Indian J. Anim. Nutr. 2024. 41 (2): 327-333
doi: 10.5958/2231-6744.2024.00042.4
Indian Journal of Animal Nutrition

Nutritional Evaluation of Extruded-Expeller Soybean Meal (EESBM) as a New Feed Ingredient for Modern Broilers Chicken

S. Mukesh, R. Kavitha, A. Natarajan and K. Rajendran
Department of Animal Nutrition, Veterinary College and Research Institute,
Namakkal, Tamil Nadu Veterinary and Animal Sciences University
*Correspondence: vetkavi2004@gmail.com

ABSTRACT

This study evaluates the potential of extruded and expeller soybean meal (EESBM) compared to solvent-extracted soybean meal (SESBM) as a feed ingredient in broiler chicken / poultry diets. Chemical composition, fatty acid profile and *in vitro* protein quality assays were conducted on collected samples. EESBM demonstrated significantly higher dry matter (96.07 per cent) and ether extract (6.77 per cent) content, with a notable DM per cent advantage (96.1 per cent versus 88.61 per cent) over SESBM. EESBM's crude protein (46.4 per cent) content was slightly higher than the EESBM (45.5 per cent). Calculated gross energy and metabolizable energy values of EESBM were significantly higher (4688.50 and 2661.08 kcal/kg) than SESBM (4361.83 and 2199.36 kcal/kg), primarily attributed to increased EE content in EESBM. KOH solubility and PDI values showed marginal differences, with EESBM exhibiting higher linolenic acid (7.86 per cent) and lower levels of palmitic acid, stearic acid, arachidic acid and behenic acid compared to SESBM. Urease activity in terms of pH unit change was comparable. Based on this study the EESBM is proved to be a novel ingredient over SESBM in terms of its quality.

KEYWORDS: Chemical composition, Extruded-expeller soybean meal, Protein dispersibility index, Protein solubility, Solvent extracted soybean meal, Urease activity,

Article received: 09 December 2023; Article accepted: 16 February 2024

INTRODUCTION

Poultry plays a major role in meeting the demand for increasing global protein consumption. However, poultry production, feed covers 65-75 per cent of the total production cost. Protein stands as one of the two principal costly ingredients in the dietary plan of poultry, the other being energy. Among various protein sources available for feed formulations, soybean meal (SBM) has proved to be a vital source in broiler diets. The fast growth of poultry sectors globally and more particularly in countries like India, results in increasing demand of key ingredients like soybean meal, especially for broilers where its use has been between 20-30 per cent in feeds. The rising demand for soybean meal in non-ruminant feed formulations is due to its high levels of crude protein (CP) and its amino acid (AA) profile that complements that of cereals, along with its superior AA digestibility (Ravindran et al., 2014). SBM is predominantly produced through solvent extraction procedure after extracting the oil using hexane.

A small portion of soybeans are also available as full fat soybean meal but the protein content of full fat soybean meal is only 36-37 per cent, though the oil content is higher with 17-18 per cent. The use of full fat soybean meal is in practice but very limited. Due to demand, the cost of SBM has been steadily increasing year after year from Rs 36000 per tonne in early 2019 to newer high of Rs 49000 per tonne in 2023. In broiler feed, use of oil is mandate to reach a ME value of 3000 kcal/kg and above and the availability and cost of oil is also highly fluctuating, apart from quality of oil. Due to this persistent problems and risk associated with the use of poor-quality oil, alternate sources of protein rich materials are in the look out. One such product that could satisfy both protein and energy needs is simultaneously the one that is extruded and expelled soybeans.

Nelson et al. (1987) introduced a pioneering process that the combination of extrusion processing followed by expelling for the processing of soybeans. In this method, intact soybeans are subjected to extrusion cooking at a temperature of 135°C for a duration not exceeding 30 seconds (Nelson et al., 1987). Followed by expulsion, remaining part of the oil, resulting in a product named EESBM with approximately 7 per cent oil. The rising popularity of the extruding-pressing process is driven by its improved cost and material efficiency, as it eliminates the need for solvents or steam dryers in animal feed ingredient production (Meyer and Bobeck, 2021). There are several quality control tests such as urease activity, protein dispersibility index, nitrogen solubility index and potassium hydroxide solubility test were used to analyse the protein quality in soybean meal for poultry (Araba and Dale, 1990; Parsons et al., 1991; Willis, 2003).

While extruded-expeller soybean meal is known as a source of crude protein and energy, its utilization in poultry ration especially in broiler chickens, remains untapped in India. Consequently, it is imperative to assess the nutritive value of the meal to utilize it as a feed ingredient for modern broilers. This study aims to investigate the comparative nutritive analysis of EESBM and SESBM concerning chemical composition and characterize the *in vitro* protein quality.

MATERIALS AND METHODS

The samples from multiple batches originating from soybean processing plants of EESBM and SESBM were collected and ground. Ground samples were stored in air-tight containers for further analysis. EESBM and SESBM were analysed for moisture by oven-drying (AOAC, 930.15), nitrogen (N) by Kjeldahl (AOAC, 984.13), Ether extract (EE) by Soxhlet (AOAC, 920.39), crude fibre by serial extraction with diluted acid and alkali (AOAC, 962.09), calcium (AOAC, 927.02), phosphorus (AOAC, 965.17) and salt (AOAC, 943.01) as per the methods of AOAC (2019). Crude protein content was calculated as N x 6.25. Total ash with a muffle furnace (IS 14827:2000) and acid-insoluble ash (IS: 14826:2000) were also analysed. The gross energy content (kcal/kg) of the analyzed samples was determined by proximate principles estimated as per the equation (Halvar et al., 1976).

The urease activity is based on the increase in the pH units from ammonia released from urea by residual urease enzyme in the soybean meal and analysed by the method described by Caskey and Knapp (1944) and AOCS (2017a). The protein solubility was determined as per the procedure of Araba and Dale (1990). The KOH solubility test is based on the solubility of soybean protein in the diluted (0.2per cent) potassium hydroxide solution. The protein dispersibility index (PDI) was determined according to the AOCS (2017b) method. All samples were analysed in duplicate in the Animal Feed Analytical and Quality Assurance Laboratory, Veterinary College and Research Institute, Namakkal.

RESULTS AND DISCUSSION

Chemical Composition of EESBM

The chemical composition of EESBM is presented in Table 1. The dry matter (DM) content of EESBM samples showed a high value of 96.1 per cent probably due to elevated extrusion and expulsion temperature followed by the dwelling time of the soybean when compared to literature reported values (90.2 to 94.6 per cent). Woodworth et al. (2001) reported a DM value of 95.9 per cent which was very close to our EESBM sample's DM value. The crude protein (CP) contents ranged widely in EESBM samples of earlier workers, from 39.57 (Jacob and Carter, 2008) to 50.1 per cent (Sakkas et al., 2019). However, majority of workers reported CP values which ranged from 40.0 (Lima et al., 2018) to 44.9 (Powell et al., 2011) per cent on as-fed basis. EESBM samples showed a mean CP value of 46.39 per cent on as-fed basis, which was actually high and could be due to very high DM (96.1 per cent) content. The ether extract (EE) content of EESBM was 6.77 per cent against values reported earlier which range from as low as 4.6 (Sakkas et al. 2019) to as high as 9.5 per cent on as-fed basis (Opapeju et al., 2006). Few authors reported further

higher EE values of 9.9 (Velayudhan, 2014) and 11.99 (Lima et al., 2018) per cent which might be due to the type of extrusion process and temperature applied. Low crude protein values reported by certain reports like 40.0 per cent (Velayudhan, 2014) and 40.0 per cent (Lima et al., 2018) could be another cause for high oil content in their EESBM samples. With the increase in extrusion temperatures from 121°C, 138°C and 154°C of conventional soybeans, Zhang et al. (1993) found the DM to be more or less similar (92.9-93.0 per cent) but a linear increase in CP (41.7, 43.5 and 46.7 per cent) with a corresponding decrease in EE values (10.9, 10.1 and 7.7 per cent). The rest of the chemical compositions were close in agreement with the values reported by the authors.

Table 1. Chemical composition and *in vitro* protein quality assay (Mean ± SE) of EESBM and SESBM

Chemical composition (per cent) [1]	EESBM	SESBM	Significance
Dry matter **	96.1 ± 0.61	88.6 ± 0.30	0.000
Crude Protein	46.4 ± 0.58	45.5 ± 0.27	0.22
Crude Fiber	6.40 ± 0.22	6.34 ± 0.17	0.83
Ether Extract **	6.77 ± 0.30	1.53 ± 0.08	0.000
Total Ash	6.71 ± 0.26	7.03 ± 0.42	0.54
Nitrogen Free Extract *	29.8 ± 0.42	28.2 ± 0.58	0.04
Acid Insoluble Ash	0.45 ± 0.11	0.69 ± 0.23	0.36
Calcium	0.50 ± 0.00	0.57 ± 0.04	0.14
Phosphorus *	0.61 ± 0.02	0.69 ± 0.02	0.02
Gross energy ** (kcal/kg) [2]	4688 ± 20.06	4361 ± 20.25	0.000
Calculated MEn ** (kcal/kg) [2]	2661 ± 22.25	2199 ± 15.12	0.000
In vitro protein quality assay			
KOH Protein Solubility (per cent CP)	84.1 ± 0.47	83.1 ± 0.60	0.19
Protein Dispersibility Index (per cent CP)	15.5 ± 0.24	16.1 ± 0.19	0.10
Urease Activity/g/min	0.005 ± 0.001	0.01 ± 0.001	0.60
pH difference	0.03 ± 0.004	0.03 ± 0.003	0.56
Free fatty acid ** (per cent)	2.10 ± 0.09	9.27 ± 0.52	0.000

Value in each cell is the mean of six observations
[1] As-fed basis
[2] Calculated values
** Highly significant (P<0.01)
* Significant (P<0.05)
Note: Extruded and expeller soybean meal (EESBM); solvent-extracted soybean meal (SESBM)

Chemical composition of SESBM

The chemical composition of solvent-extracted soybean meal (SESBM) is presented in Table 1. The common method of producing soybean meal involves a solvent extraction process using hexane as the primary solvent, resulting in a meal with less than 1 per cent oil content and consistency in other nutritional compositions. Upon comparison of the various parameters analyzed for the chemical composition of SESBM the DM, CP and EE contents showed closer values with previously reported values of 90.10 and 88.9, 45.20 and 46.4, 1.31 and 1.09 per cent of Park et al. (2002) and Ravindran et al. (2014), respectively. A few other workers also reported similar DM, CP and EE values (Woodworth et al. 2001 and Meyer and Bobeck, 2021). While considering other parameters, SESBM showed

comparable values with the previous reports of crude fibre (6.08 and 5.40), ash (7.95 and 6.27), calcium (0.46 and 0.43) and phosphorus (0.57 and 0.64) on as-fed basis by Ravindran et al. (2014) and Meyer and Bobeck, (2021) respectively. Near complete removal of ether extractives from soybeans using hexane as solvent resulted in SESBM showing almost similar values for all other parameters compared with previous reports.

Comparison of the chemical composition of EESBM and SESBM

The EESBM had significantly ($P<0.05$) higher mean values of DM, EE and NFE values than the SESBM. However, a significantly ($P<0.05$) lower value of phosphorus (0.61 per cent) was recorded in EESBM (0.69 per cent). EESBM showed a much higher DM per cent (96.07) than the SESBM (88.63) which was due to high temperature and conglomeration of particles resulting from the extrusion process ensuing in a very dry product. The CP value of EESBM was surprisingly higher than SESBM value, despite EESBM having higher EE content of 6.77, which probably could be result of low moisture content of EESBM and good seed quality. It is noteworthy to say that SESBM had 11.3 per cent moisture in it, which is as higher by 7.44 per cent.

***In vitro* protein quality assay for EESBM and SESBM**

Urease activity, KOH protein solubility and the protein dispersibility index (PDI) were employed as indicators to evaluate the protein quality of soybean meal. The results of *in vitro* protein quality assays for EESBM and SESBM samples are presented in Table 1. The KOH protein solubility of EESBM of 84.16 per cent is in agreement with the value of 83.62 (Blomme et al., 2022) and 83.2 per cent (Kiarie et al., 2020) reported earlier. The recommended value of KOH solubility for SBM is between 75 and 84 per cent (Van Eys and Ruiz, 2021) within which the present EESBM's value of KOH solubility also was found. The PDI value of EESBM (15.57 per cent CP) is higher than the value of 12.9 per cent observed by Webster et al. (2003); however, the values of PDI reported in EESBM samples collected from various plants (Karr-Lilenthal et al., 2006) varied widely between 6.6 and 25.7 per cent.

The urease activity (pH difference) value of EESBM (0.03) was found to confirm that the temperature applied removed most of the urease and also was close to the value reported by Karr-Lilenthal et al. 2006 (0.06 to 0.1) and by Blomme et al. 2022 (0.03). The recommended normal urease activity value for properly treated SBM is less than 0.05 pH unit change (Van Eys and Ruiz, 2021) and EESBM simply obeyed this. KOH solubility, PDI and urease activity values for the EESBM sample used in our study showed normal values which indicated appropriate processing. The KOH solubility of the SESBM (83.08 per cent CP) showed higher values than the reported values of 67.7, Park et al. (2002); 63.1 to 81.4, Ravindran et al. (2014). In SESBM, the PDI (16.13) values were higher than the value of 9.6 per cent observed by Park et al. (2002) and lower than the values of 19.5 per cent recorded by Garcia – Rebollar et al. (2016). The urease activity (0.03) value was closer to the values of 0.00 to 0.16 observed by Ravindran et al. (2014) but lower than the reported value of 0.28 by Park et al. (2002). The recommended normal KOH solubility values for the adequately processed SBM samples are between 78 and 85, PDI values between 15 and 30 per cent and urease activity of less than 0.05 PH unit change (Van Eys and Ruiz, 2021). The KOH solubility, PDI and urease activity values for the SESBM fall within the normal range and showed that the SESBM was adequately heat processed. When comparing the results of protein quality parameters of EESBM and SESBM, the KOH solubility was only slightly higher in EESBM (84.16 per cent CP) than in SESBM (83.08 per cent CP). The PDI value of EESBM was only slightly lower (15.5 per cent CP) than the SESBM (16.1 per cent CP) and the Urease activity in terms of pH unit change were found to be similar (0.03).

Fatty acid profile

The fatty acid profile of EESBM and SESBM is presented in Table 2. EESBM showed a lower

stearic acid and higher linolenic acid value of 3.04 and 7.86 per cent than the values of SESBM of 4.22 and 6.34 per cent respectively. However, the palmitic acid, arachidic acid and behenic acid content of 12.24, 0.26 and 0.30 (per cent) of EESBM were lower than the values of 14.30, 0.41 and 0.47 per cent in SESBM. Comprehensive work is scarce concerning the fatty acid composition of EESBM. Nonetheless, this discussion is solely based on the existing values of SESBM. The SESBM was fully oil-extracted ingredient with a low mean oil content of 1.53 ± 0.08 per cent and the fatty acid profile of this small fraction of SESBM was compared with intentionally left out oil content (EE: 6.77 ± 0.30 per cent) in the EESBM. A reduction in saturated fatty acid (SFA) contents with corresponding increase in total unsaturated fatty acid (UFA) was observed in EESBM samples; however, in light of the fact that the SESBM samples had very low leftover oil after solvent extraction, the changes were negligible. The results of 0.12, 14.30, 4.22, 24.22, 6.34, 0.41 and 0.47 per cent of myristic acid, palmitic acid, stearic acid, oleic acid, linolenic acid, arachidic acid and behenic acids in SESBM were higher than the values of 0.04, 3.07, 2.41, 20.90, 5.78, 0.20 and 0.17 per cent reported in soybean cake by Ivanov et al. (2010). However, the linoleic acid content of 49.26 per cent of SESBM was lower than the value of 67.08 per cent recorded by Ivanov et al. (2010). Later, Lee et al. (2013) reported values of myristic acid (0.14), palmitic acid (13.06) and stearic acid (4.08) which were similar to our values of 0.12, 14.30 and 4.22 respectively in SESBM samples. However, oleic acid (24.22) and arachidic acid (0.41) contents of SESBM in the study were found to be higher than the values of 16.19 and 0.19 for the two fatty acids reported in soybean meal (Lee et al., 2013). Further, linoleic acid (55.20) and linolenic acid (10.09) values were higher in their soybean meal than our SESBM (49.26 and 6.34 per cent).

Table 2. Mean (± SE) fatty acid profile (per cent in ether extractives) of SESBM and EESBM

Fatty acid (per cent)	Fatty acid Symbol	SESBM	EESBM	Significance
Myristic acid	C14:0	0.12 ± 0.00	0.11 ± 0.01	0.33
Palmitic acid **	C16:0	14.3 ± 0.14	12.2± 0.10	0.00
Palmitoleic acid	C16:1ω7	0.47 ± 0.17	0.21 ± 0.02	0.17
Stearic acid **	C18:0	4.22 ± 0.25	3.04 ± 0.05	0.001
Oleic acid	C18: 1ω9	24.2 ± 0.30	25.1 ± 0.63	0.20
Linoleic acid	C18: 2ω6	49.2 ± 0.33	50.6 ± 0.68	0.10
Arachidic acid *	C20:0	0.41 ± 0.05	0.26 ± 0.02	0.01
Linolenic acid **	C18: 3ω3	6.34 ± 0.39	7.86 ± 0.20	0.006
Behenic acid **	C22:0	0.47 ± 0.01	0.30 ± 0.02	0.00
Unidentified		0.22 ± 0.01	0.21 ± 0.02	0.85
Total SFA**		19.5± 0.32	15.9 ± 0.12	0.00
Total MUFA		24.7 ± 0.43	25.4 ± 0.63	0.39
Total PUFA**		80.3 ± 0.33	83.8 ± 0.12	0.00
USFA/SFA ratio **		4.12 ± 0.08	5.26 ± 0.05	0.00

Value in each cell is the mean of six observations

** Highly significant (P<0.01)

* Significant (P<0.05)

Note: Extruded and expeller soybean meal (EESBM); solvent-extracted soybean meal (SESBM); saturated fatty acid (SFA); mono-unsaturated fatty acid (MUFA); polyunsaturated fatty acid (PUFA); unsaturated fatty acid (USFA).

CONCLUSION

Based on the chemical composition, high dry matter content (96.1 per cent), high crude protein value (46.4 per cent), high level of ether extract (6.77 per cent) and *in vitro* protein quality values (slightly higher KOH solubility, slightly lower PDI and similar urease activity value) suggest that the EESBM can prove to be a novel feed ingredient replacing SESBM partly or fully. Further reduction in saturated fatty acid content and corresponding increase in total unsaturated fatty acid content in the fatty acid profile of EESBM confirms its superiority over SESBM. Studies are needed to prove its functional value over solvent extracted soybean meal, in biological trials involving broilers and layers.

REFERENCES

AOAC, 2019. Official Methods of Analysis, Association of Official Analytical Chemists, 19th Edn., Washington, D. C, USA.

AOCS, 2017a. Urease activity. Official method Ba 9-58. Official methods and recommended practices of the AOCS. 7th Edn., Urbana, IL: American Oil Chemists' Society.

AOCS, 2017b. Protein Dispersibility Index (PDI). Official method Ba 10b-09. Official methods and recommended practices of the AOCS. 7th Edn., Urbana, IL: American Oil Chemists' Society.

Araba, M. and Dale, N.M. 1990a. Evaluation of protein solubility as an indicator of under processing of soybean meal. Poultry Science. 69(10): 1749-1752.

Blomme, A.K., Wecker, H.K., Tokach, M.D., Woodworth, J.C., Stark, C.R. and Paulk, C.B. 2022. Using caloric efficiency to estimate the net energy value of expelled, extruded soybean meal relative to dehulled, solvent-extracted soybean meal and its effects on growth performance of nursery pigs. Translational Animal Science. 6(1): txac003.

Caskey, Jr, C.D. and Knapp, F.C. 1944. Method for detecting inadequately heated soybean oil meal. Industrial & Engineering Chemistry Analytical Edition. 16(10): 640-641.

García-Rebollar, P., Cámara, L., Lázaro, R.P., Dapoza, C., Pérez-Maldonado, R. and Mateos, G.G. 2016. Influence of the origin of the beans on the chemical composition and nutritive value of commercial soybean meals. Animal Feed Science and Technology. 221: 245-261.

Halver, J.E., Smith, R.R., Tolbert, B.M. and Baker, E.M. 1976. Animal Nutrition. New York Academic Science, 258.

Ivanov, D.S., Leviæ, J.D. and Sredanoviæ, S.A. 2010. Fatty acid composition of various soybean products. Food and Feed Research. 37(2): 65-70.

Jacob, J.P. and Carter, C.A. 2008. Inclusion of buckwheat in organic broiler diets. Journal of Applied Poultry Research. 17(4): .522-528.

Karr-Lilienthal, L.K., Bauer, L.L., Utterback, P.L., Zinn, K.E., Frazier, R.L., Parsons, C.M. and Fahey, G.C. 2006. Chemical composition and nutritional quality of soybean meals prepared by extruder/expeller processing for use in poultry diets. Journal of Agricultural and Food Chemistry. 54(21): 8108-8114.

Kiarie, E.G., Parenteau, I.A., Zhu, C., Ward, N.E. and Cowieson, A.J. 2020. Digestibility of amino acids, energy, and minerals in roasted full-fat soybean and expelled-extruded soybean meal fed to growing pigs without or with multienzyme supplement containing fiber-degrading enzymes, protease, and phytase. Journal of Animal Science. 98(6): skaa174.

Lee, J.W., Kil, D.Y., Keever, B.D., Killefer, J., McKeith, F.K., Sulabo, R.C. and Stein, H.H. 2013. Carcass fat quality of pigs is not improved by adding corn germ, beef tallow, palm kernel oil, or glycerol to finishing diets containing distillers dried grains with solubles. Journal of Animal Science. 91(5): 2426-2437.

Lima, M.F.D., Lima, C.A.R.D., Dilelis, F., Gomes, A.V.D.C. and Freitas, L.W.D. 2018. Metabolizable energy and amino acid digestibility of soybean cake subjected to different dry extrusion temperatures for broilers. Revista Brasileira de Zootecnia. 47: e20180057.

Meyer, M.M. and Bobeck, E.A. 2021. Growth performance of male broilers fed ExPress® soybean meal and high-shear dry extruded corn. Journal of Applied Poultry Research. 30(4): 100191.

Nelson, A.I., Wijeratne, W.B., Yeh, S.W., Wei, T.M. and Wei, L.S. 1987. Dry extrusion as an aid to mechanical expelling of oil from soybeans. Journal of the American Oil Chemists' Society. 64(9): 1341-1347.

Opapeju, F.O., Golian, A., Nyachoti, C.M. and Campbell, L.D. 2006. Amino acid digestibility in dry extruded-expelled soybean meal fed to pigs and poultry. Journal of Animal Science. 84(5): 1130-1137.

Park, Y.H., Kim, H.K., Kim, H.S., Lee, H.S., Shin, I.S. and Whang, K.Y. 2002. Effects of three different soybean meal sources on layer and broiler performance. Asian-australasian Journal of Animal Sciences. 15(2): 254-265.

Parsons, C.M., Hashimoto, K., Wedekind, K.J. and Baker, D.H. 1991. Soybean protein solubility in potassium hydroxide: an *in vitro* test of *in vivo* protein quality. Journal of Animal Science. 69(7): 2918-2924.

Powell, S., Naranjo, V.D., Lauzon, D., Bidner, T.D., Southern, L.L. and Parsons, C.M.. 2011. Evaluation of an expeller-extruded soybean meal for broilers. Journal of Applied Poultry Research. 20(3): 353-360.

Ravindran, V., Abdollahi, M.R. and Bootwalla, S.M. 2014. Nutrient analysis, metabolizable energy, and digestible amino acids of soybean meals of different origins for broilers. Poultry Science. 93(10): 2567-2577.

Sakkas, P., Royer, E., Smith, S., Oikeh, I. and Kyriazakis, I. 2019. Combining alternative processing methods for European soybeans to be used in broiler diets. Animal Feed Science and Technology. 253: 45-55.

Van Eys, J.E. and N. Ruiz, N. 2021. Quality manual and analyses for soybean products in the feed industry, 3rd Edn. USSEC, Chesterfield, MO, USA.

Velayudhan, D.E. 2014. Net energy of dry extruded expelled soybean meal for growing pigs determined by indirect calorimetry and validation of net energy system using a typical western canadian grower finisher diet (Doctoral dissertation, University of Manitoba).

Webster, M.J., Goodband, R.D., Tokach, M.D., Nelssen, J.L., Dritz, S.S., Woodworth, J.C., De La Llata, M. and Said, N.W. 2003. Evaluating processing temperature and feeding value of extruded-expelled soybean meal on nursery and finishing pig growth performance. Journal of Animal Science. 81(8): 2032-2040.

Willis, S. 2003, March. The use of soybean meal and full fat soybean meal by the animal feed industry. In 12th Australian soybean conference. Soy Australia, Bundaberg.

Woodworth, J.C., Tokach, M.D., Goodband, R.D., Nelssen, J.L., O'Quinn, P.R., Knabe, D.A. and Said, N.W. 2001. Apparent ileal digestibility of amino acids and the digestible and metabolizable energy content of dry extruded-expelled soybean meal and its effects on growth performance of pigs. Journal of Animal Science. 79(5): 1280-1287.

Zhang, Y.E., Parsons, C.M., Weingartner, K.E. and Wijeratne, W.B., 1993. Effects of extrusion and expelling on the nutritional quality of conventional and Kunitz trypsin inhibitor-free soybeans. Poultry Science. 72(12): 2299-2308.