW	10	56	37.3	0	30
								38.7	30.3	10
								39.5	38.1	5
								38.9	46.3	0
11	Wang et al. 2016	Turbot	*Scophthalmus maximus*	*Lactobacillus plantarum* P8	SW	30	66	50.36	0	60
								50.38	11.53	51
								49.50	23.08	42
								49.65	34.62	33
								50.18	46.15	24
12	Barnes et al. 2015	Rainbow trout	*Oncorhynchus mykiss*	*Bacillus subtilis* *Aspergillus oryzae*	WW	40	94	45.39	0	40
								45.95	35	15
								46.96	50	0
13	Yuan et al. 2013	Chinese sucker	*Myxocyprinus asiaticus*	High active microbe[3]	FW	30	56	52.4	0	65
								52.8	13	55.3
								51.1	21.7	48.8
								52.4	30.4	42.3
								53.5	39.1	35.8
								55.1	47.8	29.3
								54.3	56.5	22.8
14	Barnes et al. 2012	Rainbow trout	*Oncorhynchus mykiss*	*Bacillus subtilis* *Aspergillus oryzae*	FW	200	70	52.0	0	50
								50.5	10	40
								48.1	20	30
								46.3	30	20
								44.1	40	10
								43.0	50	0

Table 2. Standard mean difference, 95 % CI, 95% PI and statistical characteristics of final weight group.

Study or Subgroup	FSBM treatment Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Azarm et al. 2014	5.8	0.08	40	5.7	0.17	40	2.0%	0.75 [0.29, 1.20]
Azarm et al. 2014	5.7	0.18	40	5.7	0.17	40	2.0%	0.00 [-0.44, 0.44]
Azarm et al. 2014	5.6	0.02	40	5.7	0.17	40	2.0%	-0.82 [-1.28, -0.36]
Azarm et al. 2014	5.6	0.5	40	5.7	0.17	40	2.0%	-0.27 [-0.71, 0.18]
Barnes et al. 2014	13.638	0.646	40	11.822	0.639	40	2.0%	2.80 [2.17, 3.42]
Barnes et al. 2014	8.606	0.652	40	11.822	0.639	40	2.0%	-4.93 [-5.83, -4.04]
Barnes et al. 2014	375.2	22.2	40	329.9	8.8	40	2.0%	2.66 [2.05, 3.27]
Barnes et al. 2014	220.4	3.9	40	329.9	8.8	40	1.6%	-15.93 [-18.50, -13.36]
Barnes et al. 2015	250	4.8	40	219	2.2	40	1.9%	8.22 [6.84, 9.60]
Barnes et al. 2015	172.3	4.3	40	219	2.2	40	1.7%	-13.54 [-15.74, -11.35]
Barnes et al.2012	5,695	128	200	5,694	88	200	2.0%	0.01 [-0.19, 0.21]
Barnes et al.2012	5,783	97	200	5,694	88	200	2.0%	0.96 [0.75, 1.17]
Barnes et al.2012	5,402	39	200	5,694	88	200	2.0%	-4.28 [-4.64, -3.93]
Barnes et al.2012	4,656	173	200	5,694	88	200	2.0%	-7.55 [-8.11, -6.99]
Barnes et al.2012	3,603	49	200	5,694	88	200	1.8%	-29.30 [-31.35, -27.25]
Lee et al. 2016	480	13	50	473	35	50	2.0%	0.26 [-0.13, 0.66]
Lee et al. 2016	413	19	50	473	35	50	2.0%	-2.11 [-2.61, -1.62]
Lee et al. 2016	390	12	50	473	35	50	2.0%	-3.15 [-3.74, -2.55]
Lee et al. 2016	326	16	50	473	35	50	2.0%	-5.36 [-6.21, -4.51]
Lin et al. 2013	67.3	4.86	15	64.53	7.89	15	2.0%	0.41 [-0.31, 1.14]
Lin et al. 2013	59.26	3.36	15	64.53	7.89	15	2.0%	-0.85 [-1.60, -0.09]
Lin et al. 2013	55.96	2.51	15	64.53	7.89	15	2.0%	-1.42 [-2.24, -0.61]
Lin et al. 2013	53.45	2.02	15	64.53	7.89	15	2.0%	-1.87 [-2.75, -0.99]
Rombenso et al. 2013	82.6	4.8	10	76.9	4.8	10	2.0%	1.14 [0.18, 2.10]
Rombenso et al. 2013	74.3	4.8	10	76.9	4.8	10	2.0%	-0.52 [-1.41, 0.38]
Rombenso et al. 2013	58.6	4.8	10	76.9	4.8	10	1.9%	-3.65 [-5.19, -2.11]
Shiu et al. 2015	58.25	1.14	50	52.91	3.19	50	2.0%	2.21 [1.71, 2.71]
Shiu et al. 2015	52.79	1.43	50	52.91	3.19	50	2.0%	-0.05 [-0.44, 0.34]
Shiu et al. 2015	50.22	0.64	50	52.91	3.19	50	2.0%	-1.16 [-1.59, -0.74]
Shiu et al. 2015	43.59	1.86	50	52.91	3.19	50	2.0%	-3.54 [-4.18, -2.91]
Storebakken et al. 1998	126.9	0.5	30	130.8	0.9	30	2.0%	-5.29 [-6.39, -4.19]
Trushenski et al. 2014	32.4	1.2	15	32.7	1.2	15	2.0%	-0.24 [-0.96, 0.48]
Trushenski et al. 2014	28.1	1.2	15	32.7	1.2	15	1.9%	-3.73 [-4.97, -2.49]
Trushenski et al. 2014	15.4	1.2	15	32.7	1.2	15	1.3%	-14.03 [-17.90, -10.15]
Trushenski et al. 2014	74.6	1.2	15	87.8	1.2	15	1.5%	-10.70 [-13.70, -7.71]
Trushenski et al. 2014	51.8	1.2	15	87.8	1.2	15	0.6%	-29.19 [-37.15, -21.23]
Wang et al. 2016	37.26	1.1	30	37.69	1.1	30	2.0%	-0.39 [-0.90, 0.13]
Wang et al. 2016	35.76	1.1	30	37.69	1.1	30	2.0%	-1.73 [-2.33, -1.13]
Wang et al. 2016	35.01	1.1	30	37.69	1.1	30	2.0%	-2.40 [-3.08, -1.73]
Wang et al. 2016	26.46	1.1	30	37.69	1.1	30	1.8%	-10.08 [-12.01, -8.14]
Yamamoto et al. 2010	57.5	5.6	44	66.6	3.9	44	2.0%	-1.87 [-2.37, -1.36]
Yamamoto et al. 2010	65.9	3.4	44	66.6	3.9	44	2.0%	-0.19 [-0.61, 0.23]
Yuan et al. 2013	17.43	0.18	30	17.72	0.16	30	2.0%	-1.68 [-2.27, -1.09]
Yuan et al. 2013	16.89	0.18	30	17.72	0.16	30	2.0%	-4.81 [-5.83, -3.79]
Yuan et al. 2013	16.04	0.14	30	17.72	0.16	30	1.7%	-11.03 [-13.13, -8.93]
Yuan et al. 2013	14.43	0.2	30	17.72	0.16	30	1.4%	-17.93 [-21.29, -14.57]
Yuan et al. 2013	14.3	0.32	30	17.72	0.16	30	1.6%	-13.34 [-15.86, -10.82]
Yuan et al. 2013	12.74	0.16	30	17.72	0.16	30	0.9%	-30.72 [-36.43, -25.01]
Zhou et al. 2011	54.4	0.76	25	54.18	1.43	25	2.0%	0.19 [-0.37, 0.74]
Zhou et al. 2011	53.98	1.8	25	54.18	1.43	25	2.0%	-0.12 [-0.68, 0.43]
Zhou et al. 2011	52.73	0.16	25	54.18	1.43	25	2.0%	-1.40 [-2.03, -0.78]
Zhou et al. 2011	51.09	0.62	25	54.18	1.43	25	2.0%	-2.76 [-3.55, -1.97]
Zhou et al. 2011	46.49	0.95	25	54.18	1.43	25	1.9%	-6.24 [-7.62, -4.85]
Total (95% CI)			**2508**			**2508**	**100.0%**	**-3.75 [-4.49, -3.01]**

Heterogeneity: Tau² = 6.93; Chi² = 4263.58, df = 52 (P < 0.00001); I² = 99%
Test for overall effect: Z = 9.98 (P < 0.00001)

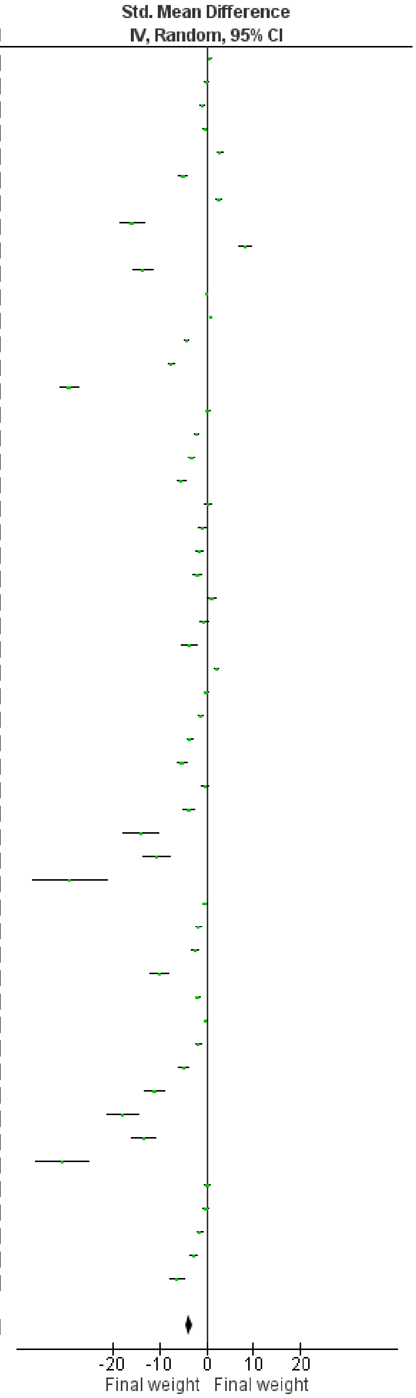
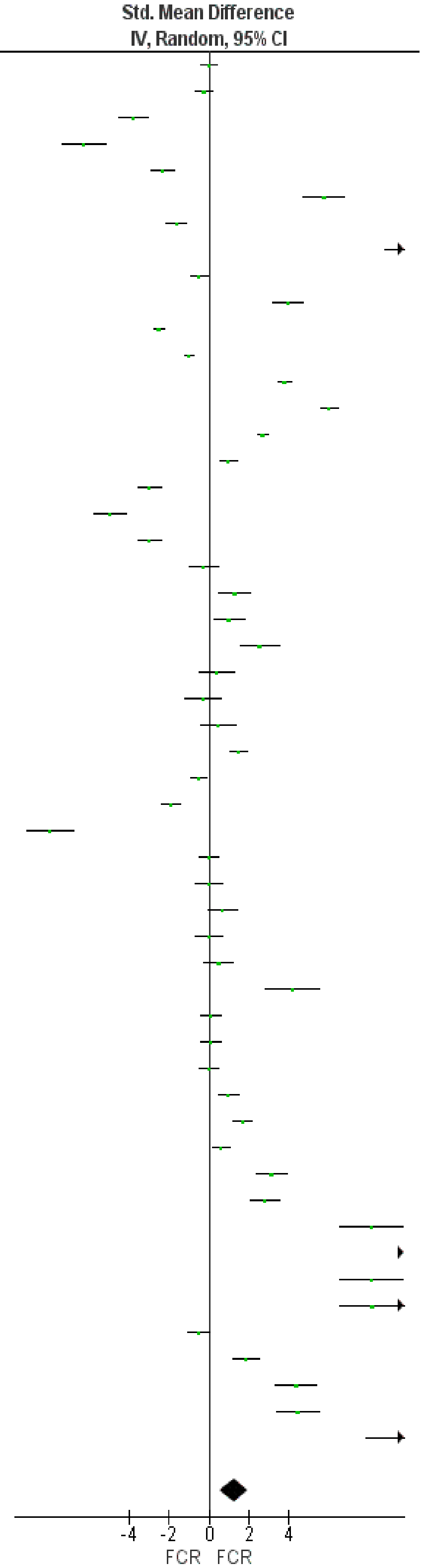


Table 3. Standard mean difference, 95% CI, 95% PI and statistical characteristics for feed conversion ratio (FCR) group.

	FSBM treatment			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Azarm et al. 2014	2.2	0.1	40	2.2	0.05	40	1.9%	0.00 [-0.44, 0.44]
Azarm et al. 2014	2.1	0.57	40	2.2	0.05	40	1.9%	-0.24 [-0.68, 0.20]
Azarm et al. 2014	1.8	0.14	40	2.2	0.05	40	1.9%	-3.77 [-4.51, -3.03]
Azarm et al. 2014	1.7	0.1	40	2.2	0.05	40	1.9%	-6.26 [-7.35, -5.18]
Barnes et al. 2014	1	0.01	40	1.1	0.06	40	1.9%	-2.30 [-2.87, -1.73]
Barnes et al. 2014	1.58	0.1	40	1.1	0.06	40	1.9%	5.76 [4.75, 6.78]
Barnes et al. 2015	1.3	0.05	40	1.39	0.06	40	1.9%	-1.61 [-2.12, -1.11]
Barnes et al. 2015	2.03	0.06	40	1.39	0.06	40	1.7%	10.56 [8.83, 12.30]
Barnes et al. 2015	1.64	0.08	40	1.69	0.12	40	1.9%	-0.49 [-0.93, -0.04]
Barnes et al. 2015	2.5	0.26	40	1.69	0.12	40	1.9%	3.96 [3.19, 4.73]
Barnes et al.2012	0.83	0.02	200	0.88	0.02	200	1.9%	-2.50 [-2.76, -2.23]
Barnes et al.2012	0.86	0.02	200	0.88	0.02	200	1.9%	-1.00 [-1.21, -0.79]
Barnes et al.2012	0.94	0.01	200	0.88	0.02	200	1.9%	3.79 [3.46, 4.12]
Barnes et al.2012	1.15	0.06	200	0.88	0.02	200	1.9%	6.03 [5.56, 6.49]
Barnes et al.2012	2.06	0.62	200	0.88	0.02	200	1.9%	2.69 [2.41, 2.96]
Lee et al. 2016	1.9	0.1	50	1.8	0.1	50	1.9%	0.99 [0.58, 1.41]
Lee et al. 2016	1.5	0.1	50	1.8	0.1	50	1.9%	-2.98 [-3.55, -2.40]
Lee et al. 2016	1.3	0.1	50	1.8	0.1	50	1.9%	-4.96 [-5.77, -4.16]
Lee et al. 2016	1.5	0.1	50	1.8	0.1	50	1.9%	-2.98 [-3.55, -2.40]
Lin et al. 2013	1.33	0.04	15	1.35	0.09	15	1.9%	-0.28 [-1.00, 0.44]
Lin et al. 2013	1.44	0.03	15	1.35	0.09	15	1.9%	1.31 [0.51, 2.10]
Lin et al. 2013	1.46	0.12	15	1.35	0.09	15	1.9%	1.01 [0.24, 1.78]
Lin et al. 2013	1.52	0.02	15	1.35	0.09	15	1.9%	2.54 [1.54, 3.53]
Rombenso et al. 2013	1.04	0.1	10	1	0.1	10	1.9%	0.38 [-0.50, 1.27]
Rombenso et al. 2013	0.97	0.1	10	1	0.1	10	1.9%	-0.29 [-1.17, 0.59]
Rombenso et al. 2013	1.05	0.1	10	1	0.1	10	1.9%	0.48 [-0.41, 1.37]
Shiu et al. 2015	0.81	0.02	50	0.78	0.02	50	1.9%	1.49 [1.04, 1.93]
Shiu et al. 2015	0.77	0.02	50	0.78	0.02	50	1.9%	-0.50 [-0.89, -0.10]
Shiu et al. 2015	0.75	0.01	50	0.78	0.02	50	1.9%	-1.88 [-2.36, -1.41]
Shiu et al. 2015	0.62	0.02	50	0.78	0.02	50	1.8%	-7.94 [-9.13, -6.75]
Storebakken et al. 1998	0.85	0.03	30	0.85	0.03	30	1.9%	0.00 [-0.51, 0.51]
Trushenski et al. 2014	1	0.1	15	1	0.1	15	1.9%	0.00 [-0.72, 0.72]
Trushenski et al. 2014	1.07	0.1	15	1	0.1	15	1.9%	0.68 [-0.06, 1.42]
Trushenski et al. 2014	1	0.1	15	1	0.1	15	1.9%	0.00 [-0.72, 0.72]
Trushenski et al. 2014	1.22	0.1	15	1.17	0.1	15	1.9%	0.49 [-0.24, 1.21]
Trushenski et al. 2014	1.6	0.1	15	1.17	0.1	15	1.8%	4.18 [2.84, 5.53]
Wang et al. 2016	0.73	0.1	30	0.72	0.1	30	1.9%	0.10 [-0.41, 0.61]
Wang et al. 2016	0.73	0.1	30	0.72	0.1	30	1.9%	0.10 [-0.41, 0.61]
Wang et al. 2016	0.72	0.1	30	0.72	0.1	30	1.9%	0.00 [-0.51, 0.51]
Wang et al. 2016	0.82	0.1	30	0.72	0.1	30	1.9%	0.99 [0.45, 1.53]
Yamamoto et al. 2010	0.98	0.01	44	0.93	0.04	44	1.9%	1.70 [1.21, 2.19]
Yamamoto et al. 2010	0.95	0.02	44	0.93	0.04	44	1.9%	0.63 [0.20, 1.06]
Yuan et al. 2013	1.49	0.01	30	1.44	0.02	30	1.9%	3.12 [2.35, 3.89]
Yuan et al. 2013	1.53	0.04	30	1.44	0.02	30	1.9%	2.81 [2.08, 3.53]
Yuan et al. 2013	1.57	0.01	30	1.44	0.02	30	1.8%	8.12 [6.53, 9.70]
Yuan et al. 2013	1.69	0.02	30	1.44	0.02	30	1.6%	12.34 [10.00, 14.68]
Yuan et al. 2013	1.7	0.04	30	1.44	0.02	30	1.8%	8.12 [6.53, 9.70]
Yuan et al. 2013	1.81	0.06	30	1.44	0.02	30	1.8%	8.17 [6.57, 9.76]
Zhou et al. 2011	1.22	0.02	25	1.23	0.02	25	1.9%	-0.49 [-1.06, 0.07]
Zhou et al. 2011	1.26	0.01	25	1.23	0.02	25	1.9%	1.87 [1.19, 2.54]
Zhou et al. 2011	1.3	0.01	25	1.23	0.02	25	1.9%	4.36 [3.31, 5.41]
Zhou et al. 2011	1.32	0.02	25	1.23	0.02	25	1.9%	4.43 [3.37, 5.49]
Zhou et al. 2011	1.39	0.01	25	1.23	0.02	25	1.6%	9.96 [7.85, 12.07]
Total (95% CI)			**2508**			**2508**	**100.0%**	**1.26 [0.58, 1.94]**

Heterogeneity: Tau² = 6.19; Chi² = 4196.91, df = 52 (P < 0.00001); I² = 99%
Test for overall effect: Z = 3.64 (P = 0.0003)



The overall effect size of the 53 comparisons between FSBM inclusion level in diet formulation and a control condition was -3.75 [95 % CI -4.49 to -3.01] for final weight and 1.26 [95 % CI 0.58 to 1.94] for FCR. Using a random-effect analysis for final weight, negative risk ratio higher than 1.0 indicates that increasing level of FSBM increased the risk for negative growth performance. Meanwhile, the inclusion of FSBM improved the FCR by at least 58 % and possibly as much as 94 %. The level of heterogeneity for final weight is I^2=99 % (p<0.00001) and FCR I^2=99 % (p<0.00001). The Z-value for final weight is 9.98 (p<0.00001) and FCR is 3.64 (p<0.00001), which allows us to predict that the slope is probably not zero, and the FSBM inclusion level is more effective when the study is conducted at a closer distance from the equator of meta-regression analysis. Meta-regression is used to relate the size of a treatment effect obtained from a meta-analysis, to a certain inclusion level of FSBM and describe the heterogeneity between studies. Each study for final weight (Fig. 1) and FCR (Fig. 2) in meta-regression, is represented by a circle that shows the actual coordinates (observed effect size by latitude) for that study and the center lines shows the predicted value. From Fig. 1, the study performed relatively close to zero, corresponding to the inclusion level of FSBM ranging from 8 % to 40 %, elicited the best response in terms of final weight. Meanwhile, as the inclusion level of FSBM to replace FM rose higher than 40 %, the final weight of fish tends to decrease. On the other hand, Fig. 2 showed that the inclusion of FSBM is more effective at the level of 15 % to 44 % to improve the FCR of the diet. While with higher inclusion level of FSBM (>44 %), dietary treatments would have a varied effect on the FCR.

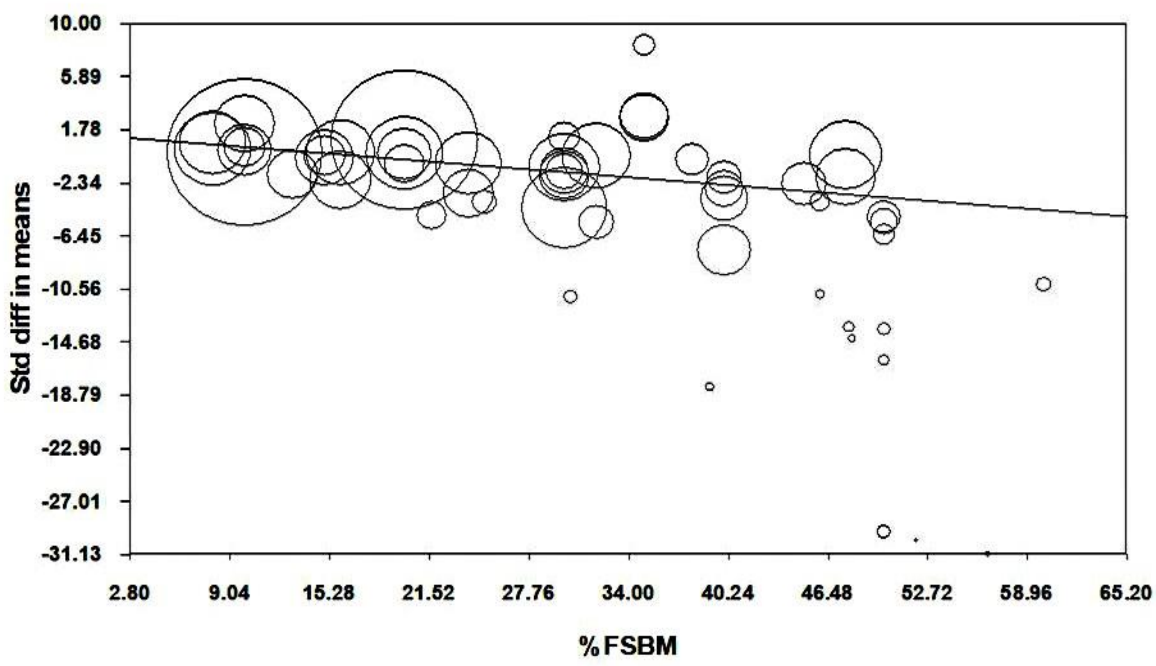


Fig. 1. Random-effect model-regression of inclusion percentage of fermented soybean meal (FSBM) on standard difference (std diff) in means of final weight

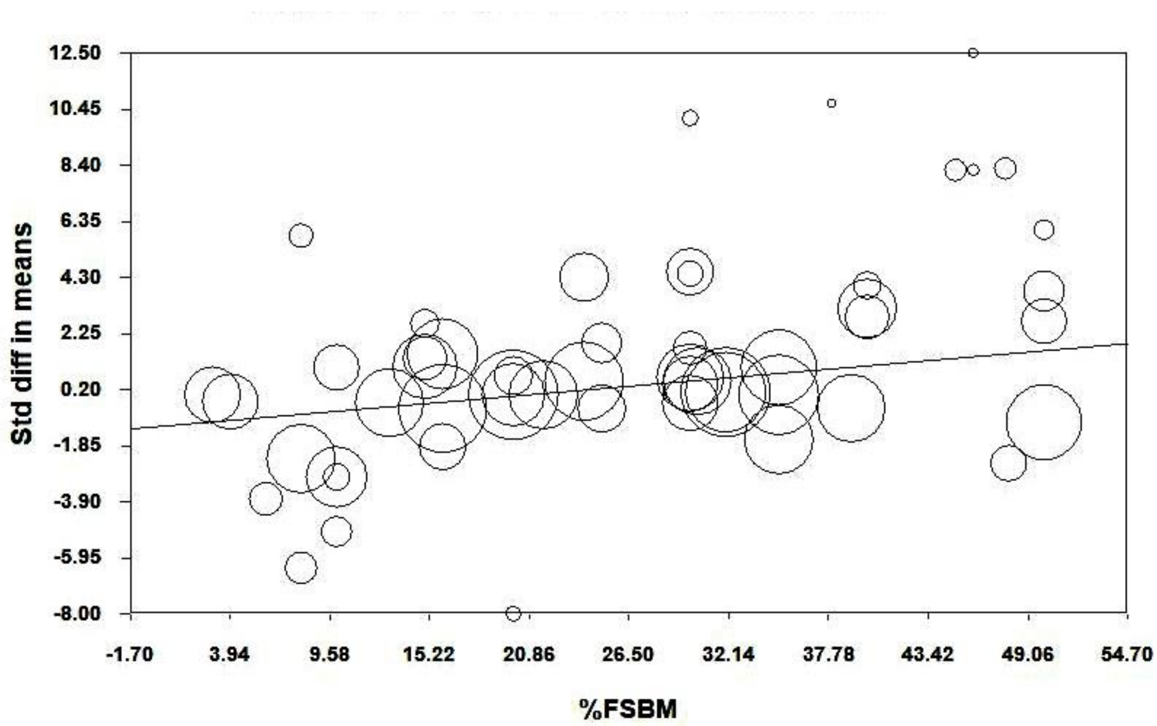


Fig. 2. Random-effect model-regression of inclusion percentage of fermented soybean meal (FSBM) on standard difference (std diff) in means of FCR

Discussion

The use of soy-source protein to replace dietary FM in an effort to develop practical diets for fish has been reviewed in several published articles (El-Sayed 1999; Gatlin et al. 2007; Sales 2009) and summarised in a book edited by Lim et al. (2008). The discussions point out that the beneficial effect of SBM depends on fish species, size and the quality of SBM used in the feed formulation (Watanabe 2002). The presence of anti-nutrients, such as proteinase inhibitor, lectins, phytic acid, saponins, phytoestrogens, antivitamins, phytosterols and antigens may limit the higher inclusion of SBM as the primary protein sources (NRC 2011). Sales (2009) suggested that the replacement of FM with defatted SBM at levels higher than 40 % causes negative effects on the growth performance of fish.

Currently, no quantitative review is available on the use of FSBM to improve the growth performance of fish. However, several authors concluded that the use of fungal or bacterial organisms during the fermentation process can lead to the production of enzyme to increase the digestibility (Lio and Wang 2012), reduce the ANFs (Jiao et al. 1992; Kiers et al. 2000), enhance the content of soybean peptides (Hong et al. 2004; Bi et al. 2015) and increase the amino acid content in soybean, such as arginine, serine, threonine, aspartic acid, alanine and glycine by 50.67 %, 45.6 %, 34.55 %, 22.25 %, 21.23 %, and 18.12 %, respectively (Foley et al. 2013).

The initial attempt to reveal the efficacy of FSBM without any supplementation in the final product based on the Web of Science and Google Scholar searching method was conducted by Shimeno et al. (1993) and, since then, the investigations concerning the use of fermented soybean meal in fish diet formulations became more popular and finally the commercial products of FSBM were readily available in the market for aquaculture purposes (Barnes et al. 2014; Barnes et al. 2015).

The wide variety of studies, environmental characteristics and type of feeding regime resulting in high heterogeneity and meta-analytics will allow us to clarify some inconsistencies concerning the use of FSBM. The results of effect size calculation and meta-regression analysis in the present study indicated that the use of high inclusion level of FSBM (> 40 %) in diet formulation to partially or totally replace FM will negatively affect the growth of fish. Lee et al. (2016) noted that FM replacement with FSBM up to 20 % improved the growth of rockfish *Sebastes schlegeli* Hilgendorf 1880, while the replacement for more than 40 % caused an adverse effect on growth of this fish. In addition, Wang et al. (2016) reported that the replacement of FM with FSBM by 60 % significantly reduced growth and feed utilisation and lowered the apparent digestibility coefficient of protein in juvenile turbot *Scophthalmus maximus* Linnaeus 1758. Several previous studies have reported that the use of higher inclusion level of soy based protein may increase the indigestible carbohydrate levels, poor protein digestibility, imbalanced dietary amino acid concentration and affect the palatability of the diet (Refstie et al. 1998; Francis et al. 2001; Deng et al. 2006). Thus, dietary formulation would need to be modified to improve the efficacy of FSBM and growth of fish.

To improve the efficacy of FSBM, amino acid supplementation and inclusion of attractants could be used in the diet formulation. Nguyen et al. (2015), showed that taurine supplementation in high inclusion level of FSBM, significantly improved the growth and lipid digestibility of yellowtail. Similarly, the combination uses of methionine, lysine and fermented soy improved the growth performance and body protein content of rainbow trout *Oncorhynchus mykiss* compared to fish fed unsupplemented FSBM (Yamamoto et al. 2012). Moreover, the combination of FSBM with attractants or fishery by-products also improves the growth performance of fish through better food palatability (Kader et al. 2011). Thus, the inclusion of attractants and essential amino acids may be needed to enhance the food search (Hartati and Briggs 1993) and the efficacy of FSBM (Novriadi et al. 2017). In this quantitative review, the inclusion of FSBM showed a positive effect on FCR at the inclusion level ranging from 15 to 44 %. At this level, fermented product appears to improve the nutritional and functional properties of SBM, probably due to the presence of soybean peptides (Min et al. 2009; Rombenso et al. 2013) and inactivation of most anti-nutrients contained in soy-source protein (Lee et al. 2016). It was interesting to observe that with high inclusion level of FSBM for more than 44 % to replace FM produces an inconsistent result to FCR but no adverse effect on feed intake (FI). Wang et al. (2016) reported that no significant differences were observed in FI when juvenile turbot (*Scophthalmus maximus*) was fed diets with graded levels of FSBM ranging from 15 to 60 %, but FCR was significantly increased as the dietary inclusion level of FSBM increases.

On the other hand, Zhou et al. (2011) reported that FI was significantly decreased as FSBM inclusion level increased and positively correlated to the FCR. Indeed, it has been suggested that fermented product may still contain ANFs and play a role in the feed efficiency (Yamamoto et al. 2012). Thus, species-specific sensitivity to the fermented product may partially influence the observed differences in feed efficiency.

Conclusion

With different culture settings, fish may react differently when exposed to the diet supplemented with FSBM to replace FM as their protein sources. Here, we systematically reviewed the effect of various inclusion levels of FSBM to replace FM on the growth and FCR of fish. The effect size of 53 comparisons data between FSBM inclusion level in diet formulation and a control condition was -3.75 [95 % CI -4.49 to -3.01] for final weight and 1.26 [95 % CI 0.58 to 1.94] for FCR. According to meta-regression analysis, FSBM inclusion level of 8–40 % improves the final weight of fish. Meanwhile, inclusion level of FSBM higher than 40 % will likely decrease the final weight of fish compared to fish that received high percentage of FM. On the other hand, the inclusion of FSBM is more effective at the level of 15–44 % to improve the FCR of the diet and inclusion levels out of this range would produce various effects to the FCR. Although FSBM does not appear to be a better protein source than FM, especially when included with high inclusion level, the threshold effect showed that the use of FSBM was able to decrease the levels of FM in diet formulation. Baseline values presented in this study conclude that FSBM could become an excellent candidate as a source of protein in practical diet formulation.

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