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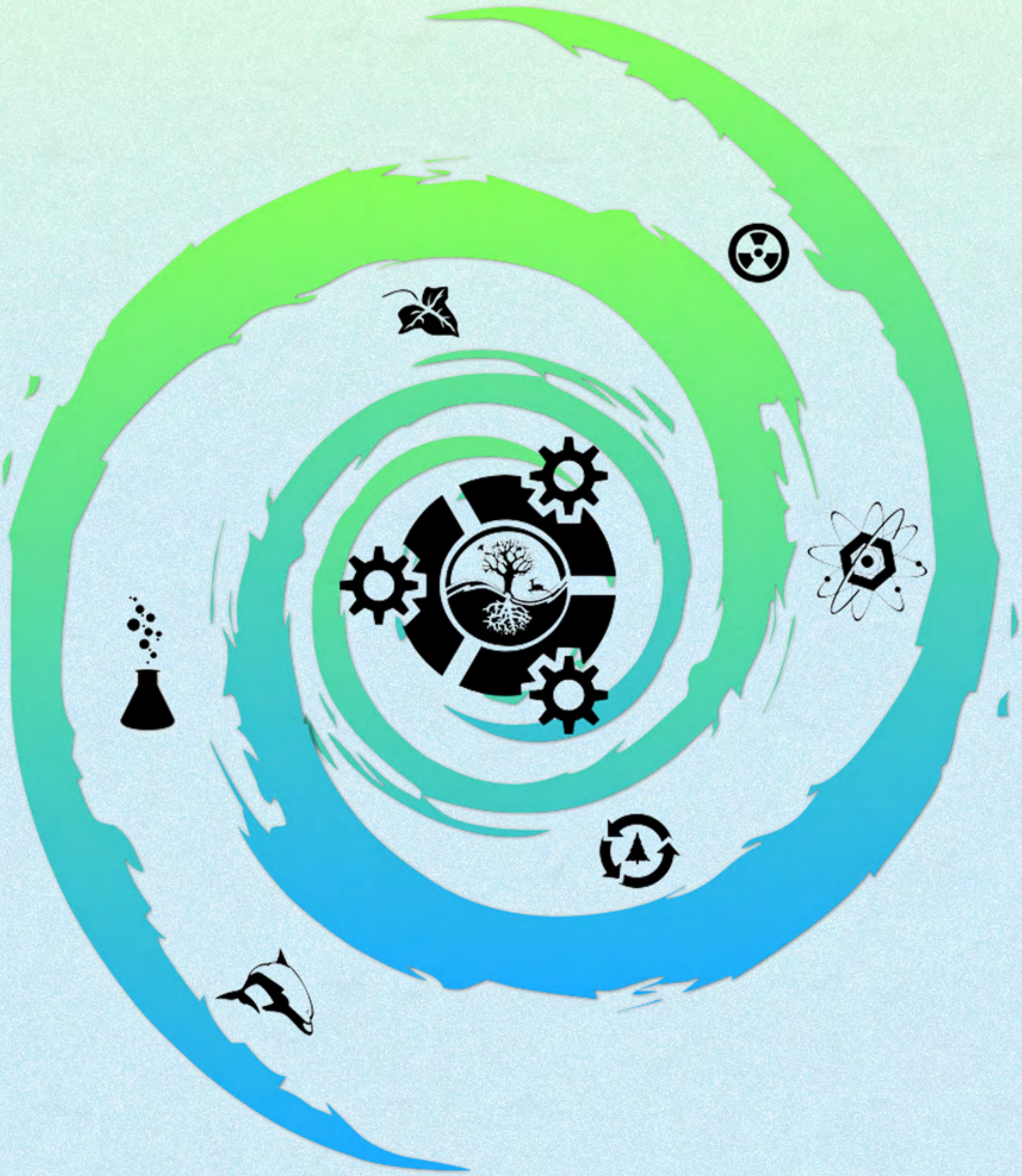

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Proximate Evaluation and Consumer's Acceptability of *Clarias gariepinus* Cured With *Citrus sinensis* Extracts

Victoria Folakemi Akinjogunla[1]✉ • Nafisa Isah Shehu[1]

[1] Department of Fisheries and Aquaculture, Faculty of Agriculture, Bayero University Kano, Kano State, Nigeria, vfakinjogunla.faq@buk.edu.ng; nefisatisahshehu@gmail.com

✉ Corresponding Author: vfakinjogunla.faq@buk.edu.ng

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ABSTRACT

The aggregate demand for seafood with minimal additives has increased over the years. *Citrus sinensis* is a common fruit that generates a lot of waste which needs to be put to beneficial use. The study investigated the acceptability of processed *Clarias gariepinus* after immersion in the extracts and their proximate compositions evaluated. The samples were immersed in *C. sinensis* peel extract and marinated with spices. These samples were used to prepare fresh catfish pepper-soup (CPS), smoked catfish using charcoal (SCC) and smoked catfish using gas (SCG) in the various forms they are widely accepted and requested for in the Northern of the Country. Samples from each batch were taken for proximate analysis. The sensory evaluation showed that SCG had better flavor, texture and general acceptability than the SCC and the CPS. The result of the proximate analyses of the samples showed that the moisture content of the SCC is lower (10.04%) than that of SCG (14.80%) while the crude protein (55.34%) and crude fiber (14.22%) of the SCC where higher than the contents found in SCG samples (52.80% and 13.29%). Therefore, it is concluded that SCG immersed in *Citrus* extract is a more acceptable variant than other processed samples in this study but the SCC retains more nutrients.

INTRODUCTION

In Nigeria, fish is eaten fresh and smoked and forms much-cherished delicacies that cut across socio-economic, age, religious and educational barriers (Adebayo-Tayo et al., 2008) and it's a cheap but rich source of protein commonly consumed compared to other sources of animal proteins due to the higher cost (Akinjogunla et al., 2017). The importance of fish in the world cannot be over-emphasized as it is a source of food and income for many people (Akinjogunla et al., 2021). The various enzymatic reactions taking place in seafood before and after harvest lead to changes in the sensory and nutritional properties that invariably reduce the shelf-life of the products (Olatunde & Benjakul, 2018).

Smoking of fish species is one of the oldest and most common methods of fish preservation in many developing countries, second is sun-drying (Kumolu-Johnson et al., 2010). About 70 - 80 % of the marine and freshwater catches harvested locally are consumed in smoked form as estimated by Adeyeye & Oyewole (2016). The African catfish, *Clarias gariepinus* is among the most commonly cultured (both inside and outside its range of tropical and subtropical environments) (Adewolu et al., 2008) and smoked finfish in Nigeria (Akinola et al., 2006).

Some of the natural plant spices generally used in food preservation include garlic (*Allium sativum Linn*.), sweet orange peels (*Citrus sinensis*), cloves (*Syzgiuma romaticum*) and ginger (*Zingiber officinale roscoe*) (Oluborode et al., 2010) and their addition had enhanced the qualities of fishes during storage (Özyurt et al., 2012). Nigeria produces about 930,000 tons of citrus fruits annually from an estimate of about 3 million hectares (Muhammad, 2017). Orange peel flavonoids exhibit antioxidant, antimicrobial, anti-carcinogenic, antiviral, anti-allergic and anti-inflammatory activities (Debbarma et al., 2013), even in higher quantities than the seeds. Orange peel apart from yielding a large quantity of essential oils, also improves the drying rate of fish and the efficiency of smoking. A report by Vijayan et al. (2021) showed that catfish cured with orange rinds enriched the shelf-life of products by 120 days of storage.

This research aimed to study the effects of sweet orange, *C. sinensis* – L. Osbeck, 1757 (peel) extracts on the proximate composition and sensory assessment of the economically and commercially important African catfish, *C. gariepinus* - Burchell 1822 in various forms of processing conditions through secondary data collection to bring about the utilization of supposed waste plant products and encourage the need to look more inward in our quest to develop healthy methods of preservation and processing of our limited seafood.

MATERIAL AND METHODS

Collection and Preparation of Fish Samples and Plant Materials

A total of forty -five (45) African catfish samples *C. gariepinus* were randomly obtained from the concrete tanks for grow-out fish sizes at the Department of Fisheries and Aquaculture fish farm, Bayero University Kano. The total weight was measured using a sensitive weight balance calibrated in grams (g) while the total length was measured using a meter rule calibrated in centimeters (cm). The measured fish species had an average mean weight of 42.21g and an average total length of 24.56 cm while the orange (*C. sinensis*) rinds/peels were collected from orange sellers at Yan Lemo fruits market, Kano State, Nigeria. The fish were gutted and washed before being placed on wire mesh and allowed to drip naturally for 40 minutes while the orange rinds were washed and shade-dried at room temperature. The dried peels were milled using local mortals to obtain the powdered form. 300 g of the powered plant (orange peel) was soaked in 150 ml of distilled water for 24 h at room temperature and extracted according to the methods of Hegazy & Ibrahium (2012). The extract was filtered through a Whatman no.2 filter paper to remove peel particles.

Experimental Design

Fish samples of *C. gariepinus* reared in concrete ponds were allocated into three treatment groups based on popular demands within the environs where this study was carried out; each treatment consisted of 15 samples of fish and soaked for 30 minutes into the orange peel crude extract. The first treatment was smoked with gas, the second sample was smoked on charcoal and the third samples were used to prepare fresh catfish pepper soup. The smoked-dried fish was packaged in cartons to prevent dust, dirt and flies. The sensory evaluation of the treatments was later carried out.

Proximate Analysis and Sensory Assessment

The proximate analysis of fresh and smoked fish was carried out according to the official methods of analysis described by the Association of Official Analytical Chemists (AOAC, 2005). The sensory evaluation of the immersed samples (smoked and fresh) with orange peel extract was carried out using a 9-point hedonic scales method of Lim (2011) with key indicators ranging from 1–9 representing dislike extremely; dislike very much; dislike moderately; dislike slightly; neither like nor dislike; like slightly;

like moderately; like very much and like extremely respectively. Coded samples accompanied by questionnaires were presented to the panels. A 5-member trained test panel was used for the assessment. The comparison was carried out on organoleptic characteristics such as taste, texture, color, odor and overall acceptability/general comment as described by Freitas et al. (2019).

Data Analysis

The data obtained were subjected to descriptive statistics, frequency and percentage method in tabular forms, one-way analysis of variance (ANOVA) and a statistical significance was set at $p<0.05$ least significance difference (LSD) and Post-hoc deacon using statistical packaged for social sciences (SPSS) ver. 16.1.

RESULTS AND DISCUSSION

Table 1 shows the extent of the acceptability of fresh catfish pepper soup and smoked catfish with gas and charcoal. The majority of the respondents accepted smoked catfish with gas. The mean score of the sensory evaluation reveals that smoked catfish retained a very good score for appearance, taste, texture, color and general acceptance. The overall acceptability mean score in fish smoked with oven gas was higher than in the treatment smoked with charcoal.

The mean proximate composition (*C. gariepinus*) is presented in Table 2 where the ash content, moisture content, crude protein, crude fiber, ether extracts, dry matter, and nitrogen-free extracts were recorded.

Table 1. The summary of the hedonic scale assessment of *C. gariepinus*

Sensorial Evaluation	Parameters	Excellence	Very Good	Good	Fair
Physical Appearance	Gas	45%	45%	10%	0%
	Charcoal	30%	55%	15%	0%
	Pepper-soup	20%	30%	40%	10%
Taste	Gas	40%	60%	0%	0%
	Charcoal	35%	60%	5%	0%
	Pepper-soup	30%	50%	20%	0%
Aroma	Gas	35%	55%	10%	0%
	Charcoal	45%	45%	10%	0%
	Pepper-soup	22%	22%	56%	0%
Texture	Gas	65%	30%	5%	0%
	Charcoal	55%	35%	10%	0%
	Pepper-soup	5%	25%	50%	20%
General Appearance	Gas	50%	50%	0%	0%
	Charcoal	30%	55%	15%	0%
	Pepper-soup	55%	35%	0%	0%

Table 2. Proximate composition of fresh and smoked *C. gariepinus*

PARAMETERS (%)	Fresh (Pepper Soup)	Charcoal	Oven Gas
Ash	$1.00±0.03^{a}$	$3.88±0.10^{b}$	$3.46±0.05^{c}$
Moisture	$77.24 ±0.99^{a}$	$10.04±1.74^{b}$	$14.80±0.34^{c}$
Crude Protein	$40.31±0.7^{a}$	$55.34±0.42^{b}$	$52.80±0.34^{c}$
Crude Fiber	$16.00±0.64^{a}$	$14.22±0.15^{b}$	$13.59±0.04^{c}$
Ether Extract	$11.00±0.28^{a}$	$13.29±0.14^{b}$	$13.47±0.07^{b}$
Dry matter	$22.76±0.99^{a}$	$88.96±1.74^{b}$	$85.92±0.034^{b}$
NFE	$31.69±1.05^{a}$	$13.27±0.14^{b}$	$16.68±0.45^{c}$

Note: Mean ± Standard Error; values with different superscripts across row are significantly different at ($P < 0.05$)

Table 2 shows that the percentage of ash is highest in smoked *C. gariepinus* using charcoal and oven gas compared to the fresh type. Ash content is generally influenced by the fish size (Akinjogunla et al., 2017). The ash content in this study increased in the fish samples from different preservation methods except in the fresh fish sample. This contradicts the earlier report of Oluwaniyi & Dosumu (2009) who reported a reduction in ash across all preservation methods while Oladipo & Bankole (2013) reported that smoked (oven gas) fish has more ash content than fresh (pepper soup) *C. gariepinus*. Smaller-sized fish species and lean fishes like tilapia tend to have higher ash content due to the higher bone-to-flesh ratio (Kapute et al., 2013).

On the other hand, the percentage of moisture is significantly lower in the smoked types compared to the fresh type. There was a high moisture content in the fresh fish sample (catfish pepper soup) compared to the smoked fish sample (charcoal smoked and oven gas smoked). This report is similar to the report of Oparaku & Ojike (2013) that also documented high moisture content in fresh fish. The fresh (pepper soup) had the highest moisture content because water was absorbed into the fish in the process of boiling. The mean deviation analysis can be used to identify significant differences in the composition of *C. gariepinus* between the different smoking methods. According to Ezembu & Onwuka (2015), the lowest moisture in sun-dried fish was within the acceptable limit for the prevention of microbial spoilage because water activity determines the storage life of fish (Daramola et al., 2007).

The highest crude protein content of 55.34% was obtained from smoked catfish with charcoal while the lowest value of 40.31% was obtained from fresh (pepper soup) catfish. Looking at the crude protein percentage, we can see that the deviation from the mean for smoked *C. gariepinus* using charcoal is higher than for the other types. This suggests that smoking with charcoal may have a greater impact on the protein content of the fish compared to smoking with oven gas or the fresh type. This finding is in line with the reports from Aladetohun & Ndimele (2010).

According to documented reports of Okereke et al. (2014), the smoking process in fish samples reduces moisture contents and increases the protein content in them through heat desiccation thereby improving the nutritional value of the processed fish product. Reduced protein content in fresh catfish (pepper soup) observed in this study has also been reported by Akinwumi et al. (2013). Catfish samples used in this study were smoked using an open fire (traditional smoking kiln) where the hotness and smoke production give room for little or no human interference to enable regulation or control. The higher level of protein in the smoked catfish (oven gas or charcoal) in this study also agrees with earlier reports by Chukwu (2009) and Olabinjo et al. (2017). Low protein in the fresh catfish pepper soup could therefore be explained by the fact that protein contents decrease with an increase in moisture content (Akinjogunla et al., 2017). The high composition of proteins from the present study can account for good sources of protein for the consumer.

The fiber content of fish samples decreased in the smoked samples (gas or charcoal) of *C. gariepinus* in the present study. The smoked fish with oven gas had the most reduced fiber content, and this could be because the fire might have destroyed the fiber content during the smoking process.

Observed low-fat content in smoked fish in this study has been earlier reported by other authors (Chukwu, 2009). Increased fat in oven gas appeared to be directly related to low moisture content. This agrees with an earlier study documented by Daramola et al. (2007), attributing increased fat content to loss in moisture content.

Charcoal smoked fish in this study appears to be the most nutritious due to its high protein and fat content which were all previously reported in several studies (Daramola et al., 2007; Chukwu 2009; Farid et al., 2014).

CONCLUSION

Sweet orange peel extract can be utilized in fish smoking at various concentrations. Fish immersed in sweet orange peel and smoked using charcoal were more attractive in color and texture, compared with those smoked using gas and while the smoked catfish using oven gas had higher values of the proximate composition contents. The use of this method of processing will guide to enhance fish value chains, minimize deterioration damages of smoked fish and provide supplementary business opportunities for investors as well as refining the freight worth of smoked-dried African catfish. Results from this work have shown that catfish, (*C. gariepinus)* preserved with sweet orange rinds/peels extract is a good quality (in terms of appearance, taste, and overall acceptability) product, which can be improved upon with further studies.

Compliance with Ethical Standards

Authors' Contributions

VFA: Conceptualization, Supervision, Data curation, Formal analysis, Writing – review & editing

NIS: Investigation, Methodology, Formal analysis, Writing – original draft.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author on request.

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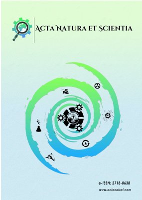

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Statistical Process Control Implementation in Inspection of Active Medicinal Compound Quality: A Model of First-Generation Antihistaminics

Mostafa Essam Eissa[1]✉

[1] Independent Researcher, Pharmaceutical and Healthcare Research Facility, Cairo, Egypt; mostafaessameissa@yahoo.com

✉ Corresponding Author: mostafaessameissa@yahoo.com

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Statistical process control

ABSTRACT

This study is part of a large project that includes surveying and screening medicinal compounds manufactured by chemical and pharmaceutical plants, notably in Asian countries and exported to developing countries. The current investigation focused on the active pharmaceutical ingredients (API) of one of the first-generation antihistamines of ethanolamine class known as 2-(diphenylmethoxy)-N,N-dimethylethanamine hydrochloride according to the International Union of Pure and Applied Chemistry (IUPAC) nomenclature. Harmonization of the specifications and analysis criteria were harmonized and all raw materials were claimed to be complying with the British Pharmacopoeia (BP) according to the manufacturers. Accordingly, all testing procedures were done according to the official standard methods detailed in the monograph of the chemical molecule. The selected tests were acidity or alkalinity, related substances, loss on drying (LOD), sulfated ash and assay (based on dried substance). Datasets were gathered and processed using Statistical Process Control (SPC) software. Preliminary data examination was done using box plots and distribution identification for screening the best-fitting one. With the exception of the assay, all results showed a failure to follow specific dispersion. All raw data failed normality tests (Anderson-Darling test, $P < 0.05$). Accordingly, the output of the tests was adjusted to fit the application of the attribute charts. Laney modification was used to correct data dispersion. The correction factor acidity/alkalinity, impurity A, any other impurities, total impurities, LOD and sulphated ash were 1.003, 1,18568, 1.21158, 1.71165, 1.44613 and 0.883609, respectively. Control chart for normal data was used after Johnson transformation following equation $0.558 + 1.211 \times \text{Ln}((X - 98.929)/(101.13 - x))$. It should be noted that even when there was no out-of-specification there were several out-of-control points that highlight the necessity for appropriate investigation and correction for assignable causes of variations between batches. There should be governmental enforcement of industrial SPC rules for the quality and safety of the supplied medicinal substances from the chemical manufacturing companies.

INTRODUCTION

In a globe of ever-growing healthcare and pharmaceutical complexity, numerous companies and enterprises contend in the medicine and medicinal products market (Eissa, 2020a, 2021; Eissa et al., 2016). Still, safety, quality and effectiveness come as the first-place precedence for the health of the final users (Liang & Mackey, 2011; Anonymous, 2019; Eissa et al., 2022). Medicinal constituents, either active or inactive, should be monitored and controlled for standard quality before the analysis and examination of the inspection properties of the final healthcare and medicinal finished product form. This should be stressed not only by the original manufacturer and the final customer but also by the regulatory industrial governmental agencies.

The implementation of statistical process control methodologies (SPCs) has become an essential and common practice in all pharmaceutical companies in order to achieve a predictable and acceptable level of quality (Mostafa Eissa, 2018; Eissa, 2018a; Essam, 2023). One of the most important SPC tools in the pharmaceutical industry is the Shewhart plot (SPC) (Eissa, 2015). It has a wide range of applications in many industries and non-industries for the assessment and control of processes and inspection parameters (Essam Eissa, 2017; Eissa et al., 2021a, 2021b, 2023a; Eissa, 2023a). Manufacturers of pharmaceutical-grade raw chemicals have expanded all over the world, making it possible to obtain them in retail markets and through brokers anywhere in the world (Eissa, 2023b). However, to ensure the current and future quality of pharmaceutical products, it is essential to ensure sustainable quality assurance for the expected chemical and physical properties.

It is expected that chemical manufacturing facilities are on the rise, especially in developing countries. The quality of chemical manufacturing firms in terms of Good Practices (G×P), including in the pharmaceutical and healthcare sectors, is in dispute (Eissa & Abid, 2018; Eissa, 2018b). The quality of the end product could be a reflection of the quality of the manufacturing process (Kim et al., 2021). Therefore, an organization that has the correct quality concept in place throughout the entire company would produce products that have acceptable, stable, and predictable properties with little chance of failure through effective strategy of SPC application.

In a crisis situation, there is a high likelihood of deterioration of the quality of the goods that are offered by the brokers, the wholesalers and the market retailers to satisfy the needs of the customers with cheap prices at the cost of the necessary quality inspection characteristics. Given the above challenges, the objective of this study was to evaluate the purity and goodness of a chosen excipient that is frequently included in the pharmaceutical preparations of chemical manufacturing companies. This study will focus on a critical test that is officially recognized as one of the essential inspection characteristics of inactive material.

MATERIAL AND METHODS

A chemical manufacturing plant of raw materials of pharmaceutical grade was assessed for the quality of the manufacturing output [16, 17]. Fifty-five samples of one of the common and classical antihistamine active medicinal materials were investigated for the acidity or alkalinity, related substances, Loss-On-Drying (LOD) and assay result trend (Eissa & Abid, 2018; Eissa, 2023). 2-N, N-dimethylethanamine (diphenylmethoxy) hydrochloride (DPHH) is a sedative and antihistamine that is mostly used to treat allergies, sleeplessness, and cold symptoms. It is also less often used to treat nausea and Parkinsonian tremors (Anonymous, 2020). All tests were done according to the standard method detailed by British Pharmacopoeia (BP) (Eissa, 2023c).

Official Tests for Acidity or Alkalinity, Related Substances, Loss on Drying and Assay

The British Pharmacopoeia monograph of Diphenhydramine outlines the detailed procedures for testing the active medicinal substance. For acidity and alkalinity, 0.15 mL of methyl red solution R and 0.25 mL of 0.01 M hydrochloric acid are to be added to 10 mL of solution S. The indicator is pink in color, and it takes no more than 0.5 mL of 0.01 M sodium hydroxide to turn it yellow.

For the test solution, 70 mg of the substance under examination is dissolved in the mobile phase and then diluted to a volume of 20.0 mL using the same mobile phase. A further dilution is performed by taking 2.0 mL of this solution and diluting it to 10.0 mL with the mobile phase. The preparation of reference solution (a) involves diluting 1.0 mL of the test solution to 10.0 mL with the mobile phase. This solution is then further diluted by taking 1.0 mL and diluting it to 20.0 mL with the mobile phase. Reference solution (b) is prepared by dissolving 5 mg of diphenhydramine impurity A CRS and 5 mg of diphenylmethanol R in the mobile phase and diluting this to 10.0 mL with the mobile phase. To 2.0 mL of this solution, 1.5 mL of the test solution is added and the resulting solution is diluted to 10.0 mL with the mobile phase.

The column used in this procedure has a length (l) of 0.25 m and a diameter (Ø) of 4.6 mm. The stationary phase is a base-deactivated octylsilyl silica gel for chromatography R (5 µm). The mobile phase is a mixture of 35 volumes of acetonitrile R and 65 volumes of a 5.4 g/L solution of potassium dihydrogen phosphate R, which has been adjusted to a pH of 3.0 using phosphoric acid R. The flow rate is set at 1.2 mL/min. Detection is carried out using a spectrophotometer set at 220 nm. An injection volume of 10 µL is used. The run time is seven times the retention time of diphenhydramine. The relative retention times, with reference to diphenhydramine (retention time = about 6 min), are as follows: impurity A = about 0.9; impurity B = about 1.5; impurity C = about 1.8; impurity D = about 2.6; impurity E = about 5.1. The system suitability is checked using reference solution (b). The resolution should be a minimum of 2.0 between the peaks due to diphenhydramine and impurity A.

The limits are as follows: the correction factor for the calculation of content is 0.7, which is applied to the peak area of impurity D. The area of impurity A should not exceed the area of the principal peak in the chromatogram obtained with reference solution (a) (0.5%). The area of any other impurity should not be more than 0.6 times the area of the principal peak in the chromatogram obtained with reference solution (a) (0.3%). The total area should not be more than twice the area of the principal peak in the chromatogram obtained with reference solution (a) (1.0%). The disregard limit is 0.1 times the area of the principal peak in the chromatogram obtained with reference solution (a) (0.05%).

The loss on drying should not exceed 0.5%, as determined on 1 g by drying in an oven at 105°C. The sulfated ash should not exceed 0.1%, as determined on 1.0 g. For the assay, 0.250 g is dissolved in 50 mL of ethanol (96%) R and 5.0 mL of 0.01 M hydrochloric acid is added. A potentiometric titration is carried out using 0.1 M sodium hydroxide. The volume added between the two points of inflexion is read. 1 mL of 0.1 M sodium hydroxide is equivalent to 29.18 mg of $C_{17}H_{22}ClNO$.

Statistical Analysis

To determine the appropriate statistical method for process behavior analysis, data distribution was initially assessed. The Anderson-Darling (AD) test was employed to evaluate the goodness-of-fit of the data to an assumed distribution at a significance level of α=0.05. This test measures the discrepancy between the observed data and the expected values under the hypothesized distribution. If the AD test indicated non-conforming data spreading, the Johnson transformation family was applied to transform the data into a more conforming distribution (Eissa, 2023c). This family of transformations includes several distributions capable of accommodating various data shapes.

For data that successfully met the distribution assumption, variable process-behavior charts, including capability analysis, were constructed using Minitab® 17.1.0. However, for datasets that did not conform to any standard distribution, even after transformation, attribute-type (after suitable processing) or Individual (I) control charts were utilized (Eissa, 2023c). In cases where the initial diagnostic U-chart indicated deviations from the assumed Poisson distribution, Laney corrections were applied to adjust for overdispersion or underdispersion. This approach allowed for a comprehensive analysis of the data, selecting the most appropriate statistical method based on the data's characteristics and ensuring accurate interpretation of process behavior.

RESULTS AND DISCUSSION

This study is a component of an organization-wide assessment aimed at achieving the chemical plant's Total Quality Management (TQM) objectives (Eissa, 2019a; Rashed & Eissa, 2020). Production mistake detection, reduction, and elimination are ongoing processes carried out by the total quality management (TQM) technique (Rashed & Eissa, 2020). It expedites supply chain coordination, guarantees that workers receive the most recent training available, and improves customer satisfaction (Rashed & Eissa, 2020). All parties engaged in the production process must be held responsible for the overall quality of the finished good or service in order to accomplish total quality management. An indispensable analytical technique to achieve this goal is the use of SPC methodologies.

Box and Whisker Plot (Box Plot)

This diagram showed the dispersion pattern of the datasets and the level of skewness (Eissa, 2022). For Figure 1, it could be noted that various degrees of distortion from the normal pattern were present in the datasets which are less evident in the LOD and assay data. Moreover, the presence of outliers further skewed the results which could be detected in the total impurities and sulfated ash records. In turn, all raw data did not pass the normality tests using the Anderson-Darling (AD) test at P=0.05. Best-fitting distribution identification did not return any valid type of spreading - except for the assay after Johnson transformation to the normal pattern of dispersion – as all P values were < 0.05.

Checking for Poisson Distribution

While the Poisson assumption is a starting point for many U-chart applications, it's essential to assess the data's distribution to ensure the chart's effectiveness. Data results that could not fit any kind of dispersion – even after transformation, could be adjusted to fit the attribute type of control charts as a number of parts per 10,000 units (depending on the sensitivity of the measurement units). However, checking for the fitness of the presumed Poisson distribution should be verified to avoid misleading control limits with the risk of low or high alarm rates depending on the presence of overdispersion or underdispersion (Eissa, 2019b). Hence, the diagnostic tool of U chart was used as could be seen in Figure 2 for six inspection characteristics. All of them demonstrated the necessity for adopting Laney correction to adjust for data spreading.

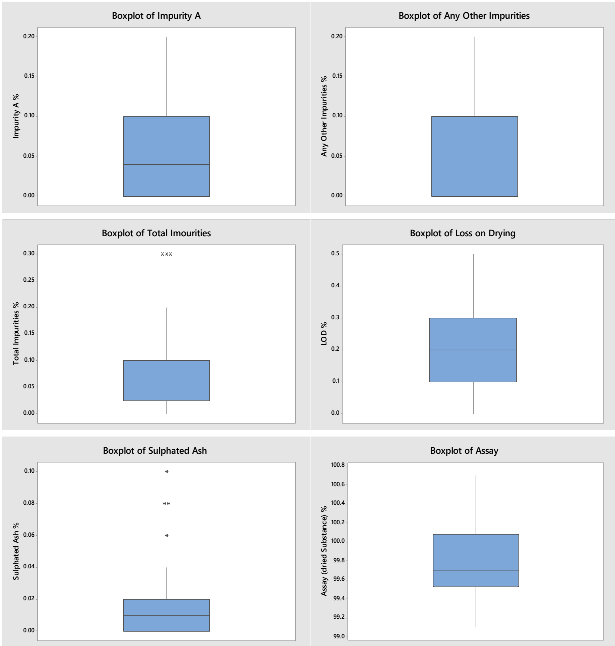

Figure 1. Box/Whisker diagram showing the dispersion and skewness of the datasets of the analyzed inspection characteristics via quartiles for one of the first-generation antihistamines of ethanolamine class. Asterisks are indication of the outlier data points

Laney Process-Behavior and Individual-Moving Range (I-MR) Plots

Many procedures that entail measuring, controlling, and monitoring of the inspection qualities under examination are built around process-behavior charts (Eissa, 2019; 2020b). It is possible to use any of the two Shewhart chart types—variable or attribute control charts—which have been used in the past (Eissa, 2019a, 2023c; Rashed & Eissa, 2020). The different kinds of warnings might be discussed in more depth in other earlier studies (Eissa et al., 2023b). The following guidelines would be used to compute the control window and average that are used in Figures 3 to 6.

Center line (CL) of an individual (I) chart: Mean of the individual data points. For the I chart, the upper control limit (UCL) is CL + 2.66 x Avg Moving Range. The Lower Control Limit (LCL) for the I chart is equal to CL - 2.66 x Average Moving Range (MR), or 0 in the event that the MR is negative. The center line (CL) of the MR chart represents the mean of MR (Eissa et al., 2023b; Rashed & Eissa, 2020). The Upper Control Limit (UCL) for the MR chart is 3.27 times the Average Moving Range. The Lower Control Limit (LCL) for MR charts is set to zero.

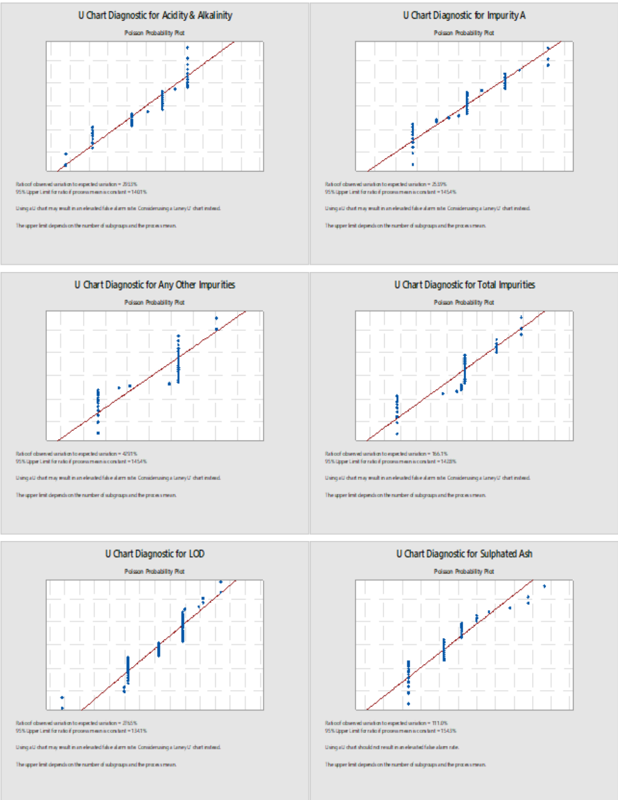

Figure 2. Diagnostic U chart for examination of the fitting to the presumed distribution for quality control tests of 2-(diphenylmethoxy)-N,N-dimethylethanamine Hydrochloride

With regard to the U charts, equations 1 through 7 show that the primary components of the trending charts may be calculated for the Laney adjustments. When the data deviates from the Poisson distribution, it might result in inaccurate control limits and subsequent alerts because of overspreading or underdispersion (Eissa, 2017). In such cases, this kind of chart is utilized. In order to use the traditional chart, the ideal dispersion ratio in the U chart diagnosis should be between an acceptable specific range (Eissa et al., 2023). where *ui* is the subgroup's number of defects, *ni* is the subgroup's size, *zi* is the z-score, *u(prime)* is the data mean, and *σz* is computed as MR(bar)/1.128, where *MR(bar)* is a moving range of length two, the figure is an unbiasing constant, and *σui* is the standard deviation. Subgroup i's count rate is ui. The standard deviation that has been adjusted for overdispersion or underspreading is sd(ui).

$$\sigma_{ui} = \sqrt{\bar{u}/n_i} \quad (1)$$

$$z_i = \frac{u_i - \bar{u}}{\sigma_{ui}} \quad (2)$$

$$u_i = \bar{u} + \sigma_{ui}.z_i \quad (3)$$

$$sd(u_i) = \sigma_{ui}.\sigma_z \quad (4)$$

$$CL = \bar{u} \quad (5)$$

$$UCL = \bar{u} + 3.\sigma_{ui}.\sigma_z \quad (6)$$

$$LCL = \bar{u} - 3.\sigma_{ui}.\sigma_z \text{ or } = \text{zero} \quad (7)$$

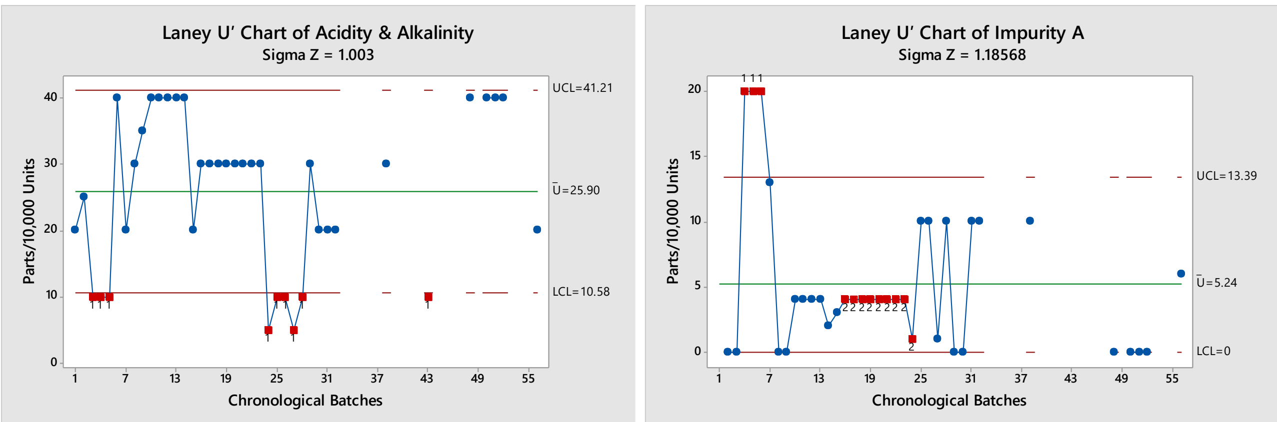

Figure 3. Laney-corrected attribute charts for the acidity/alkalinity and impurity A tests

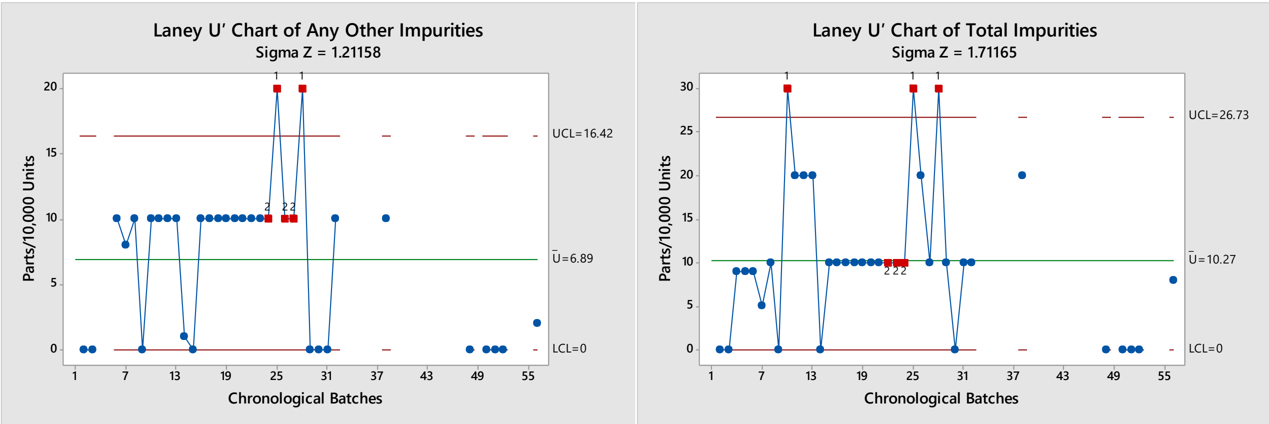

Figure 4. Laney-corrected attribute charts for the other impurities and total impurities tests

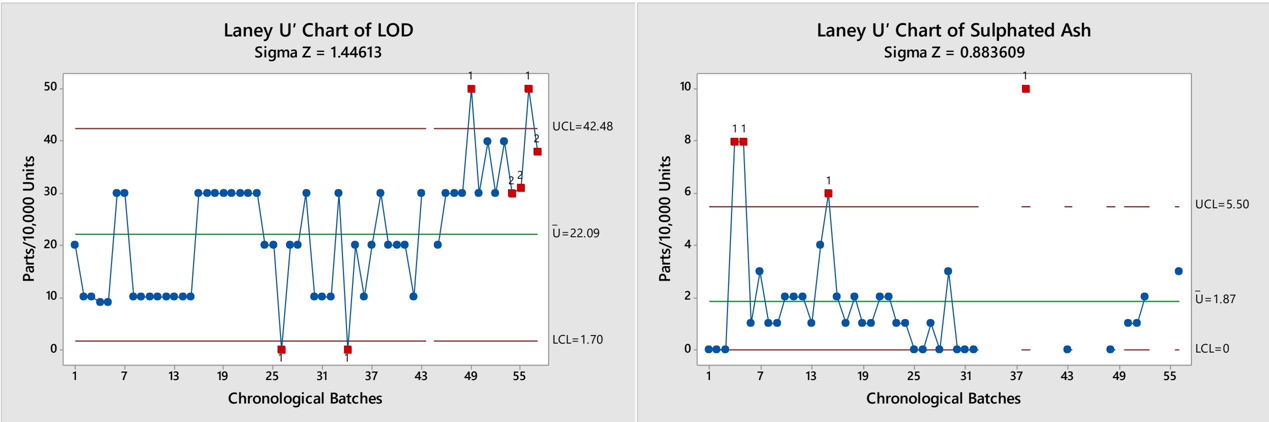

Figure 5. Laney-corrected attribute charts for the Loss on Drying (LOD) and sulphated ash tests

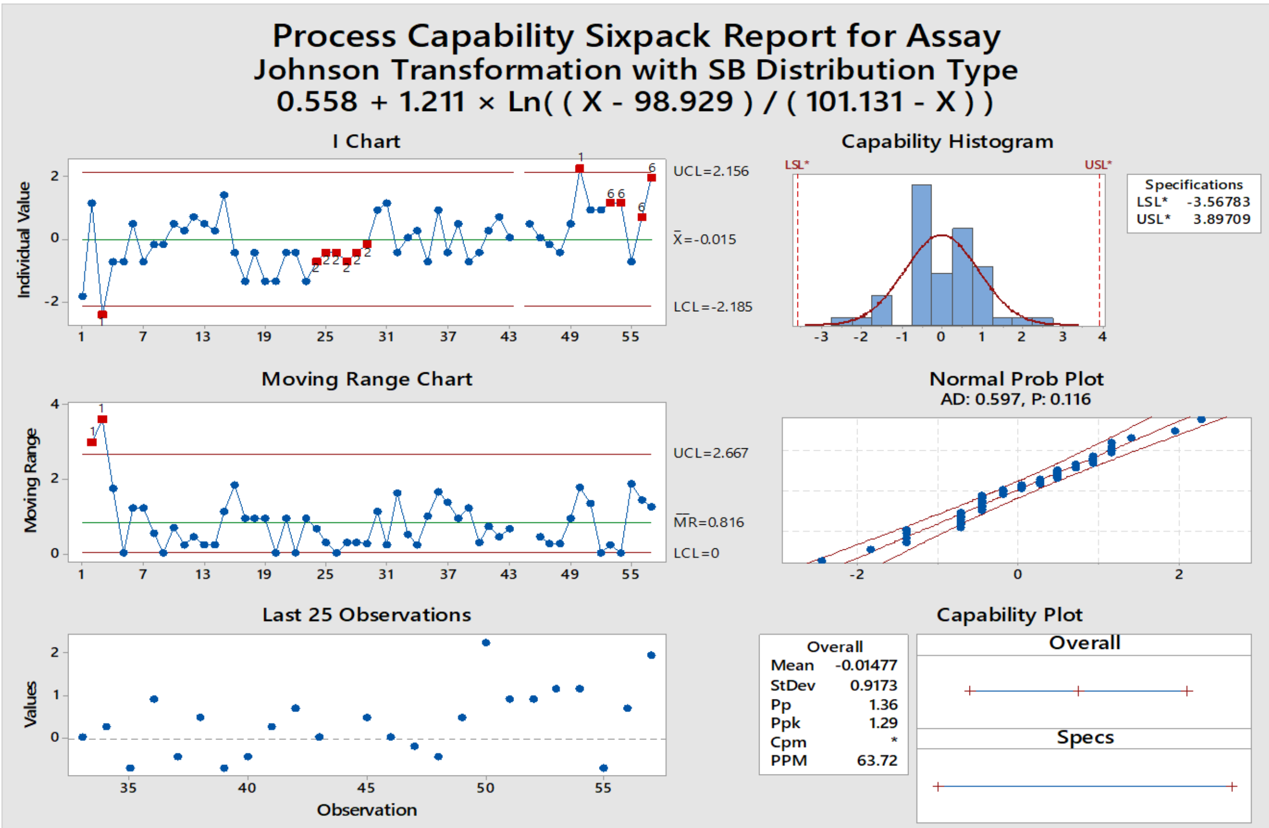

Figure 6. Comprehensive overall capability analysis of the assay test based on dried substance using variable trending chart

Based on past experiences, Laney-adjusted control charts have shown to be a useful method for trend analysis of datasets that have not followed certain distribution patterns (van den Ban & Goodwin, 2017). For widely used distributions like Gaussian and Poisson spreading patterns, all inspection criteria failed to show appropriate fitting (Mostafa, 2019). In order to assess the qualities being studied, it was necessary to adjust the data for Laney attribute charts in a way that produced results that could be understood. For the variable control chart of the assay, despite the control limits being confined within the specification range, the presence of several out-of-control points precludes the use of the capability analysis till the stabilization of the process could be accomplished.

Establishing comprehensive SPC methodology implementation is crucial for chemical manufacturing organizations, as it forms an essential component of Total Quality Management (TQM) across the whole enterprise (Ismail, 1998). To enforce safety and quality concepts into the products, however, regulatory monitoring and surveillance in the industrial sector are essential. Until the SPC procedures are properly integrated into the foundations of the legislation governing the chemical sector, the receiver customer should monitor the given lots using appropriate statistical tools to keep a watch on the goods they get (Saha et al., 2022). This is particularly crucial for emerging and economically distressed countries.

The current study identifies a significant and distinctive viewpoint in the physical and chemical criterion-based API trending and monitoring. The highly competitive world of pharmaceutical and medical products demands stringent monitoring and control of the production field's quality (Ahmed Eissa, 2018). The fundamentals, or the raw components, are where this vision starts. Seeing the trending pattern of the inspection properties of the chemical entities is an important task that provides insight into the behavior of the inspection characteristics with the produced batches provided reflecting the condition of the quality delivered to the organization's ultimate clients.

When monitoring a process in a time sequence or serial fashion, control charts are crucial. In order to detect changes in the attributes under examination and ascertain whether these changes are most likely the consequence of common or unique cause variations, limiting thresholds are specified and they display the mean. Statistical analysis and correlation studies would be useful to understand the trending pattern and the properties (chemical and physical) of the manufactured chemical product that is given as a raw material. Ensuring the production of medical supplies that meet consistent, dependable, and satisfactory quality standards is an essential analytical undertaking.

CONCLUSION

Plots of process behavior derived from datasets that were non-normally distributed as well as the normal assay dataset demonstrated that the produced raw material quality exhibited uncontrollable states as batches progressed in chronological order. In addition, process capability monitoring output cannot be considered until stabilization of the inspection trends could achieved, and in order to enhance the performance index level, there needs to be a tightening of the variances in the inspection characteristic of all tests within the specification's windows. As a result, in order to reduce the possibility of uncontrollable outcomes that exceed the upper and/or lower limiting barrier in the future, the process means should be moved closer to the center. Nevertheless, for one-sided specification, it would be desirable that the trends of the inspection characteristics could be brought toward the diminishing side. It is recommended that pharmaceutical raw materials synthesized by the company should be included in future research investigations together with other inspection qualities of the raw material.

Compliance with Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

The author declares that this document does not require ethics committee approval or any special permission. This study does not cause any harm to the environment.

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Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author on request.

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ACTA NATURA ET SCIENTIA PRENSIP

Bazı Yulaf (*Avena sativa* L.) Genotiplerinin Tane Verimi ve Kalitesi Açısından İncelenmesi

Seda Alatürk[1] • Tülay Tütenocaklı[2]✉

[1] Çanakkale Onsekiz Mart University, School of Graduate Studies, Department of Biology, 17100, Çanakkale, Türkiye, sedaalaturk@gmail.com
[2] Çanakkale Onsekiz Mart University, Lapseki Vocational School, 17100, Çanakkale, Türkiye, tulaytutenocakli@comu.edu.tr

✉ Corresponding Author: tulaytutenocakli@comu.edu.tr

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Yulaf (*Avena sativa* L.)
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Ham lif
Hektolitre ağırlığı

ÖZET

Bu araştırma bazı yulaf (*Avena sativa* L.) genotiplerinin farklı agronomik özelliklerini karşılaştırmak amacıyla yapılmıştır. Araştırma 2018-2020 yıllarında Edirne'de Trakya Tarımsal Araştırma Enstitüsü deneme alanlarında yürütülmüştür. Denemede 15 yulaf genotipi ile 5 standart çeşit (Kırklar, Kahraman, Küçükyayla, Yeniçeri ve Sebat) kullanılmıştır. Araştırma Tesadüf Blokları Deneme Desenine göre üç tekerrürlü olarak kurulmuştur. Çalışmada bin dane ağırlığı (BDA), hektolitre ağırlığı (HA), göreceli yem değeri (GYD), metabolik enerji (ME), ham lif (HL), ham kül (HK) ve sindirilebilir kuru madde (SKM) özellikleri ele alınmıştır. Yapılan çalışmanın sonucunda SKM değeri hariç diğer tüm özellikler yıllara göre önemli değişim göstermiştir. Ayrıca incelenen bütün özellikler genotiplere göre önemli oranda değişim göstermiştir. Genotiplerin ortalama BDA 24,1-43,2 g, HA 50,1-62,6 kg/hl, GYD 205,0-328,3, ME 2,56-2,76 Mcal/kg, HL %7,88-13,82, HK %4,35-5,83 ve SKM değerleri ise %73,1-78,3 arasında değişim göstermiştir. Genel olarak tane verimi bakımından 3 ve 5 numaralı genotipler, tanenin besleme değerleri bakımından ise 3, 4, 6, 10 ve 11 numaralı genotipler ön plana çıkmıştır. Yürütülen bu araştırma neticesinde benzer ekolojilerde yapılacak olan yulaf yetiştiriciliğinde 3, 4, 6, 10 ve 11 numaralı genotiplerinin diğer genotiplere göre incelenen özellikler bakımından daha yüksek değerlere sahip oldu ve bu genotiplerinin yetiştirilmesinin ekonomik yönden fayda sağlayacağı sonucuna varılmıştır.

Investigation of Some Oat (*Avena sativa* L.) Genotypes in Terms of Grain Yield and Quality

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ABSTRACT

This research was conducted to compare different agronomic characteristics of some oat (*Avena sativa* L.) genotypes. The research was carried out in the trial fields of Trakya Agricultural Research Institute, located in Edirne, in 2018-2020. In the experiment, 15 oat genotypes along with 5 standard varieties namely; Kırklar, Kahraman, Küçükyayla, Yeniçeri and Sebat were used. The research plan was designed according to the Randomized Complete Block Design using three replications. In the study, thousand grain weight (TGW), hectolitre weight (HW), relative feed value (RFV), metabolic energy (ME), crude fibre (CF), crude ash (CA) and dry matter digestibility (DMD) characteristics were examined. As a result of this study, all the characteristic values of oat showed significant differences in terms of years except for; DMD. Additionally, all the examined traits showed significant differences in terms of genotypes. The average mean values of TGW, HW, RFV, ME, CF, CA and DMD of examined genotypes showed variation between 24.1-43.2 g, 50.1-62.6 kg/hl, 205.0-328.3, 2.56-2.76 Mcal/kg, 7.88-13.82%, 4.35-5.83% and 73.1-78.3%, respectively. Generally, genotypes 3 and 5 took the first place in terms of grain yield, whereas the genotypes 3, 4, 6, 10 and 11 in terms of grain nutritional values. Consequently, it is concluded that the genotypes 3, 4, 6, 10 and 11 have higher values in terms of the examined traits as compared to the rest genotypes. So, these genotypes would be more suitable for oat cultivation under similar ecological conditions with the expectation of satisfactory economic benefits.

GİRİŞ

Yulaf (*Avena sativa*) Poaceae familyasının Poeae oymağına ait bir cinstir. Yulafın beyaz yulaf (*Avena fatua*) ve kısır yabani yulaf (*Avena sterilis*) olmak üzere iki adet yabani formu ile beyaz yulaf (*Avena sativa*), çıplak yulaf (*Avena nuda*) ve kırmızı yulaf (*Avena byzantina*) olmak üzere 3 adet kültür formu bulunmaktadır (Yürür, 1998). Yulaf tarımında dünyada hem yazlık hem de kışlık olarak ekilebilen beyaz (*Avena sativa*) ve kırmızı yulaf (*Avena byzantina*) kullanılmaktadır. Fakat insan beslenmesinde ise sadece beyaz yulaflar tercih edilmektedir (Sabandüzen, 2017). Kültürü yapılan yulaf hekzaploid (2n=42) ve %20-37 oranında taneleri kavuzludur. 1000 tane ağırlığı 15-45 g ve hektolitre ağırlığı 35-55 kg arasında değerlere sahiptir (Karaman vd., 2020).

Yulaf (*Avena sativa*) dünyada insan beslenmesinin yanında hayvan beslemede de kullanılan en önemli serin iklim tahıllarının başında gelmektedir (Hoffmann, 1995; Buerstmayr, 2007; Dumlupınar, 2010). Yulaf tanesi insan beslenmesinde bisküvi, bebek maması, yulaf ezmesi vb. olarak kullanılmasının yanında hayvanların kaslarını geliştirme ve çeki gücünü artırması, yeşil otunun ise yüksek yem değerlerine sahip olmasından dolayı hayvan beslenmesinde de yaygın olarak kullanılmaktadır (Topal vd., 2015; Özdener Şener, 2017). İçerisindeki doymamış yağ asitlerinden dolayı sütün yağ oranını ve verimini artırması nedeniyle süt üretimi amacıyla kurulan işletmelerde önemi daha da artmaktadır (Kün, 1996; Karaman vd., 2020). Yulafın saplarının yumuşak olması ve organik ile mineral element içeriğinin zengin olması diğer tahıl samanlarından bir adım öne çıkmasını sağlamıştır (Köse vd., 2019; Topkara, 2019). Saman içeriğinde yaklaşık olarak %90 kuru madde, %1-3 ham yağ ve selüloz ile %3-4 oranında ham protein ihtiva etmektedir (Kün, 1988). Tanenin nişasta oranı yaklaşık olarak %40'tır. Bu nişastanın %25-30'luk kısmını ise amilaz meydana getirmiştir (Singh vd., 2013). Yulaf ruminantlar için serin iklim tahılları içerisinde nişasta sindirilebilirliği en yüksek olan cins olarak öne çıkmaktadır (Yalçın, 2020).

Yulaf kışlık tahıllar içerisinde en yüksek yağ, lif ve β-glukan içeriğine sahip tahıldır (Dağ & Özkan, 2019). Son yıllarda yapılan çalışmalarda yulaf tanesinin içermiş olduğu β-glukan polimeri ve avenin proteini sayesinde insanlarda obezite, şeker, kanser, kolesterol, kardiyovasküler hastalıklar ve kanser gibi hastalıkların önüne geçildiği sonuçlarına ulaşılmıştır (Köksel & Özboy, 1993; Chaudhari, 1999; Çağındı, 2009; Yaver & Ertaş, 2013; Karaman vd., 2020). Yulafta protein içeriği şartlara bağlı olarak %10-24 arasında değişiklik göstermektedir (Robbins vd., 1971). Yulafın avenin adlı prolamin içermesinden dolayı protein kalitesi et ve süte eşdeğer soya proteinine benzerlik gösterdiği vurgulanmıştır (Singh vd., 2013).

Ülkemizde serin iklim tahıllarının ekim alanlarına sıralaması buğday (6,832 milyon ha), arpa (3,278 milyon ha), yulaf (1,382 milyon ha), tritikale (1,102 milyon ha) ve çavdar (989,6 bin ha) şeklinde olmaktadır. Yıllık üretim miktarları ise yine sırasıyla buğday 22 milyon ton, arpa 9,2 milyon ton, yulaf 410 bin ton, tritikale 370 bin ton ve çavdar ise 305 bin tondur. Dekara verimleri ise buğday 322 kg, arpa 281 kg, yulaf 297 kg, tritikale 336 kg ve 308 kg olarak hesaplanmıştır (TÜİK, 2023).

Bu araştırmada Marmara bölgesinde farklı yulaf genotiplerinin agronomik ve tane besin değerleri yönünden karşılaştırılması ve en uygun çeşitlerin belirlenmesi amacıyla yürütülmüştür.

MATERYAL VE YÖNTEM

Bu çalışma 2018-2020 yıllarında Edirne Trakya Tarımsal Araştırma Enstitüsünde yürütülmüştür. Çalışmada 5 standart yulaf çeşidi ile Trakya Tarımsal Araştırma Enstitüsü tarafından geliştirilen 15 yulaf hattı kullanılmıştır (Tablo 1). Araştırma Tesadüf Blokları Deneme Desenine göre üç tekerrürlü olarak kurulmuştur.

Denemenin yürütüldüğü alandan 0-20 cm derinlikten alınan toprak örneklerinin analizleri Kırklareli Atatürk Toprak Su ve Tarımsal Meteoroloji Araştırma Enstitüsü Müdürlüğü Bitki Besleme ve Toprak Bölümü laboratuvarlarında yapılmıştır. Yapılan analiz neticesinde deneme topraklarının pH değeri 7,74, toplam tuz içeriği %0,05, kireç içeriği %9,50, organik madde içeriği %1,49 (az), yarayışlı fosfor içeriği 24,81 kg/da (çok fazla) ve yarayışlı potasyum içeriği ise 89,62 kg/da (yeterli) olarak tespit edilmiştir.

Table 1. Oat lines and varieties used in the research
Tablo 1. *Araştırmada kullanılan yulaf hatları ve çeşitleri*

Numara	Çeşit veya Pedigri
1	Küçükyayla (st)
2	Kırklar (st)
3	LA09088SBS-0BD-0BD-0T-5T-0T
4	LA09092SBS-0BD-0BD-0T-13T-0T
5	Kahraman (st)
6	LA09088SBS-0BD-0BD-0T-16T-0T
7	LA09092SBS-0BD-0BD-0T-5T-0T
8	IL 3555-0BD-0T-5T-0T
9	FL0557-0BD-0T-0T-3T-0T
10	Yeniçeri (st)
11	TEY 008-0T-0T-5T-0T
12	TEY 013-0T-0T-2T-0T
13	TEY 014-0T-0T-14T-0T
14	TEY 022-0T-0T-2T-0T
15	TEY 023-0T-0T-3T-0T
16	TEY 027-0T-0T-6T-0T
17	Sebat (st)
18	TEY 029-0T-0T-10T-0T
19	TEY 029-0T-0T-11T-0T
20	FL04154-0BD-0T-0T-5T-0T-4T-0T

Denemenin yürütüldüğü yıllarda ortalama sıcaklık değerleri ilk yıl 12,5°C iken, bu değer ikinci yılda 13,2°C'ye yükselmiştir. En sıcak aylar haziran ve eylül olurken, en soğuk aylar ise aralık ve ocak olmuştur. Araştırmanın yürütüldüğü yıllara ait dönemlerde (10 aylık 2 yıllık 2 ayrı dönem) toplam yağış miktarı ilk yıl 539,2 mm iken bu değer çalışmanın ikinci yılında 419,3 mm'ye düşmüştür. En yağışlı ay 208,8 mm ile ilk yıl kasım ayı olurken, en düşük yağış ise eylül ve kasım aylarında düşmüştür (Tablo 2).

Table 2. Climate data for the study periods (2018-2020)

Tablo 2. *Araştırmanın yürütüldüğü dönemlere ait (2018-2020) iklim verileri*

Aylar	Dönem	ToplamYağış (mm)	Ortalama Sıcaklık (°C)
Eyül	2018	15,8	20,9
	2019	12,2	21,7
Ekim	2018	32,6	15,7
	2019	24,6	16,5
Kasım	2018	208,8	9,8
	2019	41,2	14,0
Aralık	2018	16,8	3,9
	2019	26,2	6,9
Ocak	2019	82,4	4,1
	2020	9,4	3,5
Şubat	2019	18,2	5,6
	2020	32,6	7,4
Mart	2019	7,6	9,8
	2020	39,3	10,5
Nisan	2019	60,4	12,4
	2020	98,2	12,3
Mayıs	2019	63,4	18,2
	2020	87,2	18,4
Haziran	2019	33,2	24,5
	2020	48,4	22,7
Toplam/Ortalama	2019	539,2	12,5
	2020	419,3	13,2

Not: İklim verileri Edirne Meteoroloji İl Müdürlüğünden alınmıştır.

Çalışmada ekimler ilk yıl 19 Ekim 2018, ikinci yıl ise 22 Ekim 2019 tarihinde gerçekleştirilmiştir. Deneme alanında parsel boyutları 1 m genişliğinde 7 m uzunluğunda olacak şekilde tanzim edilmiştir. Fakat hasat sırasında kenar tesirler (kenarlardan 0,5 cm) çıkarıldıktan sonra hasat yapılmıştır. Toplam hasat edilen alan 6 m^2 olarak gerçekleşmiştir. Ekim 500 adet tohum/m^2 olacak şekilde yapılmıştır. Denemede ekimle beraber 4 kg/da N ve 4 kg/da P olacak şekilde kompoze (20-20-0) gübreden, kardeşlenme döneminde ise 7 kg/da N üre (%46) olarak ve sapa kalkma döneminde ise 5 kg/da N da amonyum nitrat (%26) şeklinde uygulanmıştır. Denemede her iki yılda 60'ar örnek olmak üzere toplam 120 örnek üzerinden analizler yapılmıştır. Parsellerden alınan örnekler 0,5 mm elek çapına sahip laboratuvar tipi değirmende öğütülüp analize hazır hale getirilmiştir. Laboratuvara getirilen örneklerde ham kül, ham lif, NDF, ADF ve ADL analizleri NIR cihazı (Spectrastar 2400D, Unity Scientific, USA) yardımı ile yapılmıştır. 1000 tane ağırlıkları ile hektolitre ağırlıkları Kara vd. (2007)'ye göre, göreceli yem değeri Tremblay (1998)'e göre ve metabolik enerji değeri ise Khalil vd. (1986)'e göre hesaplanmıştır. Araştırmadan elde edilen verilerin varyans analizleri JMP (5) istatistik paket programı yardımıyla yapılmıştır. Ortalamalar arasındaki farklılıklar LSD testi ile yapılmıştır (Kalaycı, 2005).

BULGULAR

1000 Tane Ağırlığı (g)

Yapılan varyans değerlendirmesine göre 1000 tane ağırlıkları yıllara, genotiplere ve bunlar arasındaki etkileşimlere göre önemli oranlarda değişim göstermiştir ($p<0,05$). Araştırmada genotiplerin ilk yıl ortalama 1000 tane ağırlıkları 35,2 g iken bu değer ikinci yıl 36,3 g'a yükselmiştir. 1000 tane ağırlığı en yüksek genotip 43,2 g ile 3 numaralı genotip olurken bunu 40,4 g ile 1 ve 39,5 g ile 16 numaralı genotipler izlemiştir. En düşük 1000 tane ağırlığı ise 24,1 g ile 17 nolu genotipte tespit edilmiştir (Tablo 3).

Hektolitre Ağırlığı (kg/hl)

Yapılan varyans analizine göre yulaf genotiplerine ait hektolitre ağırlıkları uygulanan tüm faktörlere (yıl, genotip ve yıl×genotip) bağlı olarak önemli oranda değişmiştir ($p<0,05$) (Tablo 4). 1000 tane ağırlığında olduğu gibi hektolitre ağırlıklarında da ikinci yıl (58,1 kg/hl) araştırmanın ilk yılına göre (57,7 kg/hl) daha yüksek sonuçlar elde edilmiştir. En yüksek hektolitre ağılıkları 62,6 kg/hl ile 5 numaralı genotip ve 62,0 kg/hl ile 13 numaralı genotiplerde tespit edilmiştir. En düşük hektolitre ağırlıkları ise 50,1 kg/hl ile 12 numaralı genotipte belirlenmiştir. Yıl ile genotip etkileşimlerinde ise en yüksek hektolitre ağırlıkları araştırmanın ilk yılında 62,9 kg/hl ile 3 ve 4 numaralı genotipler ile 62,8 kg/hl ile 13 numaralı genotipte belirlenmiştir. En düşük değerler ise 50,0 ve 50,2 kg/hl ile araştırmanın birinci ve ikinci yılındaki 12 numaralı genotipte ölçülmüştür (Tablo 4).

Table 3. 1000 grain weights of different oat genotypes

Tablo 3. *Farklı yulaf genotiplerine ait 1000 tane ağırlıkları*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	37,5 de J-M	43,2 b B	40,4 **b**
2	36,7 e-g LMN	37,9 gh I-L	37,3 **gh**
3	41,4 a CD	45,0 a A	43,2 **a**
4	39,0 c GHI	39,7 d-f FG	39,3 **cd**
5	34,5 h O	38,3 f-h HIJ	36,4 **h**
6	37,4 d-f J-M	41,0 cd DE	39,2 **cd**
7	35,9 g N	38,3 f-h HIJ	37,1 **gh**
8	31,1 j Q	30,0 j Q	30,6 **k**
9	37,9 d IJK	39,2 fg GH	38,6 **de**
10	26,3 k R	26,1 k RS	26,2 **l**
11	37,3 d-f J-M	40,8 c-e DEF	39,1 **c-e**
12	37,1 d-f J-M	32,5 ı P	34,8 **ı**
13	36,8 ef K-N	38,3 f-h HIJ	37,5 **fg**
14	33,2 ı P	30,6 j Q	31,9 **j**
15	30,7 j Q	32,4 ı P	31,6 **j**
16	36,6 fg MN	42,3 bc BC	39,5 **c**
17	25,1 l S	23,1 l T	24,1 **m**
18	40,1 b EFG	39,4 e-g GH	39,7 **bc**
19	39,2 c GH	37,3 h J-M	38,3 **ef**
20	30,7 j Q	30,2 j Q	30,4 **k**
Ortalama	35,2 **b**	36,3 **a**	-
Önemlilik	PYıl:0,0064, PGenotip:0,0001, PYıl×Genotip:0,0001		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Table 4. Hectoliter grain weights of different oat genotypes

Tablo 4. *Farklı yulaf genotiplerine ait hektolitre tane ağırlıkları*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	58,0 d JK	60,2 bc EF	59,1 **e**
2	59,7 c FG	59,4 c-e FGH	59,5 **de**
3	62,9 a A	58,8 de G-J	60,8 **bc**
4	62,9 a A	58,1 ef IJ	60,5 **bc**
5	62,7 a AB	62,4 a ABC	62,6 **a**
6	61,5 b CD	58,8 de G-J	60,2 **cd**
7	56,7 e LM	56,6 g LMN	56,6 **hı**
8	55,0 gh OPQ	54,0 h Q	54,5 **j**
9	54,6 h PQ	58,6 de HIJ	56,6 **hı**
10	55,5 fg OP	59,1 c-e GHI	57,3 **f-h**
11	59,8 c FG	61,7 a BCD	60,7 **bc**
12	50,0 ı ST	50,2 j S	50,1 **l**
13	62,8 a A	61,1 ab DE	62,0 **a**
14	55,0 gh OPQ	52,5 ı R	53,7 **k**
15	61,7 b BCD	60,3 bc EF	61,0 **b**
16	55,6 f NOP	59,7 cd FG	57,6 **fg**
17	49,0 j T	58,2 ef IJ	53,6 **k**
18	57,0 e KL	56,9 fg KL	57,0 **g-ı**
19	56,8 e LM	55,8 g MNO	56,3 **ı**
20	57,1 e KL	58,5 de HIJ	57,8 **f**
Ortalama	57,7 **b**	58,1 **a**	-
Önemlilik	PYıl:0,0471, PGenotip:0,0001, PYıl×Genotip:0,0001		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Table 5. Relative feed values of different oat genotypes

Tablo 5. *Farklı yulaf genotiplerine ait göreceli yem değerleri*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	274,7	288,7 ab	281,7 **abc**
2	283,7	269,6 a-d	276,6 **a-d**
3	380,5	272,1 a-d	326,3 **a**
4	364,2	287,3 ab	325,8 **a**
5	229,3	243,0 b-g	236,2 **bcd**
6	307,2	280,0 abc	293,6 **abc**
7	380,5	268,6 a-d	324,5 **a**
8	272,5	259,8 a-e	266,1 **a-d**
9	179,2	230,7 d-g	205,0 **d**
10	250,8	237,1 c-g	244,0 **bcd**
11	366,0	252,5 a-f	309,2 **ab**
12	237,5	281,0 abc	259,2 **a-d**
13	209,8	277,8 a-d	243,8 **bcd**
14	261,4	235,1 c-g	248,2 **bcd**
15	250,1	201,8 g	225,9 **cd**
16	362,1	294,5 a	328,3 **a**
17	270,0	238,7 c-g	254,3 **a-d**
18	274,2	287,0 ab	280,6 **abc**
19	250,5	218,5 efg	234,5 **bcd**
20	279,1	210,5 fg	234,5 **bcd**
Ortalama	284,2 **a**	256,7 **b**	
Önemlilik	PYıl:0,0245, PGenotip:0,0218, PYıl×Genotip:0,4949		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Table 6. Metabolic energy values of different oat genotypes

Tablo 6. *Farklı yulaf genotiplerine ait metabolik enerji değerleri*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	2,78	2,71 a	2,74 **ab**
2	2,72	2,66 abc	2,69 **abc**
3	2,80	2,66 abc	2,73 **ab**
4	2,80	2,69 a	2,75 **ab**
5	2,53	2,63 a-d	2,58 **cd**
6	2,81	2,71 a	2,76 **a**
7	2,80	2,67 abc	2,73 **ab**
8	2,78	2,65 a-d	2,71 **ab**
9	2,53	2,59 cde	2,56 **d**
10	2,73	2,57 de	2,65 **a-d**
11	2,79	2,68 ab	2,73 **ab**
12	2,68	2,70 a	2,69 **abc**
13	2,62	2,63 a-d	2,63 **bcd**
14	2,72	2,64 a-d	2,68 **a-d**
15	2,71	2,57 de	2,64 **a-d**
16	2,82	2,70 a	2,76 **a**
17	2,66	2,59 cd	2,63 **bcd**
18	2,76	2,68 ab	2,72 **ab**
19	2,67	2,60 bcd	2,63 **bcd**
20	2,75	2,50 e	2,64 **a-d**
Ortalama	2,72 **a**	2,64 **b**	-
Önemlilik	PYıl:0,0001, PGenotip:0,0200, PYıl×Genotip:0,5465		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Table 7. Crude fiber values of different oat genotypes
Tablo 7. *Farklı yulaf genotiplerine ait ham lif değerleri*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	8,00	9,81 f	8,90 **efg**
2	9,92	10,06 ef	9,99 **c-g**
3	7,88	11,19 def	9,54 **c-g**
4	7,74	10,16 ef	8,95 **efg**
5	15,23	12,41 b-e	13,82 **a**
6	7,26	10,18 ef	8,72 **fg**
7	7,88	11,49 def	9,69 **c-g**
8	7,67	11,83 c-f	9,75 **c-g**
9	15,41	13,17 a-d	14,30 **a**
10	8,33	12,90 a-d	10,61 **b-g**
11	6,56	11,01 def	8,79 **fg**
12	11,28	10,21 ef	10,74 **b-g**
13	12,12	11,28 def	11,70 **a-f**
14	10,07	12,40 b-e	11,23 **a-g**
15	10,03	14,51 ab	12,27 **a-e**
16	6,12	9,65 f	7,88 **g**
17	11,72	13,17 a-d	12,45 **a-d**
18	8,52	10,16 ef	9,34 **d-g**
19	11,64	13,99 abc	12,82 **abc**
20	8,69	15,13 a	11,91 **a-f**
Ortalama	9,60 **b**	11,74 **a**	
Önemlilik	PYıl:0,0002, PGenotip:0,0080, PYıl×Genotip:0,4771		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Table 8. Crude ash values of different oat genotypes
Tablo 8. *Farklı yulaf genotiplerine ait ham kül değerleri*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	6,22 cde CDE	4,08 bcd MNO	5,15 **c-f**
2	5,61 fg FGH	4,70 a JK	5,15 **c-f**
3	4,77 ı JK	4,17 bcd L-O	4,47 **jk**
4	5,03 hı IJ	3,99 cd MNO	4,51 **ıjk**
5	5,48 fgh GHI	4,08 bcd MNO	4,78 **g-j**
6	5,89 ef EFG	3,79 d O	4,84 **f-ı**
7	4,77 ı JK	3,93 d NO	4,35 **k**
8	6,66 bc BC	4,20 a-d L-O	5,43 **bc**
9	5,87 ef EFG	4,04 cd MNO	4,95 **e-h**
10	7,55 a A	4,12 bcd L-O	5,83 **a**
11	6,24 cde CDE	3,02 e P	4,63 **h-k**
12	6,10 de DEF	4,32 a-d K-N	5,21 **b-e**
13	6,73 b B	4,08 bcd MNO	5,41 **bcd**
14	6,11 de DE	4,02 cd MNO	5,07 **d-g**
15	6,40 bcd BCD	4,18 a-d L-O	5,29 **b-e**
16	6,62 bc BC	4,47 abc KLM	5,54 **ab**
17	5,31 gh HI	4,13 bcd L-O	4,72 **hıj**
18	6,55 bcd BCD	4,08 bcd MNO	5,31 **bcd**
19	5,79 ef E-H	3,92 d NO	4,86 **f-ı**
20	6,09 de DEF	4,58 ab JKL	5,33 **bcd**
Ortalama	5,99 **a**	4,09 **b**	
Önemlilik	PYıl:0,0001, PGenotip:0,0001, PYıl×Genotip:0,0001		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Table 9. Dry matter digestibility values of different oat genotypes
Tablo 9. *Farklı yulaf genotiplerine ait kuru maddenin sindirilebilirliği değerleri*

Genotip No	1. Yıl (2018-2019)	2. Yıl (2019-2020)	İki yıllık ortalama (2018-2020)
1	78,0 abc A-E	78,2 a A-E	78,1 **a**
2	75,2 de I-M	77,2 abc C-G	76,2 **cd**
3	79,4 a A	77,2 abc C-H	78,3 **a**
4	78,3 abc A-D	77,9 ab A-E	78,1 **a**
5	77,1 cd C-I	76,0 b-f F-L	76,5 **bcd**
6	78,9 abc A-C	78,0 a A-E	78,5 **a**
7	78,4 abc A-D	76,6 a-d D-J	77,5 **abc**
8	72,8 fg NO	75,4 c-g G-L	74,1 **fg**
9	77,4 bc B-F	74,7 e-h K-N	76,0 **de**
10	78,2 abc A-E	77,8 ab A-F	78,0 **a**
11	73,0 fg NO	77,7 ab A-F	75,3 **def**
12	73,0 fg NO	76,7 a-d D-J	74,8 **ef**
13	74,3 ef LMN	76,3 a-e E-K	75,3 **def**
14	78,8 abc ABC	74,3 fgh LMN	76,5 **bcd**
15	77,7 abc A-F	77,9 ab A-E	77,8 **ab**
16	74,2 ef LMN	75,3 c-g H-M	74,7 **ef**
17	77,7 abc A-F	77,8 ab A-F	77,8 **ab**
18	71,2 gh OP	74,9 d-g J-M	73,1 **g**
19	79,2 ab AB	72,9 h NO	76,0 **de**
20	69,8 h P	73,5 gh MN	71,6 **h**
Ortalama	76,1	76,3	-
Önemlilik	PYıl:0,6313, PGenotip:0,0001, PYıl×Genotip:0,0001		

Not: Küçük harf yıl içi dikey harflendirmeyi, büyük harf ise yıllar arası yıl×genotip interaksiyon harflendirmesini vermektedir. Ayrıca koyu harflendirme ise yıl ve çeşitlerin ortalamalarının harflendirmelerini vermektedir.

Göreceli Yem Değeri

Göreceli yem değerleri yapılan varyans analizine göre sadece yıllara ve çeşitlere göre önemli oranda değişim gösterirken ($p<0,05$), yıl×genotip etkileşiminde ise bu değişim önemsiz düzeyde kalmıştır ($p>0,05$) (Tablo 5). GYD değerleri yıllara göre önemli farklılık sergilemiştir ($p<0,05$). Araştırmanın ilk yılında 284,2 iken bu değer ikinci yılda 256,7'ye düşmüştür. Çeşitlere göre en yüksek GYD değerleri 3 (326,3), 4 (325,8), 7 (324,5) ve 16 (328,3) numaralı genotiplerde belirlenmiştir. En düşük GYD değerleri ise 205,0 ile 9 numaralı genotipte tespit edilmiştir (Tablo 5).

Metabolik Enerji Değeri (Mcal/kg)

Farklı yulaf genotiplerinin tanelerinin ME değerleri sadece yıllara ve genotiplere göre yapılan varyans analizi sonucunda önemli değişimler ortaya koyarken ($p<0,05$), yıl×genotip etkileşimlerinde ise bu değişimler önemsiz düzeyde kalmıştır ($p>0,05$) (Tablo 6). Araştırmanın ilk yılına ait ortalama ME değerleri (2,72 Mcal/kg) ikinci yıla göre (2,50 Mcal/kg) daha yüksek bulunmuştur. Genotip ortalamalarında ise en yüksek değerler 2,76 Mcal/kg ile 6 ve 16 numaralı genotiplerde belirlenirken, en düşük değerler ise 2,58 ve 2,56 Mcal/kg ile 5 ve 9 numaralı genotiplerde tespit edilmiştir (Tablo 6).

Ham Lif Oranı (%)

Yapılan varyans analizine göre farklı yulaf genotiplerinin tanelerinin ham lif (HL) oranları yıllara ve genotiplere göre önemli oranda değişim gösterirken ($p<0,05$), yıl×genotip etkileşimlerine göre ise bu değişim önemsiz düzeyde kalmıştır ($p>0,05$) (Tablo 7). İki yıllık genotip ortalamalarına göre en yüksek HL değerleri %14,30 ile 9 numaralı genotipte belirlenmiştir. En düşük HL değerleri ise %8,72, %8,79 ve %7,88 ile 6, 11 ve 16 numaralı genotiplerde tespit edilmiştir. Araştırmanın ikinci yılına ait ortalama HL oranı %11,74 iken bu değer ilk yılda %9,60 olarak belirlenmiştir (Tablo 7).

Ham Kül Oranı (%)

Farklı yulaf genotiplerinin tanelerinin ham kül (HK) değerleri yapılan varyans değerlendirmesine göre yıllara, genotiplere ve yıl×genotip etkileşimlerine göre önemli oranda değişimler göstermiştir ($p<0,05$) (Tablo 8). Araştırmanın ilk yılına ait ortalama ham kül değerleri (%5,99) ikinci yıldan (%4,09) daha yüksek çıkmıştır. Genotip ortalamalarında ise en yüksek HK değerleri %5,83 ile 10 numaralı genotip öne çıkarken, bunu %5,54 ile 16 numaralı genotip izlemiştir. En düşük ham kül içerikleri ise %4,35 ile 7, %4,47 ile 3 ve %4,51 ile 4 numaralı genotipler olarak izlemiştir. Yıl×genotip etkileşimlerinde ise en yüksek ham kül içerikleri %7,55 ile araştırmanın ilk yılındaki 10 numaralı genotipte tespit edilmiştir. En düşük değer ise çalışmanın ikinci yılında %3,02 ile 11 numaralı genotipte belirlenmiştir (Tablo 8).

Kuru Maddenin Sindirilebilirliği (%)

Farklı yulaf genotiplerinin tanelerinin kuru maddenin sindirilebilirliği (KMS) değerleri yapılan varyans analizine göre genotiplere ve yıl×genotip etkileşimlerine göre önemli oranda değişim gösterirken ($p<0,05$), yıllara göre ise bu değişim önemsiz düzeyde kalmıştır ($p>0,05$) (Tablo 9). Araştırmanın her iki yılında da KMS değerleri %76 dolayında değerlere sahip olmuştur. Çeşitlere göre en yüksek KMS değerleri %78,1 ile 1, %78,3 ile 3, %78,1 ile 4, %78,5 ile 6 ve %78 ile 10 numaralı genotiplerde belirlenmiştir. En düşük değerler ise %71,6 ile 20 ve %73,1 ile 18 numaralı genotiplerde tespit edilmiştir. Etkileşimlerde ise en yüksek KMS oranları %79,4 ile 3 numaralı genotipin ilk yılına ait değerlerde belirlenirken, en düşük değerler ise %69,8 ile aynı yıldaki 20 numaralı genotipte tespit edilmiştir (Tablo 9).

TARTIŞMA

Bu araştırmada farklı yulaf genotiplerinin 1000 tane ağırlıkları arasında önemli farklılıklar ortaya çıkmıştır. Kahramanmaraş'ta yapılan çalışmada yıllara göre ortalama 1000 tane ağırlıkları 27 g, çeşitlere göre ise 21,8-34,7 arasında değişim gösterdiği ve sonuçların mevcut çalışmayla uyum gösterdiği belirlenmiştir (Başkonuş, 2023). Yapılan diğer çalışmalarda en yüksek ve en düşük 1000 tane ağırlıkları 44,8-35,12 g (Topkara, 2019), 43,22-13,55 g (Şahin vd., 2019) ve 35,66-32,91 g (Ataman, 2022) olarak rapor edilmiş ve yakın değerler arasında değiştiği gözlenmiştir. Az da olsa gözlenen bu farkların bitkilerin genetik olarak farklılık göstermesi ve yıllar arasındaki iklimsel değişkenliklerden (Tablo 2) kaynaklanmaktadır. Nitekim farklı bitkilerle yapılan çalışmalarda da çeşitler arasında farklılıkların ortaya çıkması çeşitlerin genetik olarak farklı olmalarından ileri gelebileceği sonuçlarına ulaşılmıştır (Beadle, 1993; Khan vd., 2006; Kering vd., 2011; Özyazıcı & Açıkbaş, 2019) (Tablo 3).

Hektolitre ağırlığı tanenin şekli, yoğunluğu ve homojenliği tarafından belirlenmektedir (Özkaya & Kahveci, 1990). Hektolitre ağırlığı ile tane verimi arasında ise pozitif ilişki mevcuttur (Pixley & Frey, 1991). Yapmış olduğumuz bu çalışmada genotiplere ait hektolitre ağırlıkları yaklaşık olarak 50-62 kg/hl arasında değişiklik göstermiştir. Ülkemizin farklı yerlerinde yürütülmüş olan diğer çalışmalarda bu aralıklar 45-57 kg/hl (Sarı & İmamoğlu, 2011), 34-47 kg/hl (Ercan vd., 2016), 43-60 kg/hl (Kahraman vd., 2017), 43-54 kg/hl (Naneli & Sakin, 2017), 30-49 kg/hl (Düzme, 2020) ve 43-54 kg/hl (Topkara, 2019) değerlerine sahip olarak rapor edilmiş olup mevcut araştırmanın sonuçlarıyla benzerlik göstermektedir. Genotiplerde ortaya çıkan hektolitre ağırlık farkları bunların genetik olarak farklı olmalarından kaynaklanmaktadır. Nitekim birçok araştırmacı diğer bitkilerle yapılan çalışmalarda çeşitler arasında ortaya çıkan bu farklılıkların genetik olarak farklı olduklarından dolayı kaynaklandığını ileri sürmüşlerdir (Beadle, 1993; Khan vd., 2006; Kering vd., 2011; Özyazıcı & Açıkbaş, 2019; Alatürk vd., 2023) (Tablo 4).

Farklı yulaf genotiplerinin tanelerine ait besin madde içeriklerinden GYD, ME, HL, HK ve KMS değerleri önemli farklılık göstermiştir. Genotiplere ait ortalama GYD 205-328, ME 2,56-2,76 Mcal/kg, HL %7,88-14,30, HK %4,35-5,83 ve KMS ise %71,6-78,5 arasında değişkenlik göstermiştir. Yapılan benzer bir çalışmada farklı yulaf genotiplerine ait ham kül içerikleri %1,45-1,91, ham lif değerleri %1,40-2,10 ve enerji değerleri ise 337-372 cal/100 g olarak rapor edilmiştir (Özcan vd., 2006). Yürütülen bir diğer çalışmada 31 farklı yulaf çeşidinin tanelerinin ortalama ham selüloz değerleri en düşük %9,7, en yüksek %16,10 ve ortalama ise %12,90 olarak tespit edilmiştir (Şahin vd., 2017). Arpa, yulaf, tritikale ve buğday tanelerinin besin madde içeriklerinin araştırıldığı bazı çalışmaların sonucunda buğdayda ham protein 143 g/kg DM, ham kül 17 g/kg DM, ham lif 18 g/kg DM ve ham yağ 16 g/kg DM, arpada ham protein 120 g/kg DM, ham kül 26 g/kg DM, ham lif 50 g/kg DM ve ham yağ 28 g/kg DM, kavuzlu yulafta ham protein 115 g/kg DM, ham kül 23 g/kg DM, ham lif 136 g/kg DM ve ham yağ 148 g/kg DM, kavuzsuz yulafta ham protein 144 g/kg DM, ham kül 20 g/kg DM, ham lif 32 g/kg DM ve ham yağ 84 g/kg DM ve tritikalede ise ham protein 95 g/kg DM, ham kül 13 g/kg DM, ham lif 10 g/kg DM ve ham yağ 12 g/kg DM olarak bildirilmiştir (Biel vd., 2009, 2016, 2020; Wozniak vd., 2014; Alijošius vd., 2016). Yürütülen bir diğer çalışmada 15 farklı yulaf genotipinin ortalama ham kül değerlerinin %1,43-4,20 arasında değiştiği belirlenmiştir (Çiçek, 2019). Farklı yulaf genotiplerinin tanelerine ait ortaya çıkan besin madde farkının en önemli nedenleri arasında genotiplerin genetik olarak farklı olmalar yer almaktadır (Beadle, 1993; Khan vd., 2006; Kering vd., 2011; Özyazıcı & Açıkbaş, 2019; Alatürk vd., 2023).

SONUÇ

Bu araştırma 2018-2020 yılları arasında Edirne Trakya Tarımsal Araştırma Enstitüsünde farklı yulaf genotiplerinin tane verimi ile tanenin hayvan beslemesi açısından değerlendirilmesi amacıyla yürütülmüştür. Çalışmada bitki materyali olarak beş adet standart yulaf çeşidi (Kırklar, Kahraman, Küçükyayla, Yeniçeri ve Sebat) ile Trakya Tarımsal Araştırma Enstitüsü tarafından geliştirilen 15 adet yulaf hattı kullanılmıştır. Yulaf genotiplerinin ortalama bin tane ağırlıkları 24,1-43,2 g arasında değişim göstermiştir. Bu parametre bakımından 3 numaralı genotip öne çıkmıştır. Ortalama hektolitre ağırlıkları 50,1-62,6 kg/hl arasında değerlere sahip olmuştur. Hektolitre ağırlıkları bakımından 3 ve 5 numaralı genotipler diğerlerine nazaran daha yüksek bulunmuştur. Göreceli yem değerleri 205,0-328,3 arasında değişim göstermiştir. Bu parametrede öne çıkan hatlar 3, 4, 6, 7, 10, 11 ,16 ve 17 numaralı hatlar olmuştur. Metabolik enerji değerleri 2,56-2,76 Mcal/kg arasında değerlere sahip olmuştur. En yüksek ME içeriğine 1-4, 6-8, 11, 12 ve 14 numaralı hatlarda tespit edilmiştir. Ortalama ham lif değerleri %7,88-13,82 arasında değişmiştir. Bu grupta 1, 4, 6, 11 ve 16 numaralı hatlar öne çıkmıştır. Ortalama ham kül içerikleri %4,35-5,83 arasında değerlere sahip olmuştur. Ham kül içerikleri bakımından 10 ve 16 numaralı hatlar daha yüksek değerlere sahip olmuştur. Farklı yulaf genotiplerinin ortalama KMS içerikleri %73,1-78,3 arasında değerlere sahip olmuştur. KMS içeriği en yüksek hatlar ise 1, 3, 4, 6, 10, 15 ve 17 olmuştur. Yürütülen bu araştırmanın sonucunda benzer ekolojilerde yapılacak olan yulaf yetiştiriciliğinde 3, 4, 6, 10 ve 11 numaralı genotiplerinin tane verimi ve tanenin hayvan besleme açısından kalitesinin daha uygun olacağı sonucuna varılmıştır.

Yürütülen bu araştırmanın sonucunda benzer ekolojilerde yapılacak olan yulaf yetiştiriciliğinde 3, 4, 6, 10 ve 11 numaralı genotiplerinin tane verimi ve tanenin hayvan besleme açısından kalitesinin daha uygun olacağı sonucuna varılmıştır.

TEŞEKKÜR

Bu çalışma Seda ALATÜRK'ün yüksek lisans tezinden üretilmiştir.

Etik Standartlara Uygunluk

Yazarların Katkısı

SA: Araştırma, Metodoloji, Veri küratörlüğü, Yazma – orijinal taslak hazırlama

TT: Kavramsallaştırma, Yazma – orijinal taslak hazırlama, Yazma – gözden geçirme ve düzenleme

Tüm yazarlar makalenin son halini okumuş ve onaylamıştır.

Çıkar Çatışması

Yazarlar herhangi bir çıkar çatışması olmadığını deklare etmektedir.

Etik Onay

Yazarlar bu çalışma için resmi etik kurul onayının gerekli olmadığını bildirmektedir.

Veri Kullanılabilirliği

Yazarlar, bu çalışmanın bulgularını destekleyen verilerin makale içinde mevcut olduğunu onaylamaktadır.

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info@actanatsci.com
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Tracking Stability Using Shewhart Charts to Elucidate Trending Patterns in Glyceryl Guaiacolate Assay: Paving the Way for Quality Improvement in Medicinal Chemical Industry

Mostafa Essam Eissa[1]✉

[1] Independent Researcher, Pharmaceutical and Healthcare Research Facility, Cairo, Egypt; mostafaessameissa@yahoo.com

✉ Corresponding Author: mostafaessameissa@yahoo.com

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ABSTRACT

Shewhart charts are a crucial part of statistical process control, or SPC, which tracks and regulates the pharmaceutical compound's inspection properties. It serves to shed light on the process's present state and, if necessary, the future improvements that will be needed. The trending pattern for the glyceryl guaiacolate assay is the main subject of this investigation. SPC software is used in this work. Following the selection of the most appropriate underlying distribution, Individual-Moving Range (I-MR) charts are used as a trending method for the data. Since some batches in the time series sequence show indications of out-of-control points, improvements are needed to enhance the quality of inspection attributes. Accordingly, capability analysis will not be relied on at this stage till the stabilization of the process. This study highlights the vital role of control charts in ensuring the quality of chemical materials. It contributes to building a robust industrial regulatory system by analyzing the quality of medicinal compounds from chemical manufacturers, especially in developing countries.

INTRODUCTION

There is fierce competition among numerous businesses and corporations in the pharmaceutical and healthcare industries for drugs and medical supplies (Eissa, 2021a). The patient's health comes first, with safety followed by efficacy and quality (Eissa et al., 2016a; Eissa, 2022). Active or inactive medicinal substances ought to serve as the foundation for the standard quality prior to the examination of the inspection qualities of the completed dosage forms.

To reach a high degree of consistent and acceptable quality, statistical process control (SPC) techniques are now widely utilized and deemed vital in all pharmaceutical organizations (Eissa, 2018a). The Shewhart plot is one of the most important SPC tools (Eissa, 2015). It is widely used to evaluate and regulate processes and inspection features in both industrial and non-industrial domains (Eissa et al., 2021a; Eissa, 2023a; Eissa et al., 2023; Eissa et al., 2021b; Eissa, 2019). The producers of pharmaceutical-grade raw materials have spread across the globe, making them easily accessible to brokers and retail marketplaces everywhere (Eissa & Mahmoud, 2016). However, maintaining consistent quality assurance of the anticipated chemical and physical attributes is crucial to ensuring the pharmaceutical products' worth both now and in the future.

A crisis can lead to a significant drop in the quality of goods accessible from brokers, wholesalers, and market retailers, who may sacrifice important quality inspection features in order to satisfy consumer demand for low costs. Aiming to evaluate the quality and goodness of a particular Active Pharmaceutical Ingredient (API) that is frequently used in pharmaceutical respiratory preparations from chemical manufacturing companies, the current investigation was motivated by the highlighted issues. The investigation will center on a significant test viz. the assay that is formally regarded as one of the essential features for active material inspection.

MATERIAL AND METHODS

Study Subject

A chemical manufacturing facility using pharmaceutical-grade raw materials was evaluated for the quality of its manufactured products (Eissa & Abid, 2018). The assay result trend was examined for more than 120 batches of a common medical substance that is used in cough preparations (Eissa & Mahmoud, 2016; Eissa & Abid, 2018). This expectorant material is (RS)-3-(2-methoxyphenoxy) propane-1,2-($C_{10}H_{14}O_4$). It is ether of glycerin and guaiacol chemically. It can be taken in addition to other prescription drugs for treatment of respiratory conditions.

Analysis of Active Pharmaceutical Compound

The United States Pharmacopeia (USP) standard official procedure – after verification - was used to analyze each manufactured batch with 98.0% to 102.0 % of the anhydrous material is the analytical limit (Eissa & Mahmoud, 2015). HPLC (C18 column) with UV detection (254 nm) would be the assay method. The manufacturing firm executed the assay after performing method validation according to the official compendia.

Results collection and processing

The results of the chemical analysis of the 120 material samples were tabulated in Microsoft Excel Spreadsheet in chronological order after verification of the suitability of the assay test records. Preliminary screening for any error or anomaly was examined before further processing.

Screening for Best Distribution Fitting

The distribution was identified at 95% Confidence Interval (CI) and α 0.05; the Anderson-Darling (AD) test was used to confirm the best-fitting spreading plot. The Johnson family technique was used to normalize raw data that did not follow any clear trend (Eissa, 2023b). If the data passes the normality test, it may then be used for additional analysis. The variable process-behavior charts were drawn using the most appropriate distribution types, together with the corresponding capability plots and capability histograms (Eissa, 2023b). Statistical software was used for all calculations and visualization.

Statistical Process Control of Assay Trend

After distribution identification, the SPC selection will undergo execution following the nature of data spreading using commercial SPC program. Minitab® version 17.1.0 was used to analyze the inspection characteristics in order to check for distribution fitting and create a suitable SPC examination profile (Eissa, 2018b; Eissa e al., 2016b). The control charts, capability assessments, and histograms might be used to determine the initial state of control based on the output findings.

RESULTS AND DISCUSSION

To meet the chemical plant's Total Quality Management (TQM) objectives, the organization is being thoroughly examined, and this project is a part of it (Eissa, 2021b). Reducing, eliminating, or continuously detecting production defects are the goal of total quality management (TQM). Customer satisfaction rises, supply chain coordination is accelerated, and staffs receive the most recent training available (Eissa, 2021b). Holding all manufacturing process participants accountable for the overall quality of the finished good or service is necessary to attain total quality management.

Figures 1, 2, and 3 present the dataset's detailed dispersion pattern using probability plots. According to the results of the goodness of fit test, only three distributions— the biggest extreme value, Weibull and normal (after Johnson transformation)—are legitimate in that ascending order. The AD, goodness-of-fit figure probability charting and p-values were used to make the selection. This and a related study on the same project line partially agree. The p-value, a probability, evaluates the strength of the evidence refuting the null hypothesis (Rashed & Eissa, 2020). In an AD test, the predicted distribution of the data is the null hypothesis (Eissa, 2021c). Thus, lower p-values provide more evidence that the data deviate from the distribution.

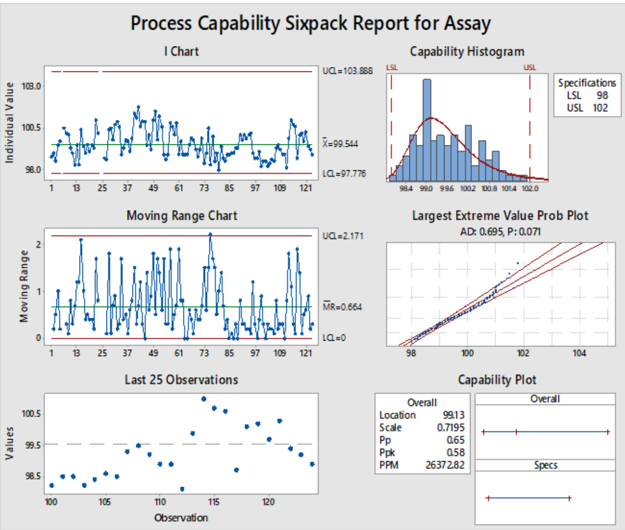

Figure 1. Statistical process inspection of the assay results trend using the largest extreme value distribution assumption

The preliminary examination of Individual-Moving Range (I-MR) process behavior charts in Figures 1, 2 and 3 showed unstable variations – at least at one point - and hence would affect the process means according to the selected types of the best-fitting distributions. Each corresponding dispersion was acceptable according to the probability plot (Eissa & Rashed, 2023). Moreover, the capability histograms illustrated that the spreading of data was not confined within the Lower Specification Limit (LSL) and the Upper Specification Limit (USL).

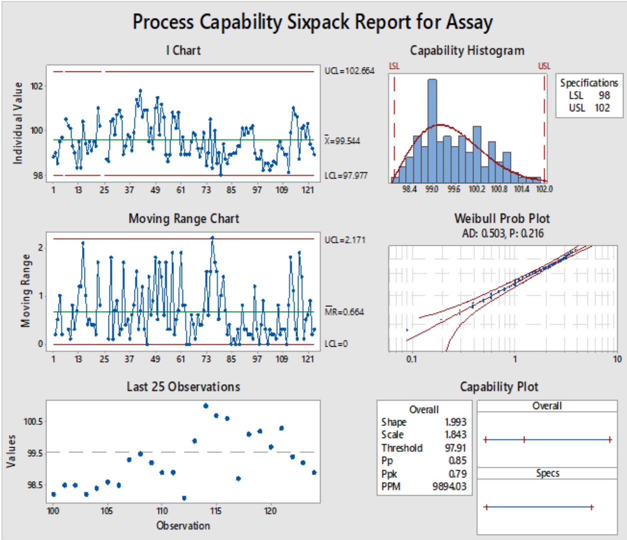

Figure 2. Statistical process inspection of the assay results trend using the Weibull distribution assumption

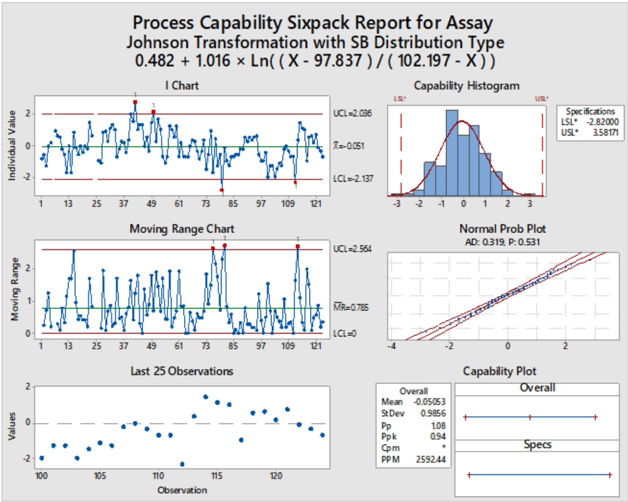

Figure 3. Statistical process inspection of the assay results trend using the normal distribution assumption using Johnson transformation family of SB

Furthermore, the dispersion frequency of the bins approaches the fictitious assumed underlying distribution assumption (Eissa & Hamed, 2019). It is clear from the preliminary findings that the control windows are not centered within the specification's boundaries, increasing the likelihood of an excursion below the lower threshold as well as the upper side, and that the process average is not centered in the middle of the specification window. Based on the previous observations, the current capability analyses cannot be relied upon until the inspection characteristic can be brought back fully under control through observing the control chart, then reanalyzing the capability plots to verify the state of the process.

It is important to note that in order to guarantee the procurement of raw materials with stable, predictable, and conforming inspection properties indicating a Good Manufacturing Practice (GMP) throughout the production processes, statistical quality monitoring must be established from the outset of the manufacturing process for chemical production. This duty should not be undervalued. When it comes to taking the lead in a competitive market, any respectable business that uses GxP—a typical acronym for quality standards and suggestions that are regarded as "good practice"—must use the system (Eissa & Rashed, 2020). The "x" stands for the various fields in which it might be used. A collection of quality standards is commonly referred to by the acronym GxP. The final dosage forms' functional values would represent the quality of each individual component. In a world where the number of sick people is always rising, this is vital when it comes to the lives and health of the patients.

The above implemented technique could guarantee the monitoring and management of the inspection properties, but transformation might alter the time series plot's original shape, which might make extrapolation during investigation more complex and harder. Additionally, more data—and hence, more batches—are needed to create reliable criteria using control charts in order to restore the inspection characteristic under investigation's quality standards.

CONCLUSION

Based on the non-normally distributed dataset, process-behavior plots were used to illustrate how the manufactured raw material quality fluctuated between batches, exhibiting out-of-control states. Additionally, the process capability monitoring revealed that tightening the differences in the inspection characteristic (assay) between consecutive products is necessary to attain a better performance index level and that performance needs to be improved. The average line is also moved away from the reference center. In order to reduce the possibility of uncontrollable outcomes that are either above or below the limiting thresholds in the future, the process mean should be moved as close to the center as possible. Other medicinal substances made by the manufacturer should be incorporated in future research investigations along with other inspection characteristics of the pharmaceutical raw material. Additionally, as a crucial component of the quality improvement system, the inquiry would include all the chemicals that the pharmaceutical manufacturer produces.

Compliance with Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author on request.

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ACTA NATURA ET SCIENTIA PRENSIP

Verim ve Kalite Özellikleri Bakımından Danelik Hibrit Mısır Çeşitleri Arasındaki Farklılıkların İncelenmesi

Abdullah Nas[1] • İsmail Karakaş[1] • Fatma Aykut Tonk[1]✉

[1] Ege University, Faculty of Agriculture, Department of Field Crops, İzmir, Türkiye, abdullahnas703@gmail.com; karakasgiller@outlook.com; fatma.aykut@ege.edu.tr

✉ Corresponding Author: fatma.aykut@ege.edu.tr

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ÖZET

Bu çalışma farklı danelik hibrit mısır çeşitlerinin verim ve verim parametreleri ile kalite özelliklerinin belirlenmesi amacıyla 2022 yılında ana ürün olarak Balıkesir/Altıeylül ilçesi Ovaköy ekolojik koşullarında yürütülmüştür. Araştırmada bitki materyali olarak toplam on farklı danelik hibrit mısır çeşidi kullanılmıştır. Araştırma tesadüf blokları deneme desenine göre üç tekerrürlü olarak kurulmuştur. Araştırmada incelenen verim ve verim özelliklerinden; bitki boyu 2,37-2,99 m, bitki sap kalınlığı 20,93-24,47 mm, koçan uzunluğu 16,56-21,57 cm, koçan çapı 4,77-5,29 cm, tane koçan oranı %0,86-0,95, koçanda tane sayısı 527,67-746,65 adet, tane verimi 193,33-284,41 g/bitki, bin tane ağırlığı 362,00-468,67 g arasında değişim göstermiştir. Araştırmada kalite özellikleri; tane nemi %20,73-24,33, tane nişasta oranı %67,84-71,46, hektolitre ağırlığı 73,60-76,33 kg, kül değeri %1,04-1,22, protein oranı %8,25-9,25 selüloz oranı %2,15-2,28, yağ oranı %2,20-2,67 arasında değişmiştir. Araştırmada incelenen çeşitler arasında özellikle DKC 6980 ve SY Bambus isimli çeşitler tane verimi, koçan uzunluğu, koçan çapı, koçanda tane sayısı, hektolitre ağırlığı ve protein oranı özelliği bakımından ön plana çıkmışlardır.

Investigation of Differences Among Grain Hybrid Corn Varieties in Terms of Yield and Quality Characteristics

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ABSTRACT

This study was carried out to determine the yield, yield parameters and quality characteristics of different grain hybrid corn varieties in Ovaköy ecological conditions of Balıkesir/Altıeylül district as the main crop in 2022. A total of ten different grain hybrid corn varieties were used as plant material in the study. The experiment was established according to the randomized block design with three replications. Among the yield and yield characteristics examined in the study; plant height varied between 2.37-2.99 m, plant stem thickness between 20.93-24.47 mm, ear length between 16.56-21.57 cm, ear diameter between 4.77-5.29 cm, grain to ear ratio between 0.86-0.95%, number of grains per ear between 527.67-746.65 pieces, grain yield between 193.33-284.41 g/plant, thousand grain weight between 362.00-468.67 g. Quality characteristics in the study; grain moisture varied between 20.73-24.33%, grain starch ratio between 67.84-71.46%, hectoliter weight between 73.60-76.33 kg, ash value between 1.04-1.22%, protein ratio between 8.25-9.25%, cellulose ratio between 2.15-2.28% and oil ratio between 2.20-2.67%. DKC 6980 and SY Bambus stood out among the varieties examined in the research regarding plant yield, cob length, cob diameter, number of grains per cob, hectoliter weight and protein ratio.

GİRİŞ

Mısır, 2n=20 kromozom sayısına sahip diploid bir bitkidir (Iqbal vd., 2019; Shinde vd., 2021). Teosinte, Poeaceae familyasından yabani bir bitki olup, mısır bitkisinin yakın akrabalarından biri olduğu düşünülmektedir (Yan vd., 2020). Anavatanı Orta Amerika olduğu düşünülen teosinte, günümüz mısır bitkisinin genitörü olarak bilinmektedir (Beadle, 1980). Fotosentez yeteneği yüksek tipik bir C4 bitkisi olan mısır bitkisi (Prioul, 2017), optimum koşullarda bir C3 bitkisi olan buğdayın iki katı fotosentez yapabilme kapasitesine sahiptir (Baldocchi, 1994). Mısır bitkisinde yaprakların anatomik olarak farklı olması, yaprak yüzeyine yakın konumda bulunan mezofil hücrelerinin kloroplastlarında ihtiva ettiği oksijenin yüksek olması, ayrıca PEPC (Phosphoenolpyruvate Carboxylase) enziminin aktivitesinin yüksek olması fotosentez etkinliğini arttıran faktörlerdendir (Zhang vd., 2014). Özellikle buğday ile karşılaştırıldığında mısır bitkisinin ışık yoğunluğunun düşük olduğu ortamlarda bile fotosentezin normal olarak devam etmesi, mısır bitkisinin verim potansiyelini arttıran önemli ögeler arasında yer almaktadır. Yine mısırda diğer C4 bitkileri gibi fotorespirasyonun düşük olması, daha az kuru madde harcanmasına yol açarak fotorespirasyon kayıpları buğdaya nazaran yok denecek kadar azdır (Hatch, 1987; Ku vd., 1996; Gençtan & Balkan, 2013).

İnsan ve hayvan beslenmesi için önemli bir besin kaynağı olan mısır, dünya çapında üretilen ilk üç tahıldan biridir ve aynı zamanda çok çeşitli endüstriyel ürünler için hammadde olarak kullanılmaktadır (FAO, 2020). Bitkisel üretime ilişkin verilere göre, 2020-2021 yılları arasında küresel olarak üretilen ilk üç tahıl, 1,125 milyon ton mısır, 775,8 milyon ton buğday ve 505 milyon ton pirinç olmuştur (Shahbandeh, 2021). Geçtiğimiz beş pazar yılı boyunca küresel mısır üretimi 1,1 milyar ton seviyesini korumuş olup, önümüzdeki dönemde mısır üretimi ve tüketimi arttıkça bu konumunu korunacağı ve daha da ivme kazanacağı öngörülmektedir. En fazla mısır üretimi yapılan ülkeler sırasıyla Amerika Birleşik Devletleri 384 milyon ton mısır üretimi ile ilk sırada yer alırken Çin 231 milyon ton üretimi ile ikinci, Brezilya 64 milyon ton üretimi ile üçüncü ve Arjantin 39 milyon ton üretimi ile dördüncü sırada yer almakta olup, Türkiye ise 6,4 milyon ton üretim ile 21. sırada yer almaktadır. Ülkemizde mısır ekim alanlarının %32'si silajlık, %68'i ise tanelik amaçlı kullanılmaktadır. Ülkemizdeki mısırının dörtte birini üreten Güneydoğu Anadolu Bölgesi'nde, birincil ürün olarak en çok Diyarbakır, Batman, Adıyaman ve Siirt illerinde, ikincil ürün olarak ise Şanlıurfa ve Mardin illerinde yetiştirilmektedir (TÜİK, 2021). Türkiye'de mısır üretimi 2021/2022 yıllarında 6,75 milyon ton olarak gerçekleşmiş olup, üretimde Konya, Şanlıurfa ve Adana illeri ilk sıralarda yer almıştır.

Mısır bitkisinde yapılan yoğun ıslah ve biyoteknolojik araştırmalar ile geliştirilen ticari hibritler, eski ve yerel çeşitlere kıyasla performans ve kârlılık açısından üstün hale gelmiştir. Mısır bitkisinde yoğun ıslah çalışmalarının yapılması, yüksek verimli hibrit çeşitlerin üretime girmesi, yetiştirme tekniklerindeki ilerlemeler, dane ve silajlık mısırın destekleme programına dâhil edilmesi, son yıllarda mısır üretiminde gözlenen kayda değer artışa katkıda bulunmuştur (Kara, 2021). Ülkemizde tohumluk mısır üreten işletme sayısının artması, mısır tarımının ülkemizde yaygınlaşmasının başlıca nedenleri arasındadır. Pek çok kurum ve kuruluş tarafından tescillenen yeni çeşitlerin bulundukları bölgeye uygun olup olmadığı önemli bir araştırma konusudur (Koca & Erekul, 2011). Mısır bitkisinin birim alanda verimliliğini artırmak için yüksek verim potansiyeline sahip hibritlerin seçilmesi tartışmasız çok önemlidir. Bu çalışmada, araştırma bölgesinin çevresel koşulları için en uygun hibrit çeşitleri belirlemek amacıyla yakın zamanda geliştirilen potansiyel mısır hibritlerini verim ve kalite özellikleri bakımından karşılaştırmaktır.

MATERYAL VE YÖNTEM

Araştırma 2022 yılı mısır üretim sezonunda Balıkesir ili Altıeylül ilçesinin Ovaköy Mahallesinde kurulmuştur. Araştırmada Güney Marmara Bölgesi'nde ticari amaç ile satışı yapılmakta olan farklı firmalara ait danelik hibrit mısır çeşitleri ana ürün olarak yetiştirilmiştir. Mısır çeşitlerine ait olgunlaşma süreleri (FAO) ve çeşitlerin temin edildiği firmalar Tablo 1'de verilmiştir.

Deneme alanının yer aldığı Balıkesir ilinin 2022 yılı mısır üretim sezonuna ait iklim verileri Tablo 2'de aylara göre verilmiştir. Çalışmanın yapıldığı 2022 yılı mısır üretim mevsiminin toplam yağış miktarı uzun yıllar toplam yağış miktarından daha düşük olarak gözlenmiştir. Diğer taraftan ortalama sıcaklık yönünden çalışma yılının uzun yıllar ortalamasından önemli bir farklılık göstermediği izlenmiştir. Araştırmanın yapıldığı deneme alanına ait bazı fiziksel ve kimyasal toprak özellikleri Tablo 3'de verilmiştir. Tablo 3 incelendiğinde; deneme alanı toprak yapısının killi, hafif alkali yapıda, tuzsuz, kireçli ve organik madde bakımından orta derecede olduğu görülmektedir. Ekim öncesinde toprak hazırlığı amacıyla ilk olarak pulluk ile toprak devrilerek işlenmiş ve sonrasında diskaro ile toprak işleme çalışmaları tamamlanmıştır. Araştırmada kullanılmak üzere seçilen on adet danelik hibrit mısır çeşidi 15 Mayıs 2022 tarihinde tesadüf blokları deneme desenine göre üç tekerrürlü olacak şekilde ekim mibzeri kullanılarak ekilmiştir. Araştırmada her bir çeşidin tohumları 12 m'lik sıralara, sıra arası 70 cm ve sıra üzeri 15 cm ekim sıklığında ekim yapılmıştır.

Table 1. Varieties used in the study, FAO groups and companies from which they were obtained
Tablo 1. *Araştırmada kullanılan çeşitler, FAO grupları ve temin edildikleri firmalar*

No	Çeşit	FAO	Temin Edildiği Firma
1	**Elektro**	700	KWS Türk Tarım Tic. A. Ş.
2	**P 2088**	700	Pioneer Tohumculuk A. Ş
3	**DKC 6980**	700	Monsanto Gıda ve Tarım Tic. Ltd. Şti.
4	**LG 31.695**	700	LIMAGRAIN San. Tic. A. Ş.
5	**DKC 6897**	700	Monsanto Gıda ve Tarım Tic. Ltd. Şti.
6	**LG 30.692**	700	LIMAGRAIN San. Tic. A.Ş.
7	**AGM 1506**	700	AGROMAR TARIM Tic. Ltd. Şti
8	**SY Bambus**	700	Syngenta AG San. Tic. A.Ş.
9	**Kefrancos.**	700	KWS Türk Tarım Tic. A. Ş.
10	**PL 712**	700	Polen Tohumculuk San. Tic. A.Ş.

Table 2. Climate data for Balıkesir province for 2022 and long years
Tablo 2. *Balıkesir ili 2022 yılı ve uzun yıllar iklim verileri*

2022	Aylık toplam yağış (mm)	Uzun yıllar ortalaması (1999-2023)	Ortalama sıcaklık (°C)	Uzun yıllar ortalaması (1999-2023)
Mayıs	5,6	37,7	18,1	17,8
Haziran	28,1	34,6	23,2	22,6
Temmuz	47,0	11,6	24,7	25,5
Ağustos	16,0	4,8	25,7	25,6
Eylül	10,0	28,2	21,3	21,3
Ekim	0,5	47,9	16,2	16,0
Kasım	52,5	76,1	12,5	10,4
Top./Ort.	159,7	240,9	20,2	19,9

Table 3. Physical and chemical properties of the research area soil
Tablo 3. *Araştırma yeri toprağının fiziksel ve kimyasal özellikleri*

Analiz Adı	Sonuç	Derecesi	Analiz Metodu/Referansı
Saturasyon (%)	71,5	Killi	TS 8333 (+%10) (Hava Kuru)
Ph	7,81	Hafif Alkali	Yurdakul 2018
Toplam tuz (%)	0,08	Tuzsuz	TS 8334 (Çamurda)
Kireç (%)	2,59	Kireçli	TS EN ISO 10693 (Modifiye)
Organik madde (%)	2,48	Orta	TS 8336
Alınabilir fosfor P_2O_5 (kg/da)	16,93	Olsen’e göre çok yüksek (kg/da)-Bray ve Kurt’a göre az	Olsen (Konsantrasyon)
Alınabilir potasyum K_2O (kg/da)	182,04	Yüksek (kg/da)	TS834 (Konsantrasyon)

Mısır ekimi tamamlandıktan sonra can suyu sulaması ile birlikte bitkilerin boyu 40-50 cm olana kadar damlama sulama ile sonraki dönemlerde ise karık sulama ile sulama yapılmıştır. Sulama zamanı toprak nemi göz önüne alınarak genel olarak haftada bir kez olacak şekilde sulama yapılmıştır. Bitkilerin gelişimini desteklemek ve besin elementi ihtiyaçlarını karşılamak için ekimle birlikte dekara 7 kg 15.15.15 gübresi ve bitkiler 8 yapraklı döneme (V8) geldiğinde dekara 10 kg üre gübresi verilmiştir. Ekimden sonra çimlenmenin başlamasıyla birlikte yabancı otların yoğunluğuna göre herbisit uygulanmış ve daha sonra elle ot mücadelesi yapılmıştır.

Mısır bitkileri gelişimini tamamlayıp tane neminin yeterli seviyeye ulaştığı gözlemlendikten sonra hasada başlanmıştır. Hasat işlemi her sıradan, sıra başından ve sonundan 50 cm’lik kenar tesirleri hariç tutularak 10’ar bitki seçilerek 10-16 Kasım 2022 tarihleri arasında gerçekleştirilmiştir. Her sıradan hasat edilen 10 bitki üzerinde bitki boyu, sap kalınlığı, koçan uzunluğu ve koçan çapı, tane koçan oranı, koçanda tane sayısı, tane verimi, BDA (bin dane ağırlığı) ve tane nemi parametreleri (Mini Gac Plus) ölçülmüştür.

Araştırmada kullanılan mısır çeşitlerinin tane kalite özellikleri Ege Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü laboratuvarında bulunan FPI-SupNIR-2700 cihazı kullanılarak yapılmıştır. Tane kalite özellikleri olarak çeşitlerin tane nişasta oranı, hektolitre değeri, kül değeri, protein değeri, selüloz değeri ve yağ değeri elde edilmiştir. Araştırma sonucunda elde edilen bulgular Totem-Stat (Açıkgöz vd., 2004) paket programı kullanılarak varyans analizine (ANOVA) tabi tutulmuş ve çeşitlerin LSD gruplandırılması $P \leq 0,05$ önemlilik düzeyinde gerçekleştirilmiştir.

BULGULAR VE TARTIŞMA

Mısır çeşitlerinin verim ve verim parametrelerine ait sonuçları Tablo 4'te ve kalite özelliklerine ait sonuçları Tablo 5'de verilmiştir. Tablo 4 ve Tablo 5 incelendiğinde çeşitler arasında bitki boyu, koçan uzunluğu, tane verimi, BDA ve hektolitre ağırlığı özelliklerinde istatistiki açıdan önemli farklılıklar bulunmuştur.

Bitki Boyu

Bitki boyu bakımından çeşitler arasında P≤0,05 düzeyinde önemli farklılıklar bulunmuştur. Çeşitler arasında Elektro isimli çeşit en yüksek bitki boyuna (2,99 m), Kefrancos isimli çeşit ise 2,37 m ile en düşük bitki boyu değerine sahip olmuştur. Bitki boyu kantitatif bir özelliktir ve çevreden oldukça etkilenmektedir. Ege Bölgesinde yapılan daha önceki çalışmalar incelendiğinde; mısırda bitki boyu değerleri Manisa koşullarında 201,8 cm ile 240,8 cm (Sarı, 2009), Aydın koşullarında farklı ekim sıklıklarında 181,8 cm ile 212,6 cm arasında (Zayim, 2020), Alaşehir koşullarında farklı ekim zamanlarında 206,27 cm ile 252,28 cm arasında (Kaya & Kuşaksız, 2012) varyasyon göstermiştir.

Sap Kalınlığı

Araştırmada incelenen hibrit mısır çeşitleri arasında PL 712 isimli çeşit en yüksek sap kalınlığını (24,47 mm) gösterirken, LG 31.695 isimli çeşit 20,93 mm sap kalınlığı ile en düşük değere sahip olmuştur. Tüm çeşitlerin ortalama sap kalınlığı değeri 22,99 mm olarak belirlenmiştir. Aydın koşullarında farklı bitki sıklıklarında mısır çeşitlerinin sap kalınlığı değerleri 10,6 mm ile 16,4 mm arasında değişim göstermiştir. Farklı sıra üzeri ekim sıklıklarının karşılaştırıldığı araştırmada, çalışmamızda kullanılan sıra üzeri mesafesine en yakın olan 16 cm sıklıkta ortalama sap kalınlığı 13,3 mm olarak belirlenmiştir (Zayim, 2020).

Koçan Uzunluğu

Araştırmada hibrit mısır çeşitlerine ait koçan uzunluğu değerleri arasındaki fark istatistiki olarak P≤0,05 düzeyinde önemli bulunmuştur. Koçan uzunluğu bakımından DKC 6980 isimli çeşit, 21,57 cm ile en yüksek koçan uzunluğuna, AGM 1506 isimli çeşit 16,56 cm ile en düşük koçan uzunluğu değerine sahip olmuştur. Elde ettiğimiz koçan uzunluğu sonuçlarından daha yüksek değerler Kaya & Kuşaksız (2012) tarafından 20,66 cm ile 26,05 cm arasında Alaşehir koşullarında bildirilirken, benzer sonuçlar Ulus & Koca (2023) tarafından Menemen koşullarında yapılan bir çalışmada saptanmış ve koçan uzunluğu değerlerinin 16,07 cm ile 20,37 cm arasında değiştiği belirtilmiştir.

Koçan Çapı

Koçan çapı mısırda tane verimini etkileyen önemli parametrelerden birisidir. Koçan çapı bakımından incelenen çeşitler arasında SY Bambus isimli çeşit en geniş koçan çapına (5,29 cm) sahip olurken, LG 30.692 çeşidi 4,77 cm ile en düşük değeri vermiştir. Ege Bölgesinde yapılan farklı çalışmalarda Sarı (2009), Manisa ilinde 50,2 ile 55,8 mm arasında, Kaya & Kuşaksız (2012), Alaşehir koşullarında 4,46 ile 4,72 cm arasında, Arıoğlu & Erekul (2022), Aydın ilinde 48,1 ile 54,3 mm arasında koçan çapı değerlerini rapor etmişler ve bu sonuçların elde ettiğimiz bulgular ile büyük oranda benzerlik gösterdiği gözlemlenmiştir.

Tane Koçan Oranı

Mısırda tane koçan oranı, koçandaki tanelerin ağırlık olarak oranını ifade etmektedir. Tane koçan oranı bakımından incelenen çeşitler arasında AGM 1506 ile LG 30.692 isimli çeşitler en yüksek değere (%0,95) sahip olurken, %0,86 ile en düşük değere DKC 6897 çeşidi sahip olmuştur. Çalışmamızda elde ettiğimiz sonuçlara benzer olarak tane koçan oranını Sarı (2009), Manisa koşullarında %82,2 ile %88,2 arasında, Piker (2010), Sakarya ilinde %83,7 ile %88,5 arasında, Akan & Kılıç (2021), Muş ekolojik koşullarında %74,3-85,8 arasında varyasyon gösterdiğini bildirmişlerdir.

Koçanda Tane Sayısı

Koçanda tane sayısı bakımından DKC 6980 çeşidi en yüksek koçanda tane sayısına (746,65 adet) sahip olurken, DKC 6897 çeşidi 527,67 adet ile en düşük değeri sergilemiştir. Aydın koşullarında farklı araştırmalardaki koçanda tane sayısı Alp & Koca (2020) tarafından 426,5 ile 696 adet arasında, Arıoğlu & Erekul (2022) tarafından 569 ile 711 adet arasında, Ulus & Koca (2023) tarafından ise 599,65 ile 715,43 arasında değiştiği bildirilmiştir. Koçanda tane sayısı bir çeşit özelliği olmak ile birlikte çeşit ve çevre interaksiyonu tarafından belirlenmektedir (Svecnjak vd., 2006).

Tane Verimi

Tane verimi bakımından çeşitler arasında P≤0,05 düzeyinde önemli farklılıklar bulunmuştur. Kullanılan çeşitlerde ölçümlenen her tek bitkiden bir adet koçan elde edilmiş ve koçandaki tane ağırlığı bitki tane verimi olarak değerlendirilmiştir. Çeşitler arasında DKC 6980 isimli çeşit 284,41 g/bitki ile en yüksek tane verimine, 193,33 g/bitki ile DKC 6897 isimli çeşit en düşük tane verimine sahip olmuştur. Koçanda tane ağırlığını Çölkesen vd. (1997), 225,70 ile 279 g arasında, İdikut & Kara (2013), 177 ila 311 g arasında, Kılınç vd. (2018), 159,33-206,00 g, İdikut vd. (2020), 114,8 ile 219,6 g arasında değiştiğini belirtmişlerdir. Koçanda tane ağırlığı yönünden elde ettiğimiz değerler daha önceki çalışmalarla benzer sonuçlar göstermiştir.

BDA

Araştırmada incelenen hibrit mısır çeşitlerinde BDA değerleri arasındaki fark istatistiki olarak P≤0,01 düzeyinde önemli bulunmuştur. İncelenen çeşitler arasında Kefrancos isimli çeşit 468,67 g ile en yüksek BDA değerine, 362,00 g ile P 712 isimli çeşit en düşük BDA değerine sahip olmuştur. Kahramanmaraş koşullarında ikinci ürün koşullarında yürütülen başka bir çalışmada (İdikut vd., 2020), PL 712 çeşidi 337,3 g ile daha düşük BDA değeri göstermiştir. Bu farklılığa değişen iklim ve diğer çevre koşulları yanında çalışmamızın ana ürün koşullarında yürütülmüş olmasının neden olduğu düşünülmektedir. Mısırda farklı lokasyonlarda yapılmış çalışmalarda BDA 198,4 g ile 378,6 g varyasyon göstermiştir (Çölkesen vd., 1997; Kılınç vd., 2014; Kahraman, 2016). Bu çalışmada elde edilen BDA değerleri daha yüksek olarak saptanmıştır. Bu farklılığın nedeninin farklı ekolojik koşullar ve farklı mısır çeşitlerinin kullanılmış olması yanında son yıllarda geliştirilen çeşitlerin daha üstün verim potansiyeline sahip olmasının da etkilediği söylenebilir.

Table 4. Results on yield and yield characteristics of maize varieties
Tablo 4. *Mısır çeşitlerinin verim ve verim özelliklerine ait sonuçlar*

Çeşitler	Bitki boyu (m)	Sap kalınlığı (mm)	Koçan uzunluğu (cm)	Koçan çapı (cm)	Tane koçan oranı (%)	Koçanda tane sayısı (adet)	Tane verimi (g/bitki)
Elektro	2,99 a	24,00	21,10 ab	5,07	0,94	659,33	268,83 ab
P 2088	2,83 ab	24,00	20,41 a-c	4,90	0,93	655,80	261,01 abc
DKC 6980	2,67 a-d	21,80	21,57 a	5,21	0,94	746,65	284,41 a
LG 31.695	2,64 b-d	20,93	17,75 de	4,97	0,92	595,67	225,03 b-d
DKC 6897	2,64 b-d	22,60	18,51 b-e	4,93	0,86	527,67	193,33 d
LG 30.692	2,72 a-c	22,33	17,85 c-e	4,77	0,95	618,33	210,51 cd
AGM 1506	2,38 cd	23,24	16,56 e	4,92	0,95	594,20	214,30 b-d
SY Bambus	2,82 ab	23,63	20,01 a-d	5,29	0,94	616,83	270,30 ab
Kefrancos	2,37 d	22,86	18,90 b-e	5,18	0,94	535,77	240,60 a-d
PL 712	2,69 a-d	24,47	19,59 a-d	5,07	0,92	615,00	223,47 b-d
Ortalama	2,67	22,99	19,23	5,03	0,92	616,56	239,17
F değeri	2,67 *	0,41	3,29*	1,15	0,99	2,46	2,52*

Not: * (P≤ 0,05), Her sütunda aynı harfle gösterilen ortalamalar arasında 0,05 önem düzeyine göre fark yoktur.
Note: * (P≤ 0.05), There is no difference between the means indicated with the same letter in each column according to 0.05 significance level.

Table 5. Results on quality traits of maize varieties
Tablo 5. *Mısır çeşitlerinin kalite özelliklerine ait sonuçlar*

Çeşitler	Bin Dane Ağırlığı (g)	Hasat Nemi (%)	Nişasta Oranı (%)	Hektolitre Ağırlığı (kg)	Kül Değeri (%)	Protein Oranı (%)	Selüloz Oranı (%)	Yağ Oranı (%)
Elektro	409,90 bc	21,27	67,84	75,63 ab	1,04	8,52	2,27	2,67
P 2088	398,43 bc	22,00	70,25	75,27 a-c	1,09	8,54	2,28	2,50
DKC 6980	380,27 c	23,77	70,48	76,33 a	1,05	9,25	2,24	2,60
LG 31.695	409,10 bc	20,84	71,16	75,6 ab	1,06	8,79	2,27	2,67
DKC 6897	364,33 c	22,77	69,72	73,63 c	1,20	8,62	2,28	2,38
LG 30.692	379,20 c	22,37	70,66	74,10 bc	1,13	8,49	2,24	2,40
AGM 1506	363,27 c	24,33	69,79	73,60 c	1,22	8,43	2,22	2,56
SY Bambus	450,73 ab	23,30	70,23	74,17 bc	1,18	9,00	2,20	2,20
Kefrancos	468,67 a	20,73	70,82	75,43 ab	1,09	8,60	2,15	2,50
PL 712	362,00 c	22,63	71,46	74,50 bc	1,16	8,25	2,16	2,41
Ortalama	398,59	22,40	70,54	74,83	1,12	8,65	2,48	2,23
F değeri	3,66**	1,22	0,72	2,85*	1,83	0,68	0,71	0,98

Not: * (P≤ 0,05), ** (P≤ 0,01), Her sütunda aynı harfle gösterilen ortalamalar arasında 0,05 ve 0,01 önem düzeyine göre fark yoktur.
Note: * (P≤ 0.05), ** (P≤ 0.01), There is no difference between the means indicated with the same letter in each column according to 0.05 and 0.01 significance levels.

Hasat Nemi

Hasat nemi bir bölgede mısır yetiştirildiğini belirleyen faktörlerin başında gelmektedir. Yetiştirme sezonunun kısalığı tanelerin yeterince kuruyamamasına neden olmakta bu durum da makineli hasatta zorluklar çıkarabilmektedir (Akan & Kılıç, 2021). Araştırma sonucunda en düşük tane nemi %20,73 ile Kefrancos çeşidinde, en yüksek tane nemi oranı %24,33 ile AGM 1506 çeşidinde gözlenmiştir. Manisa ilinde yürütülen bir çalışmada mısır çeşitlerinin hasat nem değerleri %22,3 ile %29,1 arasında değişmiş olup, ortalama hasat nemi %26,8 olarak bulunmuştur (Sarı, 2009).

Nişasta Oranı

Nişasta patates, çeltik, sorgum ve buğdaydan da elde edilebilmektedir. Mısır tanesi oransal olarak daha yüksek nişasta içermektedir ve ayrıca nişasta üretim maliyetli düşüktür (Anonim, 2011). Nişasta oranı bakımından incelenen çeşitler arasında PL 712 isimli çeşit (%71,46) en yüksek nişasta oranına sahip olurken, Elektro çeşidi %67,84 ile en düşük orana sahip olmuştur. Aydın koşullarında ana ürün tane mısır yetiştiriciliğinde ve bazen silajlık olarak da değerlendirilebilen bazı mısır çeşitlerinin nişasta oranları %58,89 ile %61,49 değerleri arasında rapor edilmiştir (Alp & Koca, 2020). Watson (1987), mısır tanesinde kuru madde üzerinden nişasta oranının %61 ile %78 arasında değiştiğini belirtmiş olup bulgularımızın bu değerler arasında olduğu görülmektedir.

Hektolitre Ağırlığı

Araştırmada incelenen hibrit mısır çeşitlerine ait hektolitre ağırlığı değerleri arasındaki fark istatistiki olarak P≤0,05 düzeyinde önemli bulunmuştur. DKC 6980 isimli çeşit, 76,33 kg ile en yüksek, AGM 1506 çeşidi 73,60 kg ile en düşük hektolitre ağırlığı değerine sahip olmuştur. Ayrancı & Sade (2004), mısırda hektolitre ağırlığı değerini 67,97 kg ile 79,71 kg arasında, Akan (2017), 61,72 kg ile 68,32 kg arasında ve Kılınç vd. (2018), 79,10 ile 84,00 kg arasında değiştiğini bildirmişlerdir.

Kül Değeri

Kül değeri oranı bakımından incelenen çeşitler arasında AGM 1506 isimli çeşit %1,22 ile en yüksek kül değeri oranına sahip olurken, Elektro çeşidi %1,04 ile en düşük değere sahip olmuştur. Çalışmamızda elde ettiğimiz sonuçlarla benzer olarak Alp & Koca (2020), Aydın ekolojik koşullarında mısır çeşitlerinin tane kül oranlarının %1,14 ile %1,25 arasında, aynı ekolojik koşullarda Arıoğlu & Erekul (2022), %1,266 ile %2,148 arasında varyasyon gösterdiğini bildirmişlerdir.

Protein Oranı

Protein oranı diğer tahıllarda olduğu gibi mısır tanesinde de en önemli kalite parametresi olarak bilinmektedir. Protein oranı bakımından incelenen çeşitler arasında DKC 6980 isimli çeşit %9,25 ile en yüksek protein oranına sahip olurken, PL 712 isimli çeşit %8,25 ile en düşük protein oranını göstermiştir. Ege Bölgesinde farklı mısır çeşitleri ile daha önce yapılan araştırmalar incelendiğinde; Arıoğlu & Erekul (2022), Aydın koşullarında %8,12 ile %9,69 protein oranını ve Ulus & Koca (2023), Menemen koşullarında %8,28 ile %9,65 protein oranını elde etmişlerdir. Genel olarak mısır kuşağındaki mısır çeşitlerinin %9,9 ham protein içerdiği ve büyüme koşullarının besin değerleri üzerinde doğrudan etkisi olduğu bildirilmiştir (Olson & Frey, 1987).

Selüloz Oranı

Selüloz oranı bakımından incelenen çeşitler arasında P 2088 isimli çeşit (%2,28) en yüksek selüloz oranına sahip olurken, Kefarancos çeşidi (%2,15) en düşük selüloz oranına sahip olmuştur. Aydın koşullarında tam sulama ve kısıtlı sulama dozlarında mısır çeşitlerinin verim ve kalite özelliklerinin incelendiği bir araştırmada, tam sulama dozunda çeşitlerin selüloz oranı minimum %1,95 ile maksimum %2,29 arasında varyasyon göstermiştir (Arıoğlu & Erekul, 2022).

Yağ Oranı

Yağ oranı bakımından LG 31.695 isimli çeşit %2,67 ile en yüksek yağ oranına sahip olurken, SY Bambus çeşidi %2,20 ile en düşük yağ oranına sahip olmuştur. Çalışmada kullanılan çeşitler arasında yağ oranı bakımından büyük bir varyasyonun olmadığı dikkati çekmektedir. Mısır tanesinde bulunan yağ oranı daha önceki araştırmalarda %2,13 ile 6,8 arasında bulunmuştur (Pearce & Poneleit, 1998; Tiftikci, 2011; Kılınç vd. 2018; Arıoğlu & Erekul, 2022; Ulus & Koca, 2023). Bu çalışmada elde edilen yağ oranı değerleri de verilen bu bulgularla uyumlu çıkmıştır.

SONUÇ

Çalışmada ana ürün olarak yetiştirilen mısır çeşitleri arasında, mısırda tane verimini belirleyen koçan özelliklerinden koçan uzunluğu, koçan çapı, tane koçan oranı, koçanda tane sayısı ve nihayetinde tane verimi yönünden DKC 6980 çeşidi ön plana çıkmıştır. Aynı çeşit hektolitre ağırlığı ve protein oranı özellikleri bakımından da diğer çeşitleri gerisinde bırakmıştır. Verimi oluşturan ana komponentlerden bir diğeri olan BDA yönünden ise Kefrancos çeşidi en yüksek değere sahip olmuştur. Bir yıllık araştırma sonucuna göre tüm çeşitlerden elde edilen değerler dikkate alındığında; tane verimi bakımından DKC 6980, SY Bambus ve Elektro çeşitleri, protein oranı yönünden DKC 6980 ve SY BAMBUS çeşitleri, koçan uzunlukları dikkate alınarak taze tüketim için DKC 6980, Elektro, P 20288, SY Bambus ve PL 712 çeşitleri önerilebilir.

TEŞEKKÜR

Bu çalışma ilk yazarın yüksek lisans tezinden üretilmiştir.

Etik Standartlara Uygunluk

Yazarların Katkısı

AN: Araştırma, Metodoloji, Yazma – orijinal taslak hazırlama

İK: Veri küratörlüğü, Veri analizi

FAT: Kavramsallaştırma, Danışmanlık, Araştırma, Yazma – gözden geçirme ve düzenleme

Tüm yazarlar makalenin son halini okumuş ve onaylamıştır.

Çıkar Çatışması

Yazarlar herhangi bir çıkar çatışması olmadığını deklare etmektedir.

Etik Onay

Yazarlar bu çalışma için resmi etik kurul onayının gerekli olmadığını bildirmektedir.

Veri Kullanılabilirliği

Yazarlar, bu çalışmanın bulgularını destekleyen verilerin makale içinde mevcut olduğunu onaylamaktadır.

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info@actanatsci.com
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Determining Growth Drivers in Container Shipping: A Causality Analysis Between Container Throughput and Liner Shipping Connectivity

Alaattin Durmaz[1] • Abdullah Açık[2]✉

[1] Republic of Türkiye, Ministry of Trade, Aegean Regional Directorate of Customs and Foreign Trade, 35220, İzmir, Türkiye; durmazalaattin@hotmail.com
[2] Dokuz Eylül University, Maritime Faculty, Department of Maritime Business Administration 35390, İzmir, Türkiye; abdullah.acik@deu.edu.tr

✉ Corresponding Author: abdullah.acik@deu.edu.tr

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A B S T R A C T

Container transportation, facilitated by the development of standardized containers, has revolutionized global trade by increasing efficiency, reducing costs, and enhancing the competitive power of countries. The Liner Shipping Connectivity Index (LSCI) plays a crucial role in measuring the supply side of container transportation, influencing strategic decisions regarding infrastructure investments and policy development to boost global trade integration. Our study aimed to determine whether container throughput drives LSCI or vice versa, using panel data analysis to inform strategic decisions in maritime trade, investment priorities, and policy development. We conduct our analysis using a unique data set covers the years between 2008 and 2021 and consists of 85 countries and 1190 observations. The results obtained revealed that there is a two-way interaction between Container Throughput and LSCI variables, the effects of the variables are positive and reflected after 1 period, and the impact of changes in LSCI on Container Throughput is higher than the opposite situation. This shows that there is a positive feedback loop between the variables and that improvement in any one of them returns as improvement to itself after a certain period.

INTRODUCTION

Container transportation has significantly impacted global trade with the development of standardized containers (Knox et al., 2014). First, standardization has made loading and unloading activities, as well as the transfer of goods between different transportation modes, easier and faster. This has led to increased efficiency and productivity, particularly in terms of time. Second, containers allow for the consolidation of many small parcels of cargo into a single container, which can be stacked efficiently. This reduces total transportation costs due to economies of scale and lower labor costs. Third, cargo transported in metal containers is well-protected, minimizing the impact of external factors and ensuring safe transit. Fourth, the standardization of containers facilitates easy transportation across various modes, such as road, sea, air, and rail. Fifth, by reducing costs, containerization minimizes environmental damage and enhances the competitive power of countries, while also contributing to the increase in trade volumes (Miller et al., 2023). Due to the numerous advantages of container transportation, it has experienced significant demand, leading to a 255% increase in the total global container ship capacity in 2023 compared to 2000 (Statista, 2024). During the same period, the number of containers handled at ports increased by approximately 273% (World Bank, 2024a), highlighting the rapid development of container transportation in a relatively short time, driven by the mentioned advantages. To fully benefit from the advantages of container shipping, it is essential for container transportation to grow sustainably. This growth can be achieved in two macro ways: (i) supply-side growth, which involves the development of container transportation through affordable and accessible infrastructure, supported by the enhancement of infrastructure and transportation networks within the country; and (ii) demand-side growth, which is driven by the increased need for infrastructure and the expansion of container transportation as a result of growing transportation activities.

One of the most important indicators for measuring the supply side of container transportation in countries is the Liner Shipping Connectivity Index (LSCI). This index is formed by considering factors such as the number of weekly scheduled voyages in the country, deployed annual TEU capacity, the number of liner shipping services to and from the country, the largest deployed ship size servicing to and from the country, and the number of countries offering direct voyage services to the country (UNCTAD, 2024). Thus, an increase in any of these factors may indicate an improvement in liner shipping supply, and if this also stimulates demand, then supply-side growth can be observed. On the other hand, since container traffic at a country's ports is considered the demand side of the business, if an increase in demand leads to improvements in transportation infrastructure, then demand-side growth can be identified. Determining which type of growth prevails is crucial for stakeholders in container shipping because understanding this balance helps them plan investments, develop strategies, and respond effectively to market dynamics.

A higher connectivity network provides better access to global markets at lower costs and in shorter periods. Fast and secure shipping of export products to even very distant markets, as well as efficient supply of raw materials and semi-finished products for production, also provide competitive advantages for countries (Taşova, 2023). In countries, the efficient operation of each stage of the supply chain, from port infrastructure to warehousing, from hinterland transportation to container handling, can be seen as centers of attraction for other countries. Improving LSCI scores for developing or underdeveloped countries can increase the integration of these countries to world trade, attract more investments and increase their trade volumes (Notteboom et al., 2022). In addition, for policy makers, the LSCI score can play an important role in determining infrastructure investments related to maritime, identifying deficiencies and generating legislative regulations. Moreover, stronger integration means the arrival of larger ships and more frequent service, which will reduce transportation costs in the relevant country and provide a competitive advantage. The decrease in transportation costs per unit will also lead to a reduction in carbon emissions, offering significant environmental benefits.

In our study, we aimed to determine whether container throughput drives LSCI or LSCI drives container throughput by using panel data analysis. The potential outcomes of this analysis are of great importance, as they can significantly influence strategic decisions in maritime trade, investment priorities, and policy development. Understanding whether Liner Shipping Connectivity Index (LSCI) drives container throughput or vice versa is crucial because it informs strategic decisions on where to focus investments and policies. If LSCI drives container throughput, enhancing connectivity infrastructure should be prioritized to boost trade volumes. Conversely, if container throughput drives LSCI, stimulating trade through economic policies may lead to improved connectivity. This distinction is essential for effectively allocating resources and ensuring sustainable growth in maritime trade. Our results indicate a mutual feedback relationship between Liner Shipping Connectivity Index (LSCI) and container throughput; however, improvements in LSCI have a more substantial impact on driving container throughput. Therefore, policies should prioritize enhancing connectivity infrastructure, as this will not only directly boost container throughput but also generate a reinforcing cycle that further strengthens the overall efficiency and competitiveness of the maritime transportation network.

The theoretical framework and literature related to our research are reviewed in the second section. The data set and method we used in the research are introduced in the third section. The findings obtained from the panel data analysis are presented in the fourth section, and evaluations and discussions are made in the last section.

Theoretical Framework and The Related Literature

The LSCI serves as a key indicator of global container shipping connectivity. A higher LSCI value signifies enhanced access to more competitive, cost-effective, and frequent transportation services. Additionally, the LSCI reflects a country's degree of integration into the global trading system. Consequently, a higher LSCI suggests greater involvement in international trade and deeper integration into the global freight transport network (Notteboom et al., 2022). Theoretically, LSCI can be viewed as a variable that both influences and is influenced by the volume of international trade, highlighting its dual role as both a driver and a reflection of a country's trade dynamics.

Although the LSCI literature is still emerging, the number of studies exploring the topic from various perspectives is steadily growing. While the LSCI is known to comprise five core components as outlined in reports, other factors may also statistically influence this index. For instance, in the study by Jouili (2019), LSCI was treated as an independent variable, and the impact of logistics performance, container transit times, container transport costs, gross domestic product, and containers per capita on the index was examined across a sample of 100 countries. The regression model revealed that logistics performance, container transport costs, GDP, and containers per capita positively affect the LSCI, whereas container transit time has a negative impact. The LSCI is influenced by logistics performance and, in turn, can also impact it, as a higher LSCI often indicates cheaper, faster, and more efficient transportation. In this context, Chen & Hasan (2023) analyzed the effects of LSCI and the Global Competitiveness Index on logistics performance across 29 countries. The study found that increases in LSCI have a significant accelerating effect on logistics performance and contribute to greater competitiveness.

Assuming that an increase in LSCI will naturally stimulate trade, the study conducted by Şeker (2020) on European Union countries and Türkiye found a positive relationship between LSCI and the countries' exports, establishing that the index is a driving factor for export growth. A similar study was conducted by Canbay (2024) for BRICS-T countries using causality analysis. The findings revealed a bidirectional causality relationship between LSCI and trade volume for Brazil, indicating a feedback loop between the two. In contrast, for Türkiye, the analysis showed a unidirectional causality from LSCI to trade volume, positioning LSCI as a driving force for trade in the country. Since maritime transport has a derived demand structure, increased trade will naturally lead to higher container traffic in ports. In this context, Reza et al. (2015) analyzed port traffic in six Southeast Asian countries using regression analysis, focusing on the components of the LSCI rather than the index itself. Their study revealed that among the components, only ship size had a significant positive effect on port traffic. In a study from a similar perspective, Atacan et al. (2022) conducted a regression analysis in Türkiye to examine the effects of changes in LSCI on international trade, specifically focusing on export and import container traffic in ports. The findings revealed that an increase in LSCI resulted in a proportional increase in both import and export container traffic. In addition to its impact on trade, the LSCI also indirectly influences economic growth, as increased trade and container traffic contribute to heightened economic activity. In a study conducted by Del Rosal & Moura (2022), the effect of the Liner Shipping Connectivity Index (LSCI) on containerized and non-containerized cargo in trade flows between EU and non-EU countries was examined. Their findings showed that an increase in the LSCI had a positive effect on containerized exports, while it had a negative effect on non-containerized exports. Ayesu et al. (2022) studied the effect of LSCI on economic growth in 28 African countries, using the index as an indicator of port efficiency. The results demonstrated that the LSCI has a significant and accelerating effect on economic growth, playing a complementary role to port throughput.

Since container shipping operates regularly on a schedule, and follows specific routes, changes in a country's LSCI can also impact the LSCI values of neighboring countries. Additionally, certain strategically located countries are striving to attract major shipping lines, aiming to capitalize on the advantages of being a transshipment hub. In this context, it is expected that successful countries may either diverge from others or converge with similarly successful nations. A study by Açık & Atacan (2023) explored this dynamic using unit root tests, focusing on Türkiye and its neighboring countries. The results indicated that the dominant roles of Egypt and Greece in the region are likely to persist. In addition, bilateral trade agreements, economic and political unions, and memberships in common organizations between countries typically lead to increased trade, which can drive higher demand and result in the convergence of transport network connectivity. In this context, Açık (2021) analyzed whether the LSCI values of EU countries have converged using the unit root method. The findings indicated that the differences in the capacities of EU countries' transport networks have diminished, signifying a convergence in their connectivity. That is, international unions and memberships play a crucial role in enhancing trade relations, leading to increased demand and the convergence of transport network connectivity among member countries

Liner shipping operates on specific routes, so the volume and frequency of voyages between countries tend to change gradually. To measure the connectivity between countries more accurately, a variation of the LSCI, known as the Liner Shipping Bilateral Connectivity Index (LSBCI), was developed. In a study conducted by Fugazza & Hoffmann (2017) for 138 countries, the impact of this variable on international trade was examined, revealing that connectivity between countries, as measured by the LSBCI, is more effective in explaining international trade flows than traditional distance-based models. Using a similar approach, Del Rosal (2023) employed the LSBCI as a weighting tool in a gravity model and found that LSBCI significantly impacted trade in the leading regions and trade routes of the global manufactured goods market. However, the analysis revealed that this effect varied from region to region, indicating that the influence of LSBCI on trade was asymmetric. It is reasonable to consider transportation costs using a distance-based approach, as stronger bilateral connectivity between countries may lead to lower transportation costs.

Maritime transport has a derived demand structure, meaning any factor that impacts product demand also affects maritime transport. Consequently, economic shocks can naturally influence the service delivery policies of shipowners and, therefore, the LSCI. In a study conducted by Akpa (2022), which examined LSCI values for G7, BRICS, and MINT countries to determine whether these effects are permanent or temporary, it was found that G7 countries recovered more quickly from economic shocks. This quicker recovery was attributed to the fact that the G7 group consists of advanced economies.

Since the LSCI variable measures connectivity, a higher LSCI does not necessarily translate into a higher trade volume. The efficient use of the service capacity provided to enhance the network is crucial. In this context, Nadarajan et al. (2023) conducted a study on seaport network efficiency, using LSCI as an output variable. The analysis, supported by various methods, led to the suggestion of a more effective efficiency measurement methodology. As demonstrated, the Liner Shipping Connectivity Index (LSCI) is a crucial indicator for measuring a country's connectivity to the international container transportation network and, by extension, to global trade. Ongoing research is focused on enhancing the accuracy and representation of this index by diversifying its calculation methods and weighting processes (Mishra et al., 2021).

Understanding the direction of the relationship between Liner Shipping Connectivity Index (LSCI) and container throughput not only illuminates the dynamics of maritime transportation but also plays a critical role in the strategic decisions of policymakers, port authorities, and businesses. In terms of strategic planning and investment, if LSCI drives container throughput, it suggests that prioritizing factors that enhance connectivity—such as providing more frequent services, accommodating larger ships, and increasing infrastructure investments—should be the focus. Conversely, if container throughput drives LSCI, it implies that as trade volumes naturally grow, LSCI will improve. In this scenario, focusing on investments that facilitate trade and boost exports and imports would be more beneficial, with increased connectivity following as a secondary effect.

In terms of policy implementation, if LSCI drives container throughput, policymakers can focus on port infrastructure investments, negotiating more liner shipping routes, and expanding logistics networks to achieve growth through a stronger connectivity structure. On the other hand, if container throughput drives LSCI, connectivity can be increased by implementing policies such as economic growth-boosting, production-boosting trade agreements, and export incentives.

In terms of resource allocation, understanding the direction of the relationship between LSCI and container throughput can help identify where to focus efforts. If LSCI is driving container throughput, resources should be allocated to infrastructure investments that enhance connectivity. Conversely, if container throughput is the driver, resource allocation can be focused on incentives that boost trade volume. Given that port and transportation infrastructure investments are costly and long-term, accurately determining which areas should be prioritized is of great importance for maximizing the effectiveness of these investments.

There may also be feedback loops between variables, where both LSCI drives container throughput and container throughput drives LSCI. If this interaction is positive, it can be defined as a virtuous cycle; if negative, it can be defined as a vicious cycle. In a positive feedback loop, an improvement in one area leads to an improvement in the other, generating a self-reinforcing cycle of growth and development. For example, an increase in LSCI due to better infrastructure, more frequent services, and larger ships will lead to higher container throughput, which in turn attracts more investment in connectivity. This mutual enhancement generates a cycle of continuous improvement. Similarly, when increased container throughput contributes to improving LSCI, the resulting connectivity boost will generate even more container traffic. Conversely, in a negative feedback loop, a decline in one area causes a decline in the other, leading to a downward spiral that is difficult to reverse.

MATERIAL AND METHODS

The data covers the years between 2008 and 2021 and consists of 85 countries and consists of 1190 observations. The selection of countries was made to maximize the number of observations and countries as much as possible, provided that the LSCI and Container Throughput variables existed together for the same years.

The included countries are Argentina, Australia, Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Congo, Costa Rica, Cote d'Ivoire, Croatia, Cyprus, Denmark, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong SAR, China, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea, Rep., Latvia, Lebanon, Lithuania, Malaysia, Malta, Mexico, Morocco, Myanmar, Namibia, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russian Federation, Saudi Arabia, Senegal, Singapore, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Thailand, Trinidad and Tobago, Tunisia, Türkiye, Ukraine, United Arab

Emirates, United Kingdom, United States, Uruguay, and Viet Nam in alphabetical order.

Two-axis representations of the Container Throughput and LSCI variables of the countries included in the research are presented in Appendix 3. According to the figures, the relationship between variables has a positive tendency in most countries. Panel correlation values were determined as 0.649 for raw data (t=29.44, p=0.00), 0.866 for logarithmic data (t=59.71, p=0.00) and 0.135 for first differenced logarithmic data (t=4.55, p=0.00). There is a positive and significant relationship between the variables, and they generally act together, but of course this analysis cannot provide any findings about which variable affects which.

Descriptive statistics for the whole panel dataset covering all countries are presented in Table 1. In addition, individual Container Throughput descriptive statistics of the countries are presented in Appendix 1, and LSCI descriptive statistics are presented in Appendix 2.

The three countries with the highest annual average Container Throughput values are China (192,000,000), the USA (46,751,180) and Singapore (32,684,129), respectively, while the 3 countries with the lowest are Nicaragua (126,508.6), El Salvador (194,055.9) and Bulgaria (201,058.1). Since China and the USA are the two largest economies in the world, naturally the traffic in their ports occurs in the largest amounts. Singapore, on the other hand, reaches large volumes due to its role as a transshipment port due to its geographical advantage rather than a huge economic size.

The three countries with the highest average LSCI values are China (141.45), Singapore (100.44) and South Korea (94.51), respectively, while the three countries with the lowest average LSCI values are Myanmar (7.46), Bulgaria (7.83) and Barbados (7.97). In the LSCI variable, the USA could not enter the top 3 because the formation of transportation networks depends not only on the country's own demand but also on the demands of surrounding countries. Other countries, in addition to their own demands, enjoy the advantages of being located on the main container shipping route.

As the globalizing world and countries' intense commercial, political and economic relations increase the interaction between them, any change in a country can be quickly transferred to other countries (Nazlioglu et al., 2011). This situation causes especially economic variables to move together among cross section units (Das, 2019). It is defined as cross-sectional dependence in econometrics, and this causes the results to be inconsistent and biased (Bai and Kao, 2006). Therefore, when analyzing panel data, it is of great importance to determine whether there is such a dependency in the dataset and, if so, to choose appropriate methods. In this regard, to test possible cross-sectional dependencies in our dataset we have used LM test by Breusch-Pagan (1980), scaled LM and CD LM tests by Pesaran (2004), and bias-corrected scaled LM test by Baltagi et al. (2012). Although the use of these tests varies depending on the T and N status in the data set, we chose to apply all 4 tests to our data set to increase the consistency of the results. In our study, determining cross-sectional dependence is of great importance because, according to the findings, it will be determined which unit root tests and which causality test should be preferred.

While the use of first-generation unit root tests is sufficient when there is no cross-sectional dependence, second generation unit root tests must be preferred in cases where there is cross-sectional dependence (Söderbom, 2015). Since the findings obtained from the tests indicate a strong cross-sectional dependence, we preferred the Bootstrap-IPS test (Smith et al., 2004), which is one of the second-generation unit root tests. This method is an improvement of the IPS (Im, Pesaran, Shin) test developed by Im et al. (2003). In the IPS test, the augmented Dickey-Fuller test is applied to individual series and then the average of individual statistics is used. However, since this method assumes that the cross-sections are independent, it is inadequate in cases of dependency. For this reason, the Bootstrap-IPS test was developed and the dependency between units was considered. Since this test is a unit root test, the null hypothesis indicates the existence of a unit root.

Table 1. Descriptive statistics of the panel dataset

	CONTAINER	LSCI	DCONT	DLSCI
Mean	7626350	38.87799	0.040452	0.030600
Median	2114758	32.38717	0.040296	0.017699
Maximum	263000000	171.1775	2.591990	1.193361
Minimum	59471	4.582467	-0.843134	-1.161193
Std. Dev.	22187850	27.03486	0.145356	0.134375
Skewness	8.096327	1.257344	4.776400	0.701652
Kurtosis	77.18312	4.715268	92.77086	26.56703
Jarque-Bera	285864.7	459.4295	375242.5	25662.44
Probability	0.000000	0.000000	0.000000	0.000000
Observations	1190	1190	1105	1105

Note: Source: World Bank (2024a, 2024b), UNCTAD (2024)

Panel data analysis, by combining cross-sectional and time series data, enhances variability and the amount of information available, leading to more reliable and efficient forecasts. Meanwhile, panel causality analyses allow for the identification of root causes by examining the relationships between variables, enabling policymakers to focus on these underlying causes in their implementations. We concluded that a panel causality test is the most appropriate method to examine the relationship between countries' LSCI and container throughput. This approach allows us to identify potential demand-led, supply-led, or feedback loop relationships, thereby providing a decision support mechanism to determine which policy actions should be prioritized.

To apply the causal relationship between variables, we employed Granger non-causality test proposed by Juodis et al. (2021). The reasons for choosing this method are; (i) it can be used in multivariate systems, (ii) it is strong against both homogeneous and heterogeneous alternatives, (iii) it can be used in the cases of cross-sectional dependence and cross-sectional heteroscedasticity. This method also works well when there are a large number of cross-sections and a relatively medium time dimension (Xiao et al., 2023).

RESULTS AND DISCUSSION

In panel time series data analysis, it is of great importance whether the series contain cross-sectional dependence or not. Unit root and causality tests must be selected according to the structure of the series. For this reason, first, various cross-sectional dependency tests were conducted on the series. Then, based on the results, it was decided which unit root and causality tests would be used. In the analyses, logarithms of the series were taken and the analyzes were carried out on the relevant data type.

Cross-Section Dependence and Heterogeneity Tests

The presence of cross-sectional dependence in panel data sets may be due to some reasons. When there is a horizontal cross-section, a shock occurring in one of the countries spreads to other countries and affects them as well. The reasons for this may be the global economic system, the economic policies of neighboring countries, cultural factors, network effect, geographical proximity, common economic integration or similarities in management systems.

Cross-Section Dependence Tests was performed by using EViews and results were presented at Table 2. We have applied Breusch-Pagan LM (Breusch-Pagan, 1980) (Small N-Large T), Pesaran scaled LM (Pesaran, 2004) (Large N-Large T), Bias-corrected scaled LM (Baltagi et al., 2012) (Large N-Large T), Pesaran CD (Pesaran, 2004) (Smal T-Large N, Large T-Large N). Considering our panel data set consisting of 85 countries (N) for 14 years (T), Pesaran CD test is the most appropriate one. The null hypotheses of these tests indicate the absence of cross-sectional dependence in the data set. According to the results obtained, the hypothesis that there is no cross-sectional was rejected by all tests for both variables. The results show that there is cross-sectional dependence in both the Container variable and the LSCI variable and that the change or shock in one country spreads to other countries.

In econometric terms, these results indicate that second-generation tests should be preferred instead of first-generation unit root tests and that methods that take cross sectional dependence into account in panel causality tests should be preferred.

Unit Root Tests

Since cross-sectional dependency was detected in our container throughput and LSCI variables, second-generation unit root tests should be preferred instead of first-generation unit root tests. In this direction, we preferred the Bootstrap-IPS test (Smith et al., 2004), which is an improvement of the IPS (Im, Pesaran, Shin) test developed by Im et al. (2003). The Bootstrap-IPS test was applied to the Container and LSCI variables in both Constant and Constant & Trend versions, and the results were presented in Table 3. The null hypothesis of the relevant test indicates the existence of unit root in the panel variable. According to the results, the null hypothesis could not be rejected at the level for both variables. When the first differences of the variables are taken, the null hypothesis is rejected, in other words, the series become stationary.

Since the series had to be stationary in the causality analysis that takes cross-sectional dependency into account, the analyzes were continued by using the first differences of both variables.

Panel Causality Tests

To determine the direction of the relationship between variables, we employed Granger non-causality test proposed by Juodis et al. (2021). This method is a robust causality analysis that takes into account both cross-sectional dependence and cross-sectional heteroskedasticity. Stata software was used to implement the relevant test. The null and alternative hypotheses of the test were developed as follows (Equations 1-2):

Since the data set frequency is annual, the maximum lag is determined as 2. Additionally, a value of 100 was chosen for bootstrap by using seed for randomness. To talk about significant causality, the null hypothesis must be rejected. The test results regarding whether the LSCI variable is the Granger cause of the Container variable are presented in Table 4. According to the results obtained, the optimum lag was determined as 1 and the null hypothesis was rejected. The coefficient of LSCI variable with 1 lag is 0.139. That is, the LSCI variable is the Granger cause of the Container variable.

The null and alternative hypotheses developed regarding whether the container variable is the Granger cause of the LSCI variable were developed as follows (Equations 3-4):

$$H_0: lsci\ does\ not\ Granger - cause\ container\ throughput \quad (1)$$

$$H_1: lsci\ does\ Granger - cause\ container\ throughput\ for\ at\ least\ 1\ panelvar \quad (2)$$

$$H_0: container\ throughput\ does\ not\ Granger - cause\ lsci \quad (3)$$

$$H_1: container\ throughput\ does\ Granger - cause\ lsci\ for\ at\ least\ 1\ panelvar \quad (4)$$

Table 2. Cross-section dependence and homogeneity tests

	Container		LSCI	
Test	**Statistic**	**Prob.**	**Statistic**	**Prob.**
Breusch-Pagan LM	25594.20	0.00	21784.28	0.00
Pesaran scaled LM	260.6460	0.00	215.5574	0.00
Bias-corrected scaled LM	257.3768	0.00	212.2882	0.00
Pesaran CD	117.6746	0.00	111.4335	0.00
d.f.	3570		3570	
Delta Tilde	5.86	0.00	7.87	0.00
Delta Tilde Adjusted	6.61	0.00	8.88	0.00

Table 3. Bootstrap IPS unit root test results

		Container		LSCI	
	Test	**Constant**	**Constant & Trend**	**Constant**	**Constant & Trend**
Level	t-bar statistics	-1.66	-2.37	-1.58	-2.34
	p-value	0.26	0.17	0.31	0.20
First Difference	t-bar statistics	-4.16	-4.55	-4.30	-4.37
	p-value	0.00	0.00	0.00	0.00

Note: 1000 bootstrap replication, block size 50, maximum lag 2.

Table 4. Results for the panel causality test for model 1

	Coefficient	Std. Error	z	$P > \|z\|$
$lsci_{(-1)}$	0.1396	0.0548	2.55	0.011
JKS Non-Causality Result	**HPJ Walt Test**	6.4876	**P-Value**	0.0109

Table 5. Results for the panel causality test for model 2

	Coefficient	Std. Error	z	$P > \|z\|$
$container\_throughput_{(-1)}$	0.1049	0.0473	2.22	0.027
JKS Non-Causality Result	**HPJ Walt Test**	4.9091	**P-Value**	0.0267

The results of the test applied to determine whether the container variable is the cause of the LSCI variable are presented in Table 5. According to the results obtained for optimum 1 lag, the null hypothesis was rejected, and a significant result was obtained. The coefficient of Container Throughput variable with 1 lag is 0.105. That is, the Container Throughput variable is the Granger cause of the LSCI variable. This situation reveals the presence of a positive feedback loop between the variables, where an increase in one variable triggers an increase in the other, which in turn amplifies the initial variable, generating a reinforcing cycle.

In our research, we examined the relationship between LSCI variables and Container Throughputs of countries with 1190 observations consisting of 85 countries and a 14-year period. Our main motivation in this research is to determine whether supply-side growth or demand-side growth is more effective in global container shipping. Based on the results obtained, it is aimed to present policy recommendations for the development of global trade.

Since we first conducted our analyzes with the panel data set, we applied the Cross-Sectional Dependency test to both variables and determined that there was dependence in both variables. If we evaluate the situation in terms of LSCI, the presence of cross-sectional dependence indicates that the LSCI value in a country is not independent from any other country. If a country increases its infrastructure and connectivity, neighboring countries and trading partner countries may experience an increase in their LSCI variables. Because this may lead to the development of routes, an increase in the frequency of ship service or the inclusion of larger ships on the route. The reason is that it is the demands of all countries on a certain route that determine the capacity in liner shipping. Similarly, the situation in countries where the LSCI value decreases for any reason may affect the demand on the route and cause a decrease or increase of LSCI values in other countries. A decrease in the connectivity of a neighboring country may also cause ships to shift to the relevant country and achieve higher connectivity. In addition, the establishment of new ports in any country is a factor that directly affects the LSCI values of other countries. Similarly, disruptions in a country's supply chains may reduce the connectivity of some ports and increase the connectivity of others. In this respect, it is inevitable to have cross-sectional dependence in the LSCI variable as a shock in any country can easily spread to other countries

If we examine the cross-section dependency situation in terms of Container Throughput, it can be said that it is caused by many factors, as in the case of LSCI. When container traffic in a country's ports increases for any reason, this naturally causes an increase in the countries where it carries out commercial activities and is used as a transshipment port. Additionally, when ports in a country increase their capacity or efficiency, this may cause them to steal cargo from other countries. Agreements facilitating trade between countries also stand out as an important factor affecting both regional and route-based container traffic. As mentioned about LSCI, disruptions in the global supply chain have a role in dependence and interaction between countries, as they can cause the decline originating from one country to be reflected negatively or positively in other countries. All these and similar situations cause the change in a country's container traffic for any reason to be reflected in the traffic of other countries and pose inter-country dependency.

Due to the cross-sectional dependence in the series, methods that are robust to this situation have been chosen in the selection of both panel unit root tests and panel causality tests. The applied unit root tests indicated the existence of unit root in both LSCI and Container Throughput variables. While the existence of a unit root indicates that shocks have permanent effects, this can be due to many reasons. If countries make significant infrastructure investments in their ports, this generates a permanent impact on port traffic and LSCI values. In addition, if trade-facilitating agreements and policies are implemented between countries, this also induce a permanent effect. Similarly, global events that negatively affect the global supply chain and economic activities may have permanent effects on the values of countries, such as COVID 19 and Russia-Ukraine War. As a result, the variables were purified from the unit root effect by taking their first differences and causality analysis was applied with stationary series.

The results obtained from the panel Granger causality analyzes can be evaluated in different dimensions in terms of significance, coefficient and lag. In terms of significance, there are significant causal relationships both from Container throughput to the LSCI variable and from the LSCI variable to the Container Throughput variable. This shows that both variables affect each other and that a change in one variable causes a change in the other, meaning there is a two-way flow of information.

In terms of coefficient, the coefficients of the independent variables are positive in both causality equations. This indicates that the change in the LSCI variable causes an increase in Container Throughput in subsequent periods, and the changes in Container Throughput cause an increase in the LSCI variable in subsequent periods. Considering the coefficient size, the coefficient of the independent LSCI variable in the first model (0.1396) is higher than the coefficient of the independent Container Throughput variable in the second model (0.1049). This shows that improvements in infrastructure and transportation networks generate more demand, and the increase in demand also causes more transport infrastructure services to be provided in the relevant countries, but the impact in the first case is higher.

When considering the issue in terms of lag, the optimum lag for both models was determined as 1. This shows that in both models, the change in the independent variable has an effect on the dependent variable in the following period. The change in LSCI value in the current period increases the Container Throughput in the next period and vice versa.

The two-way interaction between variables can be evaluated as an increase in one variable causing an increase in the other variable and then reflecting positively on itself, in other words, a positive feedback loop. Growth in one variable stimulates growth in the other variable. While there is a two-way relationship between Liner Shipping Connectivity Index (LSCI) and container throughput, the impact of LSCI on container throughput (with a coefficient of 0.1396) is slightly stronger than the impact of container throughput on LSCI (with a coefficient of 0.1049). This suggests that improvements in LSCI have a more pronounced effect on increasing container throughput than the reverse, highlighting the importance of connectivity enhancements in driving trade volumes.

When analyzing the studies in the literature, the positive effect of container throughput on LSCI is confirmed through the variable "container per capita" (Jouili, 2019). Similarly, the positive effect of LSCI is validated through variables such as exports (Şeker, 2020), trade volume (Canbay, 2014; Fugazza & Hoffmann, 2017), container throughput (Reza et al., 2015; Atacan et al., 2022; Del Rosal & Moura, 2022), and economic growth (Ayesu et al., 2022). While there is no single study that employs a methodology capable of detecting a positive feedback loop relationship in the same manner as ours, all these studies collectively support this finding. While existing studies confirm individual relationships between variables like LSCI, container throughput, and trade volume, our research uniquely contributes to the literature by employing a methodology capable of detecting a positive feedback loop between these variables. This comprehensive approach allows us to reveal the cyclical nature of these relationships, which has not been addressed in previous studies. By uncovering this feedback loop, our work provides deeper insights into the dynamic interactions within container transportation and global trade. Our findings highlight the need to focus not only on infrastructure investments to improve transport connectivity but also on implementing trade-enhancing policies. Moreover, this finding aligns closely with Myrdal's (1957) theory of cumulative causation, which posits that economic processes are self-reinforcing, leading to cycles of development or underdevelopment. In this context, an increase in one variable, such as LSCI, can trigger positive changes in other areas, like container throughput, generating a feedback loop that amplifies growth. Myrdal (1957) argued that such processes are cumulative, meaning that initial changes tend to set off a chain reaction of further changes in the same direction, thereby enhancing the overall economic effect.

The annual nature of the data used in the study stood out as an important limitation of the study, making it impossible to apply short-term dynamic analysis. LSCI is published quarterly, if container throughput can be obtained at a more frequent frequency such as quarterly, more dynamic analyzes can be applied in future research. In addition, by clustering countries according to their profiles, it can be determined whether the relationship differs according to country groups. Future studies should expand on our investigation of the relationship between the Liner Shipping Connectivity Index (LSCI) and container port throughput by incorporating additional performance metrics such as the Maritime Transport Efficiency Index (MTEI), Logistics Performance Index (LPI), and Container Port Performance Index (CPPI). Analyzing these indices in conjunction with the LSCI could provide a more comprehensive understanding of the factors influencing maritime logistics efficiency and offer valuable insights for improving port performance and connectivity.

CONCLUSION

This study makes a groundbreaking contribution to the literature as the first to identify and analyze the cyclical relationship between LSCI and container throughput, shedding light on the dynamic interplay of these variables. Our findings reveal a two-way positive feedback loop, where advancements in one area stimulate growth in the other, emphasizing the deeply interconnected nature of transportation networks and trade volumes. Moreover, the stronger influence of LSCI on container throughput underscores the critical importance of infrastructure and connectivity enhancements in driving global trade. In alignment with the cumulative causation theory, this study demonstrates that initial improvements in connectivity can set off self-reinforcing cycles of growth, promoting economic development and trade efficiency. By establishing this novel feedback loop, our research offers a unique perspective and lays the foundation for future studies in the field.

Compliance with Ethical Standards

Authors' Contributions

AD: Writing – original draft, Investigation, Formal Analysis.

AA: Conceptualization, Supervision, Writing – review & editing.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data that support the findings of this study are available from the corresponding author on request.

Supplementary Materials

Supplementary data to this article can be found online at https://doi.org/10.61326/actanatsci.v5i2.287.

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Appendix 1. Descriptive statistics of the port throughputs of the countries

Country	Mean	Max	Min.	Std. Dev.	Skew.	Kurt.	Obs.
Argentina	1890738.	2184625.	1626835.	193480.2	0.411869	1.773397	14
Australia	7505615.	8775819.	6102342.	880085.8	-0.191040	1.899241	14
Bahamas	1363930.	1792780.	920652.0	236400.8	0.074291	2.463956	14
Bahrain	401028.2	525309.0	269331.0	66885.49	-0.484101	3.220968	14
Bangladesh	2082770.	3271732.	1091200.	774996.3	0.245559	1.533329	14
Barbados	87638.29	107098.0	72163.00	11892.22	0.315660	1.735680	14
Belgium	10745482	13075891	9528054.	1208314.	0.845533	2.256516	14
Brazil	9048580.	11801530	6590364.	1458912.	0.034956	2.359429	14
Bulgaria	201058.1	261934.0	136444.0	41905.19	-0.117837	1.810974	14
Canada	5665481.	7169607.	4191568.	944949.0	0.156480	1.820060	14
Chile	3892167.	4661306.	2795990.	603491.9	-0.315062	1.930686	14
China	1.92E+08	2.63E+08	1.09E+08	48765549	-0.286932	1.970589	14
Colombia	3431387.	4901510.	1969316.	878887.1	-0.219135	2.134680	14
Congo	606549.3	1003734.	291917.4	226231.8	0.373160	2.125152	14
Costa Rica	1266807.	1523198.	875687.0	208498.0	-0.415439	2.045512	14
Cote d'Ivoire	883827.4	1015624.	677029.0	117494.8	-0.629650	1.927502	14
Croatia	240558.9	376981.0	130740.0	82555.37	0.458502	1.822478	14
Cyprus	349222.0	416970.0	277276.0	42828.55	0.147557	2.056193	14
Denmark	792773.6	1055262.	621546.0	108124.3	0.939384	3.754460	14
Djibouti	752479.9	987400.0	356462.0	198365.4	-0.878613	2.550456	14
Dominican Republic	1579689.	2184754.	1138471.	302973.1	0.395208	2.171066	14
Ecuador	1764002.	2593926.	670831.0	548424.3	-0.366600	2.509117	14
Egypt	6207062.	7321888.	5479814.	503067.0	0.704854	2.796896	14
El Salvador	194055.9	294326.0	126369.0	45480.41	0.610987	2.801847	14
Finland	1455273.	1630089.	1125533.	146660.2	-0.823268	3.161858	14
France	4573684.	5522541.	3865087.	471921.6	0.252876	2.397520	14
Germany	14959148	17183042	13056019	1027346.	-0.043808	3.498001	14
Ghana	932553.3	1604724.	557323.2	280255.7	0.922499	3.577440	14
Greece	3685545.	6183643.	672522.0	1924048.	-0.209678	1.841218	14
Guatemala	1299610.	1735500.	906326.0	256385.6	-0.073207	1.959413	14
Honduras	712062.1	824876.0	571720.0	76839.45	-0.044505	1.997344	14
Hong Kong SAR	21109380	24494229	17772000	2323195.	0.039862	1.723648	14
India	12895229	19937138	7672457.	3978683.	0.331054	1.779968	14
Indonesia	10052807	12111471	7255005.	1655258.	-0.438193	2.038935	14
Iran	2305851.	3359250.	1253429.	609761.0	-0.041665	2.285583	14
Ireland	904758.3	1143007.	727328.0	142964.0	0.189198	1.615847	14
Israel	2603889.	3133000.	2033000.	339295.0	-0.141520	1.991919	14
Italy	10306032	11303247	9532462.	531842.1	-0.036053	2.137749	14
Jamaica	1743633.	1975401.	1560000.	137906.1	0.242396	1.634534	14
Japan	21144681	23424446	16285918	1853378.	-1.250300	4.490157	14
Jordan	759936.6	872809.0	582515.0	87965.08	-0.818081	2.649570	14
Kenya	1027581.	1435565.	615733.0	288897.5	-0.020126	1.704508	14
Korea, Rep.	24301987	29786900	15699663	4505736.	-0.537882	2.152934	14

Country	Mean	Max	Min.	Std. Dev.	Skew.	Kurt.	Obs.
Latvia	366286.8	474393.0	184399.0	91502.32	-0.712445	2.331582	14
Lebanon	1055340.	1305755.	675077.0	191066.1	-0.509424	2.377124	14
Lithuania	471314.1	749066.0	247982.0	155917.1	0.552309	2.078467	14
Malaysia	22307031	28261849	15922800	3865168.	-0.279207	2.018600	14
Malta	2740584.	3314087.	2323941.	336541.3	0.207057	1.632810	14
Mexico	5343205.	7852230.	2874313.	1501890.	-0.025515	1.996017	14
Morocco	4097127.	8457129.	919360.0	2052199.	0.501835	2.914949	14
Myanmar	724828.8	1200000.	163692.0	369687.4	-0.241180	1.546901	14
Namibia	212903.4	334410.0	115955.0	64271.47	0.273551	2.144553	14
Netherlands	12898252	15781756	10066374	1710910.	0.280013	1.957330	14
New Zealand	2862641.	3445621.	2317619.	428249.3	0.052447	1.527423	14
Nicaragua	126508.6	190756.0	59471.00	48021.36	-0.118874	1.416185	14
Nigeria	1317888.	1867409.	72500.00	551603.7	-1.652967	4.331357	14
Norway	689494.6	881238.0	318924.0	169157.1	-1.346879	3.830320	14
Oman	4104092.	5226000.	3105000.	673367.3	0.377559	1.983335	14
Pakistan	2687374.	3548000.	1938001.	539067.1	0.138176	1.487800	14
Panama	6628240.	8623927.	4597112.	1025345.	-0.223919	3.080392	14
Peru	2146009.	2874109.	1232849.	533747.1	-0.477657	2.106745	14
Philippines	6715555.	9171944.	4306965.	1612624.	-0.003760	1.682934	14
Poland	1997722.	3187943.	671552.0	819401.3	-0.101936	1.874416	14
Portugal	2432216.	3276794.	1233482.	720903.7	-0.486523	1.737429	14
Qatar	742164.9	1543600.	346000.0	456987.3	0.782109	1.865658	14
Romania	707108.7	1380935.	556694.0	198149.6	3.077263	11.11809	14
Russian Federation	4183478.	5260825.	2427744.	795838.3	-0.676371	2.658478	14
Saudi Arabia	7191968.	9875946.	4430676.	1727685.	-0.142816	1.902313	14
Senegal	516529.6	769358.0	331076.0	146462.9	0.329345	1.779942	14
Singapore	32684129	37470000	26592800	3416986.	-0.008460	1.990575	14
Slovenia	715505.6	997000.0	343165.0	233296.2	-0.252461	1.688116	14
South Africa	4364903.	4892423.	3726313.	336209.6	-0.470047	2.288348	14
Spain	14872983	17712459	11803192	1861995.	0.150417	1.918104	14
Sri Lanka	5322767.	7250000.	3464297.	1368945.	0.226162	1.546037	14
Sweden	1486502.	1635394.	1251424.	117442.3	-0.539754	2.474011	14
Thailand	8612840.	10436689	5897935.	1442404.	-0.344463	1.974752	14
Trinidad and Tobago	501358.5	593364.0	406778.0	72104.26	-0.194636	1.288896	14
Tunisia	464417.1	493366.0	418883.9	22860.99	-0.812669	2.610584	14
Turkiye	8511052.	12591327	4521713.	2536587.	0.061256	1.883381	14
Ukraine	794024.1	1123268.	480837.0	195698.3	0.177649	2.081645	14
United Arab Emirates	18169709	21238293	14425039	2124822.	-0.555849	2.290382	14
United Kingdom	9153769.	10508000	7671300.	1021768.	-0.086510	1.373314	14
United States	46751180	60554285	37353575	6591434.	0.557218	2.397849	14
Uruguay	787075.6	977922.0	588410.0	112504.1	-0.168749	2.446944	14
Viet Nam	10384812	18359845	4393699.	4348761.	0.349203	2.013772	14
All	7626350.	2.63E+08	59471.00	22187850	8.096327	77.18312	1190

Appendix 2. Descriptive statistics of the LSCI of the countries

Country	Mean	Max	Min.	Std. Dev.	Skew.	Kurt.	Obs.
Argentina	30.96455	36.03292	24.99132	3.195726	-0.416809	2.150604	14
Australia	32.42419	37.24298	28.97030	2.766408	0.176203	1.794883	14
Bahamas	26.52852	32.24168	19.83078	3.589291	-0.299387	2.481898	14
Bahrain	19.53408	31.70695	7.539293	8.073785	0.025858	1.760666	14
Bangladesh	10.48312	14.67166	7.558768	2.430573	0.269879	1.725132	14
Barbados	7.972931	10.13153	7.017093	0.805672	1.365988	4.763879	14
Belgium	82.85431	89.53596	77.65985	3.968560	0.157311	1.670544	14
Brazil	35.01462	39.74286	30.94899	2.089542	0.261540	3.627179	14
Bulgaria	7.826391	16.56726	5.745421	2.811423	2.318032	7.876985	14
Canada	41.35147	48.84237	35.18536	4.731617	0.076070	1.486465	14
Chile	30.32061	36.71491	19.10985	5.961989	-0.508160	2.033196	14
China	141.4590	171.1775	118.4559	15.67581	0.317551	2.281657	14
Colombia	40.57985	49.36579	26.89080	8.407613	-0.312090	1.502115	14
Congo	20.03714	29.75473	12.07492	5.730851	-0.017184	1.754358	14
Costa Rica	19.49613	24.55057	16.85506	2.731041	1.046107	2.533485	14
Cote d'Ivoire	20.18119	22.45795	18.97505	0.990406	1.026559	3.119223	14
Croatia	24.88254	33.74262	15.34605	7.000057	0.050508	1.316661	14
Cyprus	17.03633	19.62741	12.29363	1.774252	-1.247628	4.754305	14
Denmark	40.29397	47.49826	25.56680	8.061063	-1.015414	2.473545	14
Djibouti	24.43609	34.13277	10.16336	7.515878	-0.242648	1.897862	14
Dominican Republic	31.71584	42.22841	23.98990	6.417326	0.265374	1.455033	14
Ecuador	27.03093	38.00434	18.36905	6.261129	0.435097	2.027094	14
Egypt	55.23068	68.50873	45.50208	6.803673	0.481806	2.647568	14
El Salvador	8.590170	9.755334	7.545824	0.663217	0.255280	2.112924	14
Finland	14.77543	18.25296	13.27051	1.291570	1.310193	4.798891	14
France	68.88862	77.44940	58.36347	6.521189	-0.346869	1.749571	14
Germany	82.24557	85.53077	78.26096	2.463203	-0.337999	1.801077	14
Ghana	24.25424	39.98621	18.87242	7.511402	1.368250	3.015420	14
Greece	44.90190	60.30791	25.02042	11.64093	-0.020978	1.943168	14
Guatemala	22.37129	37.16036	15.07630	6.119593	1.019195	3.614173	14
Honduras	12.88938	14.22379	11.33643	0.957496	-0.048297	1.708139	14
Hong Kong SAR	91.96250	95.62995	89.21045	2.381223	0.409436	1.679639	14
India	50.61884	58.88920	43.07750	5.503006	0.101143	1.470186	14
Indonesia	36.76531	45.66315	32.70692	4.266872	1.218309	2.895031	14
Iran	26.08140	35.70256	18.07725	5.776118	-0.107425	1.676629	14
Ireland	11.45502	14.12884	7.682894	1.931366	-0.654579	2.532242	14
Israel	32.97455	41.58630	22.47414	7.092301	-0.200503	1.577039	14
Italy	64.78070	76.34007	55.09361	5.945144	0.676138	2.967575	14
Jamaica	27.98452	35.20139	21.78658	5.238779	0.050114	1.279875	14
Japan	74.18313	87.46395	67.18190	5.523448	1.026890	3.473085	14
Jordan	25.87674	34.47206	17.89262	5.815051	0.408852	1.732438	14
Kenya	15.56000	18.77202	13.40688	1.620006	0.389343	2.167162	14
Korea, Rep.	94.50562	111.2529	71.90017	12.05043	-0.502107	2.510654	14

Country	Mean	Max	Min.	Std. Dev.	Skew.	Kurt.	Obs.
Latvia	8.095759	10.68892	5.725775	1.436577	0.575507	2.515403	14
Lebanon	35.46079	43.17314	23.53488	6.078502	-0.694765	2.394788	14
Lithuania	13.89559	23.97688	8.116877	4.471687	1.101634	3.360717	14
Malaysia	89.15905	99.50430	72.03446	8.208888	-0.720279	2.661879	14
Malta	44.98287	57.36628	36.54769	6.173137	0.220417	2.282913	14
Mexico	41.89493	49.09624	32.49962	5.355310	-0.228559	1.776288	14
Morocco	56.62803	69.30395	39.07992	9.275945	-0.392792	2.086414	14
Myanmar	7.456856	9.964803	4.582467	1.809185	-0.374946	1.796544	14
Namibia	15.69150	22.18217	11.03919	2.686881	0.826775	3.883990	14
Netherlands	83.65366	91.92992	77.09661	5.005233	0.509206	1.773233	14
New Zealand	24.29702	30.50232	18.57568	4.906576	0.258161	1.183684	14
Nicaragua	8.166334	9.405701	6.703274	0.692092	-0.204893	2.837922	14
Nigeria	21.44753	23.65890	19.73283	1.070766	0.504167	2.791704	14
Norway	10.34331	11.33294	8.466585	0.709852	-1.232681	4.609128	14
Oman	46.75242	60.72164	31.90309	9.233506	-0.003915	1.853263	14
Pakistan	31.53769	40.78238	26.82430	3.999119	0.645167	2.892620	14
Panama	43.93122	51.59629	32.84238	6.429818	-0.557882	1.996189	14
Peru	32.27877	40.42091	17.44760	7.116350	-0.607522	2.429146	14
Philippines	25.66326	31.48116	20.37029	3.987025	0.124011	1.502093	14
Poland	41.14013	56.65120	9.659444	13.14389	-1.099879	3.383218	14
Portugal	47.06841	61.19878	36.38748	6.980314	0.988227	3.029460	14
Qatar	17.66633	37.72575	7.139217	12.96205	0.669480	1.553723	14
Romania	23.67880	26.80118	18.23991	2.862940	-0.662914	2.183685	14
Russian Federation	38.75937	53.12171	26.41942	8.566014	-0.013775	1.666635	14
Saudi Arabia	54.56156	70.00213	42.82366	8.452459	0.627242	2.441693	14
Senegal	15.84523	18.65912	13.48321	1.676057	-0.133553	1.719384	14
Singapore	100.4419	113.7750	87.54251	7.932597	0.165082	1.949325	14
Slovenia	26.29302	35.45620	16.66380	6.937836	0.003520	1.329842	14
South Africa	36.98002	41.25695	30.95964	3.247636	-0.454643	1.838635	14
Spain	79.97483	90.46702	71.02529	7.075722	0.053007	1.504303	14
Sri Lanka	52.58851	71.99261	37.16352	12.72011	0.178484	1.490491	14
Sweden	43.42030	50.98064	30.12731	7.394883	-1.028812	2.467650	14
Thailand	45.84020	68.94720	34.75399	9.410817	1.505277	4.234182	14
Trinidad and Tobago	17.83764	21.75280	13.48697	2.789975	-0.048394	1.354996	14
Tunisia	8.373053	10.83718	5.624464	1.612145	-0.039248	1.896130	14
Türkiye	51.10279	61.49812	35.00334	8.545284	-0.754023	2.335833	14
Ukraine	24.83700	28.17948	19.56299	3.116736	-0.690440	2.152890	14
United Arab Emirates	67.22895	76.49650	58.31276	5.621406	0.034626	1.722964	14
United Kingdom	82.82116	90.95084	75.78629	5.326394	0.026000	1.564488	14
United States	86.85430	103.8523	74.88604	9.219172	0.495911	2.332109	14
Uruguay	27.86916	35.18824	18.44605	4.475277	-0.566413	2.698671	14
Viet Nam	52.79039	79.77808	23.18412	16.06080	0.037296	2.351301	14
All	38.87799	171.1775	4.582467	27.03486	1.257344	4.715268	1190

Appendix 3. Graphical display of the variables for countries

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info@actanatsci.com
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Comparative Analysis of Nutritional Values of Fishmeals Produced From Whole Anchovy and Sprat and Farmed Salmon Viscera in the Black Sea Region

Barış Bayraklı[1]✉ • Sezgin Yıldız[2]

[1] Sinop University, Vocational School, Department of Seafood Technology, 57100, Sinop, Türkiye; bbayrakli@sinop.edu.tr
[2] Dalyan Fisheries and Food Products, Fish Meal and Fish Oil Factory, Dikmen, Sinop, Türkiye; sezgin.yildiz@dalyansu.com

✉ Corresponding Author: bbayrakli@sinop.edu.tr

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A B S T R A C T

Fishmeal is a nutrient-rich feed ingredient that is commonly used in commercial feed formulations for many species, primarily in the global aquaculture and pet food sectors. This study investigates the nutritional composition of fishmeals derived from whole anchovy, sprat, and salmon viscera, produced in Turkey during the 2023-2024 fishing season. A total of 91 samples were analyzed using a Bruker-type MPA brand spectrophotometer to determine crude protein, crude fat, moisture, and crude ash content. The carbohydrate content was calculated by difference, and energy content was derived using established conversion factors. Anchovy meal exhibited the highest crude protein content at 73.55%, followed by sprat meal at 70.08%, and salmon viscera meal at 63.58%. In terms of crude fat, salmon viscera meal had the highest concentration at 11.76%, compared to anchovy meal at 10.33% and sprat meal at 9.92%. Moisture content was highest in salmon viscera meal (10.45%), while anchovy and sprat meals had lower moisture levels of 6.53% and 7.15%, respectively. The crude ash content was also highest in salmon viscera meal at 11.96%. Carbohydrate content was most pronounced in sprat meal at 3.77%, with salmon viscera and anchovy meals containing 3.32% and 1.52%, respectively. Energy content was highest in anchovy meal at 393.26 kcal/100g. These findings highlight the distinct nutritional profiles of the fishmeals studied, allowing for the identification of the most suitable option for aquaculture nutrition. Specifically, anchovy meal emerges as the best choice due to its high protein content and energy efficiency.

INTRODUCTION

Seafood is an important source of protein, healthy fats, vitamins, and minerals. Fish contains significant amounts of energy and essential amino acids (Bayraklı, 2024). The polyunsaturated fats in fish have many health benefits and are a crucial source of long-chain omega-3 fatty acids, which are known to prevent heart diseases. Fish also contribute significantly to the body's production of protein, fats, and micronutrients (Ahmed et al., 2022; Lall & Dumas, 2022)

The importance of aquaculture is increasing as the demand for seafood grows. With wild fish stocks being overfished, aquaculture provides a sustainable alternative for meeting this demand (Einarsson & Óladóttir, 2020; Boyd et al., 2022). The growth of aquaculture has resulted in a higher need for high-quality fish feed, with fishmeal being a critical component. (Ansari et al., 2021; Alfiko et al., 2022). However, the demand for farmed fish is leading to challenges in the supply of fishmeal and fish oil, forcing the exploration of alternative sources of protein and new formulations for fish feeds (Bayraklı, 2023; Glencross et al., 2023; Eroldoğan et al., 2023). This need for affordable fishmeal is driven by the fact that fish feed accounts for nearly 70% of the costs of aquaculture operations. Fishmeal is essential for the rapid development of farmed fish, with about 30-40% fishmeal needed in fish feed to meet the necessary requirements (Hardy et al., 2022; Alfiko et al., 2022; Boyd et al., 2022).

Fishmeal is highly valued in aquafeeds due to its high protein content and well-balanced amino acid profile (Bayraklı et al., 2022). It is primarily produced from small pelagic fish such as ringa, anchovy and sprat, as well as leftovers from fish processing like salmon viscera. (Henriksen, 2020; Ahuja et al., 2020). As aquaculture continues to expand, the demand for fishmeal is also increasing, highlighting its importance in sustaining and boosting the industry (Campanati et al., 2022). To meet this growing need, a greater quantity of fish and by-products are expected to be used for fishmeal production each year (Sandström et al., 2022; Albrektsen et al., 2022). The fishmeal industry also faces challenges such as resource sustainability, price volatility, and public perceptions of its environmental impact (Bayraklı & Duyar, 2021; Gudbrandsdottir et al., 2021). The supply of used fish for fishmeal and fish oil production is not abundant. To ensure long-term viability, these issues must be addressed, including increasing the proportion of small pelagics for direct human consumption and improving fisheries and marine ecosystems (Lam et al.2020). To address this issue, it is important to move towards more eco-friendly production methods in feed production and make use of a wider range of fish.

The aim of this study was to compare the nutritional content and energy levels of fishmeals derived from whole anchovy, whole sprat, and salmon viscera in order to determine which of these fishmeals is superior. The assessment considered components such as crude protein, crude fat, crude ash, moisture, and carbohydrate values, in order to determine if salmon viscera fishmeal could be a viable alternative or additional feed ingredient in aquaculture. The results of this research could potentially improve the efficient use of locally sourced feed resources in Türkiye’s aquaculture industry.

MATERIAL AND METHODS

The present study used a rigorous analytical method to assess the nutritional composition of fishmeals made from anchovy, sprat, and salmon internal organs. Samples were collected from fishmeal production facilities in Sinop, a region recognized for its fish processing industry. A total of 48 samples of anchovy meal were collected in December 2023, 27 samples of sprat meal in February 2024, and 16 samples of salmon internal organ meal in May 2024. Each sample underwent four independent measurements to ensure accuracy and reliability of the data.

A Bruker-type MPA brand spectrophotometer, located in the quality laboratory of a Sinop-based fishmeal factory, was utilized to analyze the primary nutritional components: crude protein, crude fat, moisture, and crude ash. This advanced spectrophotometric analysis provided high-resolution data essential for the accurate quantification of these components (Bayraklı et al, 2022).

The total amount of carbohydrates was determined by subtracting the combined amount of crude protein, crude fat, moisture, and crude ash from 100, as detailed in the methodologies by Ferris & Shanklin (1993) and Anonymous (2005). This calculation gave a thorough analysis of the carbohydrate content in the samples.

The energy content was measured in kilocalories per gram (kcal/g) and was calculated using the percentage of crude protein, total carbohydrate, and crude fat. The conversion factors used were 4.0 kcal/g for protein and carbohydrates, and 9.0 kcal/g for total fat, as determined by Ferris & Shanklin (1993) and Merrill & Watt (1973). The formula used to calculate total energy (TE) which provided an accurate estimate of the caloric value of each sample was given in Equation (1).

The SPSS version 22 software (SPSS, Chicago, Illinois, USA) was used for the statistical analyses. A one-way analysis of variance (ANOVA) was used to find significant differences in the nutritional composition of the various fishmeals. Duncan's multiple range test was then used with a significance level of $P < 0.05$ to further assess the compositional differences.

RESULTS AND DISCUSSION

The present study provides a comprehensive analysis of the nutritional composition of fishmeals derived from anchovy, sprat, and salmon viscera, highlighting significant variations in their macronutrient profiles. The data, as presented in Table 1, reveal distinct differences in crude protein, crude fat, moisture, crude ash, carbohydrate content, and energy values among the three types of fishmeals.

The protein content of anchovy meal (73.55±1.50%) and sprat meal (70.08±1.36%) is higher than that of salmon viscera meal (63.58±1.85%), with anchovy meal exhibiting the highest protein content and salmon viscera meal showing the lowest. Differences among the three were significant ($p<0.05$). The significant differences observed in the nutritional analysis underscore that anchovy meal is a superior protein source for aquafeeds, offering higher protein content compared to sprat and salmon viscera meals. Anchovy meal typically contains a protein content that can exceed 70%, making it an excellent source of high-quality protein that is rich in essential amino acids (Guo et al., 2019). This high protein content is crucial for fish, as it promotes muscle development, enhances growth rates, and improves feed conversion efficiency. The amino acid profile of anchovy meal is also well-balanced, providing the necessary building blocks for protein synthesis in fish (Foroutani et al., 2018). In contrast, sprat meal, while still a good source of protein, generally has a slightly lower protein content compared to anchovy meal. However, it can still be a valuable ingredient in aquaculture feeds, especially when combined with other protein sources to achieve a balanced diet. Sprat meal can provide essential nutrients and contribute to the overall protein intake of the fish, but it may not be as nutritionally dense as anchovy meal (Litaay et al., 2022). Fishmeal derived from salmon viscera, although it has a respectable protein content, typically ranks lower than both anchovy and sprat meals in terms of protein quality and digestibility. While salmon viscera meal can provide a good source of protein, it may lack certain essential nutrients and amino acids that are more abundant in anchovy and sprat meals (Guo et al., 2019). Additionally, the digestibility of protein from salmon viscera may not be as high as that from anchovy or sprat, potentially leading to lower nutrient absorption and growth performance in fish (Suparmi et al., 2022). Given these considerations, it is advisable to prioritize anchovy meal as the primary protein source in aquaculture diets due to its superior protein content and nutritional profile. Sprat meal can be used as a supplementary protein source to enhance the overall diet, especially in formulations where cost or availability is a concern. Fishmeal from salmon viscera can be incorporated into diets, but it should be done with caution, ensuring that it is balanced with other high-quality protein sources to meet the nutritional needs of the fish effectively.

$$TE = (Crude\ protein \times 4) + (Carbohydrate \times 4) + (Crude\ fat \times 9) \quad (1)$$

Table 1. Nutritional composition of fishmeals derived from anchovy, sprat, and salmon viscera

Nutritional Composition	Anchovy Meal	Sprat Meal	Salmon Viscera Meal
Crude Protein	73.55±1.50[c]	70.08±1.36[b]	63.58±1.85[a]
Crude Fat	10.33±0.86[ab]	9.92±0.33[a]	11.76±0.98[b]
Moisture	6.53±1.38[a]	7.15±1.43[a]	10.45±0.74[b]
Crude Ash	8.07±0.86[a]	9.07±0.87[a]	11.96±1.32[b]
Carbohydrate	1.52±0.55[a]	3.77±0.81[b]	3.32±0.69[b]
Energy	393.26±2.87[c]	384±3.68[b]	366.41±4.41[a]

Note: The difference between the means of the values indicated with different letters in the columns in each group is statistically significant ($p<0.05$).

Salmon viscera meal has the highest fat content at 11.76±0.98%, while both anchovy meal (10.33±0.86%) and sprat meal (9.92±0.33%) have lower but statistically similar ($p<0.05$) fat contents. The ideal crude fat ratio in fishmeal used in fish feed rations is a critical factor that influences the nutritional quality, growth performance, and overall health of fish. Generally, a crude fat content of around 10% is considered optimal for many aquaculture species, as it provides essential fatty acids while also contributing to the energy density of the diet (Mmanda et al., 2020; Chang, 2023). In this study, it was observed that the crude fat ratio determined was around 10% in three fishmeal types and was close to the crude fat ratio in ideal fishmeal. The specific ideal ratio can vary depending on the species being cultured, their life stage, and their dietary requirements. Having a higher crude fat content in fishmeal can be beneficial, as it enhances the energy content of the feed, which is particularly important for fast-growing species or those with high energy demands. Fish require lipids not only for energy but also for the absorption of fat-soluble vitamins and the provision of essential fatty acids, such as omega-3 and omega-6 fatty acids, which are crucial for growth, reproduction, and immune function (Mmanda et al., 2020). Moreover, higher fat content can improve the palatability of the feed, encouraging fish to consume more, which can lead to better growth rates and feed conversion ratios (Poczyczyński et al., 2014). However, excessively high crude fat levels can pose challenges, particularly concerning spoilage and rancidity. Fishmeals with high fat content are more susceptible to oxidative degradation, which can lead to the formation of off-flavors and harmful compounds that negatively impact fish health and feed quality (Zhu & He, 2011; Anuar, 2023). Therefore, while a certain level of fat is beneficial, it is essential to balance the fat content to avoid spoilage and ensure the feed remains fresh and nutritious.

Salmon viscera meal has the highest moisture content at 10.45%, whereas anchovy meal (6.53%) and sprat meal (7.15%) have comparatively lower levels. Statistical analysis revealed that salmon viscera meal was significantly different from both anchovy and sprat meals ($p<0.05$), while no significant differences were found between anchovy and sprat meals. The fishmeal used in fish feed rations is generally advised moisture under 10% to minimize bacterial growth and ensure better preservation. Maintaining a low moisture content is crucial for several reasons, primarily related to spoilage and the overall quality of the fishmeal. High moisture levels can create an environment conducive to microbial growth, leading to spoilage and the degradation of nutritional quality (Nyong, 2014). When moisture content exceeds the ideal range, the risk of mold and bacterial contamination increases, which can result in the loss of essential nutrients, including amino acids and fatty acids, as well as the production of harmful toxins (Hossen et al., 2013). Moreover, high moisture content can lead to the oxidation of lipids in fishmeal, which affects the flavor and palatability of the feed and compromises the health benefits associated with omega-3 fatty acids. This oxidation can result in rancidity, making the feed unpalatable and potentially harmful to fish health. Therefore, it is essential to ensure that fishmeal is processed and stored under conditions that minimize moisture absorption. Conversely, a low moisture content in fishmeal helps to enhance its shelf life and stability, allowing for longer storage without significant quality degradation. This is particularly important in aquaculture, where feed quality directly impacts fish growth and health outcomes (Samira & Mehrgan, 2015). Additionally, low moisture levels facilitate better handling and transportation of fishmeal, reducing the risk of spoilage during distribution. According to the findings of this study, the high moisture content present in fishmeal derived from salmon viscera may lead to deterioration during long-term storage. To prevent this, it is crucial to either rapidly convert the fishmeal into feed or implement processing techniques that effectively reduce its moisture content during production. These strategies are essential to maintain the quality and stability of the fishmeal over time.

The ash content of salmon viscera meal, anchovy meal, and sprat meal was analyzed, revealing that salmon viscera meal had the highest crude ash content at 11.96±1.32%. Meanwhile, anchovy meal and sprat meal, which have lower crude ash content, were found to be statistically similar to each other, with values of 8.07±0.86% and 9.07±0.87%, respectively. The observed differences in crude ash content were statistically significant ($p<0.05$). The ideal crude ash content in fishmeal used in fish feed rations typically ranges from 5% to 15%. This range is considered optimal for providing essential minerals while ensuring that the meal remains nutritionally balanced and effective for fish growth (Kokkali, 2023; Chang, 2023). Crude ash content reflects the mineral content of the fishmeal, which includes important elements such as calcium, phosphorus, magnesium, and trace minerals that are vital for various physiological functions in fish (Zaman et al., 2015). A lower crude ash content is generally preferred because excessively high crude ash levels can indicate a lower quality protein source or excessive mineral content, which may not be beneficial for fish health. High crude ash content can lead to an imbalance in the calcium-to-phosphorus ratio, potentially causing metabolic issues and affecting bone health in fish (Samira & Mehrgan, 2015). Moreover, high crude ash levels can negatively impact the digestibility of the feed, as excessive minerals can interfere with the absorption of nutrients (Zaman et al., 2015). Conversely, a certain level of crude ash is necessary to ensure that fish receive adequate minerals for growth and development. Minerals play crucial roles in skeletal development, enzyme function, and overall metabolic processes (Moazenzadeh et al., 2017). Therefore, while it is essential to maintain a balance, the goal should be to keep crude ash content within the recommended range to avoid spoilage and ensure optimal growth performance. According to the findings obtained in this study, three fishmeal types were found to have ideal crude ash content.

Sprat meal had the highest carbohydrate content (3.77±0.81%), followed by salmon viscera meal (3.32±0.69%), while anchovy meal had the lowest carbohydrate content (1.52±0.55%). Although no significant difference was found between sprat and salmon viscera meals, the difference between anchovy meal and the other two fish meals was statistically significant ($p<0.05$). This low carbohydrate content is particularly important for carnivorous fish species, such as salmonids, which are known to have limited ability to utilize carbohydrates effectively (Villasante et al., 2019). High carbohydrate levels can lead to metabolic issues, as these fish are not well adapted to digesting and metabolizing significant amounts of carbohydrates, often resulting in poor growth performance and health complications (Villasante et al., 2019). When considering which carbohydrate content in fishmeal should be preferred, it is essential to focus on the quality and digestibility of the carbohydrates present. Fishmeals with lower carbohydrate content are generally more beneficial, as they provide a higher concentration of protein and essential nutrients without the risks associated with excessive carbohydrate intake. For example, fishmeals that are high in protein and low in carbohydrates are more suitable for supporting the growth and health of carnivorous fish, as they align better with their natural dietary requirements (Villasante et al., 2019). In contrast, fishmeals with higher carbohydrate content may be appropriate for herbivorous or omnivorous species that can utilize carbohydrates more effectively. However, even for these species, it is crucial to ensure that the carbohydrate sources are digestible and do not contain anti-nutritional factors that could hinder nutrient absorption (Wade et al., 2013; Tadesse, 2023). Based on the findings of this study, it is recommended to use anchovy meal, which has a low carbohydrate content, in the feed for species like salmon that are widely farmed in the Black Sea. The lower carbohydrate levels in anchovy meal can offer nutritional advantages that support better growth and overall health in these fish.

Energy content analysis demonstrated that anchovy meal had the highest energy content at 393.26±2.87 kcal/100g, followed by sprat meal at 384±3.68 kcal/100g, and salmon viscera meal with the lowest at 366.41±4.41 kcal/100g. These differences were determined to be statistically significant ($p<0.05$). The ideal energy content in fishmeal used in fish feed rations typically ranges from 300 to 500 kcal per 100 grams. This range is considered optimal for providing sufficient energy to support the growth and metabolic needs of fish, particularly in aquaculture settings where energy demands can be high due to rapid growth rates and intensive farming practices (Nistor et al., 2021). Higher energy fishmeals are beneficial as they provide more calories per unit weight, which can enhance feed efficiency and growth performance in fish. This is particularly important for species with high energy requirements, such as salmon and other carnivorous fish, which benefit from energy-dense diets that support their growth and overall health (Tugiyono et al., 2020). Conversely, fishmeals with lower energy content, while still usable, may not be as effective in promoting optimal growth and feed conversion ratios. These lower energy meals might be more suitable for herbivorous or omnivorous species that can utilize a broader range of feed ingredients, including those with lower energy densities (El-Dakar et al., 2015). However, it is essential to ensure that even lower-energy meals are balanced with other ingredients to meet the overall dietary energy requirements of the fish. The anchovy, sprat, and salmon viscera flours analyzed in this study are well-suited for inclusion in fishmeal formulations due to their ideal energy content, which falls within the desirable range of 300-500 kcal. This energy range supports the nutritional needs of various aquaculture species effectively.

CONCLUSION

This study provides a comprehensive analysis of the nutritional composition of fishmeals derived from whole anchovy, sprat, and salmon viscera, highlighting significant variations in their macronutrient profiles. The results indicate that anchovy meal has the highest crude protein content (73.55±1.50%), making it a superior protein source for aquafeeds. In contrast, salmon viscera meal exhibited the lowest protein content (63.58±1.85%) and the highest moisture content (10.45±0.74%), which may affect its storage stability and nutritional quality.

Sprat meal had the highest carbohydrate content (3.77±0.81%), while anchovy meal had the lowest (1.52±0.55%). The energy content was highest in anchovy meal (393.26±2.87 kcal/100g), followed by sprat meal (384±3.68 kcal/100g) and salmon viscera meal (366.41±4.41 kcal/100g). These differences were statistically significant ($p<0.05$), underscoring the distinct nutritional profiles of the fishmeals studied.

Based on these findings, it is recommended that anchovy meal be prioritized as the primary protein source in aquaculture diets due to its high protein and energy content. Sprat meal can serve as a supplementary protein source, while salmon viscera meal should be used cautiously, ensuring it is balanced with higher-quality protein sources to meet the nutritional needs of fish effectively. Future research should focus on optimizing the processing and storage of fishmeals to enhance their nutritional quality and shelf life, as well as exploring alternative protein sources to meet the growing demands of the aquaculture industry.

Compliance with Ethical Standards

Authors' Contributions

BB: Conceptualization, Methodology, Supervision, Writing – review & editing

SY: Writing – original draft, Investigation, Formal analysis

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data that support the findings of this study are available from the corresponding author on request.

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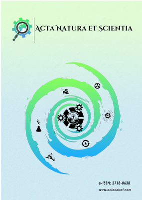

ACTA NATURA ET SCIENTIA PRENSIP

Comparative Assessment on the Growth Performance of the African Catfish, *Clarias gariepinus* Fingerlings Fed Two Commercial Feeds in Nigeria

Emmanuel A. Essien[1]✉ • Aniefiokmkpong O. Okon[1] • Enenwan Precious Udoinyang[1] • Kenneth Prudence Abasubong[1] • Victoria Folakemi Akinjogunla[2]

[1] University of Uyo, Faculty of Biological Science, Department of Animal and Environmental Biology, Akwa-Ibom State, Nigeria; emeritusessien49@gmail.com; aniefiokmkpongo@gmail.com; enenwanudoinyang@uniuyo.edu.ng; kennethabasubong@outlook.com
[2] Bayero University Kano, Faculty of Agriculture, Department of Fisheries and Aquaculture, Kano State, Nigeria; vfakinjogunla.faq@buk.edu.ng

✉ Corresponding Author: emeritusessien49@gmail.com

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ABSTRACT

Catfish is a sufficiently rich protein source in man's meals. However, the operational activities, costs of managements and fish production have caused famers to leave the industry. Therefore, this study is aimed at assessing the growth performance of the African Catfish; *Clarias gariepinus* fingerlings fed two commercial feeds. Eighty randomly selected African sharp-tooth catfish (*C. gariepinus*) fingerlings of 2.25±0.24 g (mean body weight) were fed two different commercial feeds for 10 weeks to compare their growth performance. The feeds were Coppens (Treatment 1) and Vitafeed (Treatment 2). A completely randomized design and plastic aquaria with dimensions of (40×40×50) cm^3 were used for the experiment. The fingerlings were fed 5% of their body weight twice daily after seven days acclimatization before commencement of feeding trial. The fish were designed in duplicate of 20 fish per tank. Collected data from each parameter were subjected to a one-way analysis of variance (ANOVA) and 5% level of significance ($p<0.05$) mean of various results were compared. The growth parameters considered and physicochemical parameters measured and monitored and maintained at optimal levels respectively. The results obtained showed that fishes fed Coppens performed better in final body weight (53.10±1.37) while Vitafeed recorded (38.10±0.94g). Coppens showed better performance in all growth parameters with 100% survival rate. pH, temperature, and dissolved oxygen showed no significant difference ($p<0.05$) among treatments. They were maintained at of 6.3–6.5, 27.55–28.70°C and 6.5–6.9 mg\l, respectively, which were within the recommended physiochemical parameter ranges for proper fish growth. It is concluded that, although fish fed with Coppens recorded overall best performance, Vitafeed is equally recommendable since there was no significant difference in the overall growth performance. However, based on affordability Vitafeed is more favoured for farmers in order to ensure better returns on investment.

INTRODUCTION

Aquaculture is a rapidly growing industry that is of great importance to the development of the global economy. It targets fish production to provide protein for human food (Sugunan, 2002), income and research. Fish are cultivated for food and income as well as to accommodate the rapid growth of the human population, replenishing water resources in rivers and streams to limit shortages from wild and recreational catches (FAO, 2000). Fish is a generally accepted source of protein. They are easily digestible and have the ability to prevent and control heart disorders and neurological diseases (Tan et al., 2007). One of the major factors hindering fish farming in Nigeria is the high cost of fish feed ingredients, especially fishmeal and many fish farmers rely on quality imported fish feed which is often expensive (Omitoyin, 2007). Usage of these commercially formulated feeds is responsible for the increased cost of production, thereby reducing fish farmers' profit margins (Helfrich & Craig, 2002). The most commonly farmed species in Africa are tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) (Nyina-Wamwiza et al., 2010). African catfish live in many water bodies such as swamps, lakes and rivers. From a biological point of view, it is certainly one of the ideal candidates for aquaculture in the world. Its distribution is wide and it thrives in diverse environments and even adverse environmental conditions. It is a hardy, adaptable species and is ecologically important, mainly due to its ability to breathe air. They feed on variety of natural prey and can adjust its feeding habits depending on food availability. It can withstand adverse environmental conditions, is very abundant, and is easy to reproduce artificially in captivity. It can grow in difficult conditions, especially in muddy, turbid and hypoxic waters, thanks to its accessory respiratory organs (labyrinthine organs) that allow it to breathe atmospheric oxygen (Uys, 1989). It is recognized by its long dorsal and anal fins, giving it a shape similar to an eel. Good nutrition in livestock systems is needful for the economic production of a healthy and high-quality product. In fish farming, i.e., aquaculture, nutrition is an essential factor because feeds usually account for over 50% of variable production costs (Pruszyński, 2003). According to Daily Trust (2016), fish feed prices have increased by 80 to 100% and many fish farmers have been forced into bankruptcy, especially in Lagos State. Expensive animal feed will significantly increase production costs, poor productivity and low harvests, which in the long run may cause farmers to abandon the industry. With increased catfish production, the aquafeed industry has grown and evolved since the days when research into fish nutrition and feed began at the Institute of Oceanography and the Institute of Marine Research. Nigeria (NIOMR), where a laboratory-sized pellet mill was established for this purpose to a burgeoning industry with about 12 commercial fish feed manufacturers in Nigeria (Ayinla, 2007). Due to fluctuations in the dollar, imported fish feed is expensive, so there is an urgent need to find alternative and affordable Nigerian fish feed. Additionally, since the growth response of fish depends on the quality of their food; level of crude protein, lipid, ash content and other micro-components of the feed (Okon et al., 2020), the interest in finding unique sources for fish feed production to reduce costs is very important. Seeds of leguminous plant origin provide a promising alternative (Eromosele & Eromosele, 1993). One such seed is *Bauhinia monandra* (Kutz) which has potential for use as animal feed, including fish, with a crude protein content of 33.09% (Anhwange et al., 2004). Several factors influence the feeding rate of fish in culture system which includes fish size, fish species, rearing systems etc. (Cho et al., 2003). Feeding rate is also an influencing factor contributing to the presence of the nutrients in the feed (Mihelakakis et al., 2002). In quest for Nigerian-made affordable fish feed as an alternative to expensive foreign fish feeds, Bluecrown (Nigeria-made) gave a positive result (Okon et al., 2020).

MATERIAL AND METHODS

Experimental Site

The research was conducted in a designated and secured area in Vision Park fish farm, Uyo, Uyo, Akwa Ibom State, Nigeria.

Fish Collection

Eighty randomly selected African catfish fingerlings (*C. gariepinus*) of average weight of 2.25±0.24 g, average total length of 7.00±0.30 cm, and average standard length of 6.19±0.26 were obtained from Vision Park Farms Nigeria Limited, Uyo, Akwa Ibom State.

Experimental Procedure

Acclimatization of fish was done for 14days in the four tarpaulin tanks with dimension (40×40×50) cm^3. Two Tarpaulin Tanks were allocated to each treatment; T1 (1A and 1B) and T2 (2A and 2B). The allocated experimental feeds were Coppens (foreign feed) (Treatment 1) and Vitafeeds (Nigeria made) (Treatment 2) respectively. They were starved for 24 hours in order to empty their stomachs and prepared them for the trial. They were fed at 5% their body weight for the 10 weeks twice daily.

Sampling

The fish were randomly weighed and distributed into the tanks at a stocking density of twenty (20) fish per tarpaulin. Subsequently, body weight, total and standard-length measurements were taken bimonthly and the rations fed were adjusted to 5% according to the fish weight.

Fish Feeds Composition

The composition of fish feeds was given in Table 1.

Fish Feed Collection

The fish feeds were purchased from a distributor's shop, Spring Farm Enterprise, No. 4, Ukana Offot Street, Uyo, Akwa Ibom State, throughout the period of the experiment to ensure consistency in supply and quality of feeds.

Commercial Feeds

The two treatments and their respective crude protein levels were Coppens (Treatment 1) and Vitafeed (Treatment 2) of 56% and 42%, respectively. The proximate analysis for each feed was determined.

Water Quality Parameters

The water parameters monitored and recorded on weekly basis were pH, temperature and dissolved oxygen (DO) at 8 AM with the use of pocket-sized pH metre (Milwaukee-pH 600 Tester Kit) was used in the determination of water pH, mercury-in-glass thermometer for temperature in degree Celsius (°C) while DO present in the water was measured with the aid of portable DO meter (Milwaukee MW 600). Water was changed bimonthly, thereby removing the debris at the bottom of the tanks.

Calculation And Statistical Analysis

For the purpose of measuring growth parameters, all fish were measured for length (total length and standard length) and body weight. The lengths were measured in cm^2 using a measuring board; while weight was taken using 5 kg capacity weighing balance (Model Ashton Meyers). After each sampling, survival (%), specific growth rates (SGR), food conversion ratio (FCR) and growth rate (GR) of the fish were calculated using the formula given by Aderolu et al. (2010). Dead fish in each tank were recorded every 14 days. In order to determine significant differences ($p<0.05$) between the data, One-way analysis of variance (ANOVA) was used.

Table 1. Proximate analysis of the diets

Feed types	Nutrients							
	Crude Protein (%)	*Fat (%)*	*Ash (%)*	*Moisture (%)*	*Crude Fibre (%)*	*Calcium (%)*	*Phosphorous (%)*	*Sodium (%)*
Coppens (Treatment 1)	56.00	15.00	12.00	-	2.3	3.3	1.99	0.9
Vitafeed (Treatment 2)	42.00	12.00	10.00	8.00	5.00	1.80	-	-

Note: The details in the table above are manufacturer's information that were highlighted on the bags of feed.

Table 2. Effect on the growth performance of the African catfish, *C. gariepinus* fingerlings two (imported and homemade) commercial feeds

Growth Parameters	Treatment 1 (Coppens)	Treatment 2 (Vitafeed)
Mean Initial Weight (g)	2.30±0.92[a]	2.20±0.28[a]
Mean Final Weight (g)	53.10±1.37[a]	38.10±0.94[b]
Mean Weight Gain (g)	50.80±0.20[a]	35.90±3.17[b]
Mean Initial Total Length (cm)	6.95±0.78[a]	6.60±0.02[a]
Mean Initial Standard Length (cm)	6.12±0.78[a]	6.00±0.02[a]
Mean Final Total Length (cm)	19.10±1.69[a]	16.40±3.25[a]
Mean Final Standard Length (cm)	17.90±1.69[a]	13.60±3.25[a]
Mean Growth Rate (MGR)	0.96±0.04[a]	0.93±0.03[a]
Mean Daily Growth Rate (g)	0.72±0.07[a]	0.50±0.25[b]
Specific Growth Rate (%/Day) (SGR)	5.65±0.05[a]	5.06±0.75[b]
Feed Conversion Ratio (FCR)	2.20±0.07[a]	3.23±0.09[b]
Condition Factor (K)	0.76±0.07[a]	0.82±0.07 [a]
Initial Number of fish	40	40
Final Number of fish	40	39
Survival (%)	100	97.5

Note: In each row, mean with a common subscript are not significantly different (p ≠ 05).

To further investigate distinctions within means, Duncan's multiple range was conducted. Statistical analysis was performed using Statistical Package for Social Sciences (SPSS).

RESULTS

The findings on the comparative evaluation on growth performance of the African catfish, *C. gariepinus* fingerlings fed two (imported and Nigerian made) commercial feeds of different crude protein levels showed maximum weight gained of 53.10 g and 38.01g for Treatment 1 and Treatment 2, respectively.

The mean initial weight, total and standard length for Treatment 1 and Treatment 2 were 2.30 g and 2.20 g, 6.95 cm and 6.66 cm and 6.12 cm and 6.05 cm, respectively. Treatment 1 had the highest final weight, total length and standard length of 53.10 g, 19.10 cm and 17.90 cm while Vitafeed, had final weight, total and standard lengths of 38.10 g, 16.40 cm and 13.60 cm, respectively. The daily and specific growth rates were best observed in Treatment 1 (0.72 g/day) and (5.65 g/day) while Treatment 2 recorded 0.50 g/day for daily growth rate and 5.06 g/day for specific growth rate. Initial numbers of fishes stocked and survival rate were shown in Table 2. After 10 weeks of the experiments, both treatments had a survival rate (40 and 39 fish, respectively). Feed conversion ratio was observed best in Treatment 1 (2.20). The condition factor (K) value recorded 22.03 and 32.00 for Treatment 1 and Treatment 2, respectively. The result obtained in this study revealed that fish in Treatment 1 produced the best growth in terms of length, weight, survival rate and growth rates. As shown in Table 3, the results of the physiochemical parameters of the Treatments revealed that the water pH ranged from 6.30–6.50. Mean water temperature was within the range 27.55°C–28.70°C and mean water dissolved oxygen was within the range 6.5 mg/l–6.9 mg/l.

Bimonthly growth rates of the fish are shown in Figure 1. Treatment 1 (Coppens) had the highest growth rate (Figure 1).

Table 2. Some physiochemical properties of the pond water

Parameter	T1	T2
pH	6.3±0.69[a]	6.5±0.77[a]
Temp (°C)	27.55±0.37[a]	28.70±0.19[a]
DO (mg/l)	6.9±0.015[a]	6.5±0.015[a]

Note: In each row, mean with [a] common letter are not significantly different (p ≠ 05)

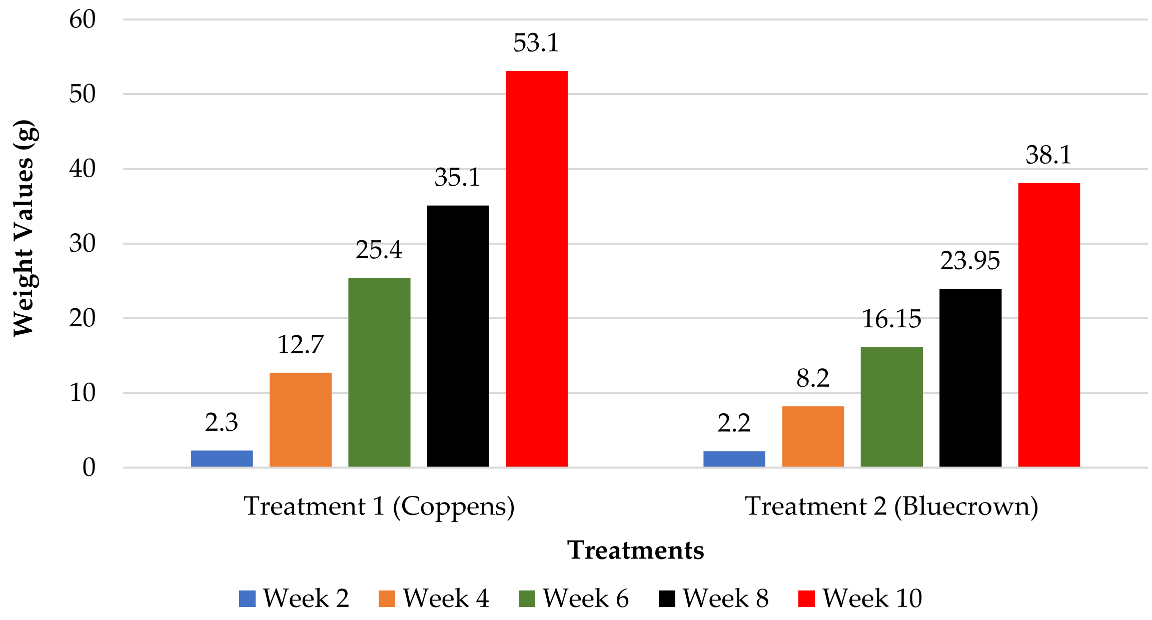

Figure 1. Bimonthly growth rate of *Clarias gariepinus* fed with two different commercial fish feeds.

DISCUSSION

Fish growth is dependent on the food intake and a host of intrinsic factors. Previous researches have shown that nutrient quality and composition of fish feed are directly proportional to the growth performance of the African catfish and many other fish species (Keremah & Esquire, 2014). The findings of this study revealed that *C. gariepinus* fingerlings fed with Coppens exhibited optimal growth with protein level 56%. According to (Okon et al., 2020), the SGR, GR, MFTL, MFSL, FCE and FCR reveal that Vitafeed was the best amongst the commercial fish feeds (Ecofloat, Bluecrown, Aqualis and Vitafeeds) in Nigeria. In this study, Vitafeed recorded no significant difference ($p<0.05$) with the performance of fish fed with Coppens. Therefore, since the growth of the fingerlings in both feed treatments did not differ when compared, it is inferred that the two feeds can be used in the culture of this species of fish. This study is supported by several studies on the growth performance with varying feeds of different crude protein levels on *C. gariepinus*. According to Craig & Helfrich (2017) the required protein levels in aquaculture feeds generally ranges between 35-40% for tilapia, 30-34% for catfish, 38-42% for hybrid striped bass, 30 to 35% for shrimp, and 40-45% for trout and other marine finfish. In this study, the crude protein levels were 56% and 45%; of course, the higher the crude protein level, the better performance in growth of *C. gariepinus*. The result of this study also revealed that fish fed with Coppens had the best bimonthly and overall weight gained. This result is in agreement to Kenneth et al. (2020) that reported Coppens and Multi feed (imported feeds) to have had the best growth performance against the Nigerian fish feeds (Vitafeed). Though Okon et al. (2020) recorded highest in all growth parameters considered in the absence of Coppens, Vitafeeds. Growth parameters like specific growth rate, daily growth rate, feed conversion ratio, lengths were not significantly different in both treatments. Regards to the difference in Crude protein levels of both feeds, they may be controversies on the comparison on the growth performance of fish fed with these feeds. On this view, the effective growth performance on Vitafeed comparable to Coppens is not strictly dependent on the CP level only, but in combination with other nutrients such as calcium, phosphorous, ash and fat levels which as stated above, are important constituents for effective fish growth (length and weight) in fish feed. This study supports Mogaji's (2019) report on the significant growth and weight gained in *C. gariepinus* fed with Skretting feed (foreign) that showed significant ($p<0.05$) higher weight increase, specific growth rate, protein efficiency ratio and low food conversion ratio than fish fed with Bluecrown feed (Nigerian made) which is strongly attributed to the high CP level than the Nigerian made feed. In his research, there was a consistent survival rate in the culture of *C. gariepinus* in both treatments from week two till the end of the study. This is because of its resistance to water quality stress as well as diseases (Limbu, 2015). Comparing the weekly weight gained, the second week had the lowest, perhaps, and this was due to the condition of the fish to adjust to the initial feed after acclimatization. More so, nutrients were rather utilized for their survival instead of effective increase in fish length and weight. However, there was a stable growth rate in later weeks which is indicative of effective adaptation to the fish feed. The physical and chemical properties of the fish cannot be ignored; as they play important roles in the growth and survival of fish even in their natural environment. The physicochemical parameters obtained from this study are shown in Table 3. It revealed that the water temperature and pH were within the appropriate range required for efficient growth of catfish under cultured system (Musiba et al., 2014). The values of DO in both treatments fell within the allowable limits suitable for fish proper growth, development, maturation and gamete production (Okey-Wokeh et al., 2020). The increased in FCR for Bluecrown is totally a function of the total weight gained. Also, the 5% body weight for determination of feed allocation increased significantly in Coppens compared to Bluecrown.

CONCLUSION

Considering the current economical state of the country, imported fish are very expensive therefore this study suggests affordable Nigerian made fish feed (Vitafeed) for Catfish sustainability in the industry. Additionally, Aqua culturists and concerned stakeholders should equip and develop fish farmers in Nigeria with the technical know-how to formulate quality fish feed with available affordable local ingredients for more profit. Based on this study, Vitafeed is commendable to keep fish famers in the business. Regular studies on new feed are necessary to inform the farmers adequately in order to sustain the industry. In view of the limited knowledge among some farmers on the choice of feed, this work recommends the information gathered from this research for use by local farmer. In addition, further researches should be considered on other common feeds known to and used by farmers to determine their effectiveness on *C.gariepinus* fish farming in Nigeria. Also, conventional plant extracts should be studied to replace fish feed protein, thereby reducing the cost of fish feeds so sustain fish farming business in the industry.

Compliance with Ethical Standards

Authors' Contributions

EAE: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing

AOO: Conceptualization, Data curation, ng acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing

EPU: Methodology, Supervision, Validation, Writing – original draft

KPA: Validation, Writing – review & editing

VFA: Supervision

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The authors declare that the study was conducted in accordance with all applicable international, national, and/or institutional guidelines for the care and use of animals. The research did not involve blood extraction or sacrifice of fish samples. Additionally, the number of fish used (80 samples) did not exceed the threshold requiring ethical approval (200 samples and above) as per the local regulations. The study was performed on a private fish farm licensed by the State Government, which lies outside the jurisdiction of the Ethical Approval Research Committee in Nigeria. For these reasons, no formal ethical approval number was issued for this study.

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Data Availability

The data that support the findings of this study are available from the corresponding author on request.

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info@actanatsci.com
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Türkiye'nin Eklem Bacaklı ve Yumuşakça Üretiminin Tahmini

Hülya Eminçe Saygı[1]✉ • Sefa Acarlı[2]

[1] Ege University, Faculty of Fisheries, Department of Aquaculture, 35100 İzmir, Türkiye, hulya.saygi@ege.edu.tr
[1] Çanakkale Onsekiz Mart University, Faculty of Marine Sciences and Technology, Department of Aquaculture, 17020 Çanakkale, Türkiye, sefaacarli@comu.edu.tr

✉ Corresponding Author: hulya.saygi@ege.edu.tr

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ÖZET

Bu çalışmada Türkiye'nin eklem bacaklı ve yumuşakça üretiminin otoregresif bütünleşik hareketli ortalama (ARIMA) yöntemi ile geleceğe yönelik tahmin modeli geliştirilmiştir. Eklem bacaklı ve yumuşakça üretim miktarının tahmininde uygun modelin belirlenmesi için ARIMA modelinin seçiminde performans ölçüm kriterleri olarak kök ortalama kare hatası (RMSE), ortalama mutlak hata (MAE) ve ortalama mutlak yüzde hata (MAPE), Theil'in U değeri kullanılmıştır. Sonuç olarak bu seçim kriterlerinin seriye en iyi uyan modellerin toplam çift kabuklular üretimi için ARIMA (1,0,1) iken kafadan bacaklılar, karından bacaklılar, toplam yumuşakça üretimi, toplam eklem bacaklı üretimi ve genel toplam (yumuşakça + eklem bacaklılar) üretimi için ise ARIMA (1,0,0) olduğu belirlenmiştir. ARIMA (1,0,0) modeli sonuçlarına göre 2030 yılında toplam yumuşakça ve eklem bacaklı üretimi için üretim miktarında azalış eğilimi öngörülmektedir. Kafadan bacaklı üretiminde ise artış eğilimi tahmin edilmektedir. Dolayısıyla, geleceğe yönelik yapılan modelleme çalışmalarında daha yüksek doğrulukta sonuçlar elde edilebilmesi adına seçilecek veri setinin daha odaklanmış şekilde seçilmesi yararlı olacaktır. İklim değişikliği, müsilaj, kaçak avcılığa bağlı olarak stok yönetimindeki düzensizlikler, istilacı türlerin girişi, hastalıklar, yasal düzenlemeler ve balıkçılık yönetimi politikaları gibi çeşitli faktörler bu türlerin üretim miktarı üzerinde doğrudan etkilidir. Bu nedenle, yumuşakça ve eklem bacaklı türlerinin üretiminin sürdürülebilirliğinin sağlanabilmesi için uygun politikalar planlanmalıdır. Sonraki çalışmalarda balıkçılık yöneticileri ve karar vericiler için gelecekteki üretim miktarlarının tahmin edilmesinde üretimi tetikleyen bu faktörlerin de dikkate alınması yapılacak tahminlerin doğruluğunu artıracaktır.

Estimation of Crustacea and Mollusca Production in Türkiye

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ABSTRACT

This study developed future prediction models for Crustacea and Mollusca production in Türkiye using the autoregressive integrated moving average (ARIMA) method. Root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE), and Theil's U value were used as performance measurement criteria in the selection of ARIMA model to determine the appropriate model for the estimation of crustacean and mollusc production. The results revealed that the best-fit model was ARIMA (1,0,1) for total bivalve production, while ARIMA (1,0,0) was best for cephalopods, gastropods, total mollusc production, total crustacean production and total (Mollusca + Crustace) production. ARIMA (1,0,0) model predicted a decreasing trend for the total crustacean and mollusc production in 2030. On the other hand, an increasing trend was predicted for cephalopod production. Therefore, it would be useful to select a more focused data set to obtain higher accuracy results in future modelling studies. Various factors such as climate change, mucilage, irregularities in stock management due to illegal hunting, the introduction of invasive species, diseases, legal regulations and fisheries management policies have a direct effect on the production amount of these species. Therefore, appropriate policies should be planned to ensure the sustainability of mollusc and crustacean production. In future studies, considering these factors that affect production when estimating future amounts for fishery managers and decision-makers will increase the accuracy of the estimates.

GİRİŞ

Mevcut gıda kaynaklarının etkin ve verimli kullanımı dünyada nüfusun artmasından dolayı gitgide zorunlu hale gelmektedir. Bu bağlamda deniz ve iç sular ekosistemi gıda üretimi için en önemli kaynaklardan biri olarak kabul görmektedir. Aynı zamanda sağlıklı yaşam ve sağlıklı yaşlanma kavramları da tanımlanmış ve bu tanımlama içerisinde kaliteli beslenmenin önemi özellikle vurgulanmıştır. Yapılan çalışmalar göstermiştir ki, obezite ve kalp hastalıklarıyla mücadelede yosunlar da dahil olmak üzere su ürünleri tüketiminin, işlenmiş kırmızı et ürünleri ve hazır gıda tüketimine karşı daha sağlıklı bir gıda alternatifi olarak ortaya çıkmış ve tercih edilir hale gelmiştir (Trondsen vd., 2004; Ahern vd., 2021; Ralston vd., 2024).

Dünyadaki su ürünleri üretimi içerisinde oldukça önemli bir paya sahip olan yumuşakça (Mollusca) ve eklem bacaklı (Crustacea) türlerinin avcılık üretimi toplam 12,4 milyon tondur. Bu üretimin içinde yumuşakça üretimi 6,4 milyon ton ve eklem bacaklı üretimi ise 6 milyon tondur. Yetiştiricilik üretim miktarı 31,7 milyon tondur. Bu üretimin içinde yumuşakça üretimi 18,9 milyon ton ve eklem bacaklı üretimi ise 12,8 milyon tondur. Türkiye'de ise yumuşakça ve eklem bacaklı avcılık üretimi toplamı 48 bin tondur. Bu üretimin içinde yumuşakça üretimi yaklaşık 43 bin ton iken, 5 bin ton eklem bacaklı üretimidir (FAO, 2021). Türkiye'deki yetiştiricilik üretimi 5,5 bin ton iken üretimin %99'unu yumuşakça grubu oluşturmaktadır (FAO FishStat, 2024).

Dünyadaki toplam (avcılık ve yetiştiricilik) su ürünleri üretimi yıllar içerisinde dalgalanmalar göstermiş olmakla birlikte tarihsel süreçte genel olarak artış eğilimi göstermiştir (FAO FishStat, 2024). Literatürde Türkiye'deki su ürünleri üretim miktarının mevcut durumu ve geleceğe yönelik projeksiyonlarının oluşturulmasına yönelik sınırlı sayıdaki çalışmada farklı yöntemler kullanılarak artış ve azalış eğilimleri tahmin edildiği rapor edilmiştir (Candemir & Dağtekin, 2020; Arısoy vd., 2021). Ancak, bu çalışmalar balık türleri üzerine odaklanmış yumuşakça ve eklem bacaklı üretimi üzerine çok sınırlı sayıdadır (Kale, 2020; Kale & Berber, 2020; Kale vd., 2021; Mazlum vd., 2024). Dolayısıyla, bu çalışmanın amacı Türkiye'deki eklem bacaklı ve yumuşakça üretiminin geleceğe yönelik projeksiyonunun oluşturulmasıdır.

MATERYAL VE YÖNTEM

Çalışma kapsamında Türkiye'de 1985-2021 yılları arasında gerçekleşen toplam eklem bacaklı (Crustacea) ve yumuşakça (Mollusca) (çift kabuklular (Bivalvia), kafadan bacaklılar (Cephalapod), karından bacaklılar (Gastropod)) üretimi verileri Türkiye İstatistik Kurumundan temin edilmiştir (TÜİK, 2024). Birleşmiş Milletler tarafından sürdürülebilir kalkınma hedeflerine ulaşmada 2030 yılı hedef alınması (FAO, 2024) nedeniyle bu çalışmada Türkiye'de gerçekleşen yumuşakça ve eklem bacaklı üretimine yönelik projeksiyonlar da 2030 yılı için oluşturulmuştur.

Verilerin normal dağılıma uygunluğu Kolmogorov-Smirnov testi (n>30) ile değerlendirilmiştir. Eklem bacaklı ve yumuşakça üretim miktarının normal dağılım göstermediği tespit edilmiştir. ARIMA modelinde normal dağılım şartı aranmamakla birlikte modelin kalitesini artırmak için kalıntıların normal dağılıma sahip olması beklenmektedir. Bu nedenle, modelin kalitesinin artırılması için logaritmik dönüşüm uygulanmıştır.

ARIMA modeli geleceğe ilişkin istatistiksel tahmin yapılabilen otoregresif süreçlerde yaygın olarak kullanılmaktadır. ARIMA, elde edilen zaman serisi verisinin kendi geçmiş değerleri ve olasılıksal hata terimi ile doğru tahminler yapabilen bir modelidir. Zaman serisi analizi için Box & Jenkins (1976) tarafından önerilen ARIMA (otoregresif bütünleşik hareketli ortalama) yöntemi kullanılmıştır. ARIMA (*p, d, q*) modelinde AR (p) otoregresif terimleri, I (d) farkları, MA (q) hareketli ortalamaları ifade etmektedir. Otoregresif modeller serideki önceki değerlerin doğrusal bir fonksiyonu olduğunu varsaymaktadır. ARIMA (p, d, q) modeli Denklem 1'de verilmiştir.

$$X_t=c+\Phi_1 X_{t-1}+\cdots+\Phi_p X_{t-p}+\theta_1 e_{t-1}+\theta_q e_{t-q}+e_t \quad (1)$$

Burada, X_t t zamanında tanımlanacak değişkeni, e_t t zamanındaki hatayı, θ q parametresi başına düşen katsayını, Φ p parametresi başına düşen katsayıyı ve c sabiti ifade etmektedir. Analizlerin gerçekleştirilmesinde Microsoft Excel kullanılmıştır.

Otokorelasyon fonksiyonu (ACF) ve kısmi otokorelasyon fonksiyonu (PACF) analizleri yardımıyla durağanlıkları incelenmiştir. Ayrıca, Dickey Fuller testi (ADF) birim kök sınaması ile serilerin durağanlığı test edilmiştir. Bu iki durağanlık testinden sonra durağan olmayan veri seti için fark alma yöntemi uygulanmıştır. ARIMA modelinin oluşturulması için eklem bacaklı ve yumuşakça üretim miktarının tahmininde uygun modelin belirlenmesi için seriyi en iyi açıklayan modeller belirlenmiştir (Tablo 1). Bunun için kök ortalama kare hatası (RMSE), mutlak ortalama hata (MAE) ve ortalama mutlak hata (MAPE) performans ölçüm kriterleri kullanılmıştır. Ayrıca, çözüm sonuçlarının gerçek değerleri ne derece yakaladığının testi için Theil'in U istatistiği kullanılmıştır.

BULGULAR

Bu çalışmada eklem bacaklı ve yumuşakça üretimi için yapılan zaman serisi analizinde yumuşakça üretiminin en yüksek değere 2021 yılında ulaşırken, eklem bacaklı üretiminin 1989 yılında maksimuma ulaştığı görülmektedir. Oluşturulan modeller içerisinden yapılan karşılaştırma sonucunda çift kabuklular veri seti dışında tüm veriler için en uygun olan modelin ARIMA (1,0,0) modeli olduğu belirlenmiştir. Çift kabuklular için ise en uygun ARIMA modeli ise (1,0,1) olarak hesaplanmıştır (Tablo 1).

Yapılan trend analizi sonucunda kafadan bacaklılar üretiminde ve eklem bacaklılar toplam üretiminde artış olacağı tahmin edilmektedir. Buna karşın, diğer yumuşakça ve eklem bacaklılar için üretim miktarında azalış olacağı öngörülmektedir. Çalışmada kullanılan tüm veri seti için yumuşakçalar ve eklem bacaklılar üretimi bir bütün olarak değerlendirildiğinde geneldeki toplam üretimde de azalış olacağı tahmin edilmektedir (Şekil 1-8).

Table 1. ARIMA values, statistic parameters, prediction for 2030 for Crustacea and Mollusca production (SE: Standard error)

Tablo 1. *Eklem bacaklı ve yumuşakça üretimi için ARIMA değerleri, istatistik parametreleri, 2030 yılı tahmini (SE: Standart hata)*

Tür	ARIMA Model	AR1 (SE)	MA1 (SE)	Sabit (SE)	RMSE	MAE	MAPE	U	2030 Tahmini	%95 Güven Sınırları	
										Alt Limit	*Üst Limit*
Çift kabuklular	(1,0,1)	0.635 (0.150)	0.990 (0.091)	0.069 (0.018)	11445.146	7337.677	39.309	0.43	↓ 12801	1692	96866
Kafadan bacaklılar	(1,0,0)	0.510 (0.145)		7.631 (0.158)	1972.257	915.869	33.458	0.57	↑ 2060	648	6544
Karından bacaklılar	(1,0,0)	0.770 (0.118)		142.724 (24.423)	2706.735	2007.932	39.102	0.35	↓ 5395	267	17043
Yumuşakçalar (Toplam)	(1,0,0)	0.806 (0.108)		10.061 (0.268)	9221.314	5672.314	42.269	0.42	↓ 19599	3793	101271
Eklem bacaklılar (Toplam)	(1,0,0)	0.740 (0.112)		8.756 (0.216)	2916.666	1954.461	30.578	0.36	↑ 6288	2079	19015
Yumuşakçalar + Eklem bacaklılar (Genel Toplam)	(1,0,0)	0.806 (0.108)		10.061 (0.268)	10004.183	6594.793	28.020	0.35	↓ 27914	8588	90736

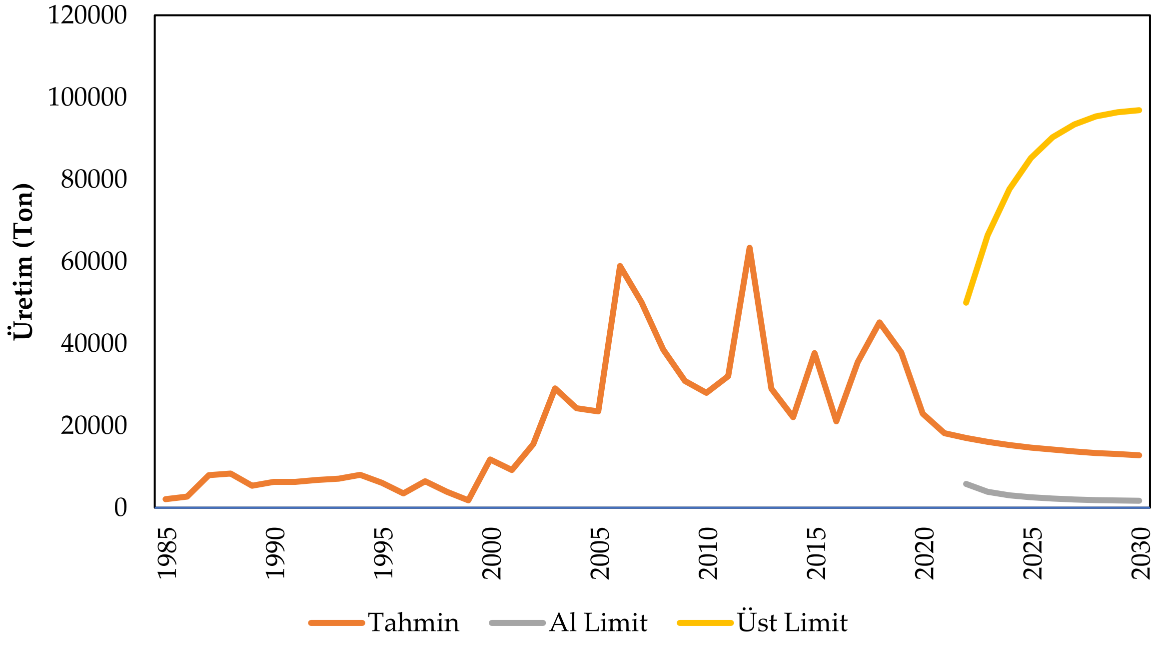

Figure 1. Predicting of Bivalvia production by using ARIMA (1,0,1) model

Şekil 1. *Çift kabuklu üretiminin ARIMA (1,0,1) modeliyle tahmini*

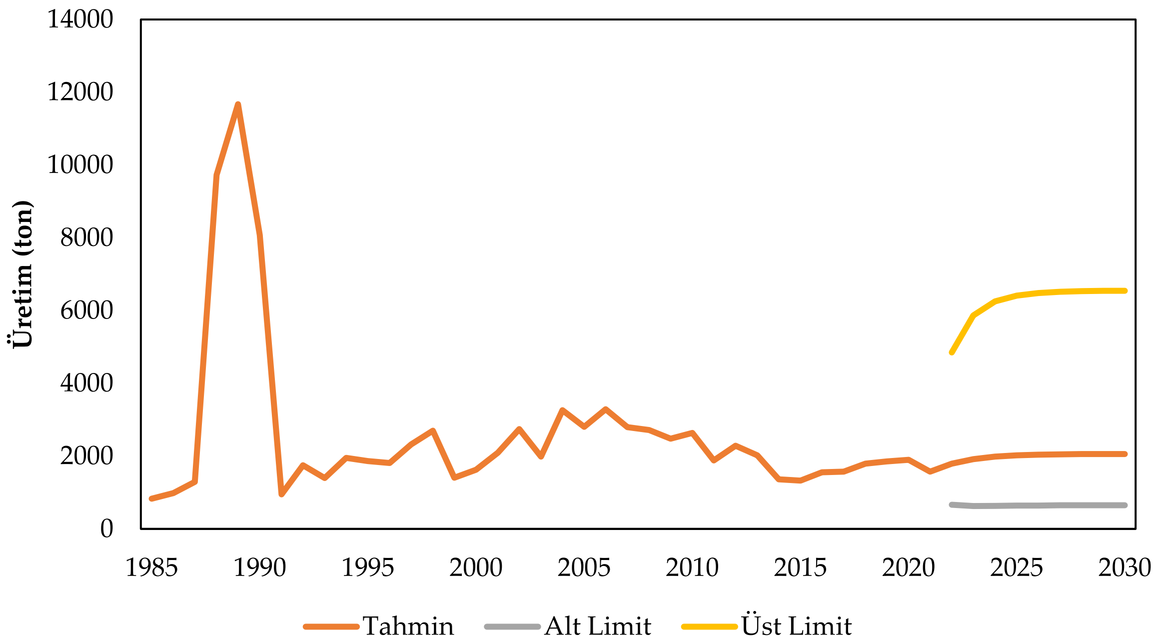

Figure 2. Predicting of Cephalopod production by using ARIMA (1,0,0) model

Şekil 2. *Kafadanbacaklı üretiminin ARIMA (1,0,0) modeliyle tahmini*

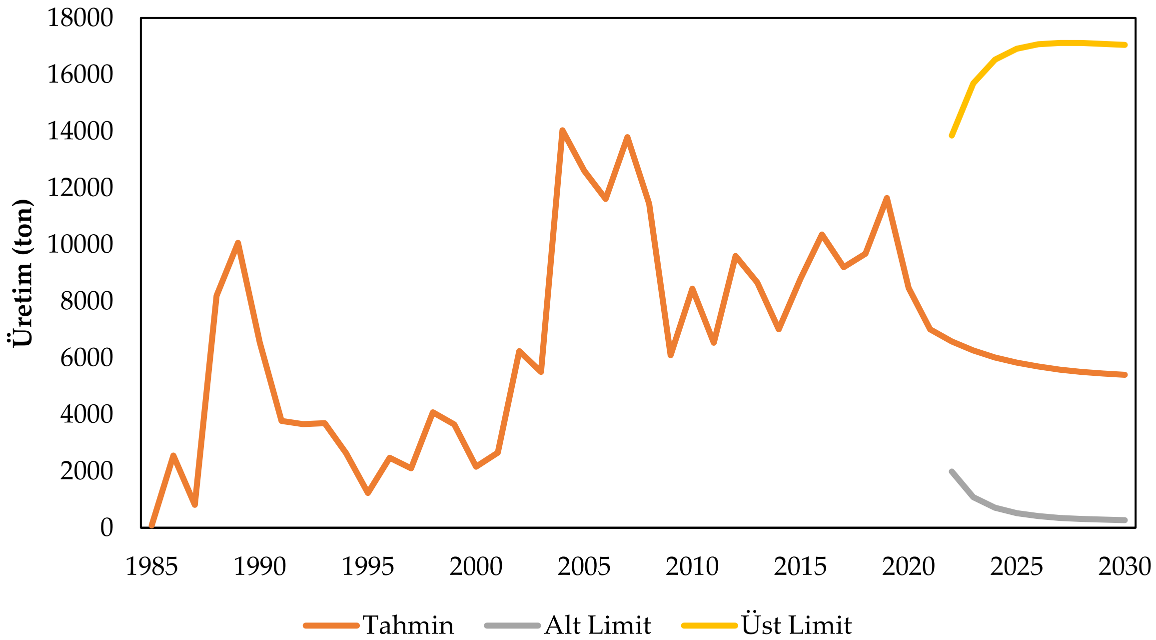

Figure 3. Predicting of Gastropod production by using ARIMA (1,0,0) model

Şekil 3. *Karından bacaklı üretiminin ARIMA (1,0,0) modeliyle tahmini*

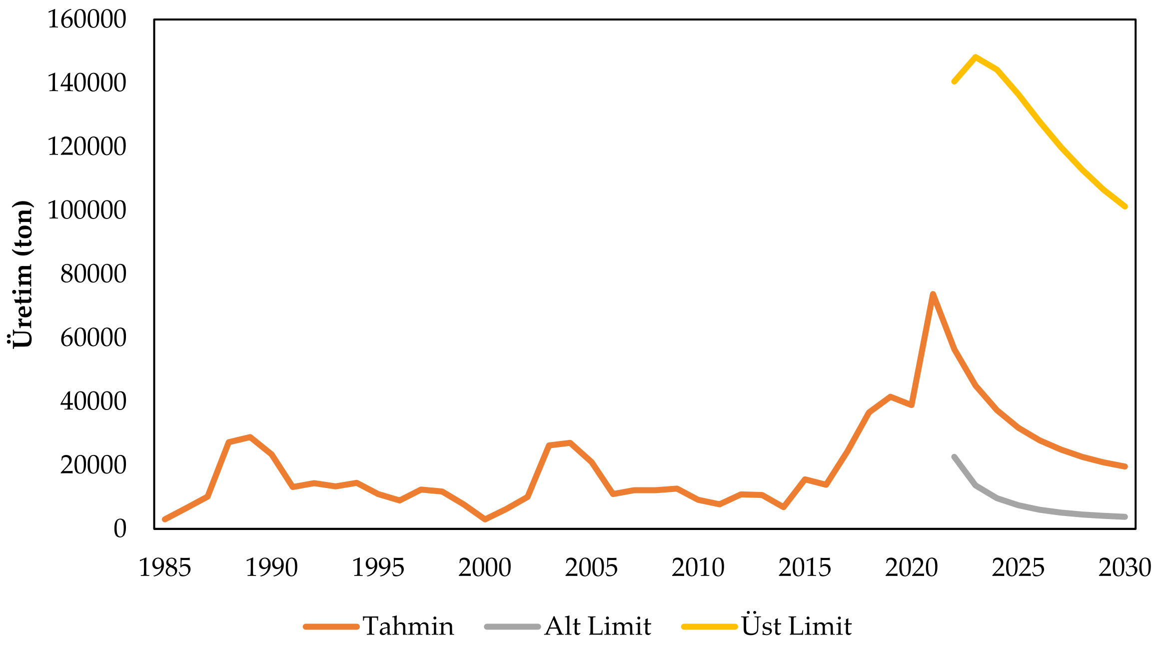

Figure 4. Predicting of total Mollusca production by using ARIMA (1,0,0) model

Şekil 4. *Toplam yumuşakça üretiminin ARIMA (1,0,0) modeliyle tahmini*

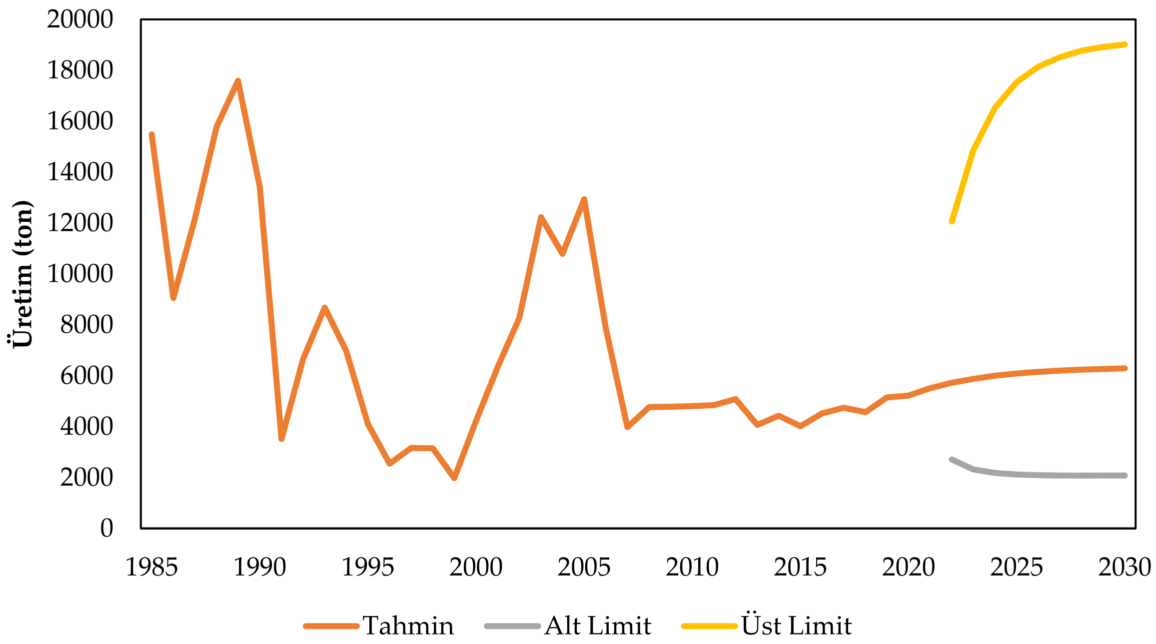

Figure 5. Predicting of total Crustacea production by using ARIMA (1,0,0) model

Şekil 5.*Toplam eklem bacaklı üretiminin ARIMA (1,0,0) modeliyle tahmini*

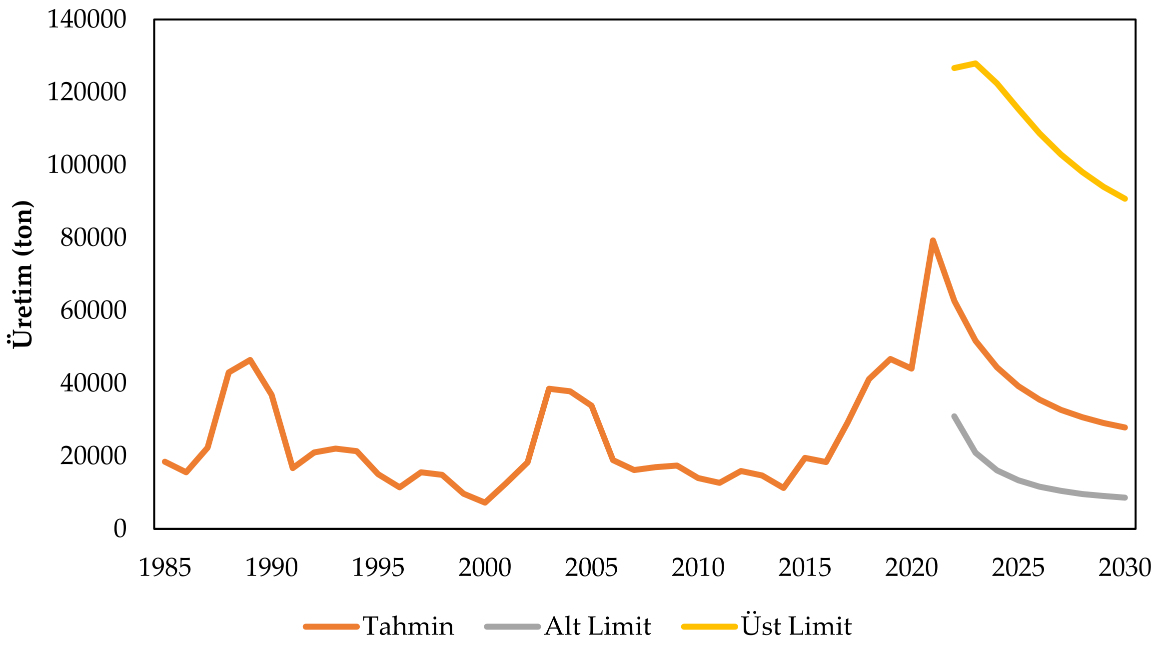

Figure 6. Predicting of Mollusca and Crustacea and production by using ARIMA (1,0,0) model

Şekil 6. *Toplam yumuşakça ve toplam eklem bacaklı üretiminin ARIMA (1,0,0) modeliyle tahmini*

TARTIŞMA

Eklem bacaklılar ve yumuşakçalar önemli bir hayvansal protein kaynağı olup modern kültür ve ticaretin, biyo-tıbbın ve ekonomik kalkınmanın, estetiğin, gastronominin, jeolojinin ve diğer birçok alanın önemli bir parçasıdır (Smaal vd., 2019; Chakraborty & Joy, 2020; Ranz, 2021). Besin içeriği ve ekonomik değerinden dolayı eklem bacaklılar ve yumuşakçalara olan talepteki artış stoklar üzerindeki av baskısının artmasına yol açmıştır (Teh vd., 2023; Ozan & Başer, 2024). Bununla birlikte, kirlilik, iklim değişikliği, habitatın ve ekosistemin bozulması da stoklar üzerindeki olumsuz etkilere neden olmaktadır (Teh vd., 2023; Ozan & Başer, 2024). Dolayısıyla, gıda ihtiyacının artması ve avlanabilir stokların sınırlı olmasının artan ihtiyacı karşılayamaması nedeniyle eklem bacaklıların ve yumuşakçaların hem avcılık hem de yetiştiricilik açısından sürdürülebilir üretiminin planlanması büyük önem taşımaktadır (FAO, 2020; Çöteli, 2022; Heimann & Delzeit, 2024).

Kale vd. (2021) yaptıkları trend analizi sonucunda *Ruditapes decussatus* türünün küresel ölçekte üretim miktarının hem avcılık hem de yetiştiricilik üretiminin azalış eğilimi gösterdiğini ve geleceğine yönelik yapılan tahminler sonucunda da azalış eğiliminin devam edeceğinin öngörüldüğünü bildirmiştir. Kale & Berber (2020) Şen'in yenilikçi trend analizi ile ARIMA modellerinin sonuçlarının çalışma dönemi boyunca dalgalanmalar göstermesine rağmen kerevit (*Pontastacus leptodactylus*) üretiminin azalan bir eğilime sahip olduğunu bildirmiştir. ARIMA modellerinden alınan sonuçlara göre kerevit üretiminin gelecek dönemlerde de azalmaya devam edeceğinin tahmin edildiği belirtilmektedir. Başka bir çalışmada, Candemir & Dağtekin (2020) Türkiye'de su ürünleri avcılık ve yetiştiricilik üretimini ayrı ayrı analiz ederek yaptıkları geleceğe yönelik tahminlerde avcılık üretiminde azalmaların beklenmesine karşın yetiştiricilik üretim miktarında artış yaşanacağının öngörüldüğü rapor etmiştir. Kale (2020) Türkiye'deki deniz balıkçılığı üretimine yönelik yaptığı çalışmada farklı trend analizi yöntemlerini karşılaştırmış ve farklı ARIMA modellerinde balık türlerini içeren veri seti için azalış eğilimi öngörüldüğünü belirtmiştir. Öte yandan, balık dışındaki diğer türleri içeren veri seti için ise avcılık üretiminde artış olacağı tahmin edildiği ifade edilmiştir. Benzer farklılıklar mevcut çalışmada da gözlenmiş olup kafadan bacaklı üretiminde artış olacağı tahmin edilmesine karşın toplam üretimde azalış olacağı öngörülmektedir. Bu tür gruplar arasındaki farklıların daha yüksek doğrulukta tahmin edilebilmesi adına ileriki çalışmalarda yapılacak tahmin ve modellemelerde genel toplam yerine belirlenen odak noktası üzerinden modellerin geliştirilmesinin yararlı olacağı düşünülmektedir.

FAO (2020), 2030 sonrası su ürünleri üretimine ilişkin yapılan tahmine göre avlanma oranı, mevcut haliyle devam ettiğinde avcılığın 2050 yılında kadar 98,3 milyon ton iken yetiştiricilik üretimi aynı şekilde devam ettiği düşünüldüğünde 140 milyon ton olurken, toplam üretim ise 238,3 milyon ton olacağı tahmin edilmektedir. Birinci senaryoda şartların aynı şekilde devam edeceği varsayıldığında, doğrudan insan tüketimi için kullanılmayan deniz balıkçılığının oranı 2031 yılı için toplam deniz balıkçılığının %21,3'ü olup, teknolojik gelişmeler devam ettikçe bundan sonra yıllık %0,05 düşecektir. İkinci senaryoda ise şartlar daha iyi hale getirildiğinde deniz ve iç su avcılığı, 2030 yılına kadar yılda sırasıyla %0,7 ve %0,55 oranında büyümektedir; ancak, iklim değişikliğinin etkilerine yönelik tahminleriyle tutarlı olarak, her ikisinin de verimi 2050'de %4,05'lik bir düşüşe maruz kalacağı vurgulanmıştır (Ahern vd., 2021). Costello vd. (2020) ekolojik, ekonomik, düzenleyici ve teknolojik kısıtlamalar göz önüne alındığında, mavi gıda tedariğinin 2050 yılına kadar 21-44 milyon ton artabileceğini ve mevcut verimlerle karşılaştırıldığında %36−%74'lük bir artışı temsil ettiğini belirtmiştir. Bu artışın 2050 yılına kadar 9,8 milyar insanı beslemek için gereken hayvansal kökenli protein miktarındaki tahmini artışın %12−%25'ini oluşturabileceği öngörülmektedir. Benzer şekilde, FAO (2022) tarafından hazırlanan raporda 2030 yılı için su ürünleri üretiminde %35 büyüme, %100 etkili balıkçılık yönetimi ve atıklarda %50 azalma gibi başarıları hedeflenmiştir. Gelişmiş teknolojiler ve azalan kayıp ve atıklarla birlikte, doğrudan insan tüketimi için kullanılmayan deniz balıkçılığının oranı 2020'de %21,3'ten 2050'de %19,35'e düşecektir. Üçüncü senaryoda ise şartlar mevcut durumdan daha kötüye giderse hem denizde hem de iç sularda balıkçılık 2040 yılına kadar yılda %0,25 üretim kaybı olacağı, 2050'de ise %0,5'e çıkacağı tahmin edilmiştir (Ahern vd., 2021). Bjørndal vd. (2024) ise dört senaryoya ilişkin 2030 projeksiyonlarına göre hem avcılık hem de yetiştiricilik üretimi için toplam üretim ele alındığında iyimser senaryoda 2030 yılında üretimin 226,9 milyon tona çıkması beklendiği rapor etmiştir. Bu da 2016 yılına göre yaklaşık üçte bir oranında artış anlamına gelmektedir. Öte yandan, iklim değişikliği etkilerinin de dikkate alındığı durumunda ise genel artış oldukça sınırlı kalmaktadır. Costello vd. (2016) çeşitli senaryolara göre yapılan tahminlerde sürdürülebilir su ürünleri üretiminin önemli ölçüde artma potansiyeline sahip olduğunu, kompozisyonda değişiklikler gözleneceğini ve gelecekteki protein ihtiyacının karşılanmasında büyük bir role sahip olabileceğini ifade etmiştir. Türkiye'de yumuşakça ve eklem bacaklıların üretimi açısından oldukça önemeli bir potansiyele sahip olan Marmara Denizinde de son yıllarda iklim değişikliğinin etkileri belirgin olarak gözlendiği ve deniz suyu sıcaklığının son 20 yılda küresel normun çok üzerinde (2-2,5°C) arttığı rapor edilmiştir (Savun-Hekimoğlu & Gazioğlu, 2021). Bu durumun müsilaj gibi sorunların ortaya çıkmasında önemli bir etken olduğu (Danovaro vd., 2009) ve sucul türler üzerinde olumsuz etkileri olduğu bilinmektedir (Acarli vd., 2021, 2023). Ayrıca yine iklim değişikliği çift kabukluların avcılık ve özellikle çift kabuklu su ürünleri yetiştiriciliğinin ve üretim miktarını doğrudan olumsuz bir şekilde etkilediği ifade edilmektedir (Lattos vd., 2022). Benzer şekilde, Marmara Denizinde 2024 yazında midye yetiştiricilik çiftliklerinde yoğun ölümlerin olduğu gözlenmiştir (Kişisel görüşme). Dolayısıyla, mevcut çalışmada geleceğe yönelik üretim miktarlarında öngörülen düşüş çevresel sorunların da tetikleyici etkileriyle öngörülenden daha yüksek hızda veya seviyede gerçekleşebilir.

Kuşat & Kuşat (2019) Türkiye'de su ürünleri yetiştiricilik üretiminde eklem bacaklı ve yumuşakçaların en zayıf ihracat performansına sahip olduğunu raporlamıştır. Benzer şekilde mevcut çalışmada da eklem bacaklı ve yumuşakçaların üretim miktarlarındaki yıllık değişimleri bu şekilde devam ederse Gastropod, Penaeidae, Bivalvia üretim miktarlarının 2030 yılında düşeceği tahmin edilmiştir. Üretimdeki bu düşüşün önlenmesi adına yasadışı ve aşırı avcılığın önüne geçilmesi için gerekli tedbirlerin alınması oldukça önemlidir. Ancak yine de literatürde dünyadaki avcılık yoluyla elde edilen üretim miktarında çok önemli bir artış görülmediği ve bu artışın sürdürülebilir avcılık üretimiyle 100 milyon tonu geçmeyeceği ifade edilmektedir (Çakmak vd., 2011; Gün & Kızak, 2019). Bununla birlikte, yetiştiricilik üretiminin artması toplam su ürünleri üretiminde de artış eğilimi gözlenmesine imkan sağlayacaktır. Dolayısıyla, mevcut çalışmada gözlenen düşüş eğilimi stokların sürdürülebilir avcılığının sağlanarak yetiştiricilik üretiminin de artırılması yoluyla önlenebilir. Öte yandan, bu çalışmada oluşturulan tahmin modelleri Cephalopod ve Crustacea üretim miktarlarının 2030 yılında artacağını öngörmektedir. Kumlu vd. (2021) 2019-2020 yıllarında iki adet karides üretim tesisinde üretimleri başarıyla gerçekleştirildiğini ve yaygınlaşacağını bildirmiştir. Destekler şekilde, Kobayashi vd. (2015) yumuşakçaların üretim miktarı açısından baskın türler olmaya devam edeceği ve karidese olan talebin çok daha yüksek olmasının beklendiği belirtilmektedir. Bununla birlikte, özellikle son yıllarda Akdeniz midyesinin yetiştiricilik yoluyla üretiminde de bir artış gözlenmektedir (Yıldız vd., 2023; Kuyumcu & Acarli, 2023). Kuyumcu (2023) Türkiye'de yetiştiricilik belgesine sahip olan toplam 47 adet Akdeniz midyesi üretim tesisi olduğunu ancak tesislerin bir kısmının kurulum aşamasında olması nedeniyle tam kapasite üretim yapılmadığını tespit etmiştir. Bu işletmeler tam kapasitede üretim yaptıklarında 44723 tonluk bir üretime ulaşacakları ifade edilmiştir. Dolayısıyla, bu üretim miktarına ulaşılması mevcut çalışmada 2030 yılı için tahmin edilen düşüşün gerçekleşmesini de engelleyebilecektir.

SONUÇ

Bu çalışmada yumuşakça ve eklem bacaklı üretimi geniş bir perspektiften değerlendirildiğinde ARIMA modeliyle yapılan trend analizi sonuçlarına göre 2030 yılında toplam üretim miktarında azalış eğilimi öngörülmektedir. Öte yandan, kafadan bacaklı üretiminde ise artış eğilimi tahmin edilmektedir. Dolayısıyla, geleceğe yönelik yapılan modelleme çalışmalarında daha yüksek doğrulukta sonuçlar elde edilebilmesi adına seçilecek veri setinin daha odaklanmış şekilde seçilmesi yararlı olacaktır. Türkiye'deki yetiştiricilik üretiminde gözlenen genel artış eğilimi ile avcılık üretiminde gözlenen genel azalış (veya durağanlık) eğiliminin birlikte değerlendirilmesi toplam üretimin modellenmesinde öngörülerin gerçekleşmesi ihtimalini etkileyebilir. Bu nedenle, avcılık üretimi ile yetiştiricilik üretiminin ayrı değerlendirilmesi tahminlerin hata payının azalmasına katkı sağlayacaktır. Sonraki çalışmalarda balıkçılık yöneticileri ve karar vericiler için gelecekteki üretim miktarlarının tahmin edilmesinde çevresel faktörler gibi üretimi tetikleyen diğer faktörlerin de dikkate alınması yapılacak tahminlerin doğruluğunu artıracaktır.

Etik Standartlara Uygunluk

Yazarların Katkısı

HES: Kavramsallaştırma, Araştırma, Metodoloji, Veri küratörlüğü, Denetim, Yazma – orijinal taslak hazırlama, Yazma – gözden geçirme ve düzenleme

SA: Kavramsallaştırma, Yazma – orijinal taslak hazırlama, Yazma – gözden geçirme ve düzenleme

Tüm yazarlar makalenin son halini okumuş ve onaylamıştır.

Çıkar Çatışması

Yazarlar herhangi bir çıkar çatışması olmadığını deklare etmektedir.

Etik Onay

Yazarlar bu çalışma için resmi etik kurul onayının gerekli olmadığını bildirmektedir.

Finansal Destek

Yazarlar bu çalışma için herhangi bir finansal destek almadıklarını bildirmektedir.

Veri Kullanılabilirliği

Veri setleri ile ilgili sorular için sorumlu yazar ile iletişime geçilmelidir.

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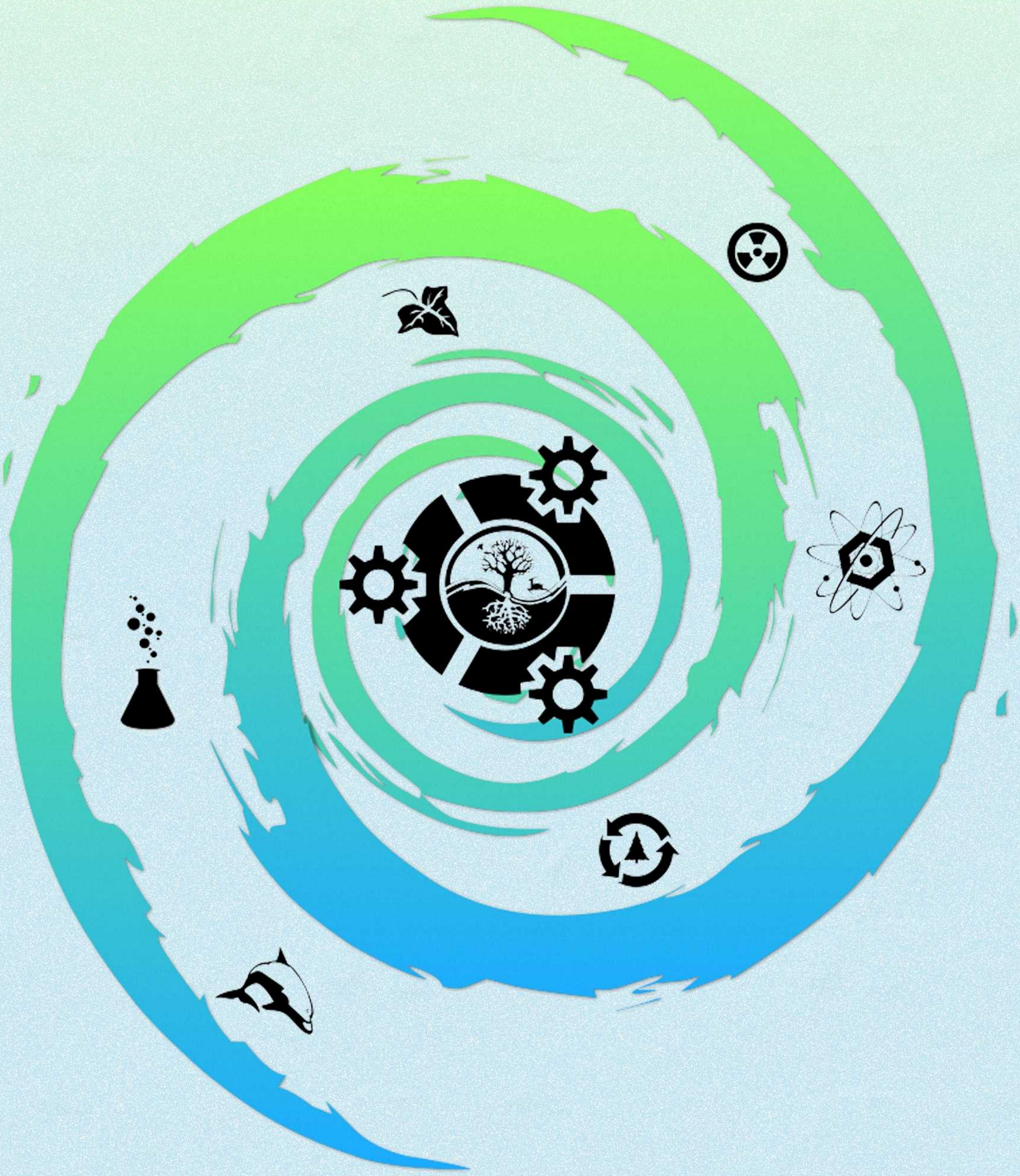

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