

Spatial Variations in Morphometry and Nutritional Composition of the Moroccan Atlantic Sardines (*Sardina pilchardus*) (Walbaum, 1792)

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ABSTRACT

The present study conducted a preliminary investigation into the morphological and biochemical characteristics of the sardine species *Sardina pilchardus*, captured along the Atlantic coasts of Morocco. Through our analysis, significant differences were identified among sardine samples collected from various fishing areas. The results revealed that Moroccan sardines have a great potential as a valuable source of essential nutrients for meeting human nutritional requirements. Moreover, a comprehensive assessment of the biochemical composition demonstrated that sardines sourced from the Central Atlantic area in Morocco consistently exhibited superior quality in terms of both nutritional content and morphological attributes. The mean height measure was 16.08 ± 1.01 cm, while the mean biochemical composition was $18.09 \pm 1.61\%$ for protein and $11.56 \pm 2.05\%$ for total lipid levels. These findings highlighted the significance of sustainable fishing practices and underscored the importance of considering specific geographic locations when evaluating the quality and nutritional value of sardine populations.

INTRODUCTION

Fish and seafood have played a vital role in ensuring food security, serving as a primary source of essential nutrients such as protein, lipids and minerals. In 2018, global marine fisheries production reached an unprecedented high of 84.4 million tons. Notably, the top seven producing countries in global capture fisheries—China, Indonesia, Peru, Russian Federation, United States of America, India and Vietnam—accounted for nearly 50% of the total catch (FAO, 2022).

Thanks to its favorable geographical position, Morocco has two maritime façades of about 3500 km of coastline, supported by an Exclusive Economic Zone (EEZ) of 1.1 million km². These advantages make the Moroccan coast one of the most fish-rich areas, with an annual production potential that exceeds 1.3 million tons of fish in 2021 (DPM, 2022). This reservoir of fishery wealth is characterized by a relatively high specific diversity: pelagic species, white fish, cephalopods, crustaceans, shellfish, etc.

The Moroccan Atlantic coast is characterized by the presence of deep cold water, called upwelling. It benefits from favorable hydro-climatic conditions manifested by a high productivity of fishery resources, in particular small pelagic (**Kifani & Gohin, 1992; Brochier *et al.*, 2009; Makaoui *et al.*, 2011**). The group of small pelagics constitutes the major part of the fishery potential of the Moroccan EEZ and represents 80% of the fishery production (**DPM, 2022**). The small pelagic resources are mainly composed of species of clupeids, scombrids, carangids and engraulids.

Fishing activities extend along the entire Moroccan coast; however, the landings of small pelagic in the Mediterranean area are significantly lower compared to those in the Atlantic. The Atlantic region accounts for over 95% of the total landings. Four types of small pelagic fisheries have developed in the Atlantic region of Morocco: a) the northern fishery (North of Safi), b) the A-stock fishery (Safi-Sidi Ifni), c) the B-stock fishery (Cap Draa-Laayoune), and d) the C-stock fishery (Cap Boujdour-Lagouira). These fisheries involve three main types of fleets: coastal/seiner vessels and pelagic trawlers, all focusing on the capture of small pelagic fish.

The sardine fishery carried out in the Moroccan Atlantic by seiners, targeting in particular the sardine *Sardina pilchardus*, is one of the main fishing activities that contributes significantly to the Moroccan economy, given its yield in terms of catches and the economic interest that it generates. The landings of this species represent about 70% of the total catches of small pelagics (**DPM, 2022**). The totality of the landings of this species is intended to satisfy the domestic market by supplying the processing factories and the Moroccan domestic consumer market.

Thanks to this production, Morocco ranks the 16th among the producing countries (capture fisheries) and the first on the African continent (**FAO, 2022**). However, despite the importance of national fisheries production, the annual consumption of fisheries products was estimated at an average of 13.6 kg/habitant in the year 2019 and remains below the world average estimated at more than 22 kg/inhabitant (**Nejar, 2020**). Morocco has set itself the strategic objective, within the framework of the "Halieutis" Plan of increasing this average to 16 kg/inhabitant/year by 2020.

To better understand the nutritional importance of the Moroccan Atlantic sardine, and in order to collect the data necessary for the valorization of this species, biometric, physicochemical and biochemical studies must be undertaken. The realization of these studies was based on the determination of certain characteristic parameters of the sardine, in particular the data on the biometry as well as the biochemical parameters.

Along the Moroccan coasts, fish populations exhibit diversity and are subject to seasonal variations in terms of composition and geographical distribution. These fluctuations are influenced by the hydro-climatic conditions unique to the Atlantic, including the strong intensity of upwelling, setting it apart from the Mediterranean area. In fact, the study of fish, from a nutritional point of view, accounts for describing an average change in diet. However, the latter varies according to the fishing area. In addition, the biochemical composition of several species of sardine varies considerably from one species to another according to size, sex, seasonal changes, food cycles and migratory behavior (**FAO, 2002; Petricorena, 2014; Barakat *et al.*, 2022**).

The present study is part of the nutritional valuation of the fresh sardines *Sardina pilchardus* from coastal fishing. As such, the main objective of this work was the analysis of biochemical composition of this species in order to highlight the importance of its consumption, which plays a role in the dietary balance.

MATERIALS AND METHODS

Study sites

In this study, our focus was twofold: firstly, to characterize the nutritional aspects of the common sardine species "*Sardina pilchardus*," and secondly, to investigate the influence of spatial variation on its nutritional quality. It is noteworthy that the samples examined were captured from eight distinct regions along the Moroccan Atlantic coastline (Fig. 1)



Fig. 1. Geographical location of the retained study sites: two sites in the North Atlantic (Casablanca and Safi); four in the central Atlantic (Essaouira, Agadir, Sidi-Ifni and Tan-Tan) and two in the South Atlantic (Laayoune and Dakhla)

Sampling

Sampling of sardines from the catches of sardine seiners were conducted at major ports along the Moroccan Atlantic coast, namely Casablanca, Safi, Essaouira, Agadir, Sidi Ifni, Tan-Tan, Laayoune, and Dakhla, during the spring season of 2022.

Morphometry

Using an ichthyometer, the total length was determined, which is the distance between the tip of the snout and the two posterior lobes of the caudal fin. The total weight of the samples was determined using a 0.01g precision scale.

Biochemical compositions

The approximate composition of homogeneous samples of sardines was analyzed in the quality control laboratory at Higher Institute of Maritime Fisheries in Agadir for water, protein, lipid and ash content. The moisture content was determined by drying in an oven at 105°C to constant weight. Crude protein content was determined by the Kjeldahl (Horwitz & Latimer, 2005). Moreover, the total lipids were determined by the Soxhlet (Horwitz & Latimer, 2005). In addition, the ash content was determined by incinerating the sample at 550°C in a muffle furnace to constant weight (Horwitz & Latimer, 2005). All samples were taken in triplicate and concentrations were given as percentage of tissue weight.

Statistical processing

Data were analyzed using one-way analysis of variance (ANOVA), and significant differences between means were determined by Duncan's post hoc multiple range test. Differences were considered significant when $P < 0.05$. Data were analyzed using the SPSS software package (version 26).

RESULTS AND DISCUSSION

Morphometric characteristics

Sardines caught in the Central Atlantic region (Essaouira, Agadir, and Sidi Ifni) were significantly smaller in size ($P < 0.05$) than those caught in the North Atlantic (Casablanca and Safi) and South Atlantic (Laayoune and Dakhla) regions. Conversely, sardines captured in the South Atlantic region (Laayoune and Dakhla) were significantly larger in size ($P < 0.05$) than those caught in the North Atlantic (Casablanca and Safi). Tan-Tan sardines exhibited a size closer to those caught in most of the studied sites, except Agadir, Essaouira and Dakhla ($P < 0.05$) (Fig. 2A). The total length of the different sardines showed variability according to the place of capture, ranging from 15.21 ± 0.50 cm for sardines from Essaouira to 22.25 ± 1.20 cm for sardines from Dakhla (Fig. 2A).

The study of the total weight of sardines showed maximum values at the port of Dakhla (99.61 ± 7.21 g) and minimum values at the port of Essaouira (41.16 ± 2.46 g), while a slight increase was reported at Casablanca, Safi and Laayoune (Fig. 2B). It is important to note that the statistical study revealed no significant difference ($P > 0.05$) between Sidi-Ifni, Agadir and Essaouira. However, the average weight of sardines from Safi

(58.80 ± 3.55 g) remains higher than those from Tan-Tan (50.08 ± 3.01 g) and lower, respectively, than those from Casa (65.80 ± 3.91 g) and Laayoune (67.69 ± 6.91 g) (Fig. 2B).

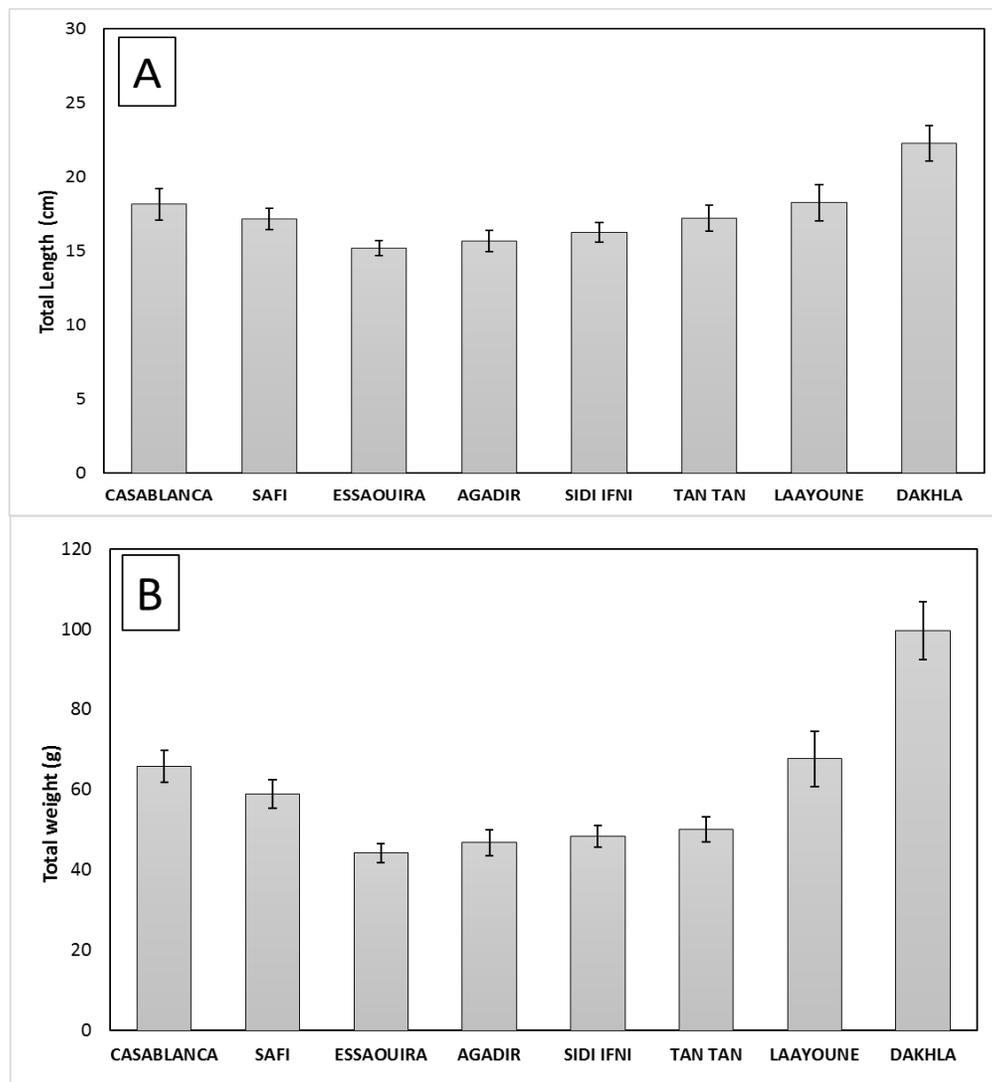


Fig. 2. Variation in total length and total weight of sardines landed in the different fishing ports of the Moroccan Atlantic coast (mean \pm standard deviation)

A: Total length; B: Total weight

The results, relating to the size and weight of the sardine, confirmed what **Amenzoui (2010)** reported at the levels of Safi, Agadir and Laayoune. However, a slight heterogeneity was observed among the sardines caught between the central Atlantic area and the northern and southern Atlantic area. However, there was a significant difference ($P < 0.05$) between sardines from Essaouira and Dakhla. In general, sardines vary in weight and size according to fishing area and sex (**Amenzoui, 2010**).

The commercial size of fish depends on environmental factors that affect metabolism and growth, such as temperature and diet (**Russell et al., 2012; Abd El-Hack et al., 2022**). From the results obtained, we found that the total length varied between

15.21 & 24.20cm, with a total weight varies between 40.20 and 108.30g, which complies with the regulation on the minimum market size of sardines fished in Moroccan marine waters (MPM, 2015).

According to the literature, weight variability can also be related to many factors, such as exercise, food quantity and quality, stress level or seawater quality (Sarà *et al.*, 1999; Amenzoui, 2010; Hammami *et al.*, 2011). Nevertheless, fish size and weight were factors that distinguished individuals by morphology, both in relation to genetic traits, age, sex and environmental conditions (Tudela, 1999; Sinovčić *et al.*, 2008).

In addition, length directly affects the reproductive potential of the species, the length of the breeding season, and the size of egg production (Sinovčić *et al.*, 2008). Indeed, the difference in size between the sexes at first maturity can be explained by the fact that female fish generally have a higher reproductive energy cost, fecundity and egg size that increase with female size (Ihssen *et al.*, 1981).

The study of the size-weight relationship of sardines caught along the Moroccan Atlantic showed highly significant positive correlations ($P < 0.01$) at the study sites (Fig. 3).

The size at first maturity of sardines in the central Mediterranean Sea ranged from 10.8 to 12.4cm (total length) for females and 10.2 to 12.2cm for males (Basilone *et al.*, 2021). In contrast, in the southern Atlantic, the mean size at first sexual maturity was 16.3 ± 0.31 cm for males and 17.5 ± 0.35 cm for females (Amenzoui *et al.*, 2004). In addition, the sizes of 19.8cm and 17.6cm were respectively recorded for males and females in the north Atlantic (Abderrazik *et al.*, 2016).

Large-scale spatial variation in length at first sexual maturity exhibits a positive correlation with the species' lifespan, maximum size, and growth during the first year of life (Silva *et al.*, 2006; Amenzoui, 2010). Sardine stocks with larger maximum sizes tend to have longer lengths. Additionally, these large spatial scale fluctuations reveal significant correlations between mean body weight and percent fat, as well as between mean body weight and body size in sardines at first sexual maturity (Silva *et al.*, 2006).

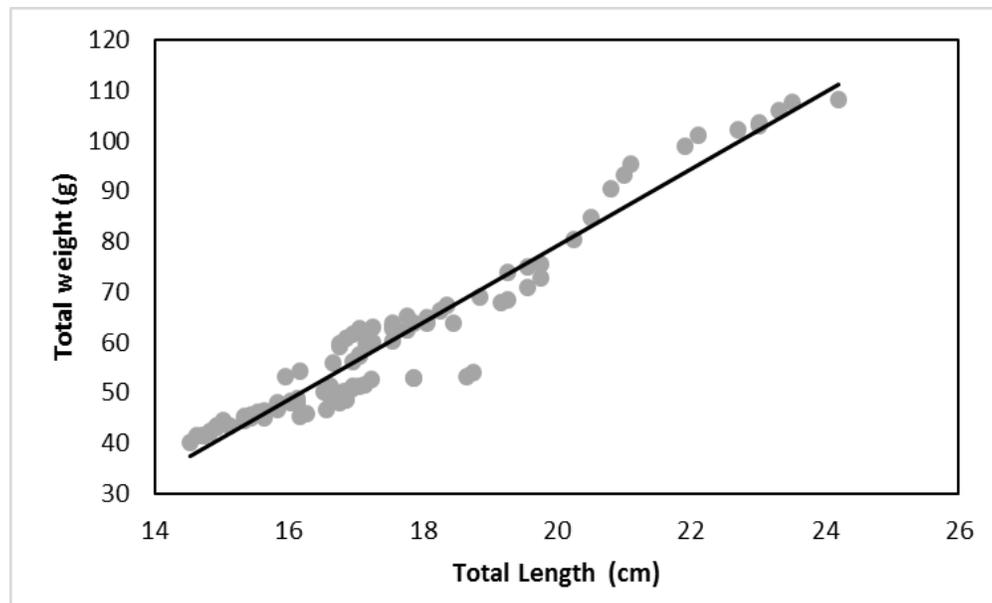


Fig. 3. Bivariate weight-for-size adjustment of Atlantic sardine in Morocco

Biochemical compositions

The study showed a significant difference ($P < 0.05$) for sardines caught in the Casablanca area, with an average of 77.28%, whereas for sardines from Essaouira and Sidi Ifni, values of 71.60 and 71.78% were respectively recorded. However, the variation in the other areas remained more or less stable, with rates ranging from 73.53 to 74.83%.

It was found that sardines from Safi had a higher mineral content than the other sites, with a value of 1.47%, while sardines from Essaouira had the significantly lowest mineral content (0.80%) (Fig. 4B).

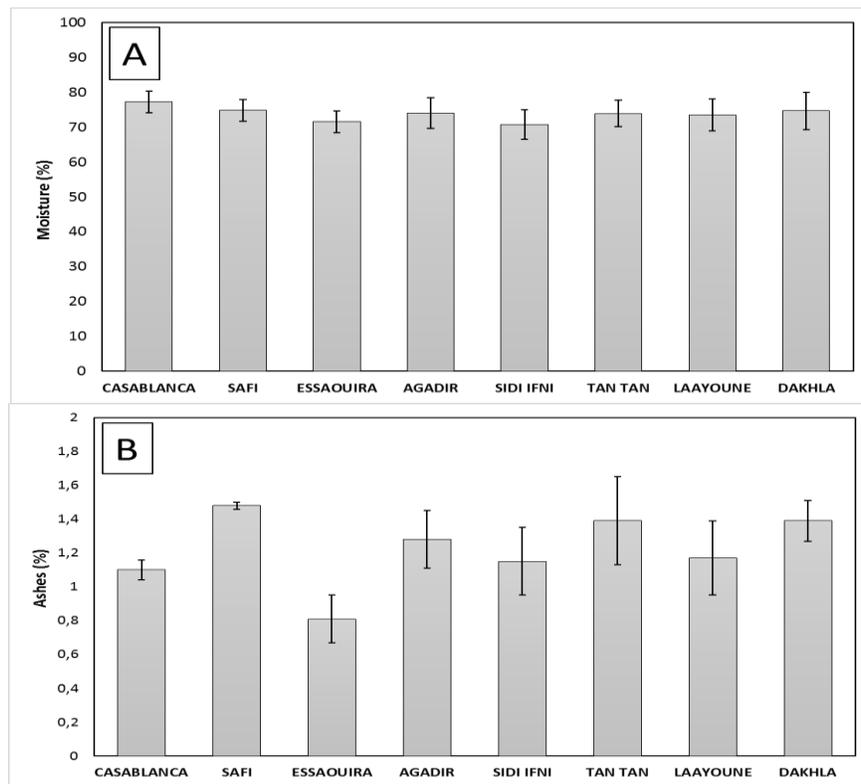
The results obtained through our study showed that the ash content of sardines was lower than those detected by other authors (Caponio *et al.*, 2004; Nunes *et al.*, 2015). Nevertheless, our findings concerning this parameter align with previous research, as reported in other studies (Simat *et al.*, 2020; Mohhdaly *et al.*, 2021).

Studying the protein content of different samples, we observed that the sardines from Dakhla are rich in protein ($P < 0.05$), with a protein content of more than 19%. With this concentration, they are closer to those of Essaouira, Casablanca, Sidi Ifni, Agadir and Tan-Tan, respectively, and largely superior to the sardines caught in the Laayoune and Safi areas (Fig. 4C).

The comparison of fat in different sardine samples showed that sardines from Sidi Ifni (12.50%), Essaouira (13.34%) and Laayoune (13.66%) show significantly ($P < 0.05$) higher values compared to the samples collected at the other study sites (Fig. 4D).

The chemical composition of fish muscle exhibits significant variation not only between different species but also among individuals within a species, influenced by factors such as age, sex, environment and season. Moreover, these variations in chemical composition are intricately linked to the dietary patterns of the fish.

The disparities observed in water content among sardines caught at various study sites primarily stem from differences in food availability, sex and seasonal variations (Lee, 1961). Furthermore, these variations in water content are inversely proportional to the lipid content. (Fig. 5A). These results coincide with findings from previous studies (Bandarra *et al.*, 1997, 2001). The relationship between fat and water content significantly impacts the proportion of dry matter in fish (Nunes *et al.*, 1992; Bandarra *et al.*, 1997; Aubourg, 2001). Notably, the protein content of fish remains generally stable, irrespective of the sex and size of the individuals (Karakoltsidis *et al.*, 1995; Robards *et al.*, 1999).



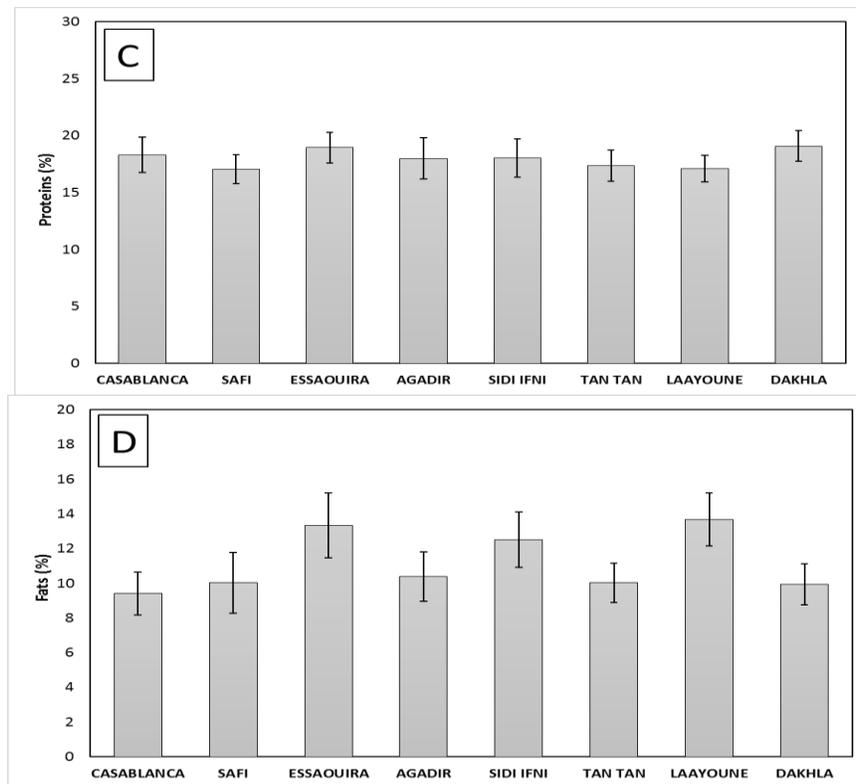


Fig. 4. Variation in the biochemical composition (A: Moisture; B: Ash; C: Protein; D: Fat) of sardines landed in the different fishing ports of the Moroccan Atlantic coast (mean \pm SD)

In general, the lipid content of fish is influenced by various factors such as diet, species, season and geographical origin (**Rasoarahona et al., 2005**). The lipid content obtained by our study showed similarities with the study conducted by **Bandarra et al. (1997)** and **Bouderoua et al. (2011)**. Indeed, the lipid content of the fillet also depends on the type of muscle considered; for lean fish, red muscle contains about twice as much fat as white muscle (**Body & Vlieg, 1989**). For fatty fish such as mackerel, the lipid content of the red muscle reaches 19.6g per 100g of muscle, whereas that of the white muscle is estimated at 3.9g. Understanding that the fat content of sardines typically ranges from 3.82% to 11.47%, it's crucial to consider these variations when assessing their nutritional composition (**Zlatanos & Laskaridis, 2007**). The results obtained in the present study fell within this standard range, emphasizing the consistency of our findings with established nutritional norms.

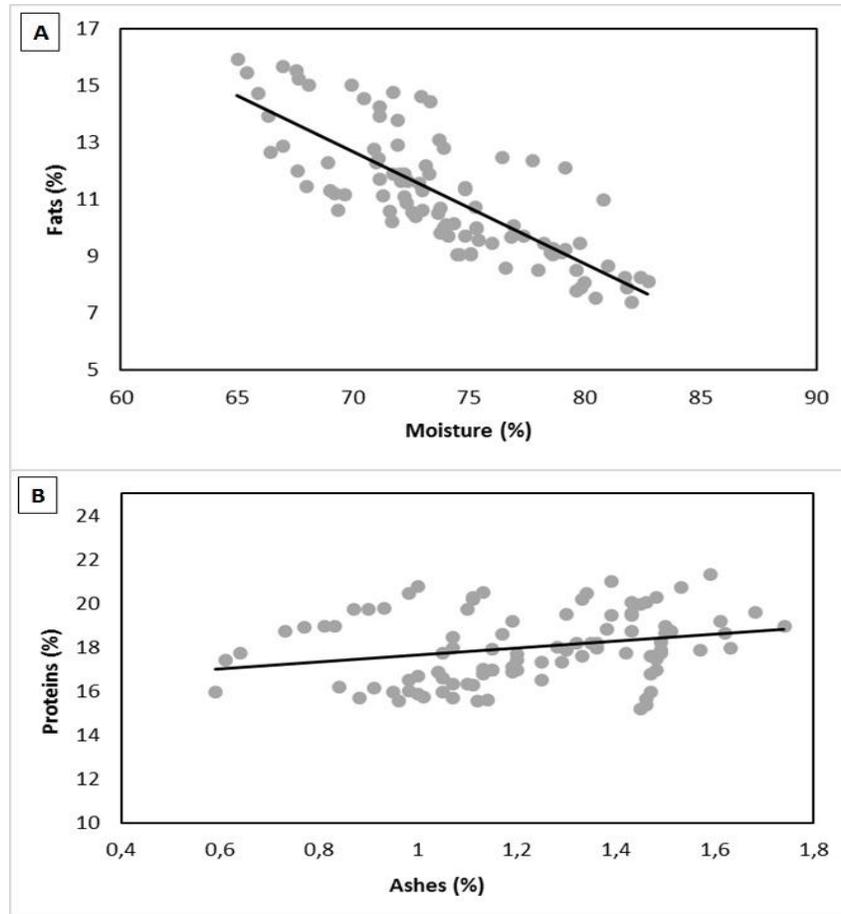


Fig. 5. Bivariate adjustment of lipids by water content (A) and proteins by ash (B) in the flesh of Atlantic sardines in Morocco

Nonetheless, our study on the variations in the moisture and lipid content in sardine flesh revealed an inverse relationship between these two variables. This implies that when one increases, the other decreases (Fig. 5A). This result is consistent with previous research conducted by several authors (Frontier-Abou, 1969; Culley, 1971; Abdelmoula *et al.*, 1980).

In contrast, the correlations between ash and protein content in sardine flesh may appear less pronounced (Fig. 5B), confirming the conclusions of previous research (Culley, 1971; Abdelmoula *et al.*, 1980).

CONCLUSION

The results obtained in this study showed that the sardines caught in the central Atlantic were smaller than those caught in the North and South Atlantic.

The analysis also revealed that the most significant changes occurred in the percentages of water and protein, as well as fat and minerals. Specifically, when fat content increased, water content decreased, and conversely, when water content

increased, fat content decreased. Moreover, when protein content increased, mineral content also increased, suggesting a direct correlation between these two variables.

These variations in the chemical composition of sardines highlight the significant impact of fishing areas on the nutritional quality of Moroccan sardines. Sardines caught in the central Atlantic region stand out as some of the best fish concerning both chemical and morphological composition.

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