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ORIGINAL ARTICLE

Soybean meal sourced from Argentina, Brazil, China, India and USA as an ingredient in practical diets for Pacific white shrimp *Litopenaeus vannamei*

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Abstract

Soybean meal (SBM) from China, Argentina, Brazil, the USA and India was collected to evaluate their performances in the diet of Pacific white shrimp. SBM samples were analysed for proximate composition, amino acid profiles, sugars, fibres, macro and micro minerals. A growth trial was conducted using SBM-based test diets (350 g kg^{-1} protein and 80 g kg^{-1} lipid), and a digestibility trial was carried out from digestibility diets formulated by mixing the basal diet and test ingredients (70:30) on a dry matter basis. Significantly higher growth (as standardized Thermal growth coefficient) was observed in shrimp fed SBM from China over Brazilian SBM. However, growth performances of shrimp fed SBM sourced from USA, Argentina and India were not different to that of Chinese and Brazilian SBM. No significant differences were observed for apparent dry matter, energy and protein digestibility coefficients (<0.05) of SBM among the countries. The differences observed in the ingredient chemical profile of SBM between countries were not reflected in the growth and digestibility data of shrimp. These results highlight the importance of multiple variables influencing the biological value of soybean meals and that simplified generalizations such as country of origin, poorly define the quality of an ingredient.

KEYWORDS
country of origin, digestibility, *Litopenaeus vannamei*, nutritional quality, shrimp growth, soybean meal

1 | INTRODUCTION

Soybean meal (SBM) is one of the premier sources of protein in livestock and aquaculture feed formulation due to its higher protein content, comparable amino acid profile, low price, advantage of being resistant to oxidation and spoilage and worldwide availability (Amaya et al., 2007; Davis & Arnold, 2000; Dersjant-Li, 2002). This was supported by the increased production of soybean worldwide from 17 to 230 million metric tons in the past 50 years. Demand for soybean meal and oil is expected to continue, supporting further expansion of the industry (Hartman et al., 2011; Uchida & Akiyama, 2013). Though worldwide availability is an advantage of SBM, variability in the nutritional value has been demonstrated among different sources of SBM, which could affect the production performance of shrimps or fish.

There are a number of factors that influence the quality of soybean and the subsequent products that are produced. It was confirmed that the bean genotype (Cromwell et al., 1999; Palacios et al., 2004) and several environmental and geographical characteristics of the production location such as rainfall (Maestri et al., 1998; Rose, 1988), temperature (Wolf et al., 1982), photoperiod (Cure et al., 1982), altitude or latitude (Maestri et al., 1998) have

significant effects on nutritional profile of soybeans, which is ultimately reflected in SBM (de Coca-Sinova et al., 2008; Goldflus et al., 2006; Van Kempen et al., 2002). Furthermore, soybean processing conditions, such as moisture, drying time and toasting or drying temperature, can contribute to the differences in SBM quality which could lead to variations in nutrient digestibility and growth of target species (Sauer & Ozimek, 1986; Waldroup et al., 1985). Optimum heating conditions are important to denature any remaining antinutritional factors present in the soybeans. If proper temperatures are not reached, high concentrations of antinutritional factors such as trypsin inhibitors and saponins remains in SBM, which will lead to a decrease in nutrient digestibility (Araba & Dale, 1990b; Karr-Lilienthal et al., 2004). However, if temperatures used are too high, portion of the lysine and certain other nutrients such as cystine, arginine and tryptophan can be rendered unavailable for the animal, because of the Maillard reaction (Araba & Dale, 1990a; Palmer et al., 1996; Parsons et al., 1992). Therefore, both over and under processing due to improper heating conditions can result in the production of poor quality SBM.

Because SBM quality is affected by processing conditions, it is important that optimal processing conditions be defined; however, these conditions may not be the same for all soybean varieties grown throughout the world. Karr-Lilienthal, Merchen, et al. (2004) sourced raw soybeans from Argentina, Brazil, China and India and processed them into SBM under standardized conditions at a pilot plant in the USA. In their digestibility study, pigs fed the particular SBM (processed in USA) had much lower amino acid digestibility than did pigs fed the SBM processed within each country. In conclusion, the authors indicated the need for adjustments in SBM processing conditions depending on the composition of soybeans.

Variations in nutritional composition of SBM based on its production location caused concerns in feed manufacturers specially in the field of swine and poultry and led to considerable research (de Coca-Sinova et al., 2008; Lagos & Stein, 2017; Ravindran et al., 2014). However, this information is still scarce relevant to fish and shrimp, which could lead to erroneous predictions in growth, energy and nutrient utilization, if different SBM sources perform differently than the rest. Filling research gaps, the current study investigates the country-wise effects of various SBM sourced from Argentina, Brazil, China, India and the USA and correlated this with growth performance, digestibility of energy, dry matter and amino acids of Pacific white shrimps (*Litopenaeus vannamei*).

2 | MATERIALS AND METHODS

2.1 | Soybean meal sourcing and experimental diets

Total of twenty-four samples of solvent-extracted soybean meal (SBM) produced in Argentina (5), Brazil (5), China (5), India (4) and USA (5) along with data for proximate composition, indispensable and dispensable amino acid profiles, sugars (fructose, sucrose, raffinose, stachyose, etc.), fibres (acid detergent fibre (ADF), neutral detergent fibre (NDF) and lignin), macro minerals and micro minerals for each source were obtained from the Monogastric Nutrition Laboratory, Division of Nutritional Sciences, University of Illinois at Urban-Champaign (Table 1) (details of analysis are available in Lagos & Stein, 2017). SBM from China and India was collected from feed mills or crushing plants located in those countries, but SBM from Argentina and Brazil was collected from feed mills in South Korea, the Philippines, Spain, and Denmark.

Twenty-five soy-based grow-out diets were formulated to be iso-nitrogenous and iso-lipidic (350 g kg^{-1} protein and 80 g kg^{-1} lipid), whereas 24 of the diets contained aforementioned SBM received from Illinois, while a control diet was prepared using a local SBM (Table 2). In addition to the SBM sources, a fixed level of 6% of menhaden fishmeal (Omega Protein Inc.) and 7% of corn protein concentrate (CPC Empyreal 75™, Cargill Corn Milling, Cargill, Inc.) were used as the dietary protein sources, while corn starch (MP Biomedicals Inc.) was used as the filler.

All soybean-based digestibility diets were formulated by mixing the basal diet and test ingredients on a dry matter basis using a 70:30 ratio while 10 g kg^{-1} chromic oxide was used as the inert marker. The test diets were prepared in the feed laboratory at Auburn University, Auburn, AL, USA, using standard practices and were analysed for proximate composition, amino acid profile, pepsin digestibility and trypsin inhibitor levels at University of Missouri Agricultural Experiment Station Chemical Laboratories (Table 3).

2.2 | Culture system

The semi-closed recirculation system used for trials consisted of a series of 75-L aquaria, aquadine bead filter (0.2 m^2 media, 0.6 m × 1.1 m), vertical fluidized bed biological filter (600-L volume with 200-L of Kaldnes media), two 0.25-hp. centrifugal pumps and a common reservoir tank (800-L). Salt water was prepared by mixing artificial crystal sea salt (Crystal Sea Marinemix) with freshwater and maintained at around 7 g L^{-1} during each trial. Dissolved oxygen was maintained near saturation using air stones in each culture tank and the sump tank using a common airline connected to a regenerative blower. Dissolved oxygen, salinity and water temperature were measured twice daily using a YSI-55 digital oxygen/temperature meter (YSI corporation), and total ammonia N (TAN) and nitrite-N were measured twice per week according to the methods described by Solorzano (1969) and Spotte (1979), respectively. The pH of the water was measured two times per week during the experimental period using the pHTestr30 (Oakton Instrument).

2.3 | Growth and digestibility trials

Dietary treatments were randomly assigned to tanks, and each trial was conducted using a double-blind experimental design. Animal care was in compliance with the Auburn University animal

TABLE 1 Chemical composition of soybean meal (SBM) sourced from Argentina, Brazil, China, India and USA[1,2,3]

	Argentina	Brazil	China	India	USA	PSD	*p*-value
Protein	47.3 ± 0.5^{ab}	49.5 ± 1.8^{a}	45.9 ± 0.4^{b}	49.7 ± 1.4^{a}	47.6 ± 1.6^{ab}	1.251	.001
Fat	1.70 ± 1.0	1.70 ± 0.7	1.30 ± 0.2	1.20 ± 0.6	1.68 ± 0.3	0.615	.556
GE, kcal kg^{3}	4203 ± 26	4234 ± 49	4198 ± 11	4156 ± 34	4147 ± 87	49.60	.076
Dry matter	89.1 ± 0.3	88.4 ± 0.9	89.5 ± 0.2	88.3 ± 0.7	88.5 ± 0.8	0.650	.038
Ash	6.98 ± 0.1	6.7 ± 0.5	6.50 ± 0.1	6.91 ± 1.3	6.75 ± 0.6	0.604	.694
Fructose	0.08 ± 0.03	0.07 ± 0.01	0.1 ± 0.0	0.11 ± 0.21	0.08 ± 0.02	0.085	.974
Glucose	0.01 ± 0.03	0.00 ± 0.00	0.0 ± 0.0	0.08 ± 0.16	0.02 ± 0.04	0.065	.421
Sucrose	7.66 ± 0.55^{a}	5.54 ± 0.71^{b}	9.1 ± 0.3^{a}	4.70 ± 1.98^{b}	8.64 ± 0.53^{a}	0.930	.000
Raffinose	1.49 ± 0.13^{ab}	1.55 ± 0.18^{ab}	1.20 ± 0.1^{b}	1.99 ± 0.37^{a}	1.46 ± 0.38^{b}	0.252	.004
Stachyose	5.29 ± 0.40^{b}	4.49 ± 0.65^{b}	5.6 ± 0.1^{ab}	5.11 ± 1.24^{b}	6.51 ± 0.19^{a}	0.614	.001
ADF	3.74 ± 0.49^{b}	4.97 ± 1.78^{ab}	5.7 ± 1.0^{ab}	6.44 ± 1.37^{a}	3.70 ± 0.71^{b}	1.153	.006
NDF	7.28 ± 1.25	8.50 ± 2.80	9.6 ± 1.5	10.0 ± 1.86	7.28 ± 0.82	1.774	.087
Lignin	0.50 ± 0.46	0.32 ± 0.24	0.2 ± 0.1	0.26 ± 0.09	0.20 ± 0.11	0.248	.317
TIU mg^{3}	2.02 ± 0.5^{b}	3.48 ± 0.9^{a}	3.0 ± 0.5^{ab}	4.12 ± 1.0^{a}	2.70 ± 0.9^{ab}	0.760	.007
Indispensable AA							
Arginine	3.31 ± 0.05^{b}	3.43 ± 0.16^{ab}	3.30 ± 0.1^{ab}	3.55 ± 0.15^{a}	3.44 ± 0.12^{ab}	0.114	.037
Histidine	1.35 ± 0.01^{a}	1.36 ± 0.05^{a}	1.3 ± 0.0^{b}	1.42 ± 0.04^{a}	1.38 ± 0.04^{a}	0.035	.000
Isoleucine	2.18 ± 0.05^{bc}	2.35 ± 0.10^{a}	2.1 ± 0.0^{c}	2.32 ± 0.09^{ab}	2.25 ± 0.07^{ab}	0.071	.000
Leucine	3.62 ± 0.04^{a}	3.78 ± 0.17^{a}	3.4 ± 0.0^{b}	3.76 ± 0.14^{a}	3.68 ± 0.10^{a}	0.110	.000
Lysine	2.99 ± 0.07^{ab}	3.06 ± 0.11^{ab}	2.90 ± 0.0^{b}	3.14 ± 0.10^{a}	3.09 ± 0.10^{a}	0.086	.005
Methionine	0.64 ± 0.01	0.65 ± 0.03	0.60 ± 0.0	0.66 ± 0.03	0.66 ± 0.03	0.022	.159
Phenylalanine	2.41 ± 0.02^{a}	2.54 ± 0.12^{a}	2.20 ± 0.0^{b}	2.50 ± 0.11^{a}	2.43 ± 0.08^{a}	0.080	.000
Threonine	1.79 ± 0.03^{a}	1.81 ± 0.08^{a}	1.60 ± 0.0^{b}	1.83 ± 0.07^{a}	1.79 ± 0.05^{a}	0.056	.000
Tryptophan	0.70 ± 0.01^{ab}	0.70 ± 0.03^{ab}	0.70 ± 0.0^{b}	0.68 ± 0.02^{ab}	0.71 ± 0.03^{a}	0.024	.019
Valine	2.28 ± 0.05^{bc}	2.42 ± 0.10^{a}	2.20 ± 0.0^{c}	2.40 ± 0.09^{ab}	2.34 ± 0.07^{ab}	0.072	.000
Dispensable AA							
Alanine	2.02 ± 0.03^{a}	2.10 ± 0.09^{a}	1.90 ± 0.1^{b}	2.07 ± 0.07^{a}	2.04 ± 0.06^{a}	0.063	.000
Aspartic Acid	5.10 ± 0.07^{bc}	5.36 ± 0.20^{ab}	4.90 ± 0.1^{c}	5.44 ± 0.20^{a}	5.25 ± 0.15^{ab}	0.147	.000
Cysteine	0.61 ± 0.01	0.63 ± 0.03	0.60 ± 0.0	0.63 ± 0.02	0.63 ± 0.02	0.019	.293
Glutamic acid	8.19 ± 0.12^{ab}	8.62 ± 0.41^{a}	7.9 ± 0.1^{b}	8.73 ± 0.35^{a}	8.48 ± 0.31^{a}	0.283	.002
Glycine	1.95 ± 0.03^{b}	2.05 ± 0.06^{a}	1.80 ± 0.1^{c}	2.07 ± 0.05^{a}	1.99 ± 0.05^{ab}	0.051	.000
Proline	2.23 ± 0.03^{bc}	2.33 ± 0.09^{ab}	2.10 ± 0.0^{c}	2.40 ± 0.11^{a}	2.30 ± 0.10^{ab}	0.079	.000
Serine	2.12 ± 0.06^{ab}	2.18 ± 0.13^{a}	2.0 ± 0.1^{b}	2.19 ± 0.09^{a}	2.09 ± 0.06^{ab}	0.085	.005
Tyrosine	1.71 ± 0.03^{a}	1.74 ± 0.08^{a}	1.5 ± 0.1^{b}	1.71 ± 0.04^{a}	1.69 ± 0.07^{a}	0.085	.003
Macro minerals							
Ca	0.26 ± 0.02^{bc}	0.30 ± 0.02^{abc}	0.20 ± 0.0^{c}	0.41 ± 0.09^{a}	0.37 ± 0.14^{ab}	0.076	.002
P	0.67 ± 0.03^{ab}	0.62 ± 0.02^{ab}	0.70 ± 0.0^{a}	0.59 ± 0.02^{b}	0.67 ± 0.08^{ab}	0.042	.018
Ca/P	2.65 ± 0.28^{b}	2.07 ± 0.16^{bc}	3.70 ± 0.2^{a}	1.48 ± 0.27^{c}	1.96 ± 0.58^{c}	0.344	.000
P in PA	0.51 ± 0.03^{a}	0.44 ± 0.03^{c}	0.50 ± 0.0^{a}	0.43 ± 0.01^{c}	0.47 ± 0.03^{b}	0.026	.000
Total PA	1.79 ± 0.13^{ab}	1.58 ± 0.10^{c}	1.90 ± 0.0^{a}	1.52 ± 0.05^{c}	1.65 ± 0.10^{bc}	0.093	.000
Non-phytate P	0.17 ± 0.02	0.18 ± 0.01	0.10 ± 0.0	0.17 ± 0.01	0.20 ± 0.06	0.029	.129
Mg	0.29 ± 0.01^{ab}	0.32 ± 0.01^{a}	0.25 ± 0.0^{b}	0.34 ± 0.01^{a}	0.30 ± 0.07^{ab}	0.032	.006
K	2.29 ± 0.02^{a}	2.17 ± 0.08^{b}	2.10 ± 0.0^{bc}	2.03 ± 0.03^{c}	2.16 ± 0.03^{b}	0.042	.000
Na, mg kg^{3}	28.4 ± 49.7	14.8 ± 17.8	5.6 ± 3.5	13.9 ± 5.9	381.4 ± 627	288.9	.218
S	0.41 ± 0.01	0.42 ± 0.02	0.4 ± 0.0	0.42 ± 0.02	0.45 ± 0.04	0.022	.118

(Continues)

TABLE 1 (Continued)

	Argentina	Brazil	China	India	USA	PSD	*p*-value
Micro minerals							
Cu, mg kg^3	11.3 ± 0.25	9.07 ± 1.24	7.6 ± 0.2	15.6 ± 1.28	18.7 ± 14.27	6.595	.088
Fe, mg kg^3	94.4 ± 24.2^b	151.7 ± 67.7^b	111.2 ± 6.1^b	848.3 ± 515.6^a	158.2 ± 101.6^b	212.7	.000
Mn, mg kg^3	41.3 ± 2.6^{ab}	29.8 ± 3.10^b	31.5 ± 0.9^b	56.6 ± 14.6^a	46.0 ± 19.3^{ab}	10.78	.009
Mo, mg kg^3	8.23 ± 1.2^a	3.96 ± 1.1^b	2.60 ± 0.4^b	1.85 ± 1.3^b	4.97 ± 3.7^{ab}	1.918	.001
Zn, mg kg^3	42.0 ± 2.26	50.7 ± 1.95	44.4 ± 0.7	57.3 ± 2.15	77.3 ± 48.0	22.07	.129

Abbreviations: GE, gross energy; PA, phytic acid; PSD, Pooled standard deviation; TIU, trypsin inhibitor units.

[1]Mean of five sources of SBM from Argentina, Brazil, China and USA and four sources of soybean meal from India.

[2]Values with different superscripts within the same row are significantly different based on Tukey pairwise Comparisons ($p < .005$).

[3]Results are expressed on an 'as is' basis (g 100 g^{-1}) unless otherwise indicated.

care policy. The growth trials were conducted in two phases; the first growth trial was conducted with 14 diets with four replicates per diet, which were prepared using SBM sourced from China (5), Argentina (5), Brazil (3) and local SBM (control diet). Rest of the diets were formulated using SBM sourced from Brazil (2), USA (5) and India (4), which were tested during the second growth trial with five replicates per diet. In both trials, 'control' treatment was used with the objective of combining the growth data from trial 1 and 2 by thermal Growth Coefficient (TGC). In each trial, ten shrimp were stocked per tank with an average initial weight of 0.23 ± 0.02 g in trial-1 and 0.67 ± 0.02 g in trial-2. Shrimp were offered test diets four times daily. Shrimp were counted weekly, and the feed was adjusted each week based on survival and observations of feeding responses of shrimp. Growth trial-1 was conducted for 6-weeks, whereas trial-2 was conducted for 5 weeks. At the conclusion, shrimp were counted, and group weighed. TGC for the shrimp in each treatment was calculated and standardized by calculating the 'percentage TGC' reference to the TGC of the control diet for that trial.

During the digestibility trial, eight Pacific white shrimp (~10.2 g mean weight) were stocked per aquaria with six replicate groups per treatment. Shrimp were offered each diet and the resulting faecal pellets from every two tanks were pooled into three replicate samples. Faeces were collected by siphoning on to a 500-μm mesh screen, four times per day during a 2- to 3-day period or until adequate samples were obtained. Each day, the first collection was discarded, and the subsequent three collections were rinsed with distilled water, oven-dried (90°C) until a constant weight was obtained and stored in freezer at −20°C for further analysis. Dry matter was determined by placing representative portions of each sample in an oven at 105°C until constant weight was obtained. Gross energy of diets and faecal samples was analysed with a semi micro-bomb calorimeter (Model 1425, Parr Instrument Co.). Chromic oxide was determined as per the method described by McGinnis and Kasting (1964) in which, after a colorimetric reaction, absorbance was read on a spectrophotometer (Spectronic Genesys 5, Milton Roy Co.) at 540 nm. Protein was determined by summing all dispensable and indispensable amino acids. Finally, apparent digestibility coefficients for dry matter (ADMD) protein (APD) and energy (AED) of diets (D)

TABLE 2 Composition (% as is) of the control diet used during the two growth trials

Ingredient (As basis g kg^{-1} feed)	
Fishmeal[a]	6.00
Soybean meal[b]	51.70[k]
Corn protein concentrate[c]	7.00
Menhaden fish oil[a]	5.76
Lecithin[d]	1.00
Cholesterol[e]	0.05
Whole wheat[f]	23.0
Corn Starch[e]	0.39
Mineral premix[g]	0.50
Vitamin premix[h]	1.80
Choline chloride[i]	0.20
Stay C 35% active[j]	0.10
CaP-dibasic[i]	2.50

[a]Omega Protein Inc., Houston, TX, USA.

[b]De-hulled Solvent Extracted Soybean Meal, Bunge Limited, Decatur, AL, USA.

[c]Empyreal® 75, Cargill Corn Milling, Cargill, Inc., Blair, NE, USA.

[d]The Solae Company, St. Louis, MO, USA.

[e]MP Biomedicals Inc., Solon, OH, USA.

[f]Bob's red mill, Milwaukie, OR, USA.

[g]Trace mineral premix (g kg^{-1} premix): Cobalt chloride, 0.004; Cupric sulphate pentahydrate, 0.550; Ferrous sulphate, 2.000; Magnesium sulphate anhydrous, 13.862; Manganese sulphate monohydrate, 0.650; Potassium iodide, 0.067; Sodium selenite, 0.010; Zinc sulphate heptahydrate, 13.193; Alpha-cellulose, 69.664.

[h]Vitamin premix (g kg^{-1} premix): Thiamin HCl, 4.95; Riboflavin, 3.83; Pyridoxine HCl, 4.00; Ca-Pantothenate, 10.00; Nicotinic acid, 10.00; Biotin, 0.50; folic acid, 4.00; Cyanocobalamin, 0.05; Inositol, 25.00; Vitamin A acetate (500,000 IU g^{-1}), 0.32; Vitamin D3 (1,000,000 IU g^{-1}), 80.00; Menadione, 0.50; Alpha-cellulose, 856.81.

[i]VWR Amresco, Suwanee, GA, USA.

[j]Stay-C® (L-ascorbyl-2-polyphosphate 35% Active C), Roche Vitamins Inc., Parsippany, NJ, USA.

[k]SBM inclusion level of test diets was adjusted based on respective protein levels of each source, and cornstarch was used as the filler to balance the formulation.

TABLE 3 Chemical composition of high soy test diets fed to juvenile Pacific white shrimp during growth trials[1,2,3]

	Argentina	Brazil	China	India	USA	PSD	*p*-value
Protein	35.9^{ab}	36.6^{a}	35.1^{b}	36.3^{a}	36.3^{a}	0.53	.003
Moisture	7.52^{ab}	6.19b	8.67^{a}	6.57^{ab}	7.03^{ab}	1.17	.032
Fat	9.73	10.09	8.24	9.91	8.21	1.89	.397
Crude Fibre	3.76^{b}	3.94^{b}	4.87^{a}	4.84^{a}	3.80^{b}	0.61	.015
Ash	6.65	6.53	6.49	6.84	6.67	0.33	.574
Pepsin Digestibility	93.6^{ab}	94.1^{ab}	92.2^{b}	93.7^{ab}	95.0^{a}	1.08	.010
TIU/g	879^{abc}	713^{bc}	1018^{ab}	1067^{a}	586^{c}	241	.031
Indispensable amino acids							
Arginine	2.146	2.196	2.156	2.19	2.178	0.04	.356
Histidine	0.94	0.96	0.92	0.97	0.96	0.04	.338
Isoleucine	1.59^{b}	1.67^{a}	1.53^{c}	1.64^{ab}	1.59^{b}	0.03	.000
Leucine	3.12^{a}	3.21^{a}	2.99^{b}	3.19^{a}	3.15^{a}	0.06	.000
Lysine	1.98	1.99	1.94	1.99	2.00	0.04	.202
Methionine	0.61	0.60	0.58	0.60	0.60	0.01	.086
Phenylalanine	1.87^{bc}	1.95^{a}	1.80^{c}	1.90^{ab}	1.88^{ab}	0.04	.000
Threonine	1.33^{a}	1.31^{a}	1.24^{b}	1.31^{a}	1.33^{a}	0.03	.001
Tryptophan	0.49	0.48	0.46	0.48	0.50	0.02	.087
Valine	1.72^{a}	1.76^{a}	1.64^{b}	1.75^{a}	1.70^{ab}	0.04	.000
Total EAA	15.79^{a}	16.13^{a}	15.26^{b}	16.01^{a}	15.89^{a}	0.28	.001
Dispensable Amino Acids							
Alanine	1.81^{ab}	1.83^{a}	1.74^{b}	1.82^{ab}	1.82^{ab}	0.04	.018
Aspartic acid	3.36^{ab}	3.43^{a}	3.22^{b}	3.42^{a}	3.40^{a}	0.08	.002
Cysteine	0.51	0.51	0.52	0.51	0.52	0.02	.912
Glutamic acid	6.63^{ab}	6.78^{a}	6.43^{b}	6.77^{a}	6.72^{ab}	0.16	.015
Glycine	1.57	1.58	1.54	1.60	1.59	0.04	.227
Proline	2.05	2.07	1.89	2.03	2.07	0.12	.133
Serine	1.52	1.51	1.44	1.48	1.55	0.06	.067
Taurine	0.17^{b}	0.17^{b}	0.17^{b}	0.19^{a}	0.18^{ab}	0.01	.006
Hydroxyproline	0.08	0.09	0.11	0.09	0.09	0.02	.085
Tyrosine	1.34^{a}	1.38^{a}	1.28^{b}	1.37^{a}	1.36^{a}	0.03	.000
Total NEAA	19.24^{ab}	19.55^{a}	18.52^{b}	19.41^{ab}	19.48^{a}	0.44	.011

Abbreviations: PSD, pooled standard deviation; TIU, trypsin inhibitor units.

[1]Mean of five diets each incorporating SBM from Argentina, Brazil, China and USA and four diets including SBM from India.

[2]Values with different superscripts within the same row are significantly different based on Tukey pairwise Comparisons ($p < .005$).

[3]Results are expressed on an 'as is' basis (g 100 g^{-1}) unless otherwise indicated.

and test ingredients (I) were calculated according to the methods described by Cho et al. (1982) and Bureau and Hua (2006) as follows,

$$\text{ADMD - } D\,(\%) = 100 - \left[100 \times \frac{\%\,Cr_2O_3 \text{ in feed}}{\%\,Cr_2O_3 \text{ in feces}}\right]$$

$$\text{ADP - } D \text{ and ADE - } D\,(\%) = 100 - \left[\left(100 \times \frac{\%\,Cr_2O_3 \text{ in feed}}{\%\,Cr_2O_3 \text{ in feces}} \times \frac{\%\text{ nutrients in feces}}{\%\text{ nutrients in feeds}}\right)\right]$$

$$\text{ADMD - } I = \text{ADMDD} + \left[\left(\text{ADMD} - \text{ADMD}_{\text{ref.diet}} \times \left(\frac{0.7 \times D_{\text{ref}}}{0.3 \times D_{\text{ingr}}}\right)\right)\right]$$

$$\text{APD} - I = \text{APDD} + \left[\left(\text{APDD} - \text{APDD}_{\text{ref.diet}} \times \left(\frac{0.7 \times D_{\text{ref}}}{0.3 \times D_{\text{ingr}}}\right)\right)\right]$$

$$\text{AED} - I = \text{AEDD} + \left[\left(\text{AEDD} - \text{AEDD}_{\text{ref.diet}} \times \left(\frac{0.7 \times D_{\text{ref}}}{0.3 \times D_{\text{ingr}}}\right)\right)\right]$$

D_{ref} = % nutrient (or KJ g^{-1} gross energy) of basal diet (dry weight)

D_{ingr} = % nutrients (or KJ g^{-1} gross energy) of test ingredient (dry weight)

2.4 | Statistical analysis

All data were analysed using SAS (V9.3. SAS Institute). Chemical variables of SBM and diets, standardized TGC values and apparent digestibility coefficients were subjected to analysis of variance (ANOVA) followed by Tukey pairwise comparison test to evaluate significant differences in performances of shrimp among the five SBM sourced countries ($p < .05$). To avoid pseudo replication due to number of SBM sources from each country and number of replicates of each SBM source (in growth and digestibility trial), a mean value was calculated for each SBM source (from replicates) and was used during the statistical analysis. Cluster analysis was used to identify the grouping patterns of SBM sources based on chemical characteristics and biological performances (growth and digestibility data) observed in Pacific white shrimp (Figure 1).

3 | RESULTS

Significant differences were observed in SBM sourced from Argentina, Brazil, China, India and USA for protein, acid detergent fibre (ADF), sucrose, raffinose, stachyose, trypsin inhibitor, indispensable and dispensable amino acids except for methionine and cysteine, macro nutrients except for sodium and sulphur and micronutrients except for copper and zinc (Table 1). Irrespective to statistical significance, some of these chemical parameters varied in a narrow range such as 47.3%–49.7% in protein, 1.20%–1.99% in raffinose, 4.49%–6.51% in stachyose and 0.59%–0.70% in phosphorus. Brazilian (49.5%) and Indian (49.7%) SBM had a greater ($p < .05$) concentration of crude protein than SBM from China (45.9%), while the protein content of SBM sourced from USA (47.6%) and Argentina (47.3%) were not significant different from the rest. As antinutritional components, significantly higher level of raffinose was detected in SBM from India (1.99%) compared with the SBM sourced from USA (1.46%) and China (1.20%), and SBM sourced from USA contained higher level of stachyose (6.51%) than that of SBM sourced from Argentina (5.29%), Brazil (4.49%) and India (5.11%). Significantly higher Trypsin Inhibitor level was detected in Indian (4.12 TIU mg^{-1}) and Brazilian (3.48 TIU mg^{-1}) SBM than the levels in SBM from Argentina (2.02 TIU mg^{-1}). The phytic acid concentrations were significantly high in SBM sourced from China (1.90%) and Argentina (1.79%) compared with the SBM sourced from Brazil (1.58%) and India (1.52%) (Table 1).

At the conclusion of growth trials, no significant differences were found between the growth performances of shrimp fed SBM sourced from China, USA, Argentina and India (Table 4). However, the growth of shrimp fed Brazilian SBM found significantly lower than that of shrimp fed SBM sourced from China but was not different from the rest of the SBM sources. Survival and feed conversion ratio (FCR) of shrimp fed SBM sourced from different countries were ranged from 86.0 to 92.4% and 1.67 to 1.86, respectively (p-value >.05). No significant differences were observed for apparent dry matter, energy and protein digestibility coefficients (p-value >.05) of SBM among the countries which were ranged from 59.7% to 74.8%, 68.7% to 80.6% and 90.5% to 94.3%, respectively (Table 4), and no significant differences were noted between SBM sources for apparent amino acids digestibility as well (Table 5). Inconsistency in grouping patterns of SBM based on chemical characteristics and biological outcomes of Pacific white shrimp was noted in cluster dendrograms (Figure 1). During trials, DO, temperature, salinity, pH, TAN and nitrite levels were maintained within the acceptable ranges for *L. vannamei* at 6.5 ± 2.2 mg L^{-1}, 28.9 ± 0.8°C, 7.4 ± 0.8 g L^{-1}, 7.5 ± 0.5, 0.11 ± 0.04 mg L^{-1} and 0.09 ± 0.03 mg L^{-1}, respectively.

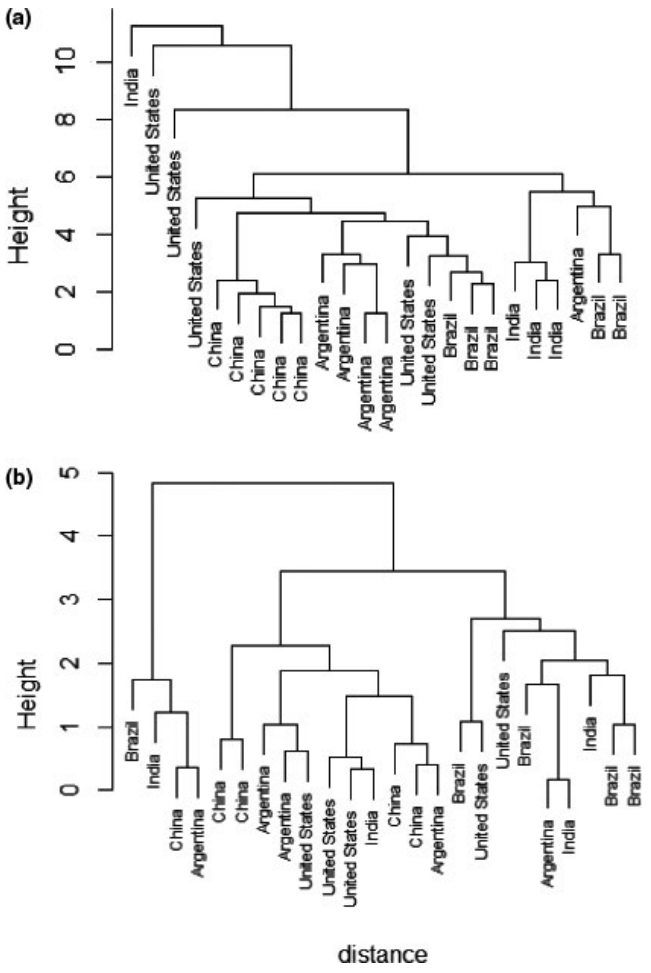

FIGURE 1 Dendrogram of Cluster analysis; grouping of SBM based on chemical characteristics (a), grouping of SBM based on growth and digestibility outcomes of Pacific white shrimp, *Litopenaeus vannamei* (b)

4 | DISCUSSION

Though SBM has risen to one of the top-traded commodities with a multitude of uses, soybean cultivation is highly concentrated

TABLE 4 Thermal growth coefficients (TGC) (as a percentage from TGC of control diet) and apparent digestibility coefficients of dry matter (ADMD), protein (APD) and energy (AED) of the diet (D) and ingredient (I) offered to Pacific white shrimp, *Litopenaus vannamei* (mean ±SD).

Country	TGC	ADMD-D	AED-D	APD-D	ADMD-I	AED-I	APD-I
Argentina	97.9 ± 2.3^{ab}	76.2 ± 3.3	81.9 ± 2.5	92.2	70.6 ± 10.9	78.1 ± 7.6	92.5 ± 3.4
Brazil	95.5 ± 2.3^{b}	73.5 ± 5.0	79.5 ± 4.4	91.7	61.6 ± 16.5	70.6 ± 13.3	91.5 ± 4.0
China	100.8 ± 1.5^{a}	77.4 ± 2.0	82.7 ± 1.6	93.0	74.8 ± 6.70	80.6 ± 4.9	94.3 ± 1.9
India	96.7 ± 2.5^{ab}	75.0 ± 4.3	80.6 ± 3.1	91.6	66.7 ± 14.2	74.2 ± 9.5	91.3 ± 3.4
USA	98.8 ± 3.8^{ab}	72.9 ± 3.1	78.8 ± 2.8	91.3	59.7 ± 10.3	68.7 ± 8.6	90.5 ± 2.2
PSD	2.49	3.62	3.02	1.35	12.08	9.18	3.05
p-value	.036	.290	.248	.366	.290	.248	.366

Values with different superscripts within the same column are significantly different based on Tukey Pairwise Comparisons.
TGC calculated as [(Final weight$^{1/3}$ – Initial weight$^{1/3}$) / duration in days * Temperature] *1000.
Abbreviations: PSD, pooled standard deviation; SD, standard deviation.

TABLE 5 Apparent amino acids (AA) digestibility for the ingredient (I) using 70:30 replacement technique offered to Pacific white shrimp (mean ± SD).

	Argentina	Brazil	China	India	USA	PSD	*p*-value
Alanine	88.3 ± 5.6	86.6 ± 6.8	90.9 ± 3.4	87.3 ± 5.2	85.1 ± 4.3	5.19	.496
Arginine	93.9 ± 2.8	93.1 ± 3.2	95.6 ± 1.6	92.7 ± 3.1	92.4 ± 1.6	2.53	.325
Aspartic Acid	92.3 ± 3.5	91.8 ± 3.6	94.1 ± 1.8	91.0 ± 3.4	90.3 ± 2.0	2.95	.338
Cysteine	81.9 ± 5.5	83.1 ± 6.8	83.4 ± 3.5	83.3 ± 5.0	79.4 ± 2.8	4.92	.679
Glutamic Acid	93.9 ± 3.1	92.9 ± 3.2	95.7 ± 1.7	91.8 ± 3.1	91.7 ± 1.6	2.64	.154
Glycine	85.6 ± 6.8	82.8 ± 9.1	88.2 ± 4.6	85.4 ± 6.9	82.1 ± 6.7	6.98	.669
Histidine	92.4 ± 3.5	91.1 ± 4.4	93.2 ± 2.0	91.3 ± 3.1	89.9 ± 2.2	3.17	.545
Isoleucine	91.9 ± 3.7	91.3 ± 3.6	94.1 ± 1.8	90.7 ± 3.2	90.0 ± 2.0	2.96	.291
Leucine	90.6 ± 3.9	89.7 ± 4.4	93.1 ± 2.1	89.4 ± 3.6	88.3 ± 2.3	3.37	.273
Lysine	93.1 ± 3.5	91.8 ± 3.7	93.9 ± 2.0	92.4 ± 3.4	91.9 ± 1.9	2.97	.787
Methionine	88.7 ± 5.7	87.5 ± 6.5	90.9 ± 3.3	87.7 ± 5.5	85.2 ± 3.4	5.02	.521
Phenylalanine	91.5 ± 3.6	90.9 ± 3.9	93.8 ± 1.9	90.5 ± 3.3	89.7 ± 2.3	3.09	.323
Proline	90.9 ± 3.6	90.2 ± 4.5	93.7 ± 2.2	90.2 ± 3.9	88.7 ± 2.4	3.40	.256
Serine	90.6 ± 3.8	89.3 ± 4.4	92.5 ± 2.1	89.7 ± 3.9	88.4 ± 2.9	3.49	.427
Threonine	87.8 ± 4.9	86.0 ± 5.8	90.9 ± 2.9	85.8 ± 4.6	84.0 ± 3.4	4.42	.183
Tryptophan	95.0 ± 1.7	93.7 ± 2.1	96.4 ± 1.3	94.1 ± 2.5	93.6 ± 1.2	1.77	.113
Tyrosine	95.2 ± 2.5	93.2 ± 3.5	95.1 ± 1.9	92.4 ± 3.7	92.2 ± 1.8	2.74	.300
Valine	88.6 ± 4.8	87.6 ± 5.2	92.4 ± 2.4	88.6 ± 3.7	86.5 ± 3.2	3.98	.216
Total AA	91.4 ± 3.8	90.4 ± 4.3	93.5 ± 2.1	90.2 ± 3.7	89.2 ± 2.4	3.36	.364

Values with different superscripts within the same row are significantly different based on Tukey pairwise comparisons.
PSD, pooled standard deviation; SD, Standard deviation.

geographically, with only four countries USA, Brazil, Argentina and China—accounting for almost 90% of world output while India being the fifth (Ash & Dohlman, 2012; Montoya-Camacho et al., 2019; Ravindran et al., 2014; Thoenes & Trade, 2007;). In line with the substantial location-wise variations in composition of SBM documented in previous studies, significant differences were observed in most of the chemical parameters of SBM tested during the study sourced from Argentina, Brazil, China, India and USA (García-Rebollar et al., 2016; Ravindran et al., 2014; Van Kempen et al., 2002). The proximate analysis of the SBM was within the range of values reported in the literature (de Coca-Sinova et al., 2008; García-Rebollar et al., 2016; Karr-Lilienthal, Merchen, et al., 2004; Ravindran et al., 2014; Sotak-Peper et al., 2015; Van Kempen et al., 2002).

During the present study, no significant differences were found between the growth performances of shrimp fed SBM sourced from China, the USA, Argentina and India except for the significantly low growth noted in shrimp fed Brazilian SBM compared with the shrimp fed SBM sourced from China. However, the growth performances

of shrimp fed Brazilian SBM were not significantly differ from the growth data of shrimp fed SBM sourced from USA, Argentina or India. Since the diets were formulated on equal protein and lipid basis, any of the chemical characteristics of SBM could have an influence on shrimp growth in different magnitudes. Galkanda-Arachchige et al., (2020) stated that the phosphorous, phosphorous in phytic acid and total phytic acid and raffinose are important components in SBM that may have significant effects on the growth performances of pacific white shrimp. However, no significant differences were detected in the level of raffinose and phosphorous between Chinese (1.20% and 0.70%, respectively) and Brazilian SBM (1.55% and 0.62%, respectively), while the level of phosphorous in phytic acid and total phytic acid were significantly high in Chinese SBM (0.50% and 1.90%, respectively) than that in Brazilian SBM (0.44% and 1.58%, respectively). Negative effects due to phytate and raffinose containing ingredients in the diets on fish and shrimp were well documented, attributed to various factors such as reduced mineral bioavailability, impaired protein digestibility and depressed absorption of nutrients (Davis et al., 1993; Francis et al., 2001; NRC, 2011; Qiu & Davis, 2017; Refstie et al., 1998; Spinelli et al., 1983; Storebakken et al., 1998). Interestingly, dose-response effect was not revealed between the level of antinutritional factors and growth outcomes of shrimp fed SBM sourced from China and Brazil, making it hard to pinpoint those variables as the culprit for the growth differences observed in shrimp fed Chinese and Brazilian SBM.

Apparent dry matter, energy and protein digestibility of SBM observed during the current study ranged from 59.7% to 74.8%, 68.7% to 80.6% and 90.5% to 94.3%, respectively, which are in agreement with previous findings (Akiyama et al., 1989; Brunson et al., 1997; Cruz-Suárez et al., 2009; Divakaran et al., 2000; Fang et al., 2016; Qiu et al., 2018). No significant differences were observed for apparent dry matter, energy, protein and amino acids digestibility coefficients of SBM among the countries. The difference detected in growth performances of shrimp fed SBM sourced from Brazil and China was not reflected through the digestibility data. However, greater digestibility is not a requisite to yield higher growth because the feed intake of shrimp or the balance of essential nutrients does not always depend on digestibility. Zhu et al., (2013), Zhou et al., (2015) and Fang et al., (2016) noted variable responses between nutrient digestibility in SBM and growth of *L. vannamei*, which were assumed to be a result of differences in palatability or segregated effects of certain chemical variables on growth.

Van Kempen et al., (2002) mentioned that the differences in nutritional profile of SBM based on its origin do not necessarily correlate to differences in digestibility or growth of an animal. In his study, nutritional composition of SBM collected from USA (samples from four regions) and Netherland varied statistically attributed to a small standard error of mean between the samples. However, no significant differences were found in SBM digestibilities of pigs (Van Kempen et al., 2002). Similar observations are common in literature (Karr-Lilienthal, Merchen, et al., 2004; Lagos & Stein, 2017), where differences in nutritional composition of SBM does not converted into digestibility or growth outcomes of the target species mainly due to several reasons. In some of the studies, statistical differences between SBM sources in chemical variables seem to be due to small standard error of mean between samples (Van Kempen et al., 2002). Difference between smallest and largest reported value of those variables (range) is narrow; hence, the probability of such a variable to make a biologically significant change should be less. Another important problem in SBM feed studies is the lack of techniques to evaluate SBM samples correctly and accuracy and precision of the data. Most of the methods available are based on changes caused by heat on the physical and chemical characteristics of the SBM. Urease activity (AOAC, 2000), protein dispersibility index (Batal et al., 2000) and KOH protein solubility (Araba & Dale, 1990a, 1990b; Parsons et al., 1991) are the tests most widely used to evaluate SBM quality, which has less reliability and consistency, and wide sensibility across laboratories (Engram et al., 1999; Valencia et al., 2008; Valencia et al., 2008). Inconsistency among cluster groupings of SBM noted during the study highlights the importance of considering interactions and augmented effect of multiple variables in an ingredient, to the growth and digestibility of cultured species (Figure 1). Francis et al., (2001) emphasized the importance of considering interactions between chemical variables in an ingredient, highlighting reduced individual toxicity of several antinutrients due to the interactions such as saponin–tannin (Freeland et al., 1985), tannin–lectin (Fish & Thompson, 1991) and tannin–cyanogen (Goldstein & Spencer, 1985). However, fairly bias conclusions are numerous in literature by attributing the observed outcome to a one chemical variable with moderate to higher richness in an ingredient.

Studies have shown substantial variation in composition of soybeans and SBM produced within a country. Grieshop and Fahey (2001) examined the variability in soybeans grown in Brazil, China and the USA, and except for the differences between countries, significant differences in crude protein and amino acid composition were reported within the each country as well. A survey conducted on SBM processing plants in USA confirmed this conclusion, which showed differences in crude protein, total dietary fibre, acid hydrolysed fat and lysine concentrations among SBM grown and processed in different regions in USA (Grieshop et al., 2003). Although no similar findings were available on other major SBM producing countries, it is safe to assume that similar amounts of variation could be exist in other countries as well. Therefore, insufficient sample size could be a major constraint in country-based studies which could lead to bias conclusions.

Since SBM is a top-traded commodity, multiple parties involve into its production chain are all fractionally responsible for its final quality. Occasionally, soybean production and processing happen in two different countries without a direct link, questioning the definition of 'production location of SBM'. In such cases, there is a possibility of a single source of beans, producing different qualities of SBM due to variations in processing conditions as well as possible transportation effects. During the current study, SBM from China and India was collected from feed mills or crushing plants

located in those countries, but SBM from Argentina and Brazil were collected from feed mills in South Korea, the Philippines, Spain and Denmark. Therefore, for similar kind of evaluator studies, it is always safe to have SBM samples produced within a one country to assign complete authority for the particular country, which could eliminate possible quality variations due to transportation between countries.

4.1 | Conclusion

Soybean meal sourced from China, Argentina, Brazil, the USA and India used in the current study differed in nutrient composition. However, these differences resulted in minimal effect on growth or apparent nutrient digestibility coefficients of Pacific white shrimp *Litopenaeus vannamei*. Albeit there may be statistical differences in chemical composition, these differences were often quite small. This limited range may not be adequate to determine biological difference in a complex matrix and may account for a lack of differences in growth and digestibility. These results highlight the importance of multiple variables influencing both the chemical composition and biological value of soybean meals and that simplified generalizations such as country of origin, poorly define the quality of an ingredient.

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