Factors influencing mussel (*Mytilus galloprovincialis*) nutritional quality

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Abstract. Mussels display interesting nutritional characteristics as they are a rich source of proteins, carbohydrates and minerals and provide an almost unlimited variety of fatty acids with beneficial roles in human health. The quality characteristics of *Mytilus galloprovincialis* mussels harvested at seasonal intervals reflect the different environmental conditions met by the animals during their growth. Their chemical composition is strictly dependent on the phytoplankton resources available and, therefore, on the season of harvest. Parameters such as water temperature, food availability and the gametogenesis cycle can influence the meat yields and the biochemical composition of the mussels, conditioning their commercial quality and organoleptic characteristics. In order to determine the nutritional value of blue mussels, it is of great relevance to identify their biochemical composition as well as the most favourable season and geographical location for mussel-harvesting. That data could be useful to indicate the periods of the year more suitable for the marketing and consumption of mussels.

1. Introduction

In many countries, mussels (*Mytilus galloprovincialis*) are considered a delicacy and important marine organisms due to their nutritional relevance. They are an important part of the global seafood market and support both commercial fisheries and aquaculture all around the world [1]. Mollusc aquaculture accounts for more than 75% (13.9 million tons) of the world's aquaculture, with mussel production being around 13% (1.8 million tons) of world aquaculture annual production [2]. Mussels are usually marketed as raw or frozen but also as processed products, i.e. smoked mussels. Consumption of fresh mussels is growing owing to their high nutritional quality. Mediterranean mussel farmers are increasingly interested in technologies to obtain high quality final products, so high quality of raw material is essential. Mussels are appreciated by consumers for their organoleptic properties, retained also after processing, and for their competitive price if compared with other bivalves [3].

1.1. Biochemical composition of mussels

Mussels are filter-feeders, acquiring proteins, lipids, carbohydrates and other components from phytoplankton (e.g., diatoms, dinoflagellates), bacteria and detritus suspended in the water, and using them to build their own biomass [4]. The main factors of molluscs' nutritional value are proteins, lipids, carbohydrates, free amino acids, vitamins (A, B1, B2, B6, B12 and C), fatty acids, particularly

the n3 polyunsaturated fatty acids (PUFAs) such as eicosapentaenoic (EPA, 20:5n3) and docosahexaenoic (DHA, 22:6n3), which clearly shows their importance for human health [5]. They play an important role in prevention of cardiovascular disease, regulation of blood pressure and the immune system and have anti-inflammatory properties [6].

The biochemical composition, condition index and meat yield are useful indicators of the nutritional and commercial quality of bivalves. These parameters are affected by season and capture areas and fluctuate as a result of the interaction between the variations in the seston (the natural diet of suspension-feeders) quality and quantity and the bivalves' reproductive cycle [7,8]. The reproductive cycle of *M. galloprovincialis* starts with the development and ripening of the gonad during autumn-winter, and major spawning events take place during the spring upwelling season, after which the gonad restores, leading to secondary spawning events during late summer. The most important ecological factor affecting the rate of growth is food (different groups of phytoplankton), the composition of which can be different in differing aquatic environments. Other important factors are temperature and salinity of seawater. The largest amount of food in the sea and the greatest mussel growth is achieved at temperatures from 10 to 20°C. At temperatures above 20°C and below 5°C, the growth increment is usually slow [9].

In addition to seasonal variations, spatial changes in the feeding environment are common in harvesting areas. Storms or tidal cycles, changes in current speed or variable riverine nutrient outflow can lead to resuspension of bottom material, which increases the total concentration of seston, but dilutes the concentration of organic particles suspended in the water [10]. Human activities can reduce organic loads and chlorophyll levels [10]. Numerous studies have reported the amount of biochemical reserves and the condition index can vary substantially among bivalves cultured in nearby sites within the same embayment [8,11,12].

1.2. Biometric parameters

Differences in biometric parameters have a direct influence on the aspect of mussels and can be decisive for consumers' purchase decisions. Biometric parameters are measured in individual mussels using 0.05 mm precision callipers: length (maximum measure along the anterior-posterior axis), width (maximum lateral axis), and height (maximum dorso-ventral axis) (Fig. 1). Mussels are opened by cutting the adductor muscle with a scalpel, and the wet meat and shells are weighed.

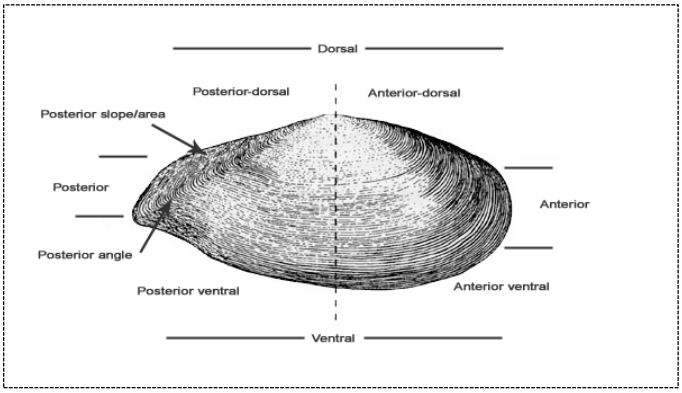

Figure 1. Biometric parameters of mussels: length (maximum measure along the anterior-posterior axis), width (maximum lateral axis), and height (maximum dorso-ventral axis).

The biometric measurements of mussels throughout all seasons did not exhibit seasonal differences in terms of total weight, length, height or width. Mussel shell contains little organic material (<5%) and changes in biometric characteristics of the shell are less susceptible to food availability and other environmental factors than mussel tissue [13].

Meat yield (MY), i.e. the percentage ratio between meat content (WT) and total wet weight of mussels (WW) is an important aspect of marketability of mussels and is calculated according to Okumus and Stirling [14] as follows:

$$MY\ (\%) = (\text{meat weight (g)} / \text{whole mussel weight (g)}) \times 100$$

Condition index (CI) is calculated after oven-drying (105°C) meat and shell according to [7] as follows:

$$CI\ (\%) = (\text{meat dry weight (g)} / \text{shell dry weight (g)}) \times 100.$$

In Wales, the largest gains in flesh weight occur between April and September, which corresponds to the season of maximum shell growth [15]. The nutritional quality of the seston peaks during the spring bloom and decreases during winter downwelling. Variations in CI are significantly correlated with the accumulation and expenditure of reserves. Mussels harvested in autumn have the highest CI and biochemical reserves, while minimum CI occurs in winter, when mussels have a low energy balance, high energy investment during the typical winter gonad development and low food quality. Thus, some results suggested that mussels harvested in spring and summer (spawning period) would be more suitable for processing, while the higher CI during autumn indicates the mussels harvested during this period are more suitable for fresh consumption [16].

1.3. Chemical analyses

For proximate chemical composition studies, chemical analyses are performed on a homogenized sample of about 10 individual mussels. Pooled mussels can be freeze-dried, milled and kept in dry conditions until further analysed [17]. The moisture and ash contents are determined according to the standard procedures of AOAC [17]. Moisture content is calculated based on the percentage weight loss after drying to a constant weight at 105°C overnight. Ash content is determined after having weighed and transferred the dry samples into a muffle furnace at 550°C overnight. Quantitative protein determination is performed by the Kjeldahl method (N × 6.25) from the nitrogen concentration of mussel. Lipid content is determined gravimetrically after Soxhlet extraction using petroleum ether. The lipid extracts are subject to fatty acid analysis by gas chromatography after transmethylation into fatty acid methyl esters (FAMEs). Glycogen content (mg g^{-1} of wet weight) can be measured by colorimetric reaction and calculated based on a mussel glycogen standard (Sigma, Saint Louis, MO) following the methodology reported by Gallardi *et al*. [18].

1.4. Seasonal variation

During the year there is a change in the biochemical composition of shellfish. Stress conditions, environmental situations requiring major energy expenditure and gamete release can be responsible for the low condition index, low meat yield and poor biochemical reserves observed in certain periods of the year [15]. Proteins have many different biological functions: transport, defence, structural elements, storage. They are considered the main energy substrate during gamete development, and the lowest protein levels in mussels are coincident with the main periods of gamete development (winter) and spawning (spring), respectively. Decreases in lipid content in mussels have also been associated with gamete formation and spawning effort (winter). Lipids are highest during spring-summer, when peak values coincide with the phytoplankton bloom [19]. In human diets, lipids have several important roles: provision of a significant proportion of the body's necessary energy requirements, as cell membrane components, and being the source of essential fatty acids [20].

Glycogen makes up more than 50% of the total carbohydrate reserves in bivalves and has two major functions: as a long-term energy store and as structural elements with lipids. An accumulation

of glycogen over the summer season, followed by a decline through the winter is coincident with low meat yields and low condition index and with spawning, was reported by Okumus and Stirling [14] in mussels. The low meat yield and low condition index in winter are coincident with the depletion of protein and lipid reserves. The ash content of the meat reaches peak levels in winter, coincident with minimum glycogen and lipid reserves.

Gas chromatographic analysis of total lipids in mussels shows the prevalence of polyunsaturated fatty acids over saturated and monounsaturated fatty acids occurs throughout the year [7]. The fatty acid composition (among the total fatty acid content) of mussels varies, ranging from 29% to 48% of PUFA, 16 to 32% of monounsaturated fatty acids and 23 to 45% of saturated fatty acids, although saturated fatty acids accounted for 57% of the fatty acids in mussels in Italy [21].

In summary, seasonal variations in the biochemical composition of mussels are closely linked to natural fluctuations in the composition of the bivalve's diet and the different stages of the annual reproductive cycle. These facts could benefit aquaculturists and local residents employed in entrepreneurship related to aquaculture, and are relevant in developing a bivalve trade that ensures a constant supply of high quality product.

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