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A REVIEW AND META-ANALYSIS OF SELECTED PLANT PROTEIN SOURCES AS A REPLACEMENT OF FISHMEAL IN THE DIET OF TILAPIAS

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Abstract

Numerous studies on the replacement of fishmeal with plant protein sources in tilapias have been undertaken. In order to quantify the effect of replacing fishmeal with plant protein sources on the growth performance of tilapias, a meta-analysis approach was applied. Despite the high heterogeneity and funnel plot asymmetry, the meta-analysis showed that replacing fishmeal with plant protein sources has a significant positive effect on the growth performance of tilapias. Thus, tilapias appear to be preadapted to utilizing plant protein sources. Furthermore, the feed value, nutritional quality and cost of the commonly used plant ingredients (soybean, sunflower, canola, cottonseed, kikuyu and azolla meals) were explored. The Solver function in Excel was used to formulate least-cost diets using the plant meals. Azolla had the highest nutritional index (9.7436). This was attributed to its excellent amino acid profile that exceeded the requirements of tilapias. Nutritional index and feed value were lowest in kikuyu because of its poor amino acid profile as it registered the lowest amino acid index (0.4918). These results indicate that the amino acid profile is more important in the determination of nutritional quality than the percent protein content. Azolla and soybean meal are good candidates for the replacement of fishmeal in the diets of tilapias.

Key words: meta-analysis, fish feed, formulation, growth, essential amino acid index

The cost of fish feed continues to be a major challenge for fish farmers. This is attributed to the ever-increasing cost of fishmeal. Replacement of fishmeal using plant meals, insect meals and other non-conventional sources, is a key research priority (Yigit and Olmez, 2009; Lin and Luo, 2011; Rapatsa and Moyo, 2017). Despite all the efforts, it is only soybean meal and to some extent sunflower meal that have had a significant commercial uptake. Soybean meal is not only cheap but it is highly digestible, has a protein content ranging from 43 to 45%, a good amino acid profile and has high palatability (Lin and Luo, 2011). In most studies, soybean meal could replace fishmeal between 67 and 100% depending on fish species (Soltan et al., 2001; Lin and Luo, 2011; Suloma et al., 2014). However, soybean meal is low in methionine, lysine and cysteine. Like most plant meals, it also has anti-nutritional factors. However, some of the anti-nutritional factors such as trypsin inhibitors are heat liable and can be inactivated by boiling (Chen et al., 2019). The major challenge of boiling is that protein solubility is affected when soybean meal is exposed to heat (Watanabe et al., 2021). Although sunflower meal is cheaper than soybean meal, it has a lower crude protein content that varies from 27 to 37% (Merida et al., 2010) and its amino acid profile is not as good as soybean meal. Sunflower meal also has low levels of sulphur containing amino acids, high fibre and high phenolic compounds, which reduce protein digestibility (Hassaan et al., 2018). Cottonseed meal has also been used to replace fishmeal with limited success. Gossypol is the main anti-nutritional factor in cottonseed (Hassaan et al., 2018). Some studies have also used canola meal to replace fishmeal in fish diets. However, the digestibility of canola meal is affected by prominent anti-nutritional factors, such as glucosinolate, phytic acid and tannins (Mohammadi et al., 2020).

Aquatic plants such as Azolla pinnata have been investigated as potential replacements of fishmeal (Sheeno and Sahu, 2006). However, fish growth declined at replacement levels greater than 25% (El-Sayed, 1992; Sheeno and Sahu, 2006). Leaf meals such as leuceana, papaya and kikuyu have also been investigated as potential ingredients in the replacements of fishmeal (Tiamiyu et al., 2015; Hlophe and Moyo, 2014) and the results were not promising except for kikuyu meal. The utilization of plant protein sources is dependent on the fish species. Predatory fish like salmonids have little capacity to utilize plant protein sources because they lack the requisite enzymes to digest plant-based diets (Desai et al., 2005). Several studies have shown that anti-nutritional factors associated with plant proteins cause gut inflammations in salmonids (Desai et al., 2005). On the other hand, herbivorous fish such as tilapias have the requisite enzymes

to digest plant-based diets. Hlophe et al. (2014) investigated the enzyme profile of tilapias and the opportunistic predatory African catfish and they concluded that tilapias had the requisite enzymes to utilize plant-based protein sources. One unique feature of tilapias is the characteristically low stomach pH that enhances the hydrolyses of plant-based material. In the wild, tilapia is one of the few fish species that can utilize diatoms and this is attributed to the low stomach pH that enhances digestion of the silica-coated cell wall (Teuling et al., 2017).

As indicated above, several studies have been carried out to ascertain the effect of plant-based protein on fish growth. However, to our knowledge, no reviews have been carried out on the effect of plant-based diet on the culture of tilapias. It is important to undertake a meta-analysis of the replacement of fishmeal with plant protein sources in tilapias because of the high aquaculture potential of tilapias and their physiological adaptation to utilizing plant-based protein sources. One of the major hindrances in the expansion of tilapia production in most African countries is the expensive fish feed (Moyo and Rapatsa, 2021). It is therefore prudent to ascertain plants protein sources that can replace fishmeal.

The most readily available plant protein sources that can replace fishmeal in tilapia diets are soybean, sunflower, cottonseed, canola, azolla and kikuyu meals. In this study, least-cost diets using these ingredients will be formulated using a linear algebra software. Furthermore, nutritional characterization along with cost will be used to define the feed value of each plant meal. The concept of feed value is important as it incorporates nutritional quality, cost and availability (Rapatsa and Moyo, 2022). Most studies in fish nutrition focused on nutritional characterization and this does not give a true reflection of the feed value of the ingredients. This study will explore the concept of feed value. However, availability will not be considered because the plant ingredients are deemed to be readily available in South Africa. The specific objectives of this study were (i) to undertake a meta-analysis on the effects of replacing fishmeal with plant protein sources on growth performance of tilapias, (ii) to characterize the nutritional quality and feed value of selected plant meals and (iii) to formulate least-cost diets using selected plant meals.

Material and methods

Nutritional quality of plant diets

The nutritional value of soybean, sunflower, canola and cottonseed (seed meals), kikuyu (leaf meal) and azolla (aquatic plant meal) was determined using data from the literature. Crude protein, lipids, carbohydrates and ash of each of these plants were recorded. The essential amino acid index of each plant was determined using Penaflorida (1989) formula given below:

$$EAAI = \sqrt[n]{\frac{aa1}{AA1} \times \frac{aa2}{AA2} \times \ldots \ldots \frac{aan}{AAn}}$$

where *aa* is the amount of amino acid in the insect ingredient, *AA* is the requirement of the same amino acid in fish tissue, and *n* is the total number of amino acids used in the calculation. Thus, the *EAAI* is a ratio between the concentration of amino acid in the ingredient and the requirement of the fish for the amino acid.

The nutritional value of the plant ingredients was determined as follows:

$$Ni = 2P_i + 4EAAI_i + A_i + EE_i$$

where: P_i is the proportion of protein in the ingredient; $EAAI_i$ is the essential amino acid index of the ingredient, A_i is the ash content of the ingredient and EE_i is the ether extract of the ingredient.

The plant ingredients were ranked according to feed value. The feed value was calculated using the formula below:

$$Feed\ value\ index = 2N_i + C_i$$

where N_i is the nutritional index and C_i is the cost of the plant ingredient.

Meta-analysis of the effects of plant meal on the growth of tilapias

Meta-analysis was carried out to determine the effect of replacing fishmeal with soybean, sunflower, cottonseed, canola, kikuyu and azolla meals. A systematic literature search using Google Scholar, Science Direct, Scopus, Microsoft Academic, BASE, CORE, and semantic scholar on the incorporation of plant-based protein in the diets of tilapias was undertaken and is summarized by the flow chart (Figure 1). The keywords used were tilapia, fish diet, growth rate and plant proteins. The following criteria were used to select papers:

(i) Studies with a control (fishmeal) and fish fed to satiation

(ii) Studies with experimental diets using plant-based meals as a replacement for fishmeal

(iii) Studies where there is random allocation of test ingredients to animals

(iv) Studies that use tilapia species

(v) Papers that are written in English

(vi) Studies that determined specific growth rate (SGR) and feed conversion ratio (FCR) or both indices could be calculated from given data. The SGR and FCR had to have standard deviation or standard error or data to calculate them. Based on these criteria only 8 papers were selected (Figure 1).

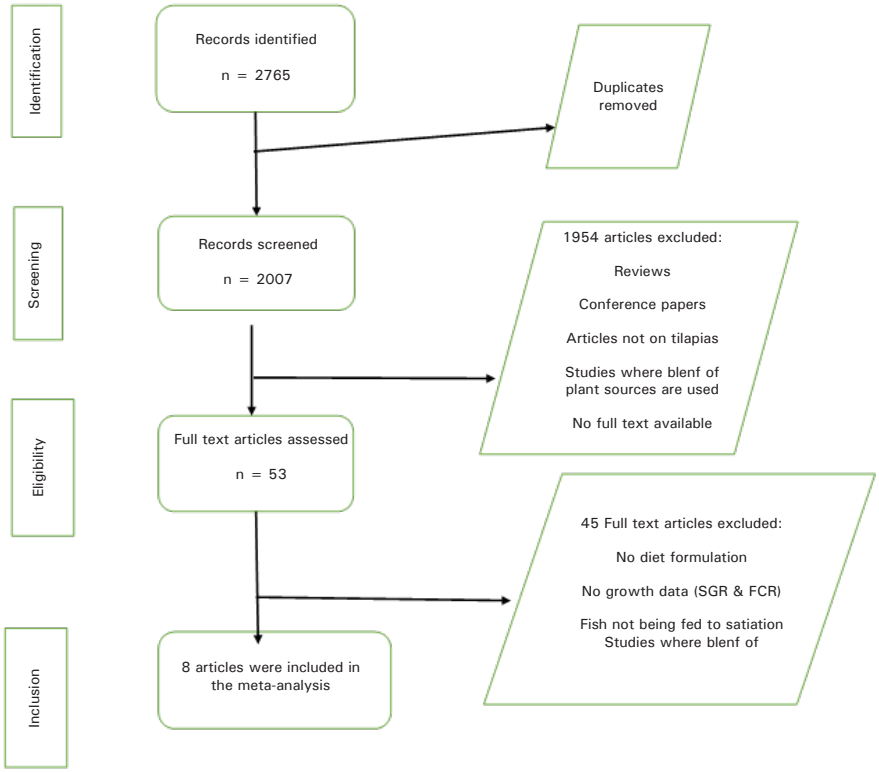


Figure 1. Schematic diagram on selection of articles used for meta-analysis

The data extracted from each individual study was type of tilapia species, test ingredient type, inclusion level, SGR, FCR and standard deviations (Table 4). The mean effect size was determined for the two responses (SGR and FCR). This was done following the random effects approach using R program version 4.1.1. Comparisons of the different studies were done by calculating the response ratio (Borenstein et al., 2009). The response ratio was calculated by dividing the growth parameters of the experimental group and the control group. This shows the proportionate change resulting from experimental manipulation. For all the SGR reported the following formula was used:

$$SGR = 100 \times \frac{ln\, W_t - ln\, W_0}{t}$$

where W_t = final body weight (g); W_0 = initial body weight; *ln* = natural logarithm; t = feeding period (days). For FCR the following formula was used:

$$FCR = \frac{feed\ consumed\ (g)}{weight\ gain\ (g)}$$

The standardized differences between the means of the experimental and control groups were determined using Hedges "g". Heterogeneity was taken into account using the random effects model to calculate the summary statistics. Linear regression analysis of replacement levels on Hedges "g" was carried out. The heterogeneity between studies was estimated as I^2 as previously described by Harrer et al. (2021).

Funnel plots were plotted in order to determine publication bias. Publication bias was also determined using the Eggers test in R version 4.1.1. Egger's test is based on the funnel plots which use the graph of estimates of each trial vs sample size to detect publication bias by examining asymmetry.

Formulating least-cost diets for tilapia farmers

Least-cost plant diets were formulated for sub-adult tilapias in Excel using the SOLVER function as described by Rapatsa and Moyo (2022). The plant ingredients, their cost, crude protein and metabolizable energy were listed as a database. The feeds were balanced for protein and energy. In the SOLVER function the cost US$/kg was selected as the target cell and the optimum diet was produced.

Ethical Statement

In this paper, no fish was handled. The data is based on published papers.

Results

Among the plant diets, soybean meal had the highest crude protein content of 48% (Table 1). Azolla meal had the lowest crude protein content of 23.2%. Sunflower

and kikuyu meals had high fibre content of 23.63 and 18.58%, respectively (Table 1). Azolla and kikuyu meals registered the highest ether extract of 4.4 and 4.38%, respectively. However, these are low in comparison to 10.7% found in fishmeal. Azolla and kikuyu meals also had the highest ash content but the ash content level was below that of fishmeal.

All the amino acids in azolla meal exceeded the requirements of tilapias (Table 2). Its essential amino acid index is higher than that of fishmeal. In comparison, soybean meal amino acid content is below the requirements for tilapias, except for histidine and leucine. However, despite soybean meal amino acid limitations it had the second highest EAAI among the plant meals (Table 2). The amino acid index of kikuyu meal was the lowest among the plant meals.

Azolla meal has the highest nutritional index and feed value (Table 3), both of which exceeded fishmeal. Soybean meal has the second highest nutritional index and feed value among the plant diets. Kikuyu meal has the lowest nutritional index and feed value among the plant diets. Thus the feed value can be ranked in ascending order as azolla meal> soybean meal> cottonseed meal> canola seed meal> sunflower meal> kikuyu meal.

The meta-analysis showed that replacing fishmeal with plant protein sources has a significant effect on the SGR of tilapias (Figure 2 A). The overall mean effect size was –2.44 (95% CI: –3.80; –1.09). Heterogeneity was significantly high ($P<0.001$) with an I^2 index of 99%. This indicates significant differences between studies. The slope of linear regression of replacement level on effect size was negative (Figure 3). Feeding tilapias at more than 20% replacement level decreased effect size. Only two studies showed that replacing fishmeal with plant meal has an effect on FCR in tilapias (Figure 2 B). The overall effect size was 3.12 (95% CI: 1.53; 4.72). Heterogeneity was significantly high ($P<0.01$) with I^2 at 99%. I^2 above 50% indicates little homogeneity in the studies. Overall, the meta-analysis showed that replacement of fishmeal with plant meal did not affect FCR. The funnel plot for SGR also showed publication bias (Figure 4 A). However, the Egger's test was negative for SGR (95% CI [–18.5– –1]; $P = 0.038$). FCR funnel plot was asymmetrical (Figure 4 B) and this probably indicates publication bias. Egger's test was positive (95% CI [6.38–20.92]; $P= 0.001$) and this again shows that the results may be influenced by publication bias.

Table 5 shows the resultant least-cost formulation using the Solver function for different plant meals. The inclusion levels ranged from 18.96% for kikuyu meal to 46.38% for sunflower meal (Table 5). Soybean and sunflower meals registered the least cost. The cost reduction for both of them was 35% when compared to fishmeal (control) diet. The cost reduction for azolla meal was 12.8%.

Table 1. Source of proximate composition (%) of plant meals and fishmeal used in feed value determination

Components	Fishmeal[1]	Azolla meal[2]	Kikuyu meal[3]	Cotton seed meal[4]	Canola seed meal[4]	Sunflower meal[4]	Soybean meal[5]
Crude protein	65.5	23.2	26.84	41	38	34.98	48
Crude fibre	12.0	11.77	18.58	13.6	12	23.63	6.5
Ether extract	10.7	4.4	4.38	2.0	1.5	1.19	0.6
Ash	18	11.2	9.5	7.0	7.2	6.95	6.0

[1]Rapatsa and Moyo (2017); [2]Leterme et al. (2009); [3]Hlophe and Moyo (2014): [4]Nwokolo et al. (1976); [5]Merida et al. (2010).

Table 2. Source of essential amino acids (g/100 g) profile of plant meals and fishmeal used for EAAI determination

	Fishmeal[1]	Azolla meal[2]	Kikuyu meal[3]	Cotton seed meal[4]	Canola seed meal[4]	Sunflower meal[4]	Soybean meal[5]	Tilapia requirements[6]
Methionine	1.5	1.7	0.45	0.70	0.84	0.58	0.75	0.4
Valine	3.1	6.2	1.56	2.48	0.75	1.87	1.02	0.88
Isoleucine	2.6	4.8	1.12	1.22	1.30	1.66	1.92	0.80
Leucine	4.5	9.4	2.33	2.85	2.57	2.38	3.71	1.35
Phenylalanine	2.9	5.5	1.34	2.48	1.49	2.28	2.44	1.00
Histidine	1.4	2.6	0.51	1.37	0.98	1.07	1.23	0.42
Lysine	4.8	5.3	1.42	2.19	2.08	1.06	2.95	1.51
Threonine	2.5	5.3	0.93	1.51	1.48	1.43	1.88	1.71
Tryptophan	3.4	1.5	–	–	–	–	–	–
Essential Amino Acid Index (EAAI)	**1.5729**	**2.2809**	**0.4918**	**0.7671**	**0.6866**	**0.6468**	**0.9050**	

[1]Rapatsa and Moyo (2017); [2]Leterme et al. (2009); [3]Hlophe and Moyo (2014): [4]Nwokolo et al. (1976); [5]Merida et al. (2010), [6]Jauncey et al. (1983).

Table 3. Nutritional index, cost and feed value of readily available plant meals in South Africa

Ingredients	Nutritional index	Cost ($/kg)	Feed value
Fishmeal	7.8886	1.49	17.2672
Azolla meal	9.7436	0.10	19.5872
Kikuyu meal	2.6356	0.10	5.3712
Cotton seed meal	3.9784	0.27	8.2268
Canola seed meal	3.5934	0.38	7.5668
Sunflower meal	3.3682	0.35	7.0864
Soybean meal	4.646	0.92	10.212

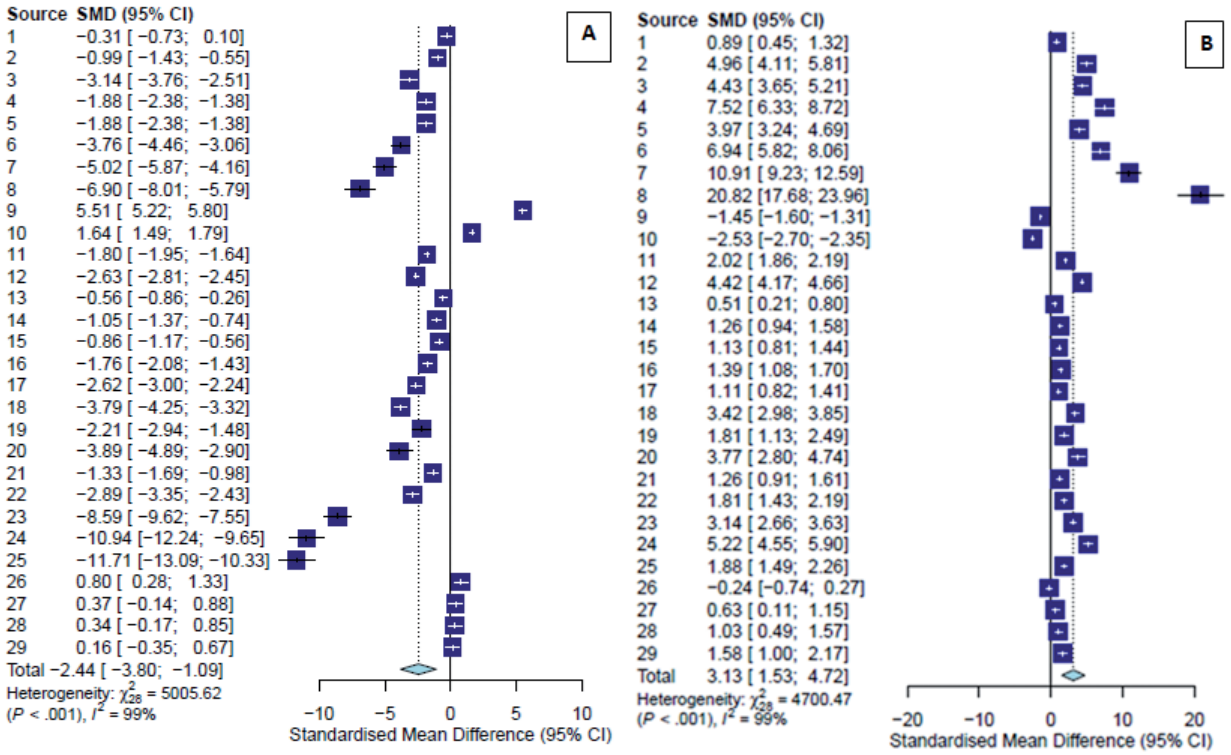


Figure 2. SGR (A) and FCR (B) forest plots of the meta-analysis of trials on the effects of plant meals in tilapia diets

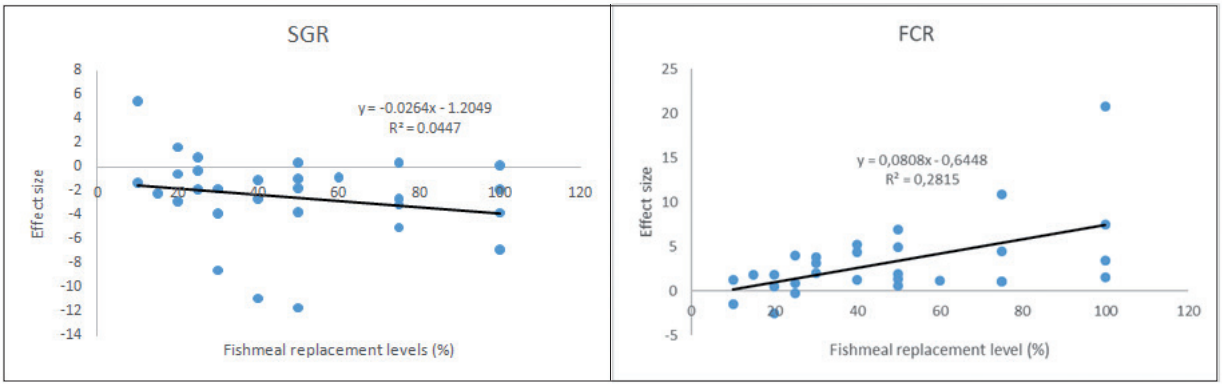


Figure 3. The relationship between effect size (SGR and FCR) and fishmeal replacement levels using plant meals in tilapia diets

Table 4. Source of data used for meta-analysis consisting of 8 published articles

Author	Fish species	Fish size (g)	Plant species (plant meals)	% replacement level of fishmeal	SGR ± SD	FCR ± SD
Hlophe and Moyo, 2014	*Tilapia rendalli*	11.5	*Pennisetum cladestimum* (kikuyu meal)	0, 25, 50, 75, 100	2.1±0.2, 2±0.4, 1.9±0.2, 1.6±0.1, 1.5±0.4	1.6±0.1, 1.8±0.3, 2.1±0.1, 2.6±0.3, 2.8±0.2
Hlophe and Moyo, 2014	*Tilapia rendalli*	11.5	*Moringa oleifera* (moringa meal)	0, 25, 50, 75, 100	2.1±0.2, 1.8±0.1, 1.5±0.1, 1.3±0.1, 1±0.1	1.6±0.1, 2±0.1, 2.3±0.1, 2.7±0.1, 3.7±0.1
Yildrim et al., 2014	*Oreochromis mossambicus*	0.8	*Arachis hypogaea* (peanut meal)	0, 10, 20, 30, 40	2.88±0.10, 3.36±0.04, 3.15±0.21, 2.64±0.16, 2.43±0.22	1.48±0.04, 1.35±0.12, 1.40±0.02, 2.17±0.48, 2.83±0.43
Krome et al., 2014	*Oreochromis niloticus*	10-15	*Jatropha curcas* (kernel meal)	0, 50, 75, 100	2.29±0.04, 2.06±0.18, 2.14±0.07, 1.95±0.12	1.08±0.02, 1.20±0.12, 1.13±0.06, 1.28±0.08
Yigit and Olmez, 2009	*Oreochromis niloticus*	1.2	*Brassica napus* (canola meal)	0, 10, 20, 30, 40, 50	1.65±0.02, 1.59±0.06, 1.52±0.06, 1.43±0.03, 1.43±0.02, 1.35±0.03	2.01±0.06, 2.13±0.12, 2.16±0.10, 2.29±0.11, 2.30±0.05, 2.55±0.11
Yousif et al., 2019	*Oreochromis niloticus*	3	*Ipomoea aquatica* (water spinach)	0, 25, 50, 75, 100	4.66±1.30, 5.44±0.38, 5.19±1.49, 4.98±0.29, 4.83±0.73	2.05±0.50, 1.96±0.18, 2.28±0.08, 2.47±0.27, 3.10±0.78
Meric et al., 2011	*Oreochromis niloticus*	63.8	*Gossypium* spp. (cotton seed meal cake)	0, 15, 30	0.83±0.04, 0.74±0.04, 0.69±0.03	1.48±0.06, 1.61±0.08, 1.73±0.07
Ahmad et al., 2020	*Oreochromis niloticus*	15.58	*Glycine max* (soybean meal)	0, 20, 40, 60	2.04±0.038, 1.96±0.197, 1.89±0.197, 1.72±0.52	2.21±0.12, 2.34±0.34, 2.55±0.36, 2.81±0.74

Table 5. Software predicted nutritional composition (% DM) and cost ($/kg) of formulated feeds (% plant inclusion)

Component	Control (FM)	Azolla meal	Kikuyu meal	Cotton seed meal	Canola seed meal	Sunflower meal	Soybean meal
Maize	25.14	42.29	43.07	34.46	43.76	32.28	42.99
Fishmeal	41.62	33.18	32.97	24.20	23.19	16.34	12.07
Plant meal	0	19.54	18.96	36.34	28.04	46.38	39.95
Oil	1	1	1	1	1	1	1
Vitamin premix	2	2	2	2	2	2	1
Binder	2	2	2	2	2	2	2
Total	100	100	100	100	100	100	100
CP	30	30	30	30	30	30	30
ME (MJ/kg)	12.91	12.04	12.01	12.10	12.01	12.11	12.36
Cost ($/kg)	0.78	0.68	0.66	0.61	0.60	0.51	0.51

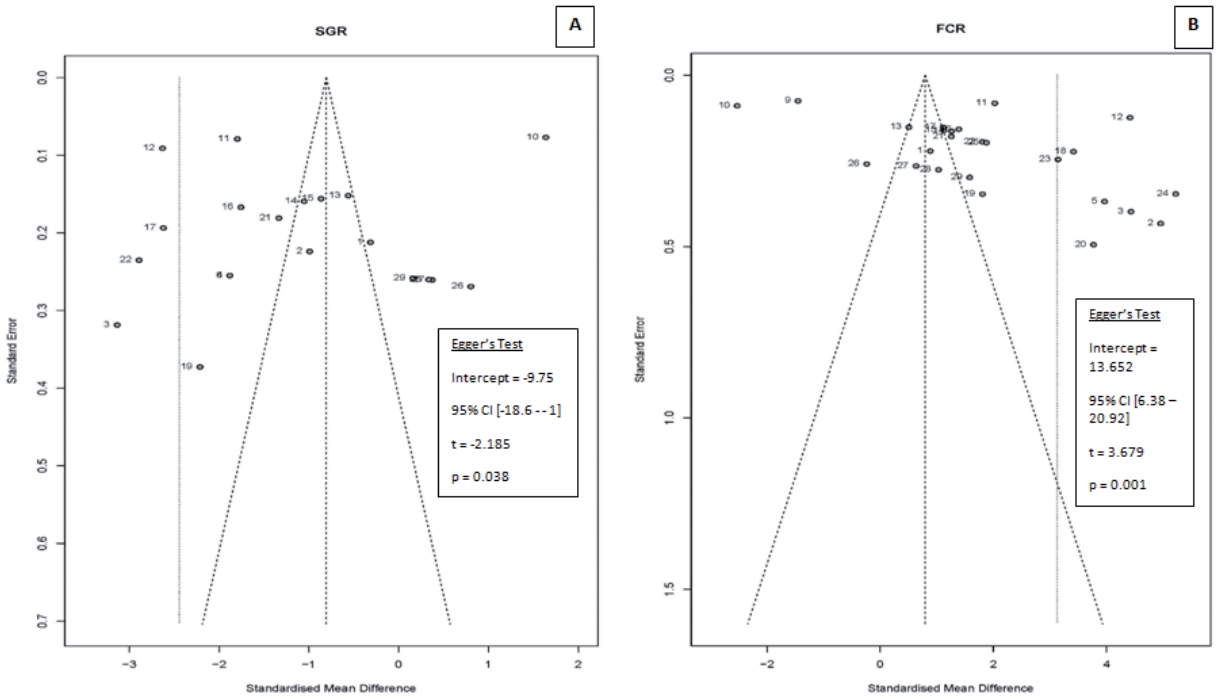


Figure 4. SGR (A) and FCR (B) funnel plots showing publication bias in articles used for meta-analysis

Discussion

The estimated protein requirement for tilapias is between 30 and 45% depending on the size of the fish (El-Sayed and Tashima, 1992). Soybean, sunflower, cottonseed and canola seed meals evidently meet the protein requirements of tilapias. Soybean meal has extensively been used in the formulation of tilapia diets more than any of the other plants (Shiau et al., 1990; Soltan et al., 2001; Merida et al., 2010; Ahmad et al., 2020). Phytate, tannins and trypsin inhibitors are some of the common anti-nutritional factors found in soybean meal. The application of heat has been suggested as one of the ways to get rid of anti-nutritional factors in soybean meal, but not all anti-nutritional factors are heat liable (Ranjan et al., 2019). Sunflower meal has lower sulphur containing amino acids compared to soybean meal. Sunflower meal is high in fibre and phenolic compounds, both of which reduce protein solubility. However, despite its limitations sunflower meal is cheaper than soybean meal. The main anti-nutritional factor in cotton seed meal is gossypol (Lim and Lee, 2011). This is a phenolic aldehyde that acts as an inhibitor for several dehydrogenase enzymes. The amino acid profile of cottonseed meal is not good because none of the sulphur containing amino acids meet the requirement of tilapias. Cottonseed meal is generally less expensive per unit of protein than soybean meal and is highly palatable. Canola meal has a relatively high protein content compared to other oilseed meals except for soybean meal. However, its amino acid profile is poor because very few of the essential amino acids meet the requirements for tilapias. The main limitation of using canola meal is its high glucosinolates (GLS), phenolic compounds, phytate and fibre (Khajali and Slominski, 2012). Canola meal's nutritive value is also dependent on the oil extraction and processing method. From a nutritional perspective, the plant ingredients were ranked as azolla meal> soybean meal> cottonseed meal> canola seed meal> sunflower meal> kikuyu meal.

A good amino acid profile appears to be an important factor in the formulation of tilapia diets (El-Sayed and Tashima, 1992). In this study, azolla meal despite its low protein content, had the highest EAAI, followed by soybean meal. Studies that have evaluated the effect of azolla meal inclusion in animal feed have shown that it is a promising ingredient in the replacement of fishmeal. Abou et al. (2007) indicated that azolla meal could be incorporated into tilapia diets up to 30% without adversely affecting fish growth. Azolla meal also has a good profile of EPA and DHA fatty acids and this may enhance fish growth. Two anti-nutritional factors associated with azolla meal are phytate and tannin and these compromise fish growth at higher inclusion levels. Kikuyu meal has a higher protein content than azolla meal but its EAAI was the lowest of all plant ingredients. Its crude fibre is also very high. Hlophe and Moyo (2014) identified a number of anti-nutritional factors in kikuyu meal such as phytate, saponins and tannins. They improved the digestibility of kikuyu meal by adding Natuzyme in the formulated kikuyu diets (Hlophe et al., 2016).

Azolla meal had the highest feed value. This is because of its high nutritional index. Azolla meal is also a relatively cheap ingredient. The concept of feed value incorporates nutritional value, cost and abundance. Abundance was not determined in this study because plant ingredients are generally assumed to be ubiquitous. Thus, in this paper feed value was based on two components, nutritional quality and cost. The excellent amino acid profile of azolla meal accounts for its high feed value. Kikuyu meal had the lowest feed value. This is consistent with its poor nutritional quality. However, it is relatively cheap. Kikuyu meal also has high fibre content and this may mitigate against its wide use as a replacement of fishmeal, unless Natuzyme is added in the formulating of kikuyu meal diet. Alternatively, pretreatment of kikuyu like boiling may improve its digestibility (Hlophe and Moyo, 2014). Soybean meal had the second highest feed value after azolla meal. This again can be explained by its very good amino acid profile. However, because of increased commercialization, soybean meal is becoming expensive. There are marginal differences in the feed value of cottonseed, canola seed and sunflower meals. Some measures of pre-treatment may improve the digestibility of these three ingredients.

Least-cost diet formulation optimizes the combination of feed ingredients that supply the required levels of nutrients at the lowest cost. This is important because fish feed accounts for more than 60% of the production costs in aquaculture (Fiedler et al., 2016). The use of Solver in feed formulation in this paper has the following advantages:

– user can choose the ingredients to work with,
– user can vary the chemical composition,
– user can fix the inclusion level,
– user can change ingredient cost,
– user can carry out diet formulations as many times as necessary.

The flexibility of the Solver formulated diets is a big advantage over software packages that are already pre-programmed. In this regard, rural fish farmers who have access to azolla, kikuyu, cottonseed, canola, sunflower and soybean can formulate their own tilapia diets at their farms. In this paper, six plants were incorporated to achieve 30% crude protein and 12 MJ/kg dry matter of metabolizable energy in the tilapia diet. These diets represent the normal diet that is given to sub-adult tilapias. The Solver function was able to converge a solution because of the fairly good quality of the plant diets. This suggests that all the selected ingredients can be used to replace fishmeal although they are ranked differently. The inclusion levels ranged from 18.96% for kikuyu meal to 46.38% for sunflower meal. The cost reduction was highest in soybean and sunflower meals and this is because of their high protein content. The use of Solver in the formulation of tilapia diets is strongly recommended for tilapia fish farmers who have access to computers. This will give them greater control of the quality of feed that they give to the fish. Profit margins are likely to improve when the tilapia farmers formulate their own feed because they will be using locally available resources, which will be cheaper as they exclude transport costs.

A number of studies have investigated the effect of plant diets on tilapias (El-Sayed and Tashima, 1992; El-Sayed, 2003; Abou et al., 2007; Yang et al., 2013; Maas et al., 2020). However, there is no consensus on the effect of replacing fishmeal with plant meals in tilapias. The major challenge is that the studies used different methodologies to assess different plant diets. Furthermore, the use of the control and the inclusion levels also vary, as well as the way growth is depicted. Some studies use average daily gain, specific growth rate and thermal growth coefficient. The most popular way of reporting growth is specific growth rate and feed conversion ratio, and these were adopted in this study. The forest plot showed that plant ingredients have a positive effect on the specific growth rate of tilapias. This is primarily because tilapias are herbivorous and physiologically adapted to utilizing plant-based diets. They have brush-like teeth that can triturate the plant material. The plant material is further hydrolyzed by the acid produced in the stomach of tilapias. Tilapias also have requisite enzymes to break down plant material in the stomach and intestines (Buddington, 1979; Gominho-Rosa et al., 2015; Maas et al., 2020). The relationship between fishmeal replacement levels and effect size showed that at high inclusion levels effect size declines. This is because of the anti-nutritional factors that are found in most plant diets. Even the most promising ingredients, namely, azolla, soybean and sunflower meals have anti-nutritional factors. It has been suggested that the anti-nutritional factors in soybean meal can be inactivated through boiling (Yang et al., 2013; Chen et al., 2019). However, heat application is likely to destroy heat-liable vitamins and amino acids, e.g. lysine and cysteine become unavailable at high temperatures (He et al., 2017). Overall, the plant ingredients did not affect FCR. However, the effect size against fishmeal replacement plot showed that effect size increased with fishmeal replacement. This shows that FCR increased at higher fishmeal replacement levels. This is consistent with our previous observations on SGR. It must however be stressed that heterogeneity was very high for the meta-analysis of both SGR and FCR. The funnel plots showed publication bias for both SGR and FCR. However, it must be noted that the asymmetry observed in the funnel plots may of necessity not be due to publication bias. Page et al. (2021) recently highlighted the limitations associated with the interpretation of funnel plots. In this study, asymmetry might have been caused by dissemination bias, the existence of true heterogeneity and possibly change.

Conclusion

Soybean meal has the highest protein content and the second highest essential amino acid index. However, it does not meet all the amino acid requirements of tilapias. Azolla meal had lower protein content, yet it met all the

amino acid requirement of tilapias. Feed value was highest in azolla meal, this is largely because of its good amino acid profile. However, the Solver software predicted that azolla meal diet was expensive. Azolla meal's high feed value is not reflected in the diet formulation because fish diets were formulated based on protein and energy levels. Soybean and sunflower meals had the lowest fishmeal inclusion levels and were consequently the cheapest diets. Meta-analysis showed that the plant ingredients have a positive effect on the growth performance of tilapias. It is recommended that local tilapia farmers formulate their own diets at their farms using local ingredients described in this paper. Furthermore, it is recommended that a more detailed investigation on meta-analysis be undertaken using sensitivity analysis techniques.

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