Science for Impact in Africa: Bridging the Gap between Academia and Societal Needs in Agri-Food Systems

Valorization of marine co-products by the extraction of gelatin with food interest

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General introduction: Valorization of bio-resources

Tunisia

Bio-resources: MAP, Algae, Agricultural co-products. etc.

No/Little processed (low price)

(very high prices)

Europe….

Food supplements

Nutraceuticals

Cosmetic products

Strategy for the valorization of bio-resources

Developpement of Bio-ressources valorization

Social, economic and environmental benefits

General introduction: Fishery co-products

World production of fishery products: 180 million tons (FAO, 2020)

⇩

In Tunisia: Production > 150,000 tons/year (DGPA, 2019)

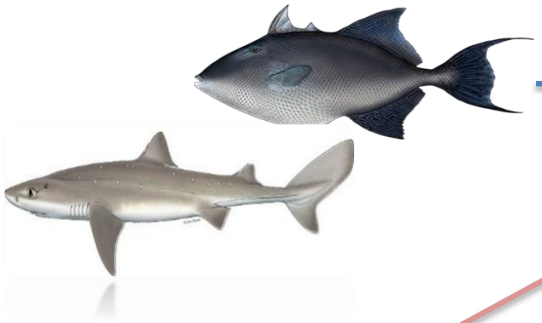
⇩

≈25% of these products are processed

Co-products : 30-60%

We usually only eat half of the whole fish

General introduction: Fishery co-products



Transformation

Head, viscera, cartilage, skin, etc.




Co-products

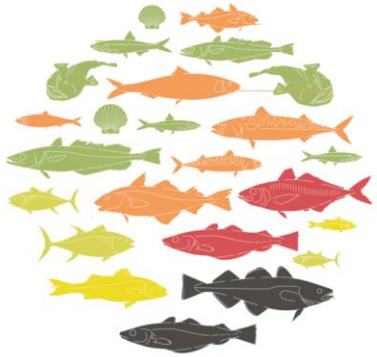
Valorisaztion :
- **Pollution reduction**
- **Production of high added value molecules**

Valorization:
- Nutraceuticals
- Food Industry

- **Chondroitin sulfate; Chitin/Chitosan**
- **Bioactive peptides**
- **Refined oils**
- **Minerals (Ca, P and Mg)**
- **Marine lecithin**
- **Peptone**
- **Collagen/Gelatin**

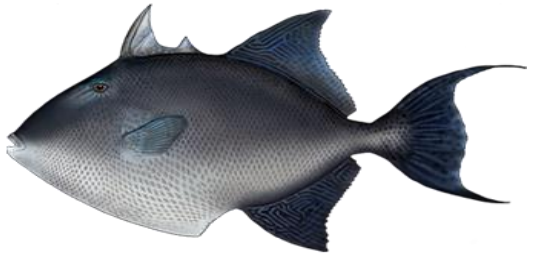
Sustainable Development

General introduction: Fishery co-products



Grey triggerfish

Baliste capriscus



Smooth-hound shark

Mustelus mustelus

National production of cartilaginous fish > 42,000 tons/year (ONAGRI)

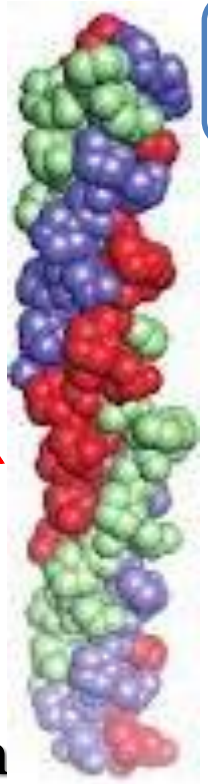
General introduction: Gelatin

Protein obtained by partial hydrolysis of collagen in the skin, connective tissues and bone matrices

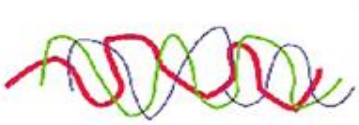
Chain 1

Chain 2

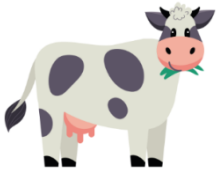
Chain 3



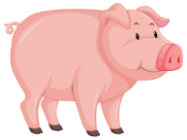
Collagen triple helix



Bones – Skin
Bovine/Porcine



BSE



Label !

Fish skin

Pre-treatment (degreasing) of the raw material

Acid/Alkaline pre-treatment

Washing

Extraction of gelatin (40-50°C)

Filtration/Centrifugation
Drying

Gelatin

General introduction: Gelatin

Gelatin

Commercial bovine gelatin (Powder): 500 g ≈ 15 Euros

Gelling | Thickening | Emulsifying | Foaming | Stabilizing | **Filmogen**

Thermoreversible Gel

Melting at T ~ Body

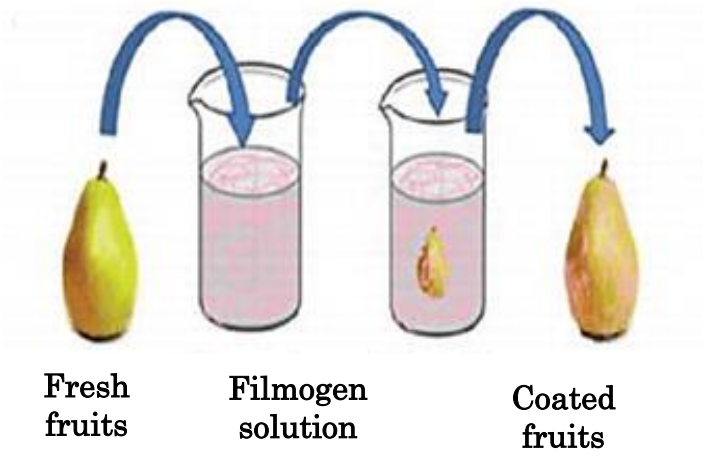
- Food Industries
- Pharmaceuticals
- Cosmetics
- Packaging

General Introduction: Edible Packaging & Coatings

Gelatin

Edible packaging
(Film)

Edible Coating
(Spray/Dip)

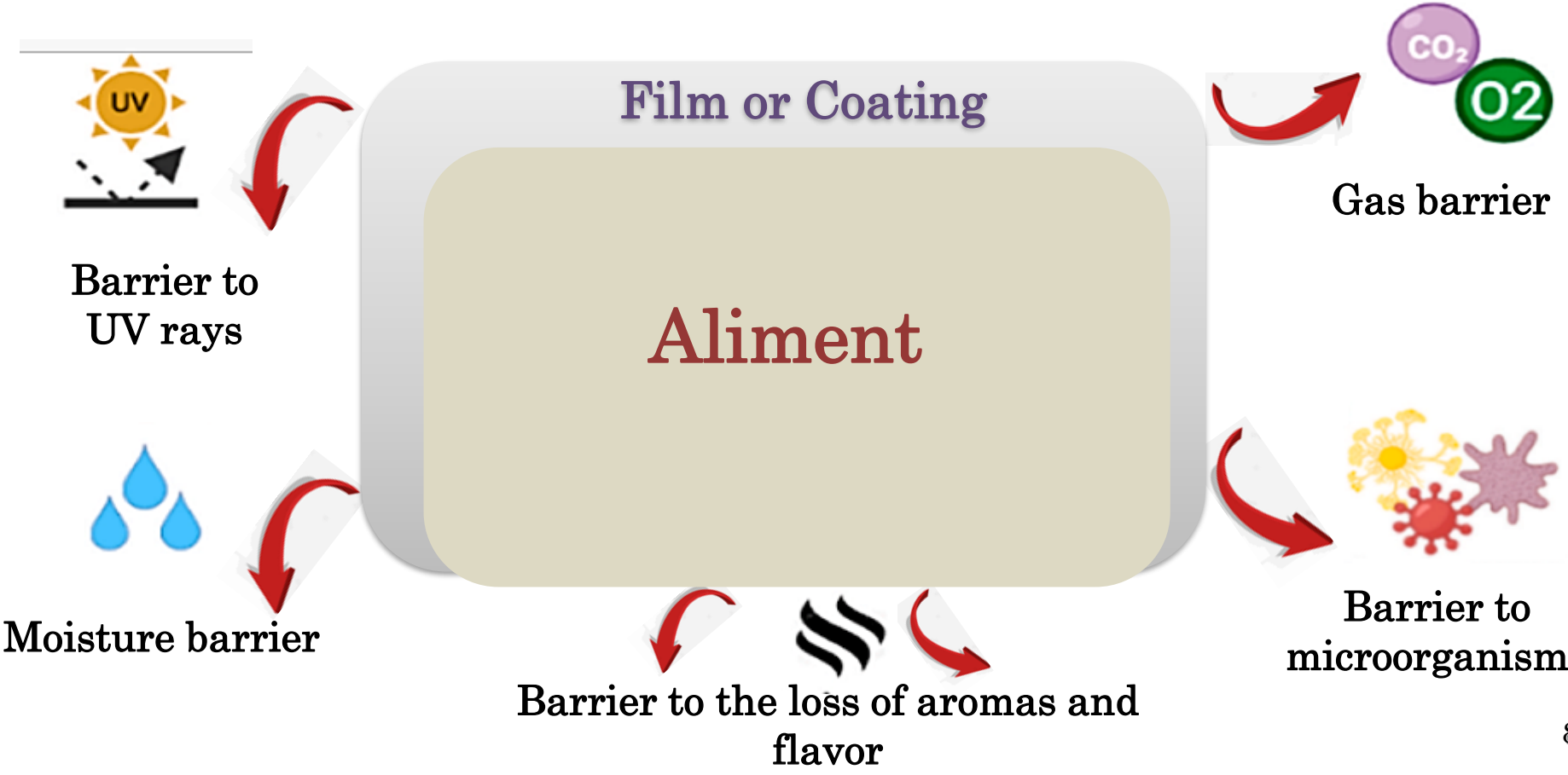


Thin layer of edible material deposited on a food as a coating or in the form of a film arranged around food constituents

General Introduction: Edible Packaging & Coatings

Gelatin coatings exhibit good mechanical, barrier and transparency properties

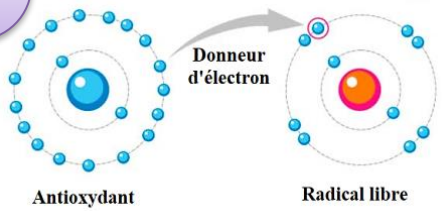
Selective functions of edible films and coatings



General Introduction: Edible Packaging & Coatings

What modifications to gelatin packaging/coatings could improve their functional properties?

- Cross-linking
- Mixture: Macromolecules ; Inorganic nanoparticles ; Bioactive molecules
  - Lipids ; Polysaccharides ; Proteins
  - ZnO ; TiO_2
  - Bioactive molecules; Plant extracts



Strengthen the barrier role: Antimicrobial/Antioxidant

I. Extraction of gelatin from fish skin: Effect of extraction process and drying

- Effect of two skin pre-treatment methods: Microwave or oven drying
- Effect of two gelatin drying methods: Lyophilization or Atomization

I. Extraction process and gelatin quality

Fish skin (100 g)

Oven drying at 105°C

Microwave drying

Untreated skin

Wash in cold water

Cutting

Alkaline treatment (0.05 M NaOH; 1:5 (m/v); 1 hr)

Washing with distilled water (pH ~7)

Acid treatment (pH=2) (18 to 24 h)

Heat treatment (50°C. 24 h)

Centrifugation (6000 rpm. 20 min)

Lyophilization

Atomisation

Freeze-dried gelatin

Atomized Gelatin

Several gelatin preparations

I. Extraction process and gelatin quality

- Several types of gelatin preparations: Different properties

- Raw material: Species
- Yield (5-10%)
- Physico-chemical and amino acid compositions
- Functional properties: Foaming, emulsifying and gelling properties
- Thermal and structural properties

I. Extraction process and gelatin quality

Example of Gelatin: Fresh Triggerfish skin/Freeze-dried gelatin

		Gelatin	
(g/100 g)	Triggerfish skin	Triggerfish	Bovine
Moisture	69.58±2.10	7.40±0.32	8.52±0.43
Proteins	26.13±3.30	89.94±0.25	90.22±0.68
Lipids	0.31±0.01	0.03±0.01	0.21±0.04
Ash	2.47±0.17	0.91±0.12	0.29±0.11

I. Extraction process and gelatin quality

Amino acids (AA)	AA number1000 residus	
	Triggerfish gelatin	Bovine gelatin
Hydroxyprboline (Hyp)	74	96
Acide aspartique (Asx)	59	44
Thréonine (Thr)	29	17
Serine (Ser)	40	29
Acide glutamique (Glx)	60	74
Proline (Pro)	102	123
Glycine (Gly)	289	341
Alanine (Ala)	113	115
Cystéine (Cys)	0	0
Valine (Val)	28	21
Méthionine (Met)	8	5
Isoleucine (Ile)	17	11
Leucine (Leu)	25	25
Tyrosine (Tyr)	7	1
Phénylalanine (Phe)	19	12
Hydroxylysine (Hyl)	9	7
Histidine (His)	11	5
Arginine (Arg)	78	48
Lysine (Lys)	32	26
Iminoacides (Pro + Hyp)	176	219
Total	1000	1000

I. Extraction process and gelatin quality

Gelatin	(%)	Emulsifying Activity Index (m^2/g)	Emulsion Stability (min)	Foaming Power (%)	Foaming Stability (%)
Fish skin	0.5	18.59 ± 0.15	50.20 ± 0.15	109.45 ± 0.72	79.21 ± 0.25
	1	21.44 ± 0.29	42.77 ± 0.71	123.04 ± 1.35	117.22 ± 0.54
	2	34.12 ± 0.99	40.90 ± 0.91	125.43 ± 0.96	110.21 ± 0.98
	3	40.51 ± 2.21	31.21 ± 2.84	131.26 ± 1.01	113.14 ± 1.21
	4	42.21 ± 0.98	24.89 ± 1.92	135.95 ± 0.98	115.47 ± 0.54
Bovine	0.5	19.22 ± 0.55	41.56 ± 0.74	110.00 ± 0.72	80.22 ± 0.71
	1	27.02 ± 2.50	39.77 ± 1.43	119.16 ± 1.31	100.94 ± 1.88
	2	34.00 ± 1.34	34.04 ± 1.73	130.77 ± 1.55	106.33 ± 1.44
	3	39.25 ± 0.65	30.32 ± 2.90	137.52 ± 1.15	114.07 ± 0.02
	4	43.86 ± 0.23	23.45 ± 5.69	141.38 ± 2.04	112.22 ± 0.22

I. Extraction process and gelatin quality

Physical properties	Gelatin	
	Fish	Bovine
Bloom degree (g)	210.01 ± 1.05	259.65 ± 2.78
Texture Profile Analysis		
Gel strength (g)	168.30 ± 3.75	872.00 ± 13.50
Springiness (mm)	12.82 ± 0.09	8.95 ± 0.15
Cohesiveness	0.52 ± 0.05	0.962 ± 0.02
Chewiness (N × mm)	883.45 ± 9.69	815.75 ± 17.67
Adhesive strength (g)	12.83 ± 0.78	15.80 ± 0.91
Color		
*L**	36.88 ± 0.21	81.20 ± 1.61
*a**	−1.56 ± 0.01	−0.24 ± 0.02
*b**	2.37 ± 0.2	19.21 ± 0.32

II. Production of biodegradable films

Improved physical and techno-functional properties:

- Enrichment with bioactive extracts (several plants)
- Combination: Gelatin/Agar
- Combination: Gelatin/TiO2

II. Elaboration of Gelatin/Moringa films

Gelatin 3%

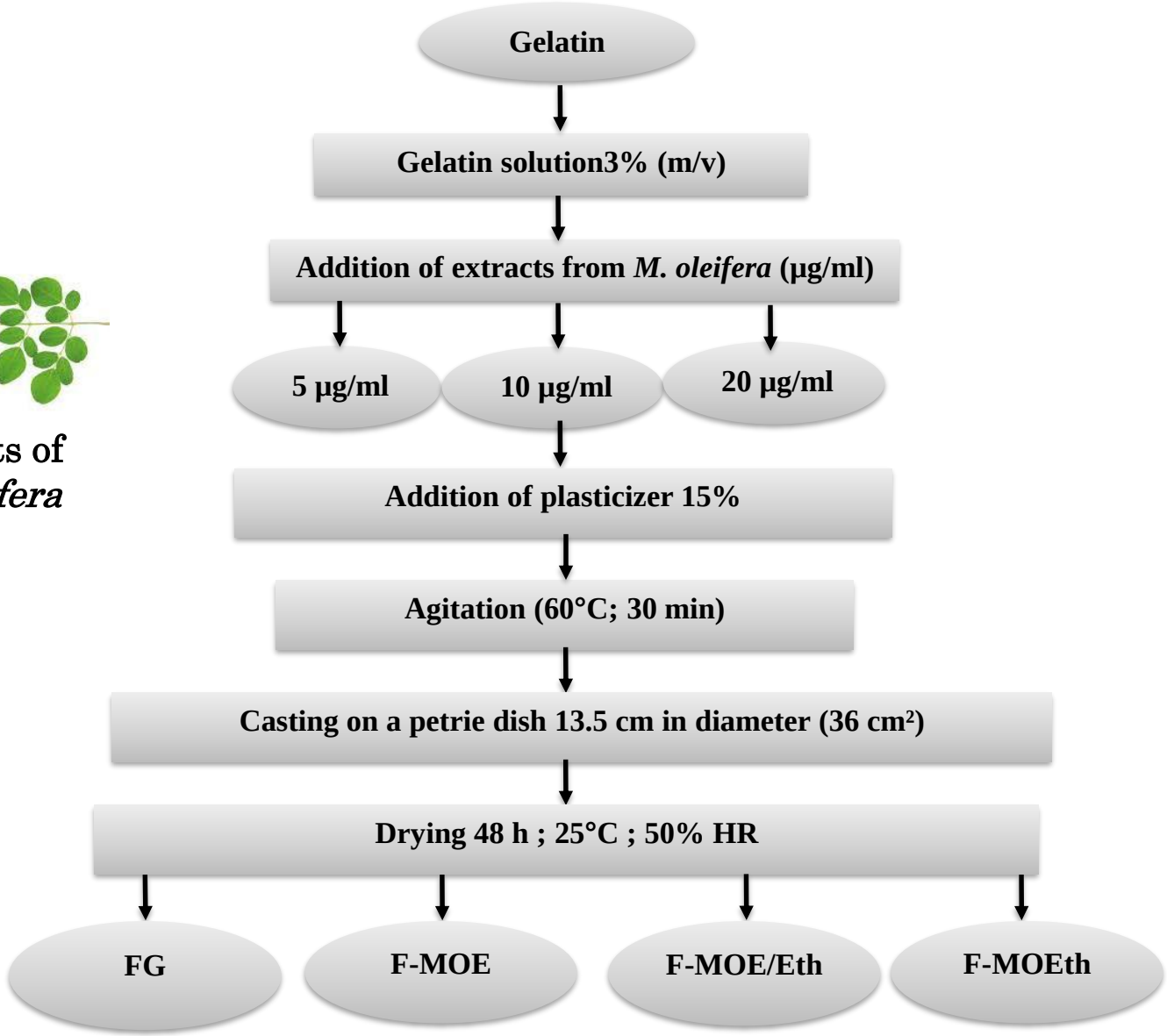
Glycerol (15%)

Extracts of *M. oleifera*

Casting

Drying

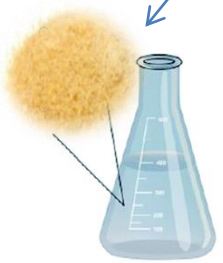
25°C. 24-48 h



Improvement of antioxidant and antimicrobial properties

II. Elaboration of Gelatin/Agar films

Glycerol (15%)



Gelatin 3%

+

Agar 3%
(different proportions)

Several films

Ultrasound treatment(10 min)

Casting

Drying (25°C. 24-48 h)

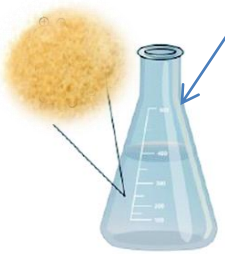
Physical characterization: Improvement of

- UV barrier properties
- Mechanical properties
- Hydrophobicity

II. Elaboration of Gelatin/TiO2 films

Gelatin 3%

Glycerol (15%)



+

E171: TiO2 (0.01-0.03%)

Ultrasound treatment (10 min)

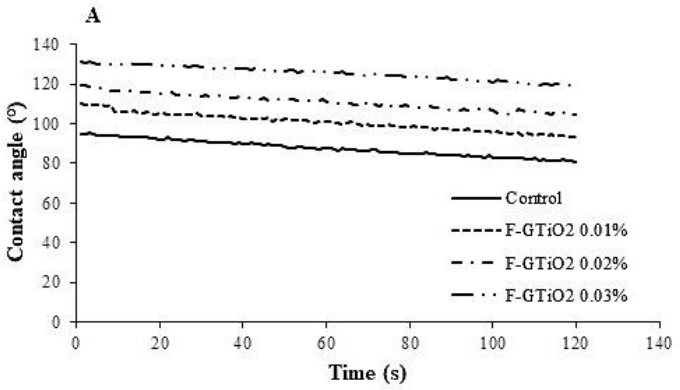
Casting

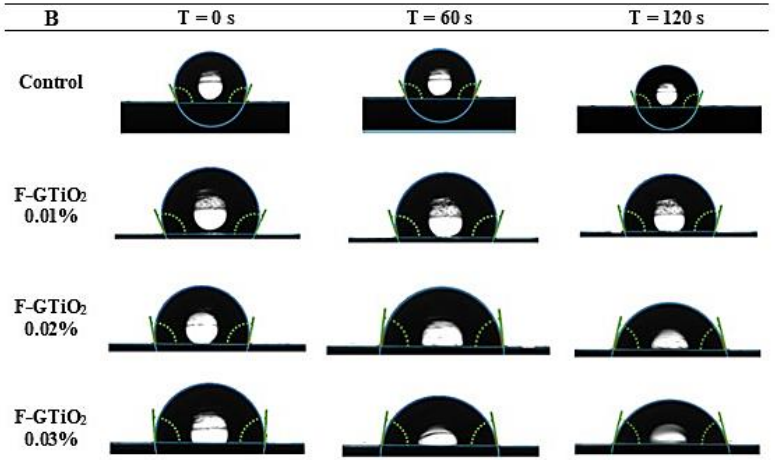
Drying (25°C. 24 à 48 h)

Several Gelatin/TiO2 films

Physical characterization:

- Improved UV barrier property
- Improved hydrophobicity



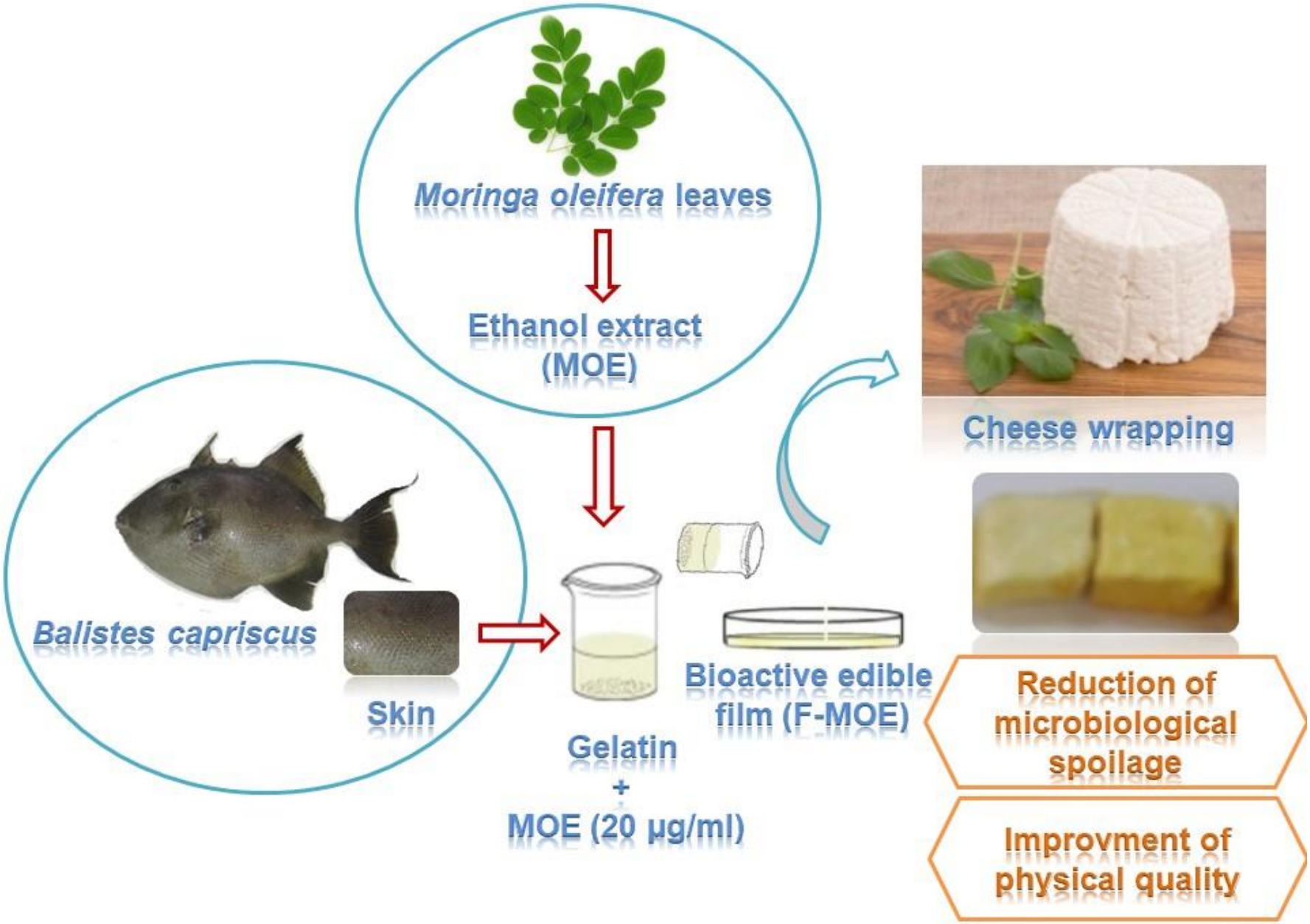


III. Food applications

1. Wrapping ricotta cheese with gelatin film enriched with *M. oleifera* extract

2. Coating of the fish fillet with gelatin enriched with *M. oleifera* extract

1. Ricotta Cheese Wrapping



1. Ricotta Cheese Wrapping

Film of gelatin	Extract enrichment (µg/ml)	Thickness (µm)	Tensile strength (MPa)	Elongation at break (%)	Water vapor permeability (× 10−10 g m−1 s−1 Pa−1)
FG	0	57.6 ± 1.5[a]	43.5 ± 0.1[a]	104 ± 0.1[a]	2.1 ± 0.1[a]
F-MOE	5	58.3 ± 1.6[a]	42.6 ± 1.5[a]	103 ± 2[a]	2.1 ± 0.2[a]
	10	57.6 ± 0.8[a]	43.8 ± 1.5[a]	108 ± 1[a]	2.1 ± 0.3[a]
	20	57.0 ± 1.8[a]	44.9 ± 1.5[a]	106 ± 1[a]	2.1 ± 0.1[a]
F-MOE/Eth	5	58.6 ± 1.8[a]	44.8 ± 1.1[a]	103 ± 1.8[a]	1.89 ± 0.16[a]
	10	56.2 ± 1.4[a]	43.6 ± 1.2[a]	104 ± 1.5[a]	1.78 ± 0.13[b]
	20	57.3 ± 0.5[a]	44.6 ± 0.9[a]	107 ± 1.9[a]	1.76 ± 0.18[b]
F-MOEth	5	57.1 ± 0.11[a]	42.9 ± 0.94[a]	108 ± 1.6[a]	1.59 ± 0.10[c]
	10	59 ± 1.75[a]	42.2 ± 1.35[a]	107 ± 1.8[a]	1.50 ± 0.2[c]
	20	57.5 ± 1.78[a]	43.7 ± 1.88[a]	107 ± 1.2[a]	1.35 ± 0.2[c]

Gelatin/Phenolic compounds interaction: Denser film

1. Ricotta Cheese Wrapping

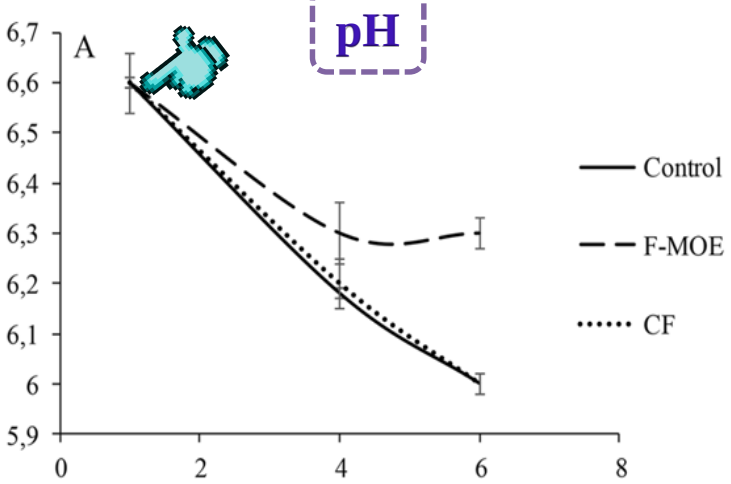
Gelatin film	Extract enrichment (µg/ml)	*L**	*a**	*b**	ΔE	*C**
FG	0	90.6 ± 0.26^{a}	-0.36 ± 0.01^{a}	0.35 ± 0.03^{a}	-	-
F-MOE	5	90.1 ± 0.19^{a}	-0.42 ± 0.13^{a}	0.75 ± 0.15^{b}	0.6 ± 0.1^{a}	0.40 ± 0.01^{a}
	10	90.0 ± 0.14^{a}	-0.58 ± 0.12^{a}	0.88 ± 0.12^{b}	0.8 ± 0.01^{b}	0.57 ± 0.02^{a}
	20	89.9 ± 0.15^{a}	-0.8 ± 0.1^{b}	0.9 ± 0.1^{b}	0.96 ± 0.12^{b}	0.7 ± 0.1^{a}
F-MOE/Eth	5	89.4 ± 0.17^{a}	-1.1 ± 0.1^{b}	0.97 ± 0.16^{b}	1.45 ± 0.14^{c}	0.98 ± 0.10^{a}
	10	89.2 ± 0.05^{a}	-1.4 ± 0.1^{c}	1.12 ± 0.11^{b}	1.93 ± 0.11^{d}	1.31 ± 0.15^{b}
	20	89.1 ± 0.04^{b}	-1.55 ± 0.04^{c}	1.22 ± 0.10^{b}	2.08 ± 0.10^{d}	1.47 ± 0.22^{b}
F-MOEth	5	88.9 ± 0.48^{b}	-1.65 ± 0.10^{c}	1.55 ± 0.21^{b}	2.46 ± 0.21^{e}	1.76 ± 0.19^{b}
	10	88.8 ± 0.10^{b}	-1.77 ± 0.12^{d}	1.86 ± 0.21^{c}	2.75 ± 0.24^{e}	2.06 ± 0.52^{c}
	20	88.1 ± 0.12^{b}	-1.89 ± 0.18^{d}	2.01 ± 0.12^{c}	3.34 ± 0.17^{e}	2.25 ± 0.14^{c}

Increase in b*. C* and ΔE

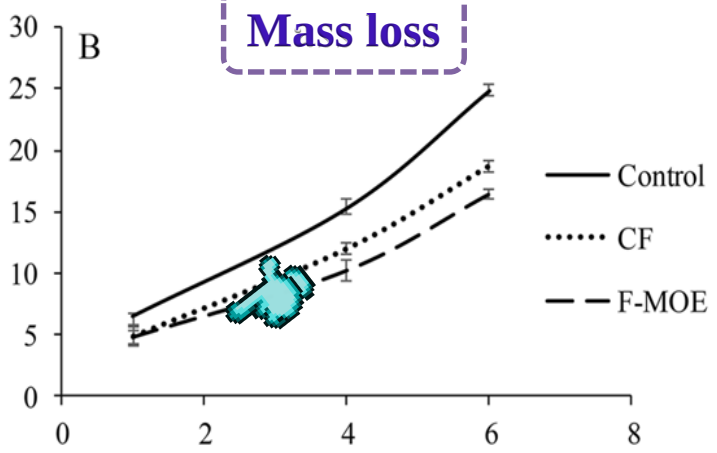
Richness in pigments and phenolic compounds: Color change

1. Ricotta Cheese Wrapping

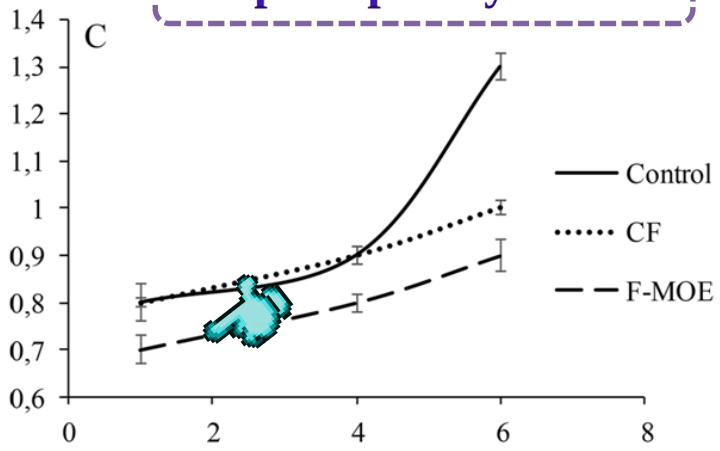
pH



Mass loss



Lipidic peroxydation



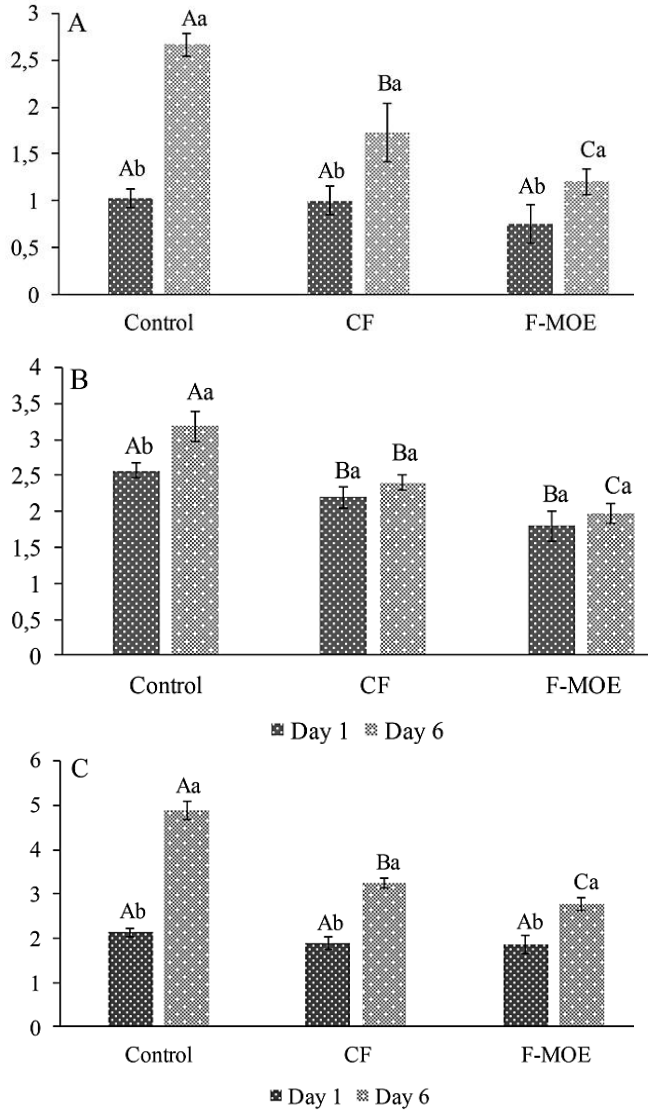
Better conservation of ricotta

1. Ricotta Cheese Wrapping

Paramètres	Storage time (days)	Ricotta		
		Control	FG	F-MOEth
Gel strength (g)	1	140 ± 1aA	144 ± 1aA	135 ± 1aB
	6	255 ± 1bA	205 ± 1bB	172 ± 1bC
Cohesiveness	1	0.4 ± 0.04aB	0.5 ± 0.1aA	0.3 ± 0.1aB
	6	0.2 ± 0.03bA	0.2 ± 0.02bA	0.3 ± 0.04aA
Springiness (mm)	1	2.8 ± 0.1aB	3.3 ± 0.4aA	2.5 ± 0.2aB
	6	0.9 ± 0.01bB	1.2 ± 0.2bA	1.5 ± 0.1bA
Chewiness (N × m)	1	1.6 ± 0.2aA	1.7 ± 0.4aA	1.3 ± 0.3aA
	6	0.8 ± 0.1bB	1.3 ± 0.3aA	1.1 ± 0.2aA
*L**	1	89 ± 1aB	90 ± 0.3aA	90.2 ± 0.3aA
	6	85.1 ± 0.4bB	85.6 ± 0.3bB	88.2 ± 0.2bA
*b**	1	9.8 ± 0.1aA	9.6 ± 0.2aA	9.5 ± 0.3aA
	6	11.9 ± 0.2bA	11.8 ± 0.2bA	10.1 ± 0.2bB

Better ricotta texture

1. Ricotta Cheese Wrapping



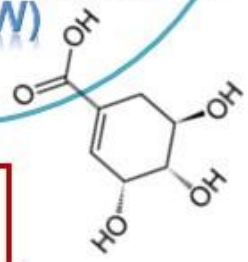
Better microbiological quality of ricotta

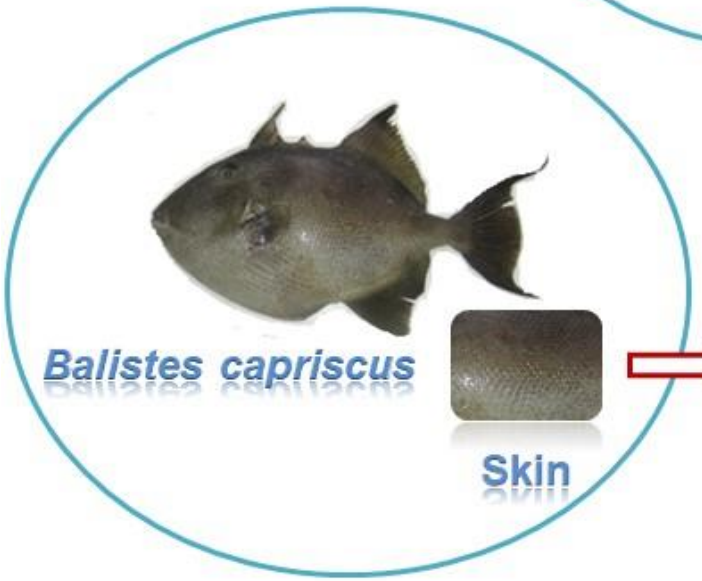
Evolution of psychrophilic bacteria (A). mesophilic bacteria (B). and yeasts and molds (C) (log CFU/g cheese)

2. Fish fillet coating

Moringa oleifera leaves

Ethanol/Water extract (MOE/W)





Balistes capriscus

Skin

Gelatin + MOE/W (20 µg/ml)

Dogfish filet coating

Reduction of microbiologic al spoilage

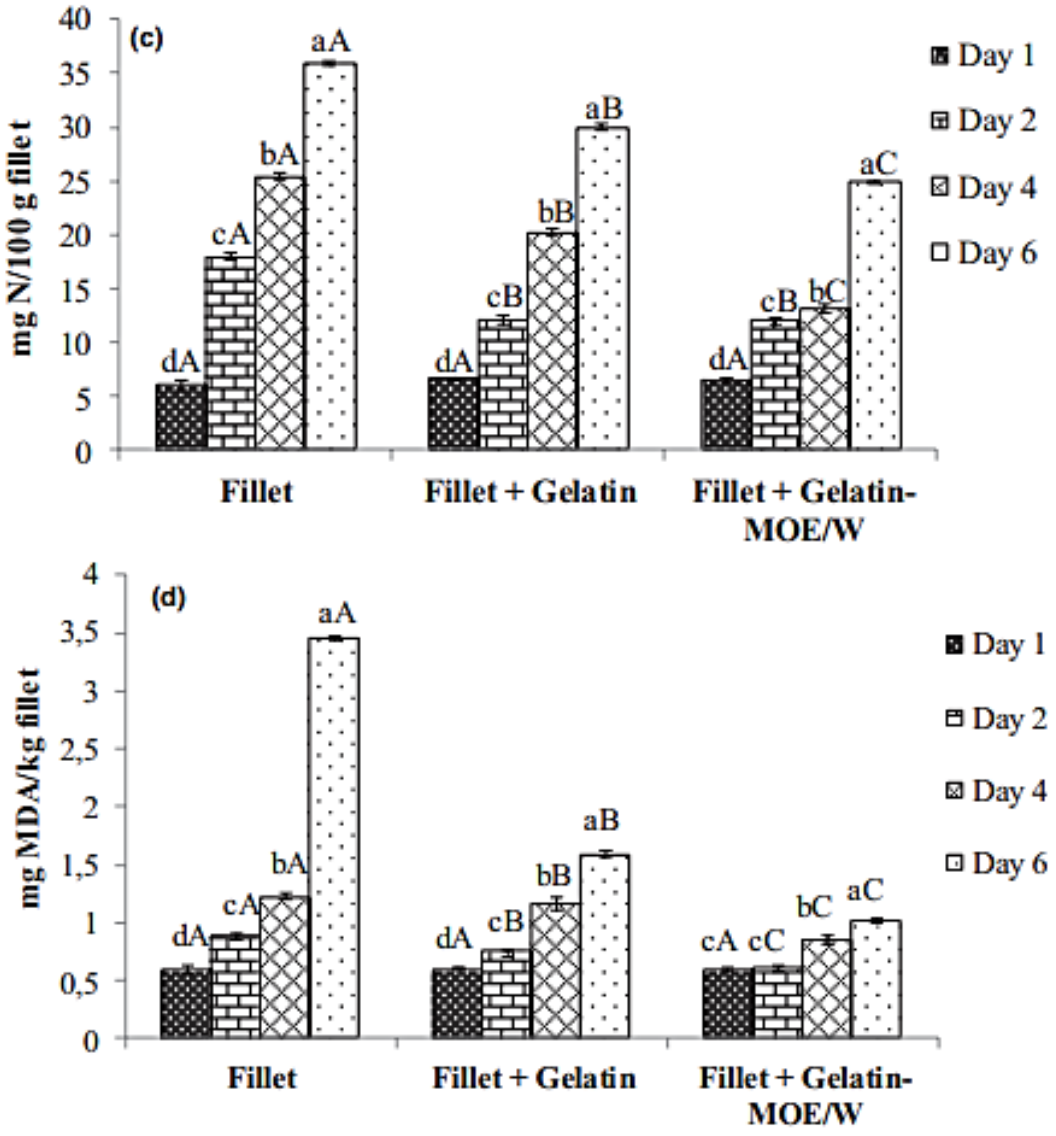
Improvment of sensory and texture properties

2. Fish fillet coating

Paramètres	Days	Control	Fillet + Gelatin	Fillet + Gelatin + 20 µg/ml MOE/Eth
pH	1	6.16 ± 0.03^{aA}	6.16 ± 0.03^{aA}	6.16 ± 0.03^{aA}
	2	6.02 ± 0.07^{aA}	6.10 ± 0.04^{aA}	6.12 ± 0.16^{aA}
	4	5.65 ± 0.03^{bB}	6.01 ± 0.13^{aA}	6.02 ± 0.13^{aA}
	6	5.26 ± 0.11^{cB}	5.84 ± 0.10^{aA}	5.74 ± 0.03^{aA}
Mass loss (%)	1	14.25 ± 0.49^{cA}	10.75 ± 0.45^{cB}	9.58 ± 0.16^{cB}
	2	16.22 ± 0.28^{cA}	11.24 ± 0.20^{cB}	10.04 ± 0.41^{cC}
	4	33.46 ± 0.28^{bA}	23.84 ± 0.40^{bB}	21.63 ± 0.31^{bC}
	6	45.19 ± 0.15^{aA}	35.08 ± 0.37^{aB}	33.47 ± 0.27^{aC}

Water exudation

2. Fish fillet coating



Total Volatile Basic Nitrogen

Lipidic Peroxydation

2. Fish fillet coating

Parameters	Day	Fillet	Fillet + gelatin	Fillet+gelatin-MOE/Eth
Strength (g)	1	175.56 ± 0.25^{bA}	189.23 ± 0.12^{bB}	182.42 ± 1.71^{bC}
	6	256.48 ± 1.25^{aA}	215.25 ± 0.79^{aB}	204.56 ± 1.82^{aC}
Cohesiveness	1	0.53 ± 0.12^{aA}	0.42 ± 0.03^{aA}	0.45 ± 0.06^{aA}
	6	0.32 ± 0.05^{bA}	0.34 ± 0.06^{aA}	0.39 ± 0.02^{aA}
Springiness (mm)	1	2.96 ± 0.05^{aA}	3.01 ± 0.45^{aA}	3.11 ± 0.75^{aA}
	6	1.89 ± 0.15^{bB}	2.24 ± 0.62^{aA}	2.86 ± 0.56^{aA}
Chewiness (N × mm)	1	1.53 ± 0.36^{aA}	1.45 ± 0.25^{aA}	1.51 ± 0.52^{aA}
	6	0.75 ± 0.11^{bB}	1.11 ± 0.14^{aA}	1.42 ± 0.07^{aA}

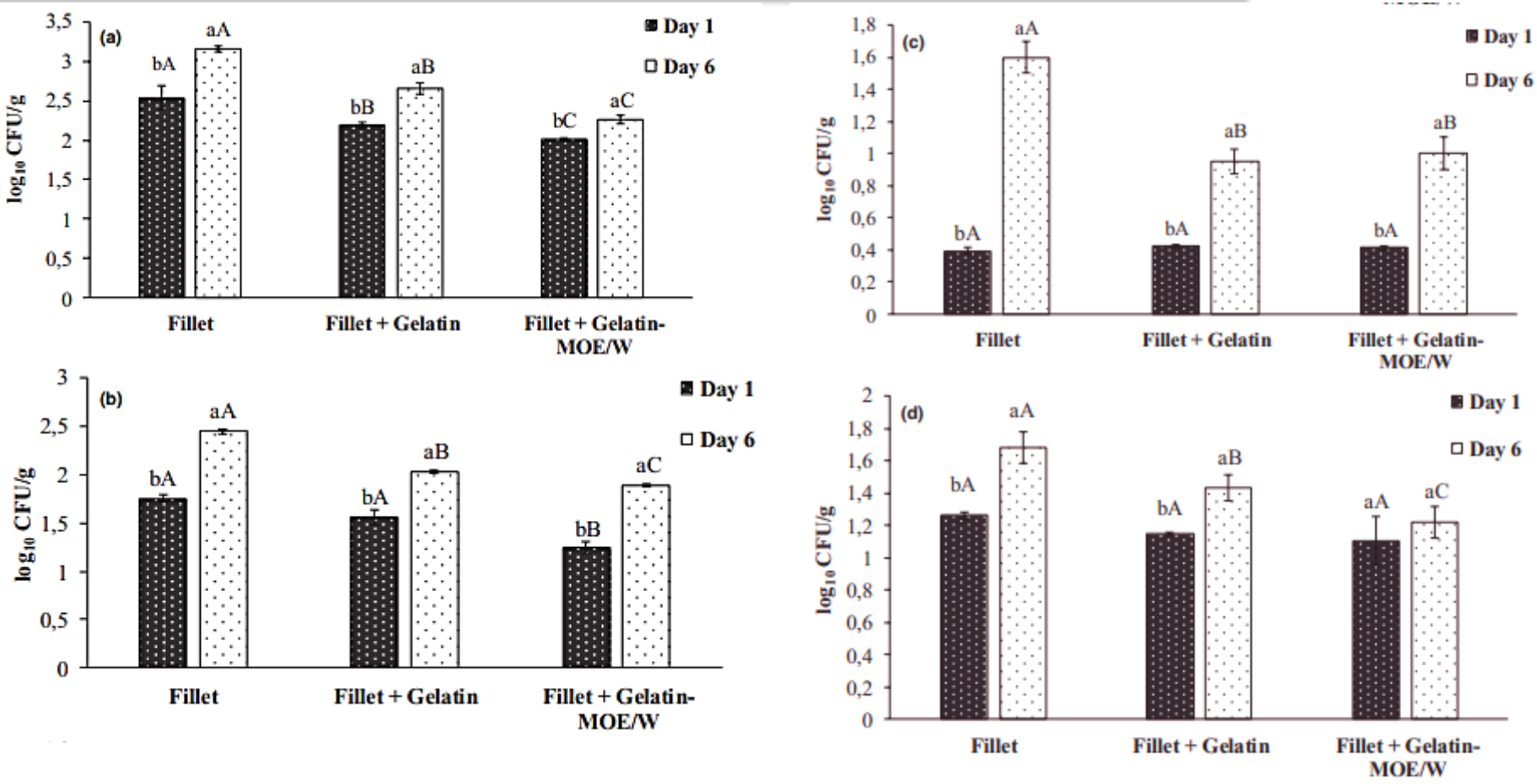
↘ Strength

2. Fish fillet coating

	Storage period (days)					
	1			6		
	Fillet	Fillet + gelatin	Fillet + gelatin-MOE/Eth	Fillet	Fillet + gelatin	Fillet + gelatin-MOE/Eth
L^*	61.73 ± 0.15^{bA}	61.59 ± 0.59^{bA}	61.02 ± 0.47^{aA}	63.98 ± 0.37^{aA}	62.91 ± 0.44^{aA}	61.78 ± 0.60^{aB}
a^*	2.58 ± 0.23^{aA}	2.89 ± 0.24^{aA}	2.90 ± 0.14^{aA}	1.02 ± 0.03^{bB}	2.48 ± 0.44^{aA}	2.58 ± 1.08^{aA}
b^*	10.77 ± 0.02^{bA}	10.25 ± 0.12^{aA}	10.12 ± 0.48^{aA}	12.75 ± 0.24^{aA}	11.01 ± 0.65^{aA}	10.78 ± 0.53^{aA}
c^*	13.35 ± 0.23^{aA}	13.14 ± 0.14^{aA}	13.02 ± 0.22^{aA}	13.77 ± 0.10^{aA}	13.49 ± 0.72^{aA}	13.36 ± 0.44^{aA}
ΔE	–	0.62 ± 0.13^{bB}	1.01 ± 0.09^{bA}	3.37 ± 0.13^{A}	1.20 ± 0.11^{aB}	0.05 ± 0.13^{aC}

Stable Color

2. Fish fillet coating



Changes in (a) mesophilic, (b) psychrophilic, (c) lactic acid, and (d) H2S-producing bacteria of coated fish samples during storage.

Improved microbiological stability

Conclusions

Extraction of gelatin


- ✓ Skin Pre-treatment
- ✓ Drying method of gelatin

Influence la Qualité de Gélatine

- AA Composition
- Structural properties
- Functional properties

Gelatin films enriched with Agar/TiO2

Improvement of :

- Hydrophobic character
- Mechanical properties
- Barrier properties to UV rays
- Antioxidant and antimicrobial properties

Gelatin films enriched with bioactive extract

Moringa extract 

➡ **Better Antioxidant Activities**

DPPH•	Fe^{3+}	Fe^{2+}	β-carotène

➡ **Interesting antibacterial activities**

Food applications

Gelatin 
+
20 µg/ml Moringa extract

Coating of fish/cheese fillets

- **Better conservation**
- **Better sensory quality**

Outlook

- **Gelatin extraction process on an industrial scale**
- **Other applications of gelatin: Biodegradable dressings, etc.**
- **Biodegradable materials: Chitosan. etc.**

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https://doi.org/10.1007/s11694-021-00818-9

ORIGINAL PAPER

The effects of agar addition and ultrasound treatment on thermomechanical and physical properties of smooth hound (*Mustellus mustellus*) skin gelatin film

Ali Salem[1,2] · Ola Abdelhedi[1] · Hela Kchaou[1] · Nahed Fakhfakh[1,2] · Moncef Nasri[1] · Mourad Jridi[1,3] · Nacim Zouari[1,2] · Frederic Debeaufort[4,5]

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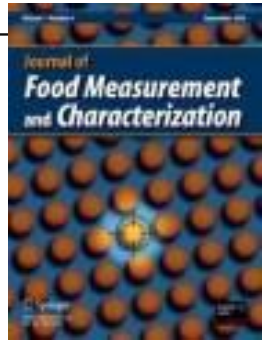

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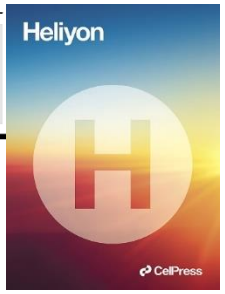

Research article

Development and characterization of fish gelatin-based biodegradable film enriched with *Lepidium sativum* extract as active packaging for cheese preservation

Ali Salem [a,b], Mourad Jridi [a,c], Ola Abdelhedi [a], Nahed Fakhfakh [a,b], Moncef Nasri [a], Frederic Debeaufort [d,e], Nacim Zouari [a,b,*]

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International Journal of Biological Macromolecules

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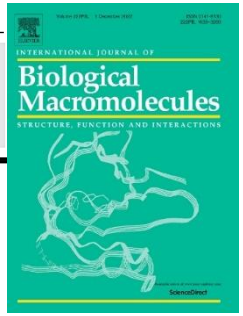

Microstructure and characteristic properties of dogfish skin gelatin gels prepared by freeze/spray-drying methods

Ali Salem [a,b], Nahed Fakhfakh [a,b], Mourad Jridi [a,c,*], Ola Abdelhedi [a], Moncef Nasri [a], Frédéric Debeaufort [d,e], Nacim Zouari [a,b]

Waste and Biomass Valorization
https://doi.org/10.1007/s12649-022-01911-w

ORIGINAL PAPER

Smooth Hound Skin Gelatin-TiO_2 Films: Physicochemical and Structural Characterization

Ali Salem[1,2] · Ola Abdelhedi[1] · Haifa Sebii[3] · Nahed Fakhfakh[1,2] · Mourad Jridi[1,4] · Hela Kchaou[1] · Moncef Nasri[1] · Frederic Debeaufort[5,6] · Nacim Zouari[1,2]

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ORIGINAL PAPER

Edible films from triggerfish gelatin and *Moringa oleifera* extract: Physical properties and application in wrapping ricotta cheese

Maram Mezhoudi[1,2] · Ali Salem[1] · Ola Abdelhedi[1] · Nahed Fakhfakh[1,2] · Frederic Debeaufort[4,5] · Mourad Jridi[1,3] · Nacim Zouari[1,2]

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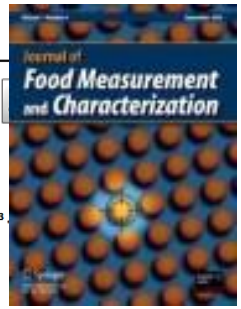

ORIGINAL ARTICLE

Food Science & Nutrition WILEY

Development of active edible coatings based on fish gelatin enriched with *Moringa oleifera* extract: Application in fish (*Mustelus mustelus*) fillet preservation

Maram Mezhoudi[1,2] | Ali Salem[1,2] | Ola Abdelhedi[1] | Nahed Fakhfakh[1,2] | Mahmoud Mabrouk[3] | Touhami Khorchani[4] | Frederic Debeaufort[5,6] | Mourad Jridi[1,7] | Nacim Zouari[1,2]

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Thank you for your attention