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Review Article
Potential of Corn Oil as Alternative Dietary Lipid Source in Aquaculture Feeds

[1]Andrews Apraku, [1,2,3]Xuxiong Huang, [2]Christian Larbi Ayisi and [1]Abdullateef Yusuf

[1]Center for Research on Environmental Ecology and Fish Nutrition, Ministry of Agriculture, Shanghai Ocean University, 201306 Shanghai, China
[2]Shanghai Engineering Research Center of Aquaculture, Shanghai 201306, China
[3]National Demonstration Center for Experimental Fisheries Science Education, Shanghai Ocean University, Shanghai 201306, China

Abstract
Dietary lipids play an essential role in the development and growth of the aquaculture industry. They are the basic source of energy and essential fatty acids to produce the final products in this sector. The increase in demand for high value fishery products and competition from other industries has exerted much pressure on the main dietary ingredients for fish. This has called for the search of alternative measures to be employed in replacing this resource. However, this replacement has come with its complications on some nutrient deficiencies which still leaves a gap open to fill with other alternatives whereas, other sources have not been deeply explored. This study presents work overview on corn oil as a potential dietary lipid source to replacing dietary fish oil in aquafeeds. On-going studies and trends in corn oil use and production has been briefly discussed, coupled with its qualities compared to other oil sources, availability and cost effectiveness. The review concludes that, corn oil does not impair growth when used in diets for some species. Its possession of vitamin E and strong antioxidant properties makes it essential to packaging and storage whiles digestibility and immune systems of consumers are boosted with this oil. Much has not been researched into this oil as other alternative lipids and as such a detailed study to explore its full potential will practically impact the aquaculture sector and contribute to its growth and development and also for consumers welfare.

Key words: Aquafeeds, dietary lipids, antioxidants, polyunsaturated fatty acids, vitamin E

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Corresponding Author: Xuxiong Huang, Center for Research on Environmental Ecology and Fish Nutrition, Ministry of Agriculture, Shanghai Ocean University, 201306 Shanghai, China Tel/Fax: 0086 156 9216 5253

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INTRODUCTION

The nutritional value and higher cost coupled with environmental impacts and effects to consumers have made fish feed one of the most important services which requires constant attention for improvement [1]. However, the traditional resources which make up the feed almost have been fully explored and limited and facing constant competition from other sectors which also use the resource. Not only does this limit the supply, but an increased in demand for fish food and the quality it presents counts.

A progress in fish feed production is noted to be the key to driving the expansion of the aquaculture industry in the near future[2]. More than 50% of the cost of production in the aquaculture sector is fish feed (fish oil and meal) of which is made up of approximately forty essential nutrients such as fatty acids, amino acids, vitamins and minerals[3].

As such, the aquaculture industry has been looking for suitable alternatives to substitute the basic components of the feed to provide the required nutrients with a cheaper cost as well as reduce the pressure on fishery resources. While looking at replacing these ingredients, their sustainability must also be considered to ensure its continuity in production and also their impact on the environment and cost effectiveness.

In an attempt to reduce the pressure on fish oil over the past years, vegetable oils have been the most researched oil in the aquaculture sector with some breakthroughs reported[4]. The better economic value, availability and steady increase in production of the vegetable oils makes it a viable option to replace fish oil if it meets or has the nutritional properties required[5]. Vegetable oils such as soybean, rapeseed, palm, linseed, olive and sunflower oils have commonly been incorporated in fish feeds[6]. Although, there are other sources of oils which has not been really explored much such as coconut oil, corn oil and others. It is deemed from authors view point that, these lipids also be studied and investigated since they also possess some qualities and properties worth investigating.

This brief outlines the status of corn oil as a viable alternative source to replace dietary fish oil in aquaculture. Results published and overview of the methods used in its production as well as further discussing the physicochemical properties, anti-oxidant activity and phenolic contents and authentication studies.

QUALITIES OF CORN OIL

Upon refining, it is tasteless and odorless oil which is mostly used in producing hydrogenated oils and in cooking medium[7]. Corn oil presents its uniqueness as a highly dense PUFA (essential FA) oil with low levels of saturated FAs and linolenic acid[8] coupled with a pleasing flavor.

The high content of the essential PUFA is noted to meet the requirements in human nutrition. Linolenic acid (18:2) contributed 60% of the PUFA whiles 24% is made of MUFA (Oleic acid, 18:1). About 15% of palmitic acid (16:0) and stearic acid (18:0) at 1% makes up the saturated FA of corn oil[7,9]. Fatty acids that are needed for a better growth and nutrition and cannot be biosynthesize by the body and are necessary to be incorporated in diets are the essential FAs. As such, corn oil presents a good option for this need. The essential FAs are necessary for the skin regeneration, boosting the immune system and membrane cells functioning. It helps in the synthesis of eicosanoids which aids in renal, cardiovascular, reproductive process and also gastrointestinal functions and disease resistance.

Furthermore, they are highly effective for primary low LDL-cholesterol and also low serum cholesterol whiles also being a high source of energy and aiding in digestion[7]. Corn oil is documented to provide 9 kCal (38 kjoules/g) and it is an oil which is digested and absorbed by at least 97% in both human and other animals[10].

A refined corn oil (high oil) is deemed to present nutrient rich properties in the form of higher levels of balanced essential amino acids like lysine, threonine and methionine. This high corn oil is also an excellent source of vitamin E and antioxidant (tocopherols). One of the highest levels of phytosterols in vegetable oils is obtained from this cereal which serves as a good indicator to reducing blood cholesterol and thereby inhibiting it absorption in the intestine whereas, its antioxidant properties also retards rancidity[7,9]. Amongst all vegetable oils, three phytonutrients which are phytostanol ester, phytosterol ester and free phytosterol occurs naturally at a time in only corn oil[7]. Table 1 indicated the qualities of corn oil amongst others.

Upon reversed phased HPLC techniques as reported by Moreau[9], corn oil was found to possess 19-27 individual molecular species of triacylglycerol of which the two most abundant presented were linoleate-linoleate-linoleate and oleate-linoleate-linoleate[11]. Tocopherols are recognized as abundant in corn oil of which γ-tocopherol is deemed superior to α-tocopherol due to its ability to delay the formation of thrombus and prevent oxidation of LDL although the later comes with higher levels of vitamin E which is good indicator to resist disease susceptibility. Tocopherols has also been reported by Wang *et al.*[12], to be in significant levels in the corn oil. This also provides valuable antioxidant properties and

Table 1: Comparing the features of important edible oils in summary

Parameters	Corn oil	Canola	Sunflower	Olive	Sunflower	Soybean	Rice Bran	Mustard oil
Total oil content	3-4%	43%	45%	30%	30-40%	20%	3%	34%
Temperature/ melting point	Medium 457°F	Medium 45°F and not to be used at high temperature	High 475°F	375-468°F (depending on type and not advisable to use at higher temperature)	High 509°F	High 440°F	High 490°F	High 489°F
Vitamins/minerals (ppm)	Vitamin C, highest in antioxidants	Vitamin A, D, E, K, Omega-3, beta-carotene	Vitamin E (highest), Omega-6	Antioxidants Omega-6Cis-linoleic	Vitamin E, vitamin E	Omega-3, nutraceutical,	Vitamin E, squalence, essential gamma-oryzanol	Antioxidants, vitamins
Fats MUFA/Oleic	25%	61%	20%	77%	13%	24%	47%	60%
PUFA/Linoleic acid	62%	33%	69%	9%	77%	61%	33%	21%
Saturated fats/SFA	13%	7%	11%	14%	10%	15%	20%	13%
SFA:MUFA:PUFA	13:25:62 (High PUFA)	6:62:32 (Low SFA)	9:82:9 (High Oleic), 9:65:26 (regular), 11; 20: 69 (linoleic)	14: 77: 8, 1-Omega 3 (Highest MUFA)	9:13:78 (High PUFA)	15:24:58, 3-Omega 3	22:43:35 (High MUFA)	3: 65: 25, 7-Omega 3
Digestibility	High	Slows digestion	Improves apparent digestibility of MUFA and PUFA but reduces their retentions	Good at high temperatures	Good	Low	Easily digested	Stimulates digestion
Color	Golden, yellow, reddish, shade	Light yellow	Pale, transparent, yellow	Yellow or greener (in pure state)	Pale yellow	Water-like or light yellow	Light golden	Yellow
Taste/aroma	Tasteless	Mild flavor	Flavor when having high oleic, no flavor when regular	Strong flavor	Odorless	Low odor	Pleasant nutty and buttery taste	Pungent taste and spicy odor
Viscosity/oil density	Low	Slightly thicker	Low			Slightly	Light	
Uses	Frying, baking, salad, dressing, margarine, shortening	Frying, baking, salad, dressing, margarine, shortening	Cooking, salad, dressing, margarine, shortening	Sautee, stir, frying, cooking, salad oils, margarine	Cooking, salad, dressing, margarine	Cooking, salad, dressing, vegetable oil, margarine	Cooking, frying, deep frying, salad	Cooking, frying, deep frying, salad
Benefits	Easy to digest Beneficial to healthy heart Reduces risk of chronic diseases	Lower risk of heart disease and cancer	Lower bad cholesterol levels	Influences body fat distribution and reduces diabetes and cancer as well as heart diseases	Contributes to weight loss and lower cholesterol levels Strengthen immunity and helps in diabetes treatment and promotes hair growth with a healthy skin	Reduces cancer cell activity. Lower cholesterol and control osteoporosis and blood sugar level. Cheap	No cholesterol and trans fatty acids and low in SFAs. Rich in oleic and linoleic fatty acids	Used as an antibacterial oil. Protects teeth from germs and helps in preventing cancer and slows down ageing
Additional	Recommender by the American Health Commission (AHC). Retains 100% taste of food	Approved as healthiest oil by many associations (American diabetic Association and American Heart Association)	Retain moisture in skin and resist infection in infants	Longer storage life and healthiest when cooked	Does not get solidified when chilled and can be used in both states	Contains natural antioxidants which remain in oil even after	Recommended by the American Heart Association	Keeps the body warm and used as irritant to stimulate sensations and driving up muscles

Source: Adopted and redrawn from: Rajendran *et al.*[7]

mostly believed to have limiting effect on cholesterol biosynthesis[13]. Zeaxanthin and lutein are the most abundant carotenoids reported[9]. Sommerburg *et al.*[14] documented the effect of carotenoids as one related to decreasing the risk for age-related muscular degeneration when consumed or incorporated in diets.

Availability: There is high unit production in corn and is planted in larger planting area which presents it as a commercially important crop with high interest. It has been reported by Rajendran *et al.*[7] that, the high productivity of this cereal makes it have a higher cost benefit ratio.

An increase of about 25% (39 Mt) over an outlook period in vegetable oil production, relative to 2010-2012 averagely was expected. Eight major producing countries were expected to dominate the production of these oils of about 80% in total production[15]. Corn (*Zea mays* L.) in recent years accounts for almost three-quarters of the global coarse-grain trade components worldwide[16]. It is estimated to be produced in the region of about 800 million Mt per year globally of which the dominant producing countries are America and China[17]. In the marketing year of October, 2016-2017, America (US) was the leading producers of corn in September, 30th with 384.8 out of 1037.9 Mt recorded globally. China was the second highest producers at 219.6 Mt whiles Brazil followed with 86.7 Mt, EU-27 (60.7 Mt), Argentina (36.5 Mt), Ukraine (27 Mt), India and Russia each at 24.5 Mt and Canada (13.2 Mt) whiles the rest of the world accounted[18] for 145.2 Mt. In the year 2014, corn oil production accounted for 3500 (1000 Mt) which is 1.99% out of 176000 (1000 Mt) major vegetable oils produced worldwide[19].

It is noted that, out of the large volumes of corn productions, only a small fraction of about 7% of it is used to produce oil and other industrially applied in the United States (US)[20]. The pharmaceutical industry uses a small amount (~1.52%) of the corn oil produced for few purposes whiles a negligible percentage of it is used for non-food purposes and thus, making it more available for other uses if the need be[10].

In 2004, corn oil was estimated to be the second most valuable vegetable oil in the American market. Japan remains one of the highest importers of this product as the US, China, EU and others[10]. The corn oil market in Bangladesh was expected to account for 71.4% by the end of the 2016 which is a growth rate of 1.7% forecast. It was also forecasted that, the substantial growth and expansion of the corn in the near future will be rated at a 2.1% increase[21]. It is documented in the US that, at the end of the 2016 market year, the production of corn oil in total was 2,213,773 bushels which is expected to increase in the subsequent years due to more grants and investments into corn production[22]. The seven most dominant countries with promising increase in corn production in 2016 were Botswana (1400.00%), Bolivia (512.50%), Swaziland (203.03%), Lesotho (200.00%), Zimbabwe (95.3%), Somalia and Jamaica at 65.71% and 50.00%, respectively[23]. Figure 1 illustrates the use and production of corn cereal[24].

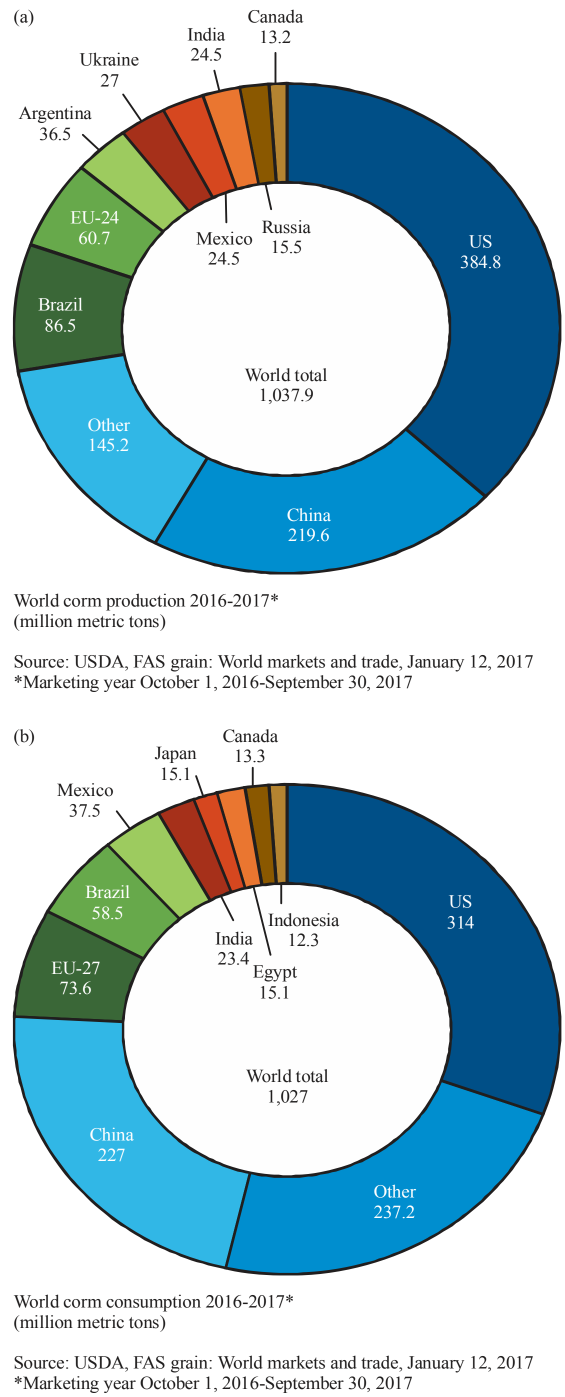

Fig. 1(a-b): Global corn production and consumption
Source: Adopted and redrawn: Spurlock and Novak[24]

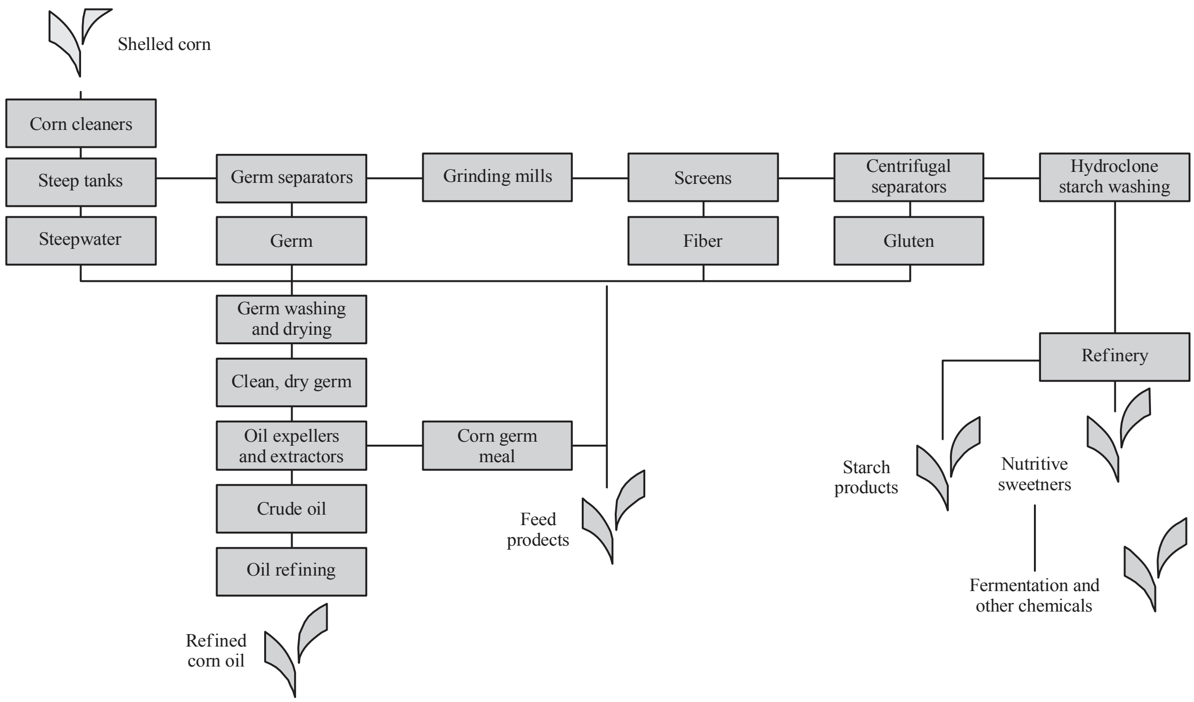

Fig. 2: Corn wet milling process
Source: Corn Refiners Association[10]

Corn oil extraction: An oil of more than 6% obtained in a corn is called the high oil corn. This oil is mostly located and extracted in the germ of the corn kernel containing of about 80-84% of the total oil[7,9].

The most commonly used process to extract corn oil is called the wet milling process which involves isolation of corn kernels from pure starch efficiently[9]. Superficial fluid extraction has also been established as an effective way of producing corn oil[25]. However, the emergence of high corn oil has led to another form of extraction which is reported by Moreau[9] as similar to the extraction of soybean oil processing. The oil is extracted typically by combination of hexane extraction and mechanical expressions from the germ. Figure 2 illustrated the extraction of the oil.

Price of corn oil: High price hike in corn product was reported over the past few years due to the higher demand it experienced. However, the prices are expected to drop low in coming years with contributing factors such as an overly-supply and slow growth of the economy[26].

There is various contrast in the price range of corn oil in the market and as such a reasonable time series data has not been established. However, it is believed the price of corn oil is traded at similar range as the soybean oil although, there is divergence in the market which creates risks[27]. Since the US has been one of the largest trading countries in the corn oil market, this study seeks to use their price rate as an estimate to report on the pricing of corn oil due to the unavailable and undocumented data for the trading prices globally. It is reported that, an increase in the product from 2006/2007 to 2016/2017 was ranged between USD $0.63-$1.05. However, within the year 2001-2016, fluctuations in the prices was noted as earlier reported on the inconsistencies of the price in the market[27].

Effect of corn oil on feed quality: According to Corn Refiners Association[10], corn oil provides desirable flavors when blended with other oils in packaging of various products. It has been documented that, corn oil usually does not deteriorate when kept for long storage periods under its high melting point, 40°C (457°F) offering it to be in a semi solid state and coupled with its high natural antioxidant properties (tocopherols and vitamin E)[10].

Corn oil is said to have lower proportions of linoleic acid which is prone to atmospheric oxidation (Rancidity)[7]. Although, this phenomenon is noted to be high in most vegetable oils, corn oil demonstrates the ability to lower and control this reaction to maintaining a good quality product in packaging which will benefit the feed production sector in aquaculture.

Table 2: Composition of crude and refined corn oil

	Typical value (%)	
Composition	Crude	Refined
Triglycerides	95.6	98.8
Free fatty acids	2.5	0.05
Phospholipids	1.5	0.0
Unsaponifiables	N/A	N/A
Cholesterol	0.0	0.0
Phytosterols	1.2	1.1
Tocopherols	0.12	0.08
Waxes	0.01	0.0
Color	Variable: Very dark to yellow	Pale yellow
Odor and flavor	Strong corn/feed	Slight corn, slightly nutty/buttery
Cold test at 0°C (32°F)	-	**Clear for 24 h

**A clear significant difference. Source: Corn Refiners Association[10]

In the crude state, corn oil possesses phospholipids which adds more FA and act as a protein source in feeds although, when the oil is refined, its purity in the terms of triglycerides is increased from 95-99% with free FAs which lowers the smoke point and as such, reduces its dark coloration under heat[10]. Table 2 showed the composition of both the crude and refined oils.

Corn oil has been established to be insensitive to the exposure of incandescent or indoor light[10]. This property makes it also unique to storage and packing whiles preserving the products unique qualities.

Corn oil contains a higher amount of PUFA which gives feed a nutrient quality of boosting the health and immune system of organisms when fed to it. As such, this quality in corn oil helps in the regulation, curing and lowering the development of atherosclerosis and coronary heart diseases[10]. It has been reported that, corn oil has been set as a standard measure for other oils in assessing cholesterol lowering abilities because it is highly stable and comes with a pleasant taste and also with multifunctional usage[10]. Corn oil amongst other vegetable oils compared is the best oil chosen to lower blood cholesterol levels and being the superior to Sunflower oil[10].

The pleasant taste and flavor of corn oil in feeds serves as an attractant and gives diets palatability to organisms which are feed such diets. This makes it easier for organism to accept the diet when given. Also, corn oil has a binding effect of which when mixed with other ingredients binds in firmly to give a smooth texture and neat package to the products[10].

Corn oil contains the highest volume of phytosterols which is an inhibiting factor to reducing blood cholesterol and its absorption in the intestine. It is the only oil containing all the mix of phytosterol, phytostanol and phytosterol ester[7]. The high PUFA content of corn oil is noted to meet the required essential FA in human nutrition which in other words is related to consumers health. This FA property is essential in boosting the immune system and synthesis of eicosanoids which is necessary for functional activities such as cardiovascular, renal, gastrointestinal functions as well as disease resistance[7].

Corn oil in other feeds for example, livestock has been reported to improve amino acid balance (lysine, threonine and methionine), increases energy density whiles also reducing the need to incorporate supplements at high cost[7]. Although, the MUFA in corn oil is not as much as its PUFA, it comes in significant amount which influences the feed quality. Thus, this FA aids in the retention and absorption of some minerals (magnesium and calcium) and other amino acids whiles also requiring little enzymatic activities and less energy in digestion and absorption in the body[28].

Effect of corn oil on growth performance and body composition: The effect of vegetable oils on growth performance on some aquaculture species has come with inconsistent and contradicting reports. Various factors such as lipid source, the specie type, culture conditions and others are suggested by authors to contribute to these variations in reports.

The use of corn oil as a dietary oil replacement for fish oil in aquafeeds also has its implications as different reports has been documented[29-39].

The performance of juvenile grouper, *Epinephelus malabaricus* was researched by replacing fish oil with corn oil in their diets in year 2007 by Lin and Shiau[35]. In their study, fish oil (F) and corn oil (C) were blended at equal levels or wholly replaced where the lipids adds up to 40 g kg^{-1}. After feeding fish for 8 weeks, weight gain was highest ($p = 0.05$) in partially replaced diets but lowest when fish oil was completely substituted. Lower production of leukocytes superoxide anion (O_{2-}) was obtained in only corn oil fed diets but the partial replacements recorded high production in plasma alternative compliment and lysozyme activities. It was concluded from this study that, blend of corn oil and fish oil at ratios 3:1 or 1:1 had similar growth rate as ones fed solely fish oil diets whiles also enhancing significantly non-specific immune responses of the grouper.

El-Marak[31] reported from an experiment conducted on the effect of dietary sources and levels of lipids on growth performance and feed utilization of fry Nile tilapia. Fish were fed three different diets containing cod liver oil, corn oil or mix of cod liver and corn oil at equal levels of 1:1 v/v at 4% for 90 days. Highest growth rate was reported with those fed the mix lipids (1:1 v/v) whereas, no significance was obtained in other parameters. However, moisture and protein contents in fish fed the mixed lipids were found to be highest. Corn oil was ascertained to give good results when blended or replaced 50% of fish oil in aqua feeds for this fish species with an optimal requirement of the oil at 4% as concluded in this study.

A study was conducted to determine the effect of replacing fishmeal with sunflower cake whereas corn oil was the sole lipid source at varying levels. A sex reversed tilapia (*O. niloticus*) were fed six formulated diets for 70 days. Low digestible energy content in feeds containing high corn oil was reported. Whole body FA was reported to be reflective of their diets FA. A higher level of linoleic acid was reported in the diets composition although they were lower in their respective whole-body composition. Thus, this change was suggested to be the ability of tilapia to bio-convert and synthesize this FA to longer chain PUFAs. It is suggested that, some of the linoleic acid was converted to arachidonic acid (20:4n-6) because it was not detected in diets[36].

Corn oil, cod liver oil, olive oil and beef tallow were incorporated in diets at 14% lipid level and fed to *Oreochromis niloticus* for 65 days. The diet with equal blends of all the lipid sources produced the best results in all measured parameters (Feed conversion ratio (FCR)-1.27, Apparent net energy retention (ANER)-20.2%, specific growth rate (SGR)-1.73%, net protein retention (NPR)-29.30%, protein efficiency ratio (PER)-2.06%, condition factor (K)-2.95) whiles those fed only beef tallow diet showed the poorest performance although it was significantly better than those fed the lipid free diets as control. No significance in growth between those fed the cod liver, corn oil and olive oil diets. The highest value of HSI recorded was in those fed corn oil (1.55) as compared to the control group (1.31%). Higher crude protein and body fat was reported in those fed diets with lipid whereas their gross energy and moisture were lower in comparison. The study was concluded with the notion that, the incorporation of different lipid sources will produce the best growth performance in *O. niloticus*[30].

In a 20 weeks feeding trial conducted by Karapanagiotidis *et al.*[33], Nile tilapia was subjected to five diets with different lipid sources [Linseed oil-(LO), linseed oil and refined palm olein oil-PO (2LO-1PO), refined palm olein and linseed oil (2PO-1LO), fish oil (FO) and corn oil (CO)]. Corn oil and FO were set as the control groups in this study. No significant difference across all treatments was recorded. Higher concentrations of C14:0 and C15:0 were reported in those fed FO due to the supply of it from their diets. Although, this study did not directly focus on corn oil, it was however noted that, CO fed fish contained high amounts of PUFA n-6 in 18:2n-6, 18:3n-6, 20:2n-6, 20:3n-6, 20:4n-6, 22:4n-6 and 22:5n-6 although, all diets had similar contents of n-6PUFAs with the exception of 18:2n-6. However, lower amounts of n-3PUFAs was recorded in those fed the CO diets whiles FO-fed diets were also lower compared to those in the LO-based groups. The n-3/n-6 PUFA ratio was lowest in muscle lipids fish fed CO diets as compared to those fed FO and LO. The predictive production series 2 and 3 of eicosanoids, (20:4n6/20:5n-3) were high in fish fed CO-diets with the lowest occurring in those fed FO-diets. The study concluded that, the inclusion of vegetable oil in tilapia feed could lower tissue concentrations of 22:6n-3 and 20:5n-3 and as such decrease the lipid nutritional value of the product.

Yildirim-Aksoy *et al.*[29] formulated six diets supplemented with 7% alternative lipid sources [corn oil (CO), beef tallow (BT), menhaden fish oil (FO), linseed oil (LO) and equal combinations of FO+CO+BT or LO+CO+BT]. Poor performance in fish fed BT in almost all measured parameters was reported in this study after 12 weeks feeding trial although, values with other treatments did not significantly differ. The feed efficiency ratio value for CO fed fish was significantly lower than that of LO-fed fish although there was significance in those fed FO, FO+CO+BT and LO CO+BT diets. A significantly lower cumulative mortality after fish were subjected to *streptococcus iniae* challenge for 15 days was recorded on those fish fed BT other than CO and FO+CO+BT although, all treatments did not significantly differ. Also, an improved growth performance has been reported in fish fed corn oil and soybean oil when compared to ones fed FO[37].

The physiological status and growth performance of hybrid Striped Bass (White Bass *Moronechrysops* X Striped Bass *M. saxatilis*) was evaluated based on production performance and stress resistance with different dietary lipid sources (fish oil, canola oil, corn oil or flaxseed oil). It was reported after 14 weeks of feeding that; dietary lipid sources had no effect on the production performance. Consistent results were obtained in hematological stress response and net-chasing and with significant effect recorded in stress exposure on osmolality and plasma cortisol and also lipid source effect on plasma osmolality. After 1 h of stress exposure, osmolality and cortisol levels recorded higher values of 384 m kg^{-1} Osm and 411 ng mL^{-1}, respectively, whereas, a decrease in these parameters was recorded 4 h after. It was noted shortly after a stressor exposure that, fatty acid (FA) profiles has been altered with an increase in saturated and monosaturated FA being recorded whiles polyunsaturated FAs decreased. Although, it was noted that, dietary lipid sources in diets were reflective in the plasma lipid FAs. No gross effects or physiological functioning was reported in this study although, lipid sources and stressor exposure influenced the differences obtained in hematological parameters. As such, it was concluded that, dietary lipids from alternative sources do not impair growth performance nor physiology status of the fish and so can replace fish oil in part or whole[38].

Fish oil (FO), linseed oil (LO), corn oil (CO), soya oil (SO), 50% LO+25% CO+25% SO (ML), 50% CO+25% LO+25% SO (MC) and 50% SO+25% LO+25% CO (MS) represents seven different experimental diets formulated for Nile tilapia, *Oreochromis niloticus* in a 10 week feeding trail. The economic efficiency for producing 1 kg gain of fish was reported to be best in diet CO at 25.33% with a lower price/kg. A significantly higher growth rate and feed utilization parameters was reported with those fish fed the FO and ML diets with no significant difference among all treatment groups. El-Tawil *et al.*[32] concluded that, mix or blend of different dietary lipids sources can wholly or partly replace FO in Nile tilapia diets with no adverse effect in production performance especially with regards to feed efficiency and cost effectiveness.

Nile tilapia were fed different dietary levels of lipid and vitamin E. Menhaden fish oil and corn oil were the main source of lipids supplemented in a basal diet at 6, 10 and 14% of 1:1 mixture. Each diet was also supplemented with vitamin E/kg at 50, 100 and 200 mg. About 12 weeks after feeding trials, dietary levels of either vitamin E or lipids had no effect on weight gain, feed intake and survival. Feed efficiency was reported to be significantly lower in fish fed 14% lipid diets compared to those fed 6% dietary lipids, however, they were not significantly different from those fed the 10% dietary lipid diets. Vitamin E levels however, did not influence any of the feed efficiency ratios as the lipids impacted. A significant increase in whole body lipid was reported as lipids and vitamin E levels were 14% and 100 mg kg^{-1}, respectively. A significant decrease in α-tocopherol levels was reported as lipid levels in diet was 14% although, these levels were reflective of their respective dietary vitamin E levels. The concentration of vitamin E levels did not have any effect on serum protein unlike the dietary lipids at 14%. Lipid levels and vitamin E concentrations did not affect hepatosomatic indexes as well as hematological parameters. An increase in lysozyme activity was reported in fish fed 200 mg kg^{-1} vitamin E whereas, lipid levels had no impact on it. An increase in alternative compliment activity was also reported when vitamin E concentration was increased to 100 or 200 mg kg^{-1} whiles a decrease was obtained in those fish fed dietary lipid levels of 10 or 14%. There was no reported effect on the resistance to *S. iniae* challenge and antibody titer as tilapia was fed the different lipids and vitamin E levels. It was noted that, an equal blend or mix of dietary lipids sources is sufficient for the Nile tilapia to reach its desired growth with no adverse effects[40].

A juvenile spotted Babylon Babylonia areolate was subjected to the partial replacement of tuna oil by corn oil in its diet for 120 days. The juvenile *B. areolate* were fed one of four diets formulated with 10% lipid. The diets were derived as A (100% tuna), B (50% tuna+20% corn oil), C (30% tuna+40% corn oil) and D (10% tuna+60% con oil). Formulated diets were accepted in all treatments with significant differences in shell length increment, weight gain and growth rate as well as feed conversion ratio. In a respective order, crude protein and fat ranged from 61.38-61.48 and 5.36-5.39% with no significant differences. However, fat content in whole body was reduced to half than those fed the formulated diets. It was concluded a partial replacement of fish oil with corn oil does not impair growth performance and as such can be considered as a good source of lipid[34].

Gibel carp (*Carassius auratus gibelio*) were fed one of seven diets for 70 days feeding trial with fish and corn oil as the major lipid sources. The lipid sources across all treatments were blended in equal volumes corn oil: anchovy oil =1:1. Zhou *et al.*[39] conducted this study to re-evaluate the optimal dietary lipid requirement based on blended lipid source for the gibel carp. Authors reported significant increase in specific growth rate (SGR), protein retention efficiency (PER) and viscera somatic index (VSI) as lipid concentrations increased from 10-81 and 81-213 g kg^{-1}, respectively, whiles a decrease in SGR was recorded in those fed concentrations of 119-213 g kg^{-1}. Feed efficiency increased as feeding rate decreased with increasing dietary lipid concentrations ($p = 0.05$). Relative contents of fatty acids (16:0 and 18:0) in liver and muscle showed a quadratic regression trend with dietary lipid concentrations whereas, a decrease in monounsaturated fatty acids (MUFAs) and an increase in long chain polyunsaturated fatty acids content was reported as lipid concentrations increased.

Increases in dietary lipid concentrations was reported to cause downregulations in relative mRNA expression levels of FAS and ACC1. Based on broken-line model of SGR, authors concluded that, an equal blend of fish oil and corn oil at 73.2 g kg^{-1} is optimum for gibel carp, although, this replacement causes a decrease of 47.9% when compared solely to the group fed fish oil at 140.5 g kg^{-1}. As such, it was indicated that, replacing fish oil by vegetable oils alter significantly the dietary lipid requirement for freshwater fish.

CONCLUSION

Corn oil has demonstrated the potential to replace fish oil with respect to its FA profile and a strong antioxidant property and vitamin E content being essentials for feed production. As such, an in-depth knowledge on how to improve the use of this oil especially with the refined oil (high oil) to boost the immune system and genetic make-up and digestibility along with its FA profile will go a long to the development of feeds in aquaculture. It is an outstanding and a sustainable source of oil due to its large commercial production worldwide which makes it a more reliable alternative.

SIGNIFICANCE STATEMENT

This study discovers the highly dense tocopherols and vitamin E content in corn oil can be beneficial for fish immune mechanisms and health status boost when fed on. This study will help researchers to uncover the critical areas of gene modulations and enzymatic reactions to corn oil that many researchers were not able to explore. Thus, a new theory on vegetable oil accumulation in fish tissues and product quality may be arrived at.

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