

Texture Engineering in Cell-Based Seafood: Insights from Structural and Compositional Benchmarks

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Background:

The growing demand for seafood continues to strain wild stocks and the aquaculture industry. Cell-based seafood presents a sustainable alternative; however, replicating the texture of conventional fish remains a key barrier to consumer acceptance. This study aimed to develop species-specific structural, chemical, and textural benchmarks to inform the design of cell-based seafood products that closely mimic their conventional counterparts

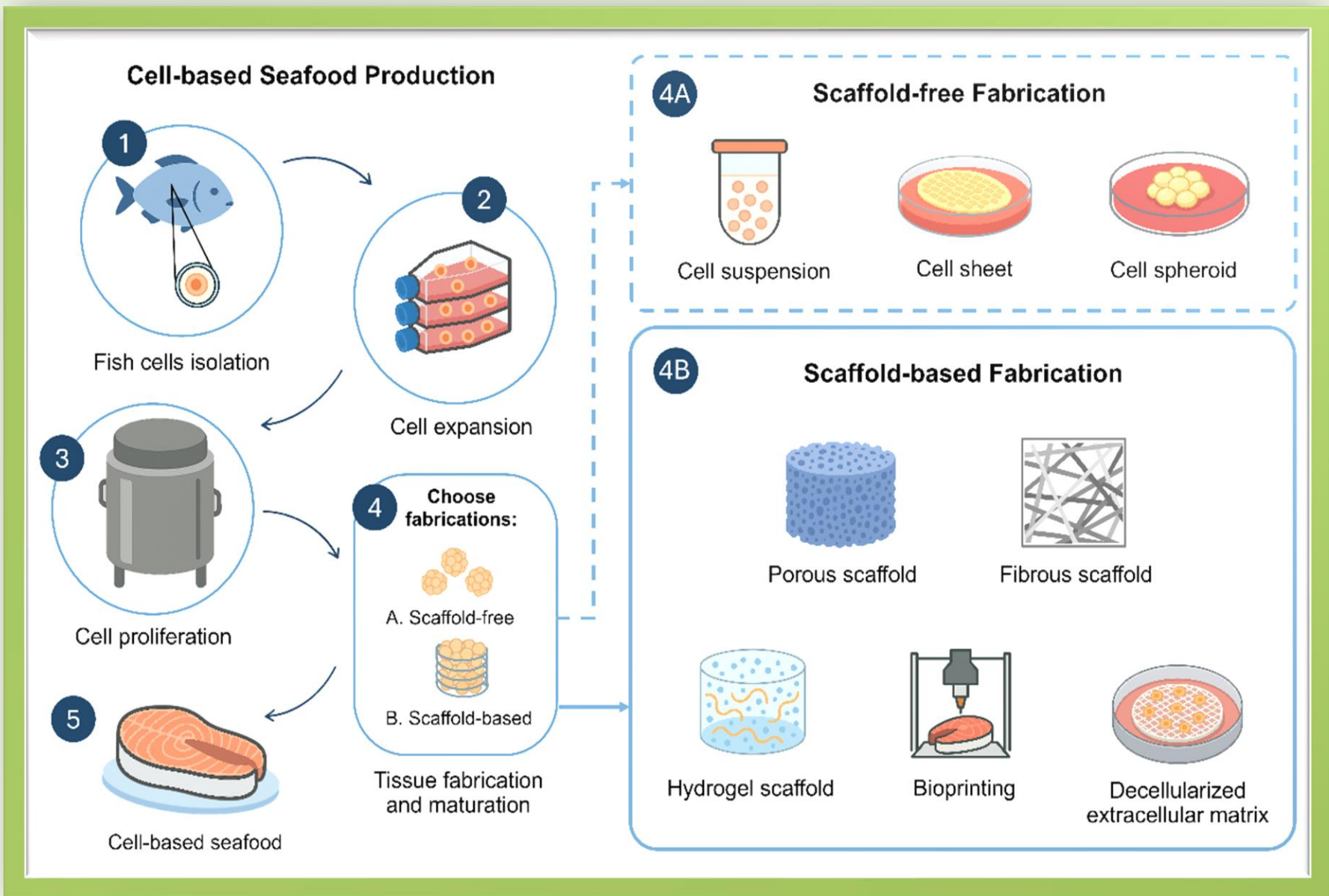


Figure 1: Overview of cell-based seafood production and fabrication strategies

Methods:

This study evaluated the structural, chemical, and textural profiles of four commercially important fish species: tilapia, grouper, salmon, and tuna. Dorsal muscle samples were analyzed for:

- Texture (hardness, chewiness, etc.) using Texture Profile Analysis (TPA),
- Composition via proximate analysis (moisture, protein, fat, ash),
- Collagen content using hydroxyproline assay,
- Muscle structure via histological imaging and muscle fiber diameter quantification.
- Statistical modeling was performed to determine how hydroxyproline, muscle fiber size, and fat content influence textural attributes.

Figure 2 shows the standardized workflow used for sampling and analysis

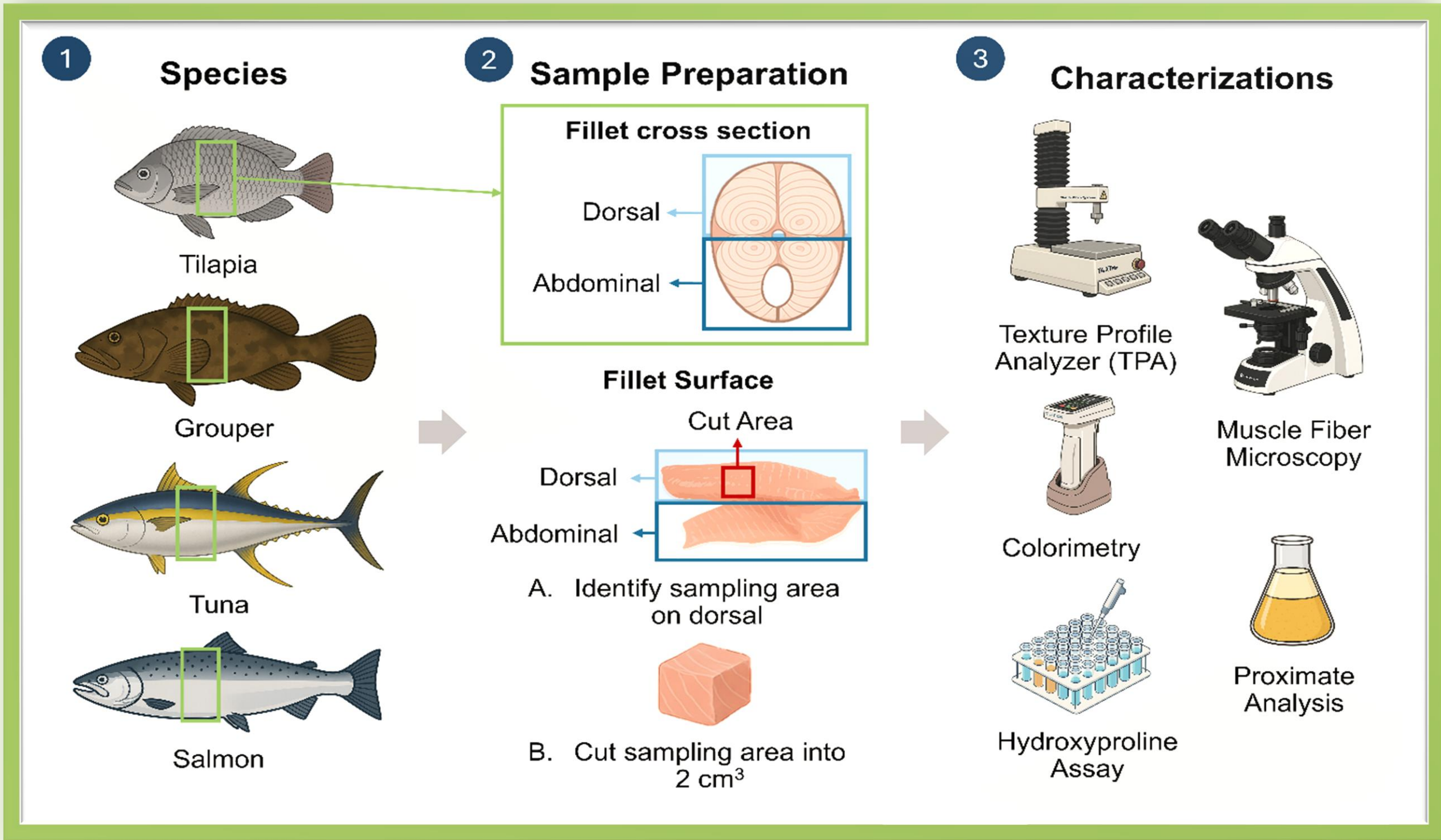


Figure 2. Sampling and analysis workflow. A 2 cm³ dorsal muscle cube was collected from a standardized fillet region in tilapia, grouper, tuna, and salmon. Samples were analyzed for texture, muscle fiber structure, color, collagen (via hydroxyproline), and proximate composition

Results:

- Tilapia had the highest hardness and hydroxyproline content, with smallest muscle fibers, correlating with firmer texture.
- Salmon exhibited softest texture, highest fat, and lowest fiber density.
- Hydroxyproline showed the strongest positive correlation with hardness.
- Smaller muscle fibers increased hardness, chewiness, and adhesiveness.
- Higher fat content significantly reduced firmness and gumminess.

These findings create a quantitative foundation for designing scaffolds and optimizing cell-based seafood textures. Figure 3 illustrates the muscle architecture of the four fish species, highlighting differences in muscle fiber size and organization, while Table 1 summarizes how hydroxyproline, muscle fiber diameter, and fat content influence key textural attributes such as hardness, chewiness, and gumminess.

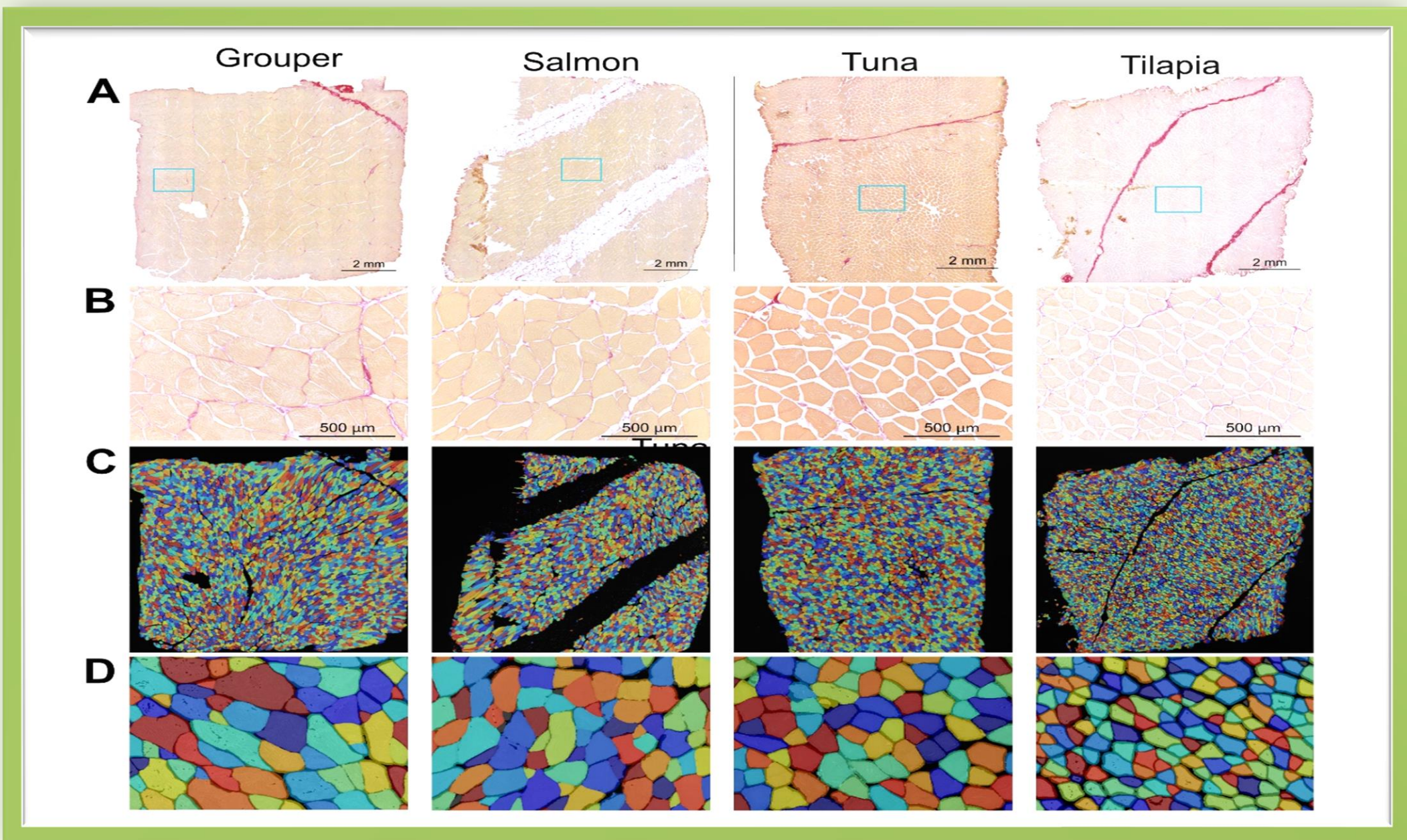


Figure 3. Histological structure of skeletal muscle from grouper, salmon, tuna, and tilapia. (A) Whole muscle cross-sections stained with Picrosirius Red (scale = 2 mm); (B) Higher magnification showing individual fibers (scale = 500 μm); (C–D) Segmented images with color-coded muscle fibers for visualization and quantification.

Table1. Key factors influencing fish texture

Texture Trait	Hydroxyproline	Muscle Fiber Size	Fat Content
Hardness	↑ Strong increase	↓ Strong decrease	↓ Moderate decrease
Gumminess	↑ Mild increase	↓ Moderate decrease	↓ Strong decrease
Chewiness	↑ Mild increase	↓ Moderate decrease	↓ Strong decrease
Cohesiveness	↓ Slight decrease	↑ Slight increase	↓ Strong decrease
Adhesiveness	— No effect	↓ Moderate decrease	— No effect
Springiness	— No effect	↓ Minor decrease	— No effect
Resilience	↓ Minor decrease	↑ Moderate increase	↓ Strong decrease

Legend:
•↑ = increases the texture trait
•↓ = decreases the texture trait
•— = no meaningful effect

Conclusion:

This study provides the first integrated benchmark of structural, chemical, and textural traits across four key fish species to inform the design of cell-based seafood. Hydroxyproline, muscle fiber size, and fat content were found to significantly influence texture attributes like hardness, chewiness, and gumminess. These insights offer a foundational framework for selecting biomaterials and engineering strategies to better replicate species-specific textures in alternative seafood products.