Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/20757
DOI URL: http://dx.doi.org/10.21474/IJAR01/20757

RESEARCH ARTICLE

INVENTORY OF VARIOUS AGRICULTURAL AND AGRO-INDUSTRIAL BY-PRODUCTS USABLE IN AQUACULTURE IN SENEGAL.

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Manuscript Info

Manuscript History
Received: 15 Febuary 2025
Final Accepted: 18 March 2025
Published: April 2025

Key words: -Inventory, agricultural and agro-industrial by-products, fish farming, Senegal.

Abstract

The study explores the potential of agro-industrial by-products available in Senegal to meet the challenges of fish farming feed. With a flourishing agriculture and agri-food industry accounting for a significant proportion of the national Gross Domestic Product (GDP), these by-products, such as groundnut oilcake, vegetable meal (maize, wheat), and cereal bran (rice, millet), offer an economical, local alternative to certain ingredients such as fishmeal, which is often expensive. The survey conducted in ten regions of Senegal revealed varying availability of resources depending on the agro-ecological zone. In the southeast (Tambacounda), annual groundnut cake production reached 51,157 tonnes, while maize production stood at 104,695 tonnes, with prices of 176 FCFA/kg and 360 FCFA/kg respectively. In central country, Kaolack produced a significant amount of maize (92,284 tonnes/year at 333 FCFA/kg) and groundnut cake (63,325 tonnes/year at 180 FCFA/kg), while Thiès stood out with its annual production of 30,349 tonnes of cowpea powder (921 FCFA/kg). By contrast, availability in the north (Saint-Louis) is more limited, with only 4,854 tonnes of maize (384 FCFA/kg) and 1,766 tonnes of groundnut cake (280 FCFA/kg). These disparities are exacerbated by constraints such as seasonality, which reduces supply during the slack months (June to September), as well as by logistical costs and price fluctuations, particularly for key resources such as fish oil, the price of which reaches up to 1,800 FCFA/litre in certain regions of the South.These factors hinder the optimal exploitation of by-products, despite their economic and nutritional potential. However, the accumulated use of these local resources could reduce production costs in fish farming, promote food self-sufficiency, and support a circular economy.

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Introduction:-

In Senegal, agriculture and industry are fundamental pillars of the national economy. Agriculture employs a large proportion of the working population, with over 60% of Senegalese engaged in agricultural activities (ANSD, 2020), and is one of the pillars of Senegal's economy, contributing an estimated 16% of GDP (DAPSA, 2023). As for industry, the majority of which is made up of agro-industries, it represents a significant part of the Senegalese economy, contributing 24% of GDP (ANSD, 2020). The country's agro-industrial profile allows for a diversity of processed agricultural products, offering a variety of by-products that can be used in animal feed, including the formulation of feed for farmed fish.

Senegal's main crops include millet, sorghum, maize, fonio, and rice. Cash crops are dominated by groundnuts, sesame, cotton, watermelon, cassava, and cowpea, which occupy a large proportion of agricultural land (DAPSA, 2023). Groundnut, cotton and sesame cakes, as well as rice and maize bran, by-products from these raw materials, are available in Senegal and can be used in fish feed, as a partial or total replacement for fishmeal (FAO, 2015).

Senegal is a major groundnut oil producer, with several industrial oil mills, including SUNEOR ex SONACOS, and other small and medium-sized enterprises processing groundnut seeds into oil and cake (Noba, et al., 2014). In 2020, groundnut oil production was around 150,000 tonnes, providing a major local source of vegetable protein from groundnut cake. The “Groupement des Transformateursd'Oléagineux du Sénégal” (GTOS) continues to play a key role in the processing and marketing of oils and cakes on a regional and international scale.

Senegal's agri-food exports, particularly of vegetable oils and fats, are growing steadily. In 2023, groundnut oil exports to France totaled several million euros, reflecting the importance of this industry to the Senegalese economy (ANSD, 2023).

Among the major constraints to the development of fish farming in West Africa, feed-related problems are of particular importance. Both the cost of feed and its quality and nutritional value are concerns raised at all aquaculture-related meetings (Sodjinou, et al., 2016). Most of the fish feed used by Senegalese fish farmers is imported and comes mainly from Netherlands, Brazil, Israel, Egypt, and Ghana (Rurangwa et al., 2014). This feed, although effective in terms of growth (nutrient intake, buoyancy), is too expensive and therefore, not within the reach of all fish farmers. Studies on the value chain have shown that the cost of feed in aquaculture represents more than 70% of total production costs, making it the most expensive part of an aquaculture business (Mongbo et al., 2014).

By using local by-products as ingredients in fish feed, Senegalese fish farmers could improve the profitability of their business while making the most of local agricultural resources. It would also help reduce dependence on fishmeal (the main source of protein for aquaculture feed), an ingredient that is often expensive and much criticized by environmentalists.

To contribute to the development of tilapia and catfish farming in Senegal, the aim of this study is to identify the agro-industrial by-products available through a socio-economic survey in the agro-ecological zones of Senegal. Specifically, it will involve: (i) making an inventory of potentially available agro-industrial by-products; (ii) analyzing the quantitative and temporal availability of these by-products that can be used by the fish species farmed in Senegal; (iii) assessing their costs, as well as the factors that may influence their variations.

This approach encourages using local resources to formulate effective and affordable fish feed.

Methodology:-

Data collection methods.

Before discussing the technical aspects of data collection, it is worth highlighting the fundamental objectives of this stage and the strategic approach adopted. The aim of these preparations was to ensure exhaustive coverage

Secondary data collection

The so-called secondary data collection phase made it possible to summarize the information available on fish farming in Senegal, particularly the socio-demographic representation and the list of producers. This secondary data collection was based on the information gathered in the first part of the questionnaires, particularly on gender, age, number of employees, status of the business, etc.

Preparing the field phase

The preparatory phase consisted of two activities, namely a meeting with the project team at the very beginning and the preparation of data collection tools. This scoping meeting, held at the start of the project, defined the main stakeholders to be surveyed and clarified certain concepts and the types of data to be collected. The following data collection tools were designed: a questionnaire for fish farmers and a questionnaire for feed producers. These questionnaires were produced using Sphinx Plus^2 software. The dean of the faculty of Agronomic Sciences, Aquaculture, and Food Technologies (S2ATA) sent a letter of introduction to the managers of the targeted flour mills to contact the feed-producing industries. Surveys of fish farmers were carried out using databases supplied by the branches of the Agence Nationale de l'Aquaculture (ANA) in the various intervention zones.

In terms of the questionnaires developed, the survey aimed to collect more quantitative data, making sample size an essential factor in guaranteeing the reliability of the results. This approach makes it possible to generalize the findings of the study to the entire target population (Loum, 2019). However, conducting a sample survey in a sub-sector such as aquaculture in Senegal presents methodological constraints. These include the geographical dispersion of producers and the absence of centralized registers, with databases that are rarely up to date or not easily accessible. This makes it difficult to accurately identify active producers. Notwithstanding this, we were able to identify a total of 239 producers based on information provided by the ANA, 125 of whom had functional structures and were active during the survey period. Of these, 91 were interviewed, and their breakdown by region is shown in Table 1.

Table 1:- Breakdown of actors surveyed by region

Actors	Agro-ecological zones										Total
	Dakar	Thiès	Saint-Louis	Fatick	Diourbel	Ziguinchor	Sédhiou	Kaolack	Tambacounda	Kolda	
Food producers	***4***	***2***	***1***	***-***	***-***	***3***	***3***	***-***	***-***	***-***	***13***
Fish farmers	***2***	***4***	***25***	***2***	***2***	***16***	***14***	***5***	***7***	***1***	***78***

Field phase

The study was conducted between February and May 2024 in the agro-ecological zones of Senegal, including the regions of Dakar, Thiès, Saint-Louis, Fatick, Diourbel, Sédhiou, Ziguinchor, Kaolack, Tambacounda and Kolda. Average annual rainfall in these regions ranges from 250 mm in the north of Senegal to 1,450 mm in the south-west (BMZ, 2022). These regions are particularly well suited to agriculture, making them the country's main farming areas. In addition to their high agricultural potential, these areas are also rich in aquaculture, an activity that is developing on a large scale. The Dakar region is home to major industrial zones, with numerous agro-industrial units and the country's largest flour mills.

The field phase consisted of collecting qualitative and quantitative data using questionnaires. The interviewers administered the questionnaires to the different categories of stakeholders, i.e. fish farmers and feed producers. In the case of feed producers, a questionnaire was administered to a resource person at the mill (production managers, head storekeepers, managers, technicians). Most structures producing feed for livestock or poultry or using agro-industrial by-products that could potentially be used for fish feed were taken into account. The survey of fish farmers was carried out in several stages. First of all, the fish farmers listed in the databases of the

National Aquaculture Agency (ANA) were contacted beforehand to make appointments and ensure their availability. The field visits enabled direct interviews with the fish farmers on their farms. This also provided an opportunity to verify some of the data by direct observation. Overall, the data collectedcovered :

- ✓ the characteristics of the respondent, the characteristics of the fish farms (type of farming, species, duration of farming, sizes at selling, destination, and production capacity), the feeding method, the workforce, etc.;
- ✓ Feed (feed production, raw materials, annual feed requirements, sources of feed supply, reasons for choosing these resources, availability in time and space, direct use of agricultural by-products as feed, protein content after formulation);
- ✓ unit prices and spatial and temporal trends in by-product prices, imported industrial feed prices, etc.;
- ✓ unknown sources of food ingredients (location, availability in time and space, other ingredients that the producer believes can also be used);
- ✓ problems and other difficulties encountered by stakeholders and approaches to solving these problems;
- ✓ producers' perception of the effect of feed on the growth performance and health of farmed fish.

Data analysis method

The data collected were analyzed and entered using Sphinx Plus² software. The qualitative data were then analyzed for content. As for the quantitative data, the analyses were essentially descriptive and the calculations were carried out using the same software.

Results:-

Identification, production and prices of agro-industrial by-products

The survey results, reported in Table 2, show that a wide variety of local by-products can be used in fish feed in Senegal. These agro-industrial by-products fall into two main categories: those used as sources of lipids and those used as sources of protein.

Among the by-products intended to supply lipids, vegetable oils occupy a marginal position. For example, palm oil is used very little by fish farmers (only 1.3%) and is not included in the statistics of food producers. This situation reflects a preference for lipids of animal origin or constraints linked to the availability and nutritional quality of palm oil. As far as animal fats are concerned, fish oil is in strong demand despite its relatively high cost (1,700 FCFA/litre). Its massive adoption by feed producers demonstrates its excellent nutritional qualities, perfectly suited to the needs of aquaculture.

Agro-industrial by-products that are sources of protein include oilcake, cereal bran, and vegetable flour such as moringa leaf flour, wheat flour, maize flour, and cowpea flour. In addition to plant protein sources, animal proteins such as shrimp meal and fish meal have been identified. Fishmeal remains the most popular animal by-product, with 20.5% used by fish farmers and 69.2% by feed producers. Annual production is 9,968 tonnes, and the price (800 FCFA/kg) remains attractive given its high nutritional value. Shrimp meal is used only marginally (1.3% and 7.7%), probably because of its limited availability or high cost, although this is not specified here.

Table 2:- Total annual production, price and percentage use of agro-industrial by-products as sources of lipids and proteins inventoried in the study area

Sources	By-products			Fish farmers	Food producers	Quantity (tonnes/year)	Price (FCFA/ Kg)
Lipids	Oil	Plants	Palm oil	1,3%	-		
		Animal	Fish oil	7,7%	38,5%	2 905	1700*
Proteins	By-products Plants	Oil cakes	Groundnut cake	12,8%	84,6%	525 524	189
			Soya cake	3,8%	15,4%	-	-
		Vegetableflour	Wheatflour	7,7%	15,4%	-	384
			Moringa flour	3,8%	38,5%	-	-
			Maizeflour	15,4%	61,5%	787 750	369
			Cowpeaflour	1,3%	15,4%	152 211	1052
		bran	Wheat bran	7,7%	15,4%	-	140
			Rice bran	15,4%	69,2%	211 368	110
			Millet bran	1,3%	30,8%	164 555	132
	By-products Animals	Animal meal	Fish meal	20,5%	69,2%	9 968	800
			Shrimpflour	1,3%	7,7%	-	-

FCFA/litre

Location of agro-industrial products and by-products in Senegal

The location of agro-industrial by-products of plant and animal origin inventoried in the study area is summarised in Table 3. The table shows that products and by-products vary from region to region.

The distribution of the latter varies greatly from region to region:

- **South-east (Tambacounda)**: This region is notable for its production of groundnut cake (51,157 tonnes/year) and maize (104,695 tonnes/year).At competitive prices (176 FCFA/kg and 360 FCFA/kg respectively), these products can be key resources for local aquaculture.
- ***North (Saint-Louis)***: Availability is more restricted. Maize (4,854 tonnes/year at 384 FCFA/kg) and a few by-products such as groundnut cake (1,766 tonnes/year) are the main options. Fishmeal, althoughavailable, islimited in volume.
- ***Centre (Kaolack, Thiès, Fatick, Dakar)***: This zone has a diversified and abundant supply, particularly of maize (up to 92,284 tonnes/year in Kaolack), groundnut cake (76,626 tonnes/year in Fatick) and cowpea powder (up to 30,349 tonnes/year in Thiès).
- ***South (Sédhiou, Ziguinchor)***: These regions have a rich diversity of by-products, with particularly high production of rice bran (53,555 tonnes/year in Sédhiou) and maize (137,535 tonnes/year). However, some by-products, such as palm oil and moringa leaves, are not included in the statistics, which may indicate under-exploitation.

These by-products can also be analyzed according to their cost. A distinction can be made between:

- ***Low-cost by-products:*** Millet bran, rice bran, and wheat bran are available at affordable prices (between 104 and 142 FCFA/kg), making them ideal for large-scale use in aquaculture.
- ***Medium-to-high-cost products:*** Fishmeal (700 to 850 FCFA/kg depending on the region) and cowpea powder (850 to 1,339 FCFA/kg) are more expensive, but their nutritional value justifies their prices. The same applies to fish oil, which remains in high demand despite its high cost (1,700 to 1,800 FCFA/litre).

Table 3: Location, quantity, and price of agro-industrial products and by-products identified in Senegal

Zones	Régions	Agro-industry by-products	Quantity (tonnes/year)	Price (FCFA/Kg)
South-East	Tambacounda	Groundnut cake	51 157	176
		Millet bran	8 342	120
		Maize	104 695	360
		Rice bran	3 153	-
		Cowpeapowder	5 545	850
North	Saint-Louis	Rice bran	-	104
		Groundnut cake	1 766	280
		Wheat bran		
		Soya		
		Fish meal	-	700
		Fish oil	-	1700*
		Maize	4 854	384
		Moringa leaf	-	-
Centre	Dakar	Groundnut cake	232	262
		Cowpeapowder	24	1339
	Kaolack	Millet bran	20 337	111
		Groundnut cake	63 325	180
		Rice bran	12 556	135
		Maize	92 284	333
		Feuille baobab	-	-
		Moringa leaf	-	-
		Cowpeapowder	1 405	1253
	Thiès	Maize	1 462	363
		Millet bran	11 276	142
		Fish meal	-	750
		Moringa leaf	-	-
		Cowpeapowder	30 349	921
		Groundnut cake	26 402	192
	Fatick	Groundnut cake	76 626	192
		Millet bran	29 711	116
		Rice bran	2 106	120
		Maize	43 038	384
		Cowpeapowder	14 538	1055
	Diourbel	Groundnut cake	19 166	197
		Maize	727	363
		Millet bran	14 387	125
		Cowpeapowder	16 005	1172
South	Sédhiou	Wheat bran	-	-
		Maize	137 535	413
		Fish meal	-	850
		Fish oil	-	1700*
		Rice bran	53 555	115
		Groundnut cake	40 550	207
		Millet bran	21 556	142
		Cowpeapowder	2 973	1169
	Ziguinchor	Rice bran	34 374	134
		Groundnut cake	14 205	273
		Fish meal	-	800
		Maize	7 827	435
		Fish oil	-	1800*
		Shrimpflour	-	-
		Mahoganynuts	-	-
		Moringa leaf	-	-
		Palm oil	-	-
		Cowpeapowder	733	1227

***Source:** ANSD/April 2023 monthly bulletin of economic and financial statistics *(FCFA/litre)*

Temporal availability of agro-industrial by-products in Senegal

Figure 1 highlights the periods of the year when certain agro-industrial by-products become unavailable, which has direct implications for their use in sectors such as aquaculture. This unavailability is mainly influenced by the seasonal factor. The availability of by-products depends on specific cycles linked to harvests or industrial production periods. For example, cereal by-products such as bran of rice or millet may be more available after the main harvests. According to producers, the months of June, July, August, and September are the periods when several by-products are in short supply simultaneously, which affects fish feed production, increasing prices or limiting production.

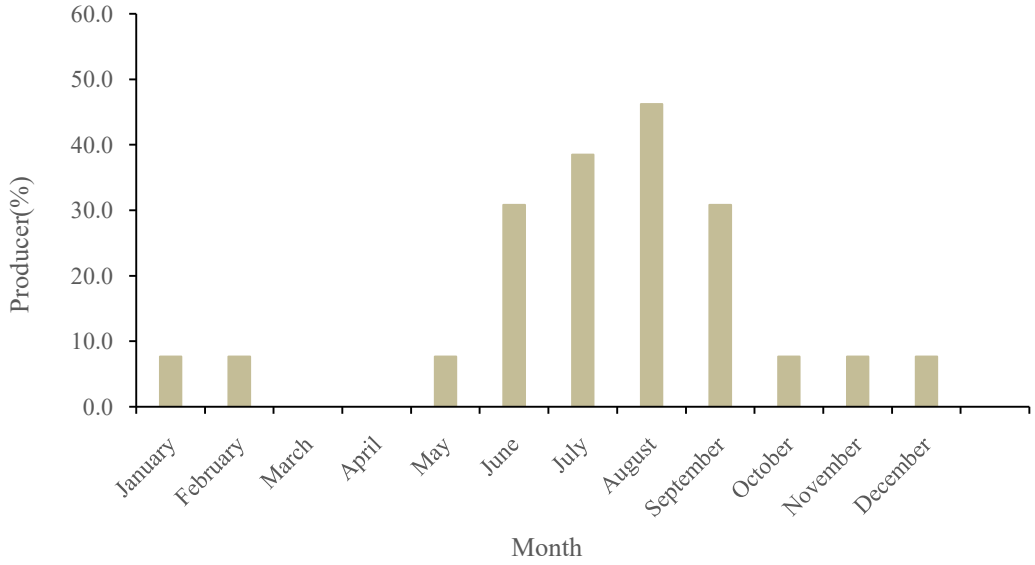

Figure 1: Periods of unavailability of by-products according to feed producers

Stakeholders' perceptions of the accessibility of by-products

The accessibility of raw materials directly impacts the supply chain of feed production for aquaculture. Figure 2 illustrates the perceptions of fish farmers and feed producers regarding the accessibility of agro-industrial by-products. There are variations in perceptions of accessibility between fish farmers and feed producers, reflecting differences in their specific needs, supply capacities, or infrastructure.

On the other hand, feed producers, who often operate on a larger scale, see accessibility as less of a problem than fish farmers, who often depend on local sources and smaller quantities. But overall, for most players, these raw materials are often within their reach.

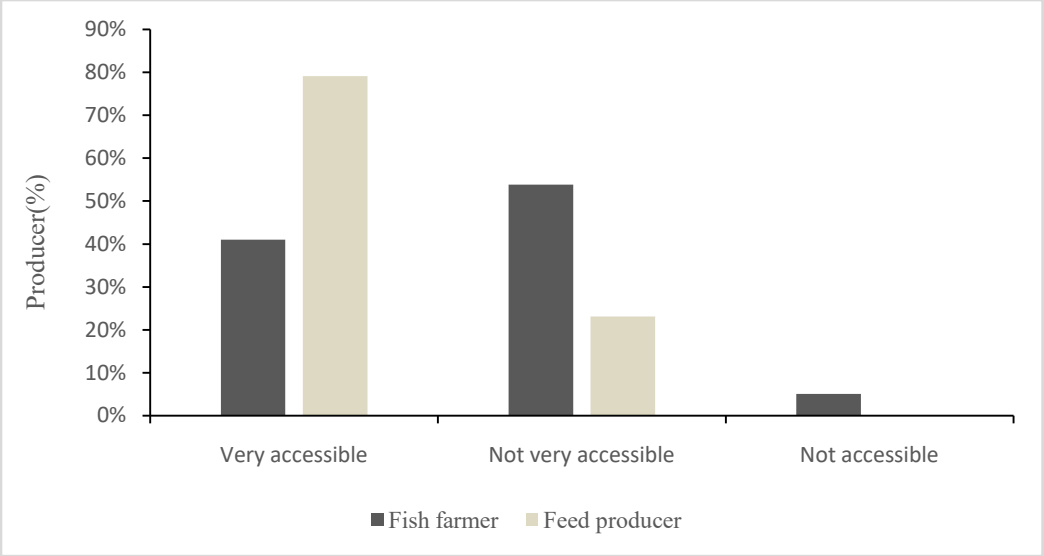

Figure 2: Stakeholders' perceptions of the accessibility of by-products

Price trends for agro-industrial by-products

Price trends for agro-industrial by-products in Senegal reveal major disparities between categories and regions, influenced by economic, seasonal, and structural factors.

Prices differ widely between by-products rich in lipids, vegetable proteins, and animal proteins. Fish oil is the most expensive, costing up to 1,800 FCFA/litre in some regions, such as Ziguinchor. Palm oil, although present, is not used to any significant extent, reflecting constraints related to its availability or nutritional quality. Oilcake, particularly groundnut oilcake (189 FCFA/kg on average), is more affordable and widely used. Vegetable meals, such as maize meal (369 FCFA/kg) or cowpea meal (up to 1,339 FCFA/kg), have a more varied price range, influenced by their nutritional value and availability. Fishmeal, at 800 FCFA/kg on average, is popular because of its high nutritional value, despite its relatively high cost. Shrimp meal, although promising, is not very accessible due to the lack of data on its price and availability.

Prices also vary from region to region. The southern regions (Sédhiou, Ziguinchor) often have higher prices, particularly for fish oil and certain by-products such as maize meal (CFAF 413/kg). This may be due to transport costs or low local production. In the Centre (Kaolack, Thiès, Fatick), the diversity and abundance of by-products (e.g. groundnut cake at 180-192 FCFA/kg) means that prices are relatively stable and competitive. In the north (Saint-Louis), supply is limited, which can lead to higher prices for products such as groundnut cake (280 FCFA/kg).

Analysis of the factors influencing price variations for agro-industrial by-products

Agro-industrial by-products play a key role in sectors such as aquaculture, but their price fluctuates according to various factors. These variations directly influence their accessibility and use.

The availability of by-products is closely linked to harvest cycles or industrial production periods. The low months (June to September) are marked by a sharp fall in stocks, which pushes up prices. This seasonality puts economic pressure on users, particularly in aquaculture, where continuity of supply is crucial.

The quantity produced each year also affects prices. Inputs produced in large quantities, such as groundnut meal (525,524 tonnes/year) and maize (787,750 tonnes/year), generally command more stable and affordable prices (between 176 and 369 FCFA/kg). On the other hand, products available in small volumes, such as shrimp meal or fish oil, are often more expensive due to scarcity (up to 1,800 FCFA/kg for fish oil).

Processing, transportation, storage, and logistical costs also affect the price of raw materials. Certain by-products, such as fishmeal and groundnut cake, are highly sought after by multiple industries (animal feed, agricultural production), further intensifying price pressures. Despite its high cost (up to 1,339 FCFA/kg), cowpea flour is

frequently used due to its nutritional qualities. The lack of adequate storage infrastructure leads to post-harvest losses, reducing the quantities available on the market and driving up prices.

Discussion:-

The agro-industrial by-products identified in Senegal offer a valuable opportunity to support the development of fish farming. They can enhance local resources while meeting economic and environmental challenges. Using these by-products as ingredients in fish feed can reduce costs, improve feed availability, and reduce dependence on imported products, which are often expensive and difficult to access. These expensive products include fishmeal, an ingredient known for its high protein value and almost indispensable in fish diets (Sourabie, 2019). Previous studies have shown that it is possible to do without fishmeal without affecting the growth of the fish by combining certain local by-products, thereby achieving the protein levels required for the nutritional needs of the fish at a lower cost (Ly, et al., 2024; Nyina-wamziza et al., 2007, 2010). Other studies using locally manufactured diets based on local by-products have produced very satisfactory zootechnical results, sometimes significantly better than those obtained with certain imported commercial (Nyina-wamziza et al., 2007).

By-products such as groundnut meal, maize, wheat or cowpea flour, and cereal bran are widely available in some regions of Senegal. However, their uneven distribution across the agro-ecological zones (South-East, Centre, North) reveals disparities influencing their accessibility. The months of June to September are marked by periods of low availability, constituting a major obstacle to continued use in aquaculture. Price fluctuations are closely linked to agricultural production cycles, amplified by periods of scarcity. Products available in large quantities (groundnut meal) are competitively priced, while rarer products (shrimp meal) are significantly more expensive. Transport, storage, and processing costs also contribute to price variability.

These results corroborate the findings of previous research (Rurangwa et al., 2014; Sodjinou, et al., 2016) that highlight the central role of local by-products in reducing fish feed costs. Furthermore, the importance of oilseed meals and vegetable meals as alternatives to fishmeal, the main source of protein, is aligned with FAO recommendations for sustainable aquaculture practices. So, to maximize the potential of these by-products, it is essential to remove the logistical and economic barriers while making greater use of local resources. An integrated approach, involving both public and private stakeholders, will be key to ensuring sustainable and competitive fish farming at the national and regional levels.

Conclusion:-

The main aim of this study was to identify the agro-industrial by-products in Senegal that could be used in the formulation of fish feed to help solve the problem of fish feed. In this way, it highlights the quantitative and temporal availability of Senegalese agro-industrial by-products to support the development of sustainable and competitive aquaculture. Identifying and locating by-products such as groundnut oilcake, vegetable meal (maize, wheat, cowpea) and cereal bran offers strategic opportunities for reducing production costs and promoting the self-sufficiency of local fish farmers. Although these resources are abundant in some regions, they are subject to geographical disparities and seasonal constraints that limit their continuous availability.

The use of some of these by-products as partial or total substitutes for ingredients such as fishmeal could address the economic and environmental concerns of fish farming. However, to maximize their potential, it is essential to remove the barriers associated with logistical costs, storage, and processing. In addition, effective coordination between public and private players, combined with an incentive policy, could strengthen the supply chain and stabilize prices.

Finally, this study's conclusions call for the wider integration of agro-industrial by-products into fish farming diets. This approach would promote economically viable aquaculture production, make the most of local resources and ensure the sustainable management of ecosystems. In-depth exploration of the nutritional properties of less-exploited by-products and the optimization of feed formulations are promising avenues of research for improving the zootechnical performance of farmed species.

This study provides a solid basis for guiding future aquaculture development strategies in Senegal while promoting a circular economy and reducing dependence on imported products. To ensure the success of these initiatives, the sector's dynamics must be regularly monitored, and stakeholders must take a participatory approach. .

Acknowledgments:-

This researchwas made possible through a grantfrom the International DevelopmentResearch Centre (IDRC), Ottawa, Canada. The authorsalsowish to express their gratitude to the African Centre for TechnologyStudies (ACTS) in Kenya and the Ministry of Higher Education, Research, and Innovation of Senegal for their support.

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