Circular Bioeconomy

Application to the Agri-Food Sector

Professorial Inaugural Lecture

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Presentation outline

- Contradictions in the food, health and environment nexus
- Circular bioeconomy: Key concepts
- Understanding agri-food waste: Sources and nature
- Agri-food waste minimisation and exploitation options
- Own contribution to agri-food waste prevention and valorisation research
- Future research

Contradictions in the food, health and environment nexus

The difference between what we are doing and what we are capable of doing would solve most of the world's problems - **Mahatma Gadhi**

- 1.3 b tons of food lost annually (FAO, 2011)
- Food production accounts for about 1/4 of GHGs (WB 2021) & > 8% of GHGs caused by food waste (FAO, 2015)

Agri-food waste	**Challenges**
Pollution	Malnutrition
Nutrients	NCDs
Nutraceuticals	Declining agro-ecologies
Industrial materials	Low returns in agri-food sector

- ≈ 811 million face hunger (FAO, 2022)
- ≈ 45% of deaths in <5s associated with malnutrition (WHO, 2021)
- NCDs responsible for ≈ 71% of deaths (WHO, 2021)

Circular bioeconomy: Key concepts

Circular economy

"Often when you think you're at the end of something, you're at the beginning of something else." –
Fred Rogers

Giving waste new life

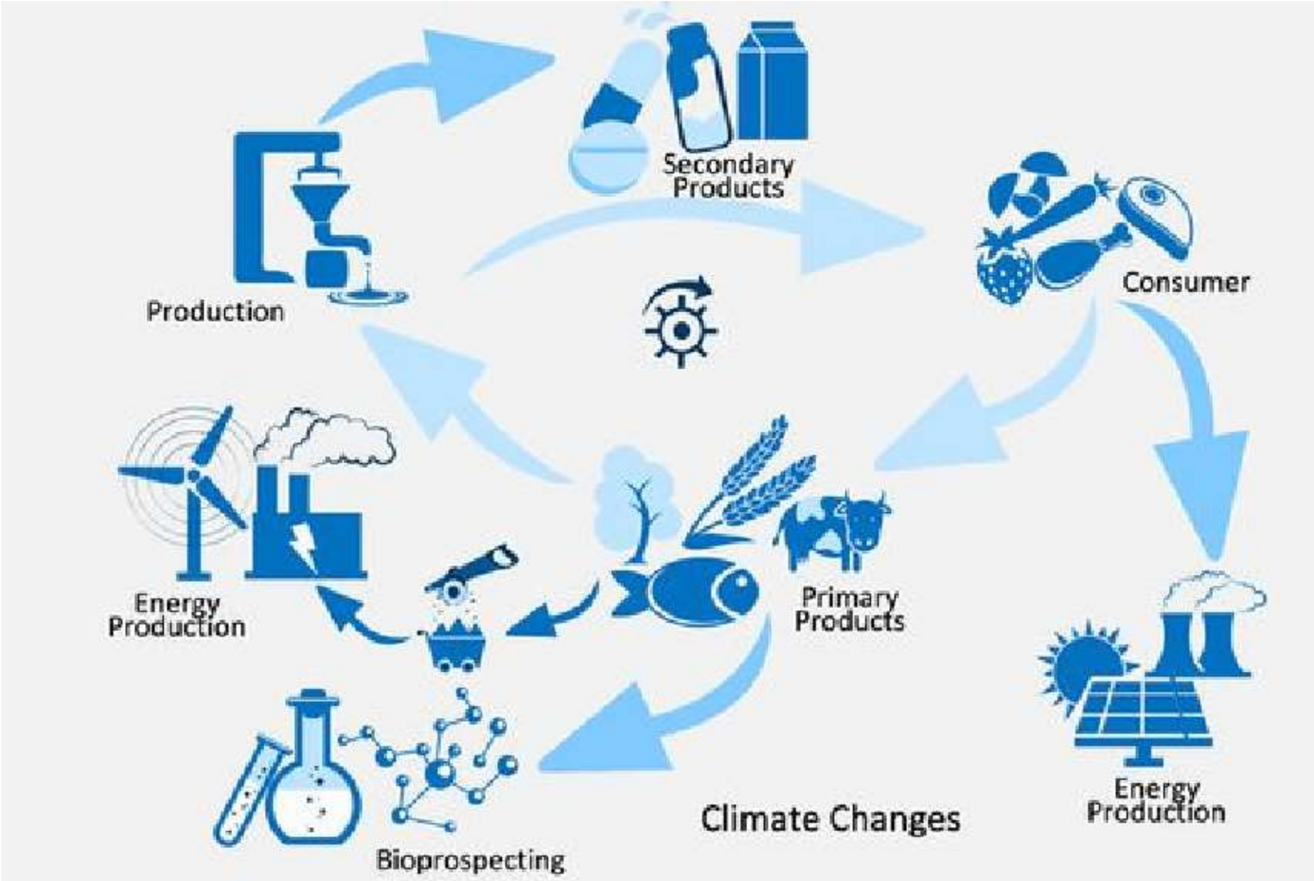
Maximise waste prevention, minimise resource inputs, recycle, reuse, regenerate the environment while delivering social benefits

Representation of linear and circular economy

Source: Harrow (2020) - https://www.mvis-indices.com/mvis-onehundred/a-circular-economy-designing-out-waste

Circular bioeconomy

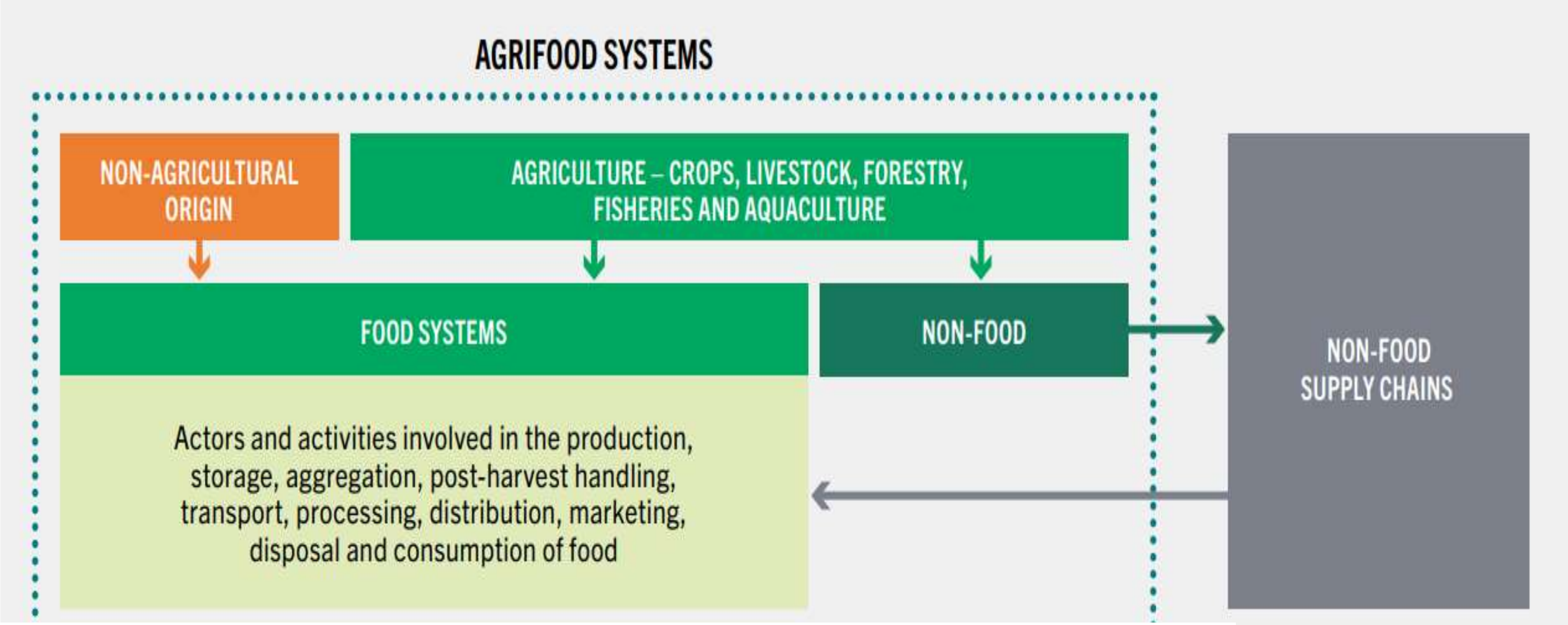
- Convergence of circular economy and bioeconomy (sustainable exploitation of bioresources and bioprocesses)
- Entails reuse of as much biowaste as possible, resulting in multiple value added products from a given volume of harvested biomass
- Contributes to sustainability



https://www.pinterest.com/pin/421157002662746198/

Understanding agri-food waste - Sources and nature

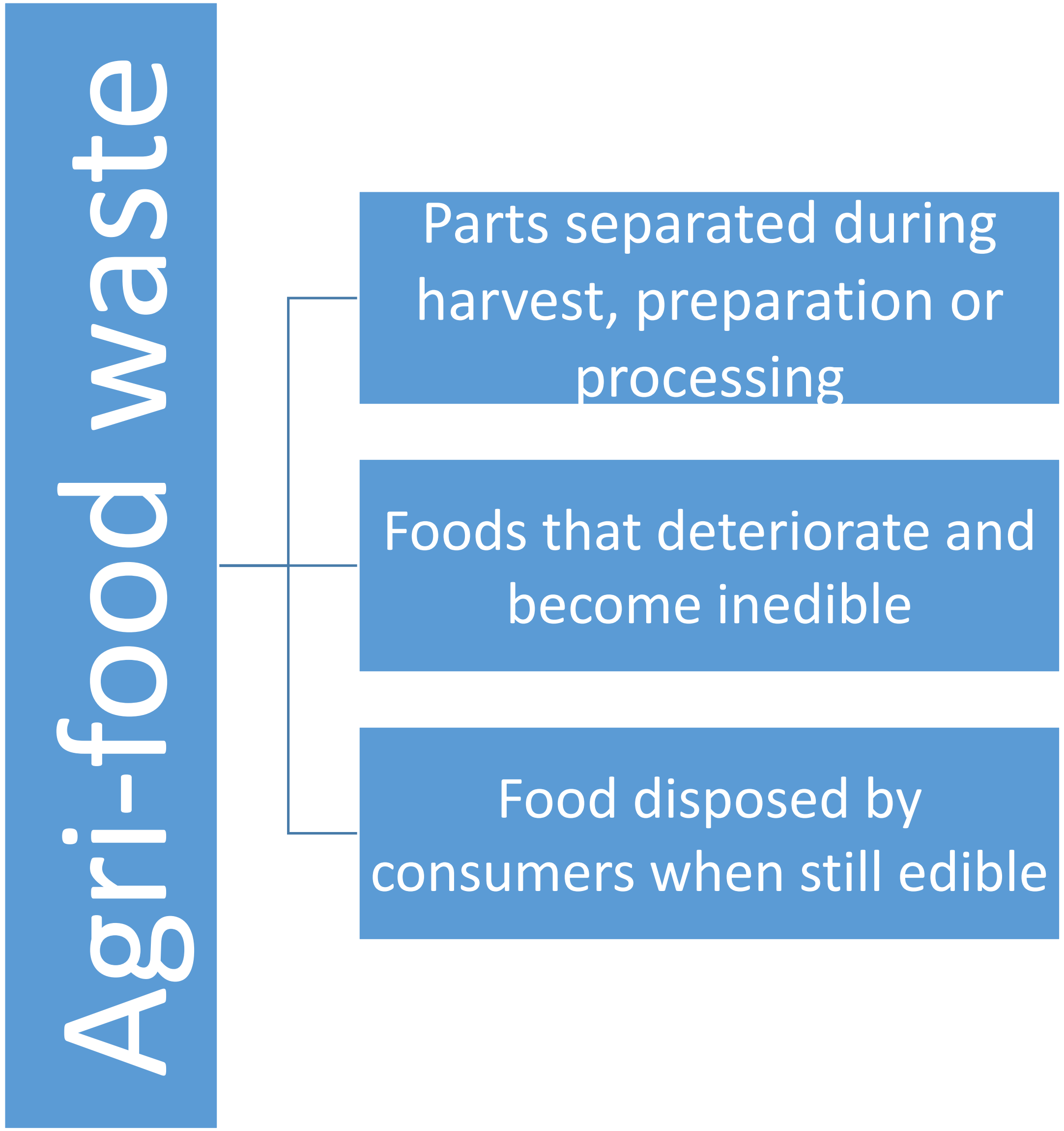
Scope of agri-food sector



Source: https://www.fao.org/3/cb4476en/cb4476en.pdf

Agri-food sector covers primary production of **food and non-food agricultural products**, as well as food storage, aggregation, post-harvest handling, transportation, processing, distribution, marketing, disposal and consumption

Sources of agri-food waste



Agri-food waste arises at different stages of agri-food value chains

Waste of plant origin

- Waste of plant origin contain nutrients and a wide diversity of non-nutrient compounds (phytochemicals), that are associated with health benefits

- Waste parts of plant-based foods like peels and bran contain higher levels of phytochemicals than the edible parts (Skendi et al, 2020)

Reported health benefits of selected phytochemicals

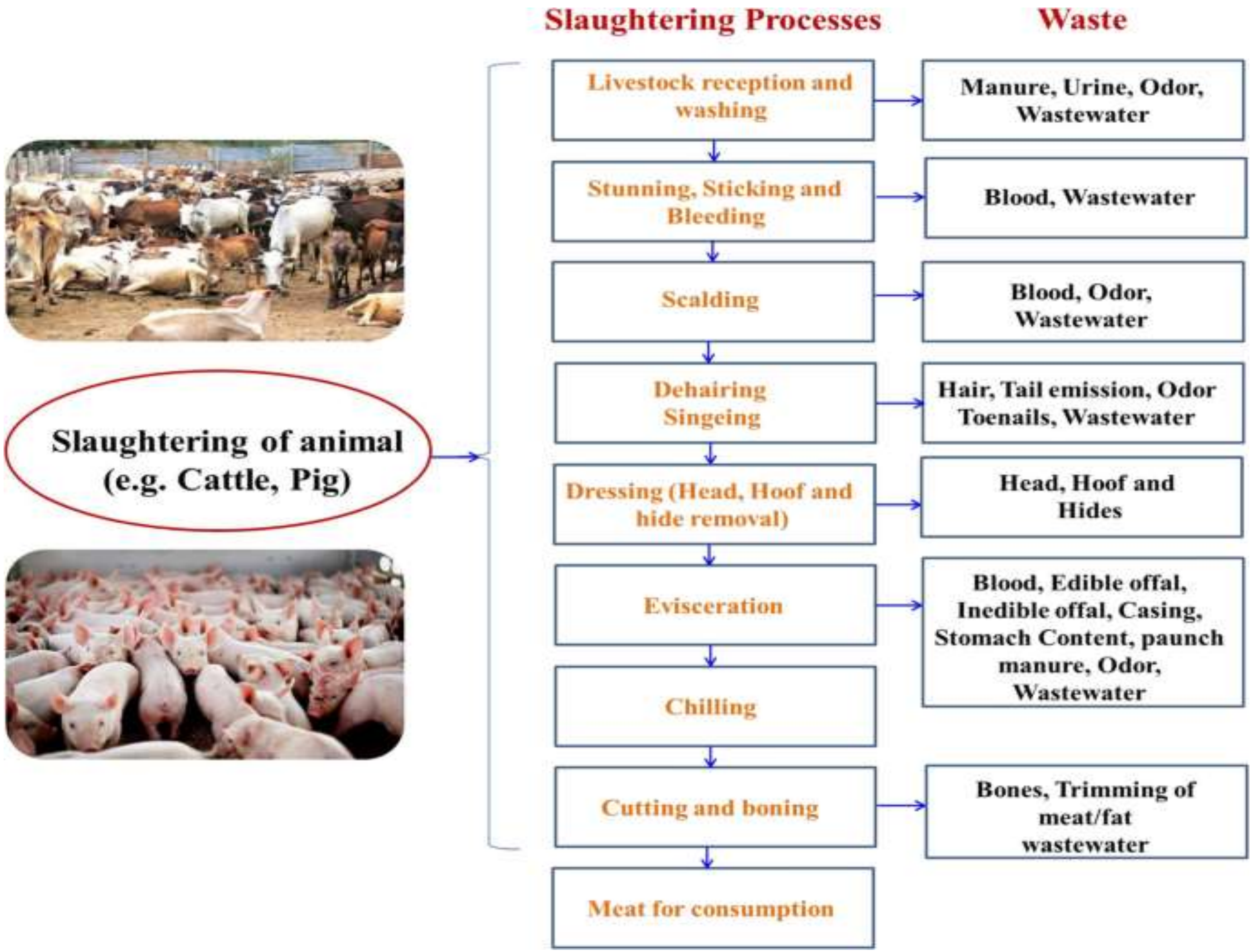
Phytochemical	Main food sources	Attributed health benefit
Non-starch polysaccharides	Fruits, vegetables and whole cereals	Gut health, anticancer, antihypertensive, hypoglycemic, hypochloresterol
Phenolics	Fruits, vegetables and whole cereals	Antioxidants, anticancer, antihypertensive, biopreservative
Carotenoids	Coloured fruits and vegetables	Antihypertensive, anticancer, anti-obesity, anti-inflamatory, supports vision
Phytosterols	Cereals and legumes	Prevention of colon cancer and hypochloresterol effect
Phytic acid	Cereals bran	Antioxidant, anti-inflammatory, anticancer, prevention of kidney stone formation, antihypertensive
Anthocyanin	Bran from dark coloured cereals	Antioxidant, anti-inflammatory, anticancer and hypoglycemic
Lignan	Bran for most cereals	Antioxidant
Saponins	Soybeans, pulses and some vegetables	Anticancer, serum glucose and lipids regulation, inhibition of dental caries and platelet aggregation, antidote against acute poisoning and treatment of hypercalciuria
Tocols	Germ from cereals	Antioxidant and vitamin E activity

Source: Fàrcas et al. (2020); Langi et al. (2018); Liu (2013); Campos-Vega and Oomah (2013); Ragaee et al. (2013); Lui (2007); Shi et al. (2004)

Valuable components of waste from selected food crops

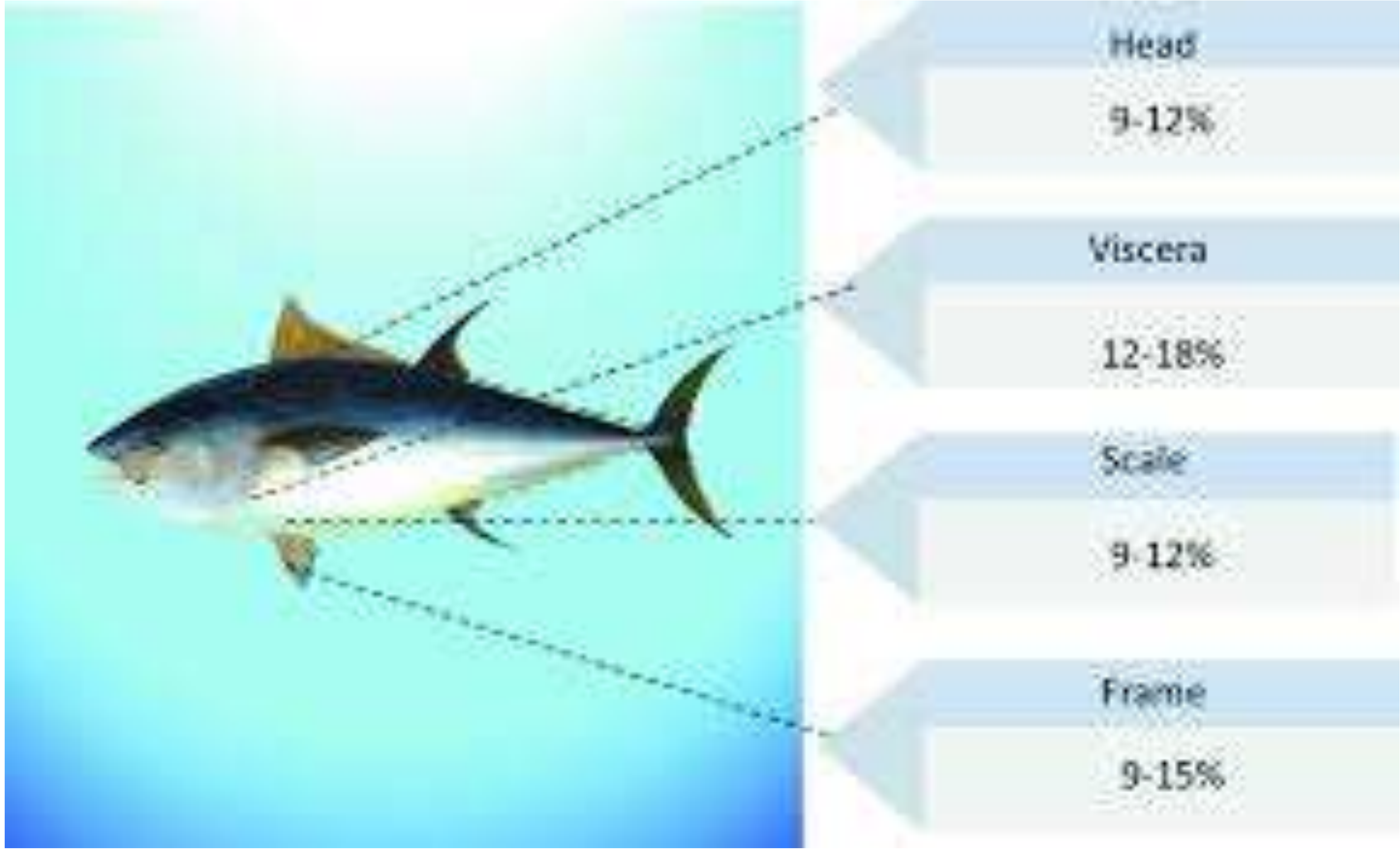
Agri-food waste	%	Valuable components	References
Citrus peels and seeds	55-60	Pectin, essences, ethanol, D-limonene, limonoids and flavonoids	Ben-Othman et al., 2020; Gavahian et al., 2018; Faustino, 2019
Mango peels and kernels	35-60	Fibre, vitamins, carotenoids and polyphenols, kernal fat and pectin	Ajila et al., 2007; Scheiber et al., 2001; Puravankara et al., 2000
Passion fruit seeds and rind	75	Pectin, linoleic acid	Maurya et al., 2015
Banana peels	30	Phenolics, beta-carotenoids, anthocyanins, fiber, amino acids, polyunsaturated fatty acids, vitamins, flavonoids and potassium.	Ben-Othman, 2020; Kanazawa and Sakabira, 2000; Subagio, 1996
Avocado seeds and peels	35	Carbohydrates, proteins, lipids, fibres, minerals, phenolics, flavonoids, fatty acids	Jaspin Stephen and Mahendran, 2022 RadhakrishnanBen-Othman, 2020
Tamarind seeds	36-70	Phenolics and flavanoids	Andabati and Muyonga, 2014; Fischer, 2010; Rao and Mathew, 2012
Jackfruit rind, perigones and seeds	55	Phenolics, lignans, flavanoids, saponins, starch, proteins, pectin and cellulose	Nansereko and Muyonga, 2021
Maize bran, germ		Starch, protein, fat, fiber, minerals, vitamins and a wide range of phytochemicals	Fărcaș et al. , 2021, Liu, 2007

Waste from animal-based foods



Source: Mozhiarasi and Natarajan (2022); https://doi.org/10.1007/s13399-022-02352-0

Waste from fish preparation

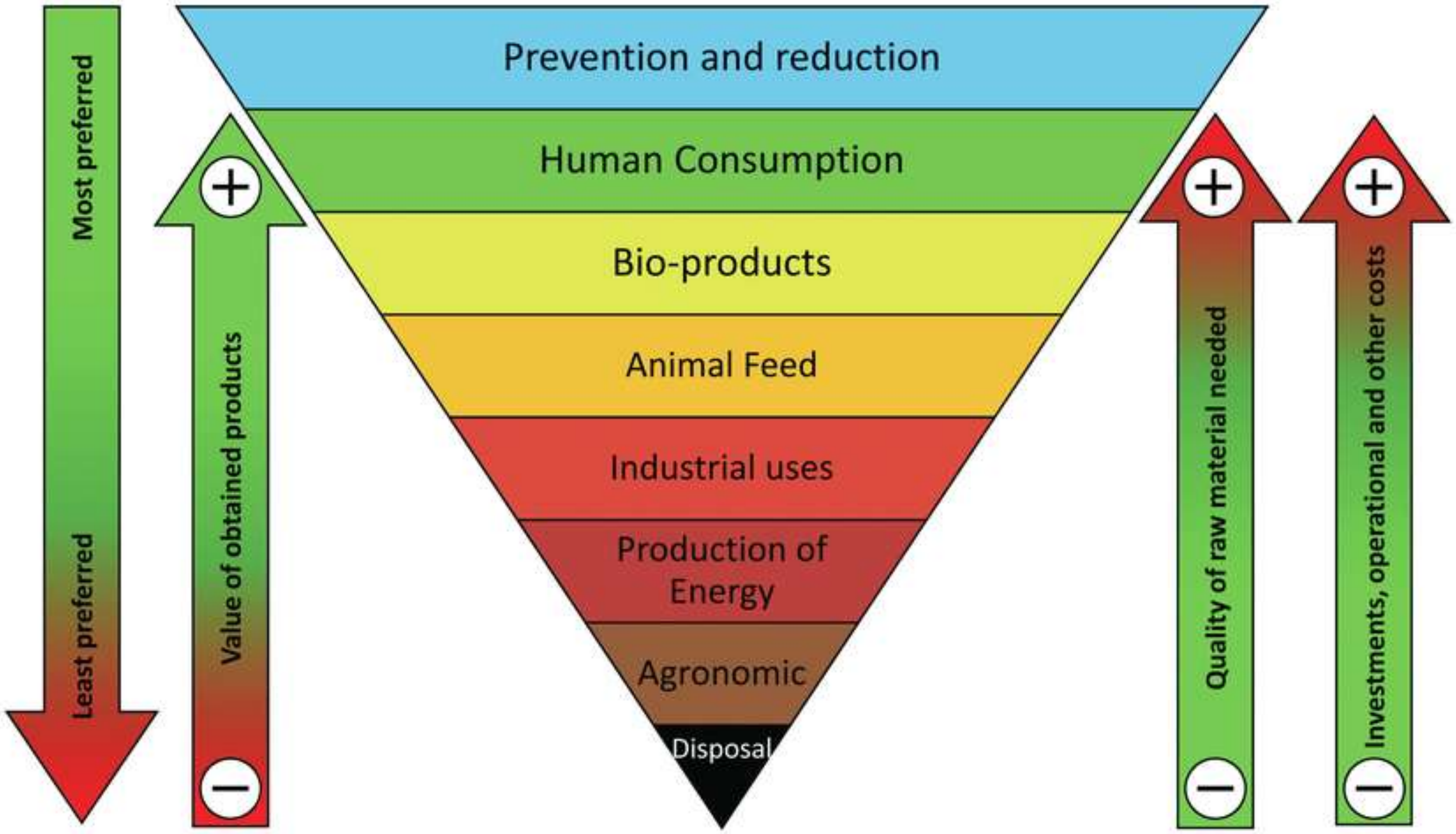


Source: Zulfigar and Ahmad (2021); https://doi.org/10.1007/978-981-16-7653-6_11

Agri-food waste minimisation and exploitation options

Ranked agri-food waste utilisation options

- Waste prevention is the most desirable option
- 2nd best option - **valorisation** (sustainable production of high value products)



Source: Iñarra et al. (2018)

Main ways of agri-food waste exploitation

All creation is a mine, and every man is a miner - **Abraham Lincoln**

Direct use

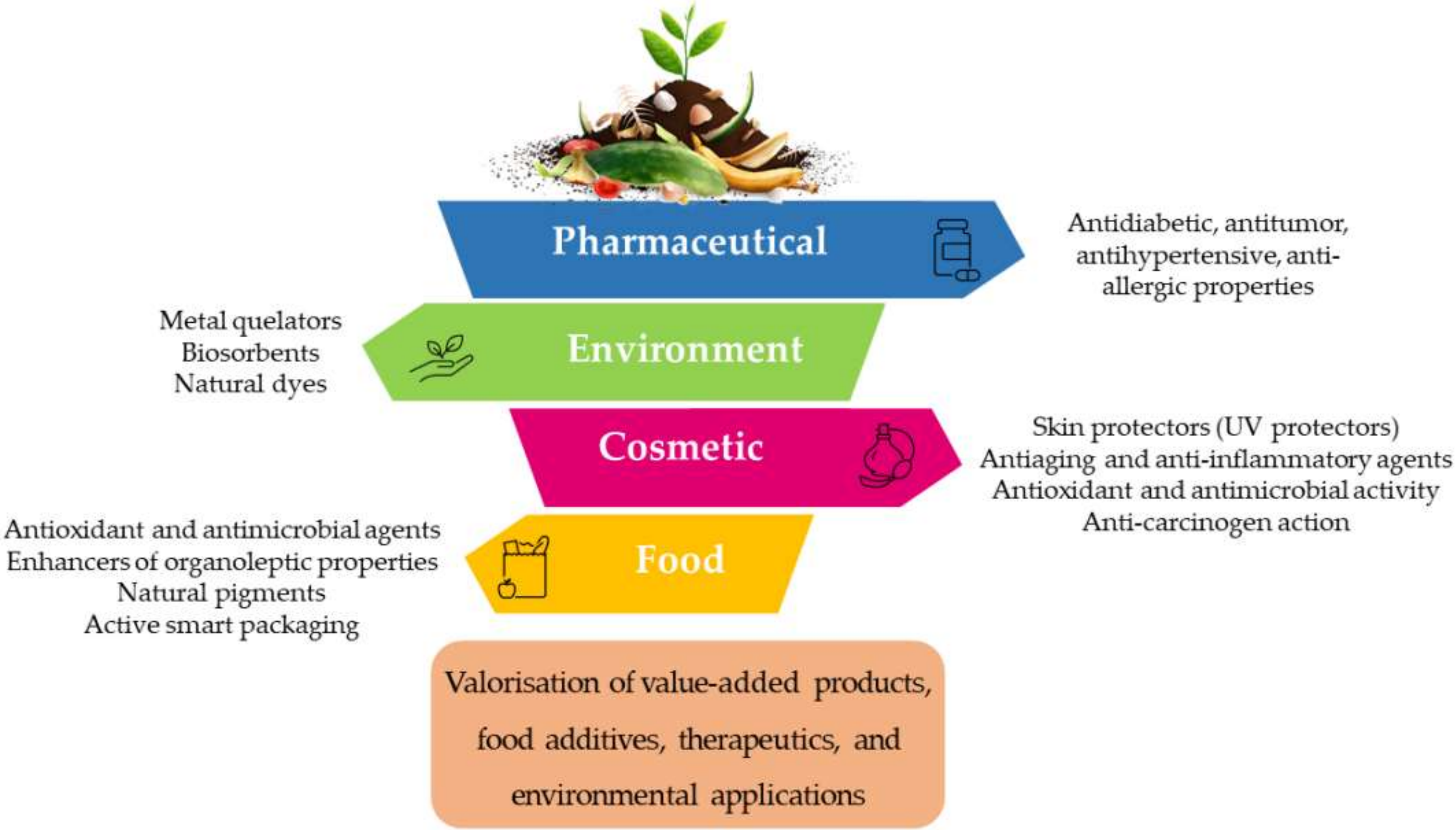
- As ingredient without transformation
- After physical tranformation

Extraction

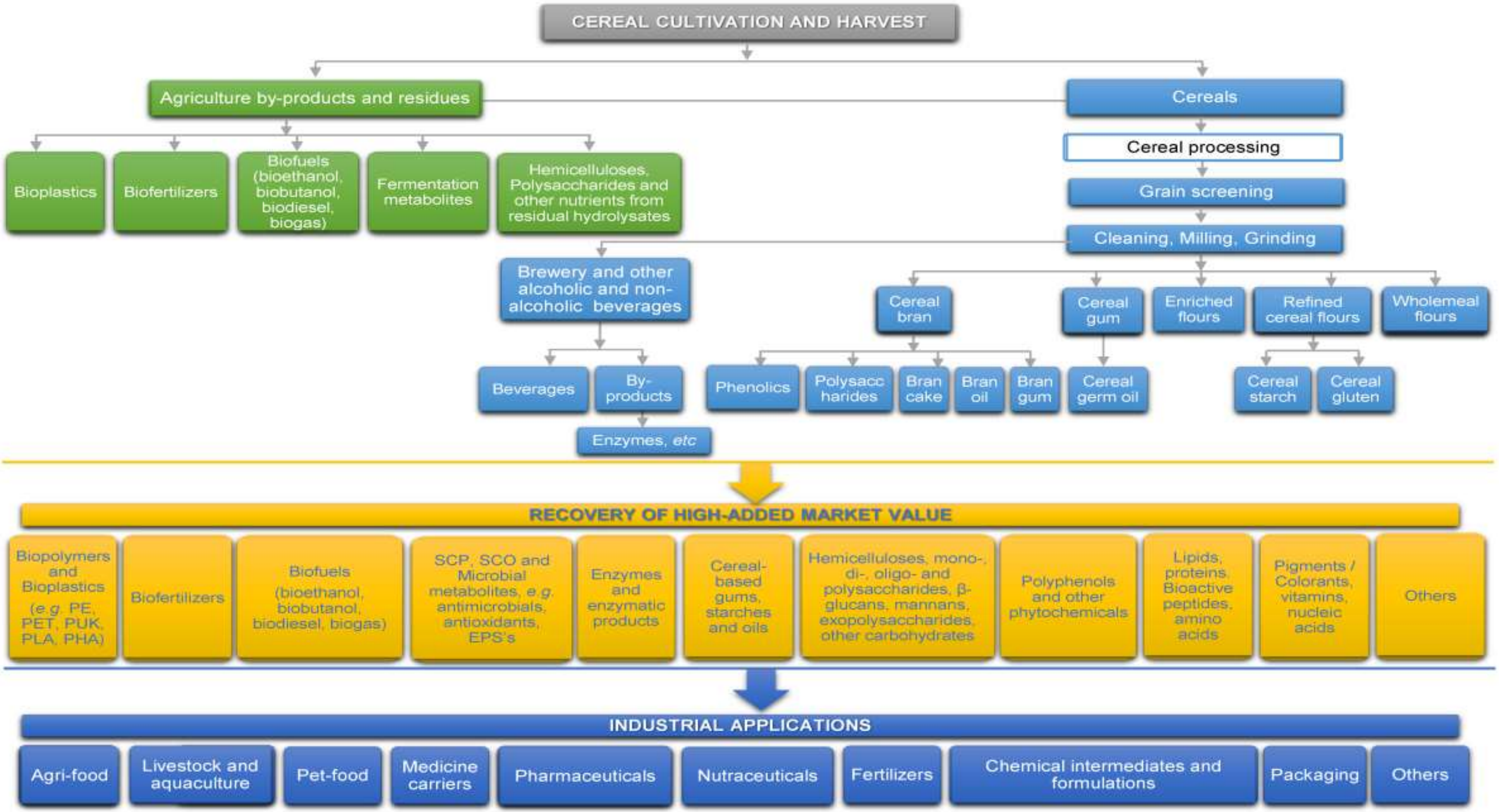
- Solvent
- Enzyme assisted
- Thermal
- Physical
- Green technologies - E.g. Supercritical fluid extraction, microwave /ultrasound assisted and pulsed electric field

Biotechnological transformation

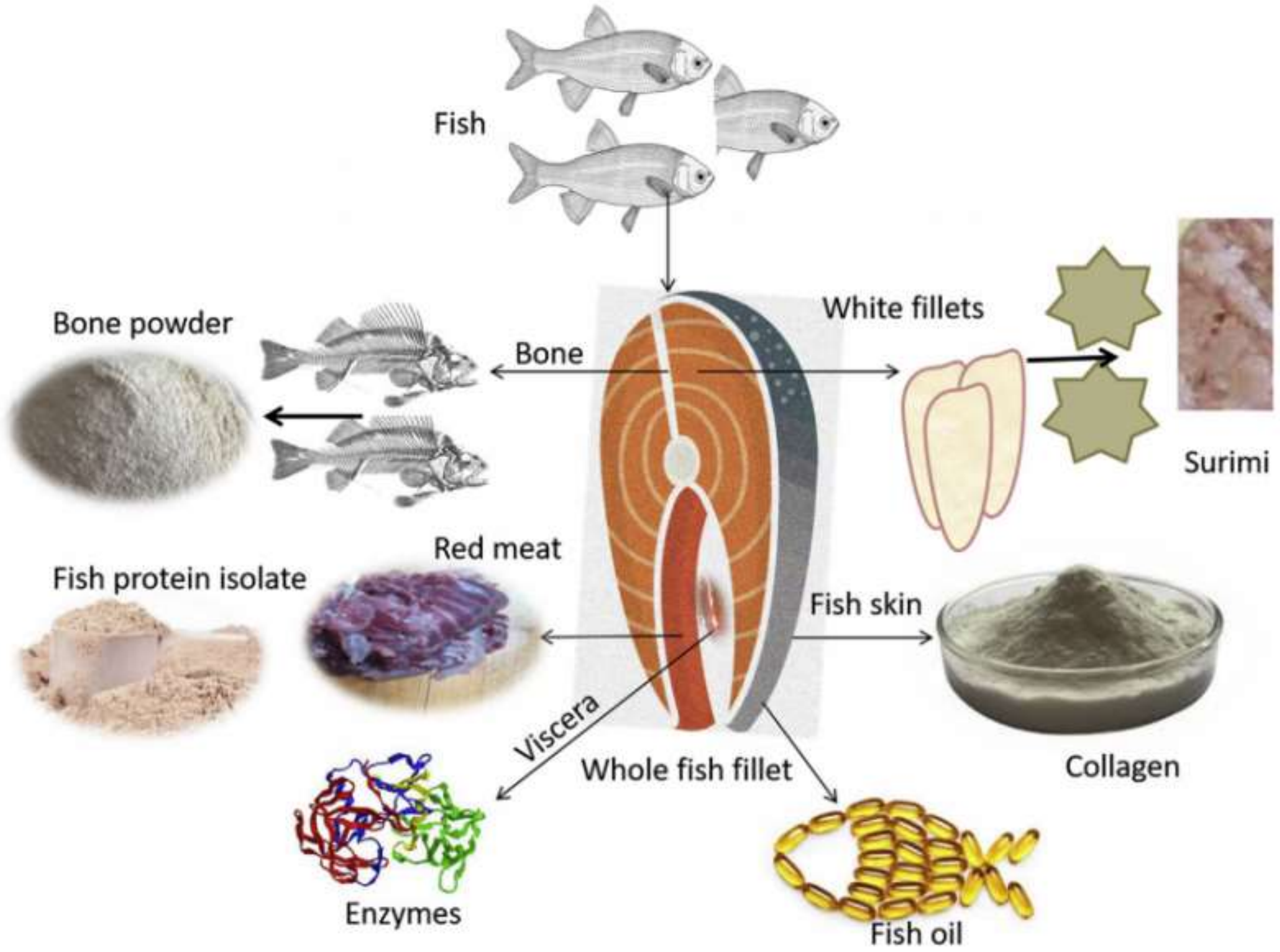
- Fermentation - Single cell protein, alcohol, organic acids, etc
- Enzyme application - Phytochemicals, nutrients



Source: Berenguer et al. (2023)



Skendi et al. (2020); https://doi.org/10.3390/foods9091243



Pictorial representation of the different products that can be derived from fish (Nawaz et al., 2020)

Source: https://bioresourcesbioprocessing.springeropen.com/articles/10.1186/s40643-017-0187-z

Own contribution to agri-food waste prevention and valorisation research and practice

Scope of my work on agri-food waste

Agri-food waste reduction

- **Development and promotion of improved postharvest handling methods and technologies**
- **Development of processes for preservation of foods**

Agri-food waste valorisation

- **Characterisation of agri-food waste materials**
- **Development of agri-waste valorisation protocols**
- **Evaluating the functionality of products obtained from agri-food waste**

Afr. J. Food Agric. Nutr. Dev. 2020; 20(5): 16522-16539 https://doi.org/10.18697/ajfand.93.19790

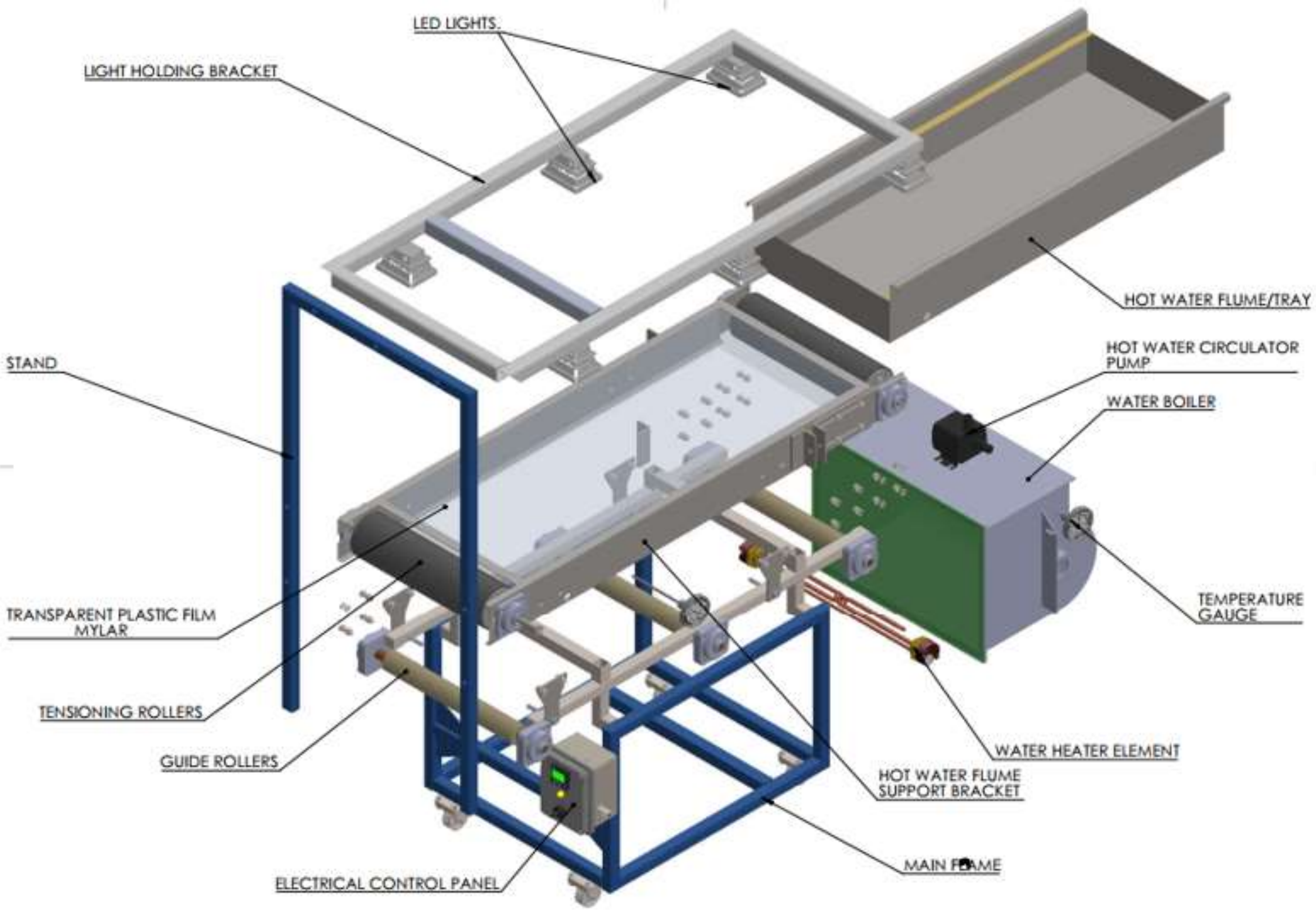
ON-FARM EVALUATION OF EFFECTIVENESS OF IMPROVED POSTHARVEST HANDLING OF MAIZE IN REDUCING GRAIN LOSSES, MOLD INFECTION AND AFLATOXIN CONTAMINATION IN RURAL UGANDA

Akumu G[1], Atukwase A[1], Tibagonzeka JE[1], Apil J[2], Wambete JM[1], Atekyereza PR[2], Kiyimba FL[3] and JH Muyonga[1]*






Refractance window drier




Design and evaluation of a refractance window lab-scale dryer

Shaffic Ssenyimba, Julia Kigozi, Peter Tumutegyereize, John H. Muyonga, Raymonds Mutumba ▾

Journal of Engineering, Design and Technology

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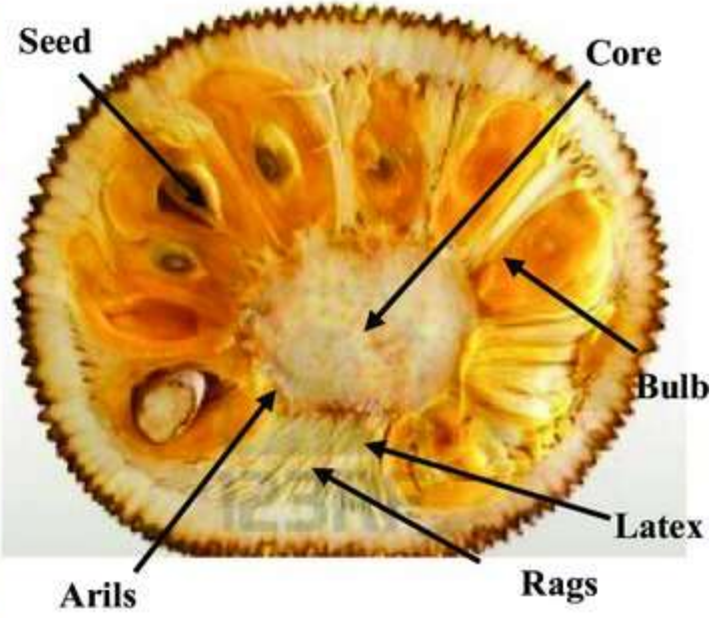
Exploded view of laboratory refractance window drier developed by Makerere University


A

Jackfruit preservation research

Jackfruit rind



Cut section of Jackfruit

Nutraceutical properties of jackfruit pulp

Phenolic compounds - Effective against chronic disease, hyperglycemia

Phytonutrients - Lignans, isoflavones, saponins, niacin. Effective against cancer, hypertension, ulcers, aging, asthama and nerve malfunction

Antioxidants - Vit E, Vit C, beta-carotene, selenium, alpha-lipoic acid and glutathione. Effective against coronary hert disease, lung and prostate cancer

Lectin - Antiviral properties

Adapted from: Swami and Kalse (2018); DOI:10.1007/978-3-319-54528-8_87-1

Jackfruit arils crushed to produce pulp

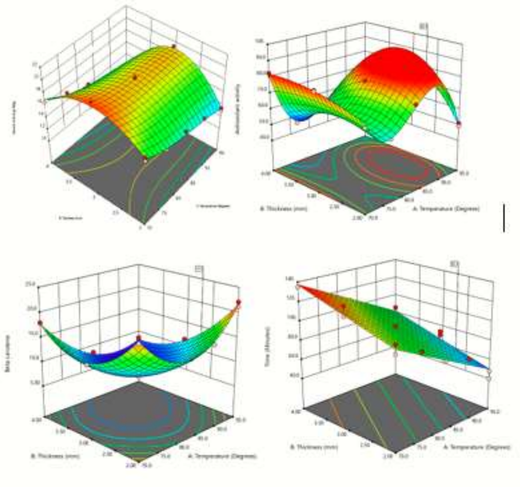
Refractance Window (RW) drying of jackfruit pulp

Jackfruit powder dried at optimum conditions

Determination of nutritional, sensory and textural properties

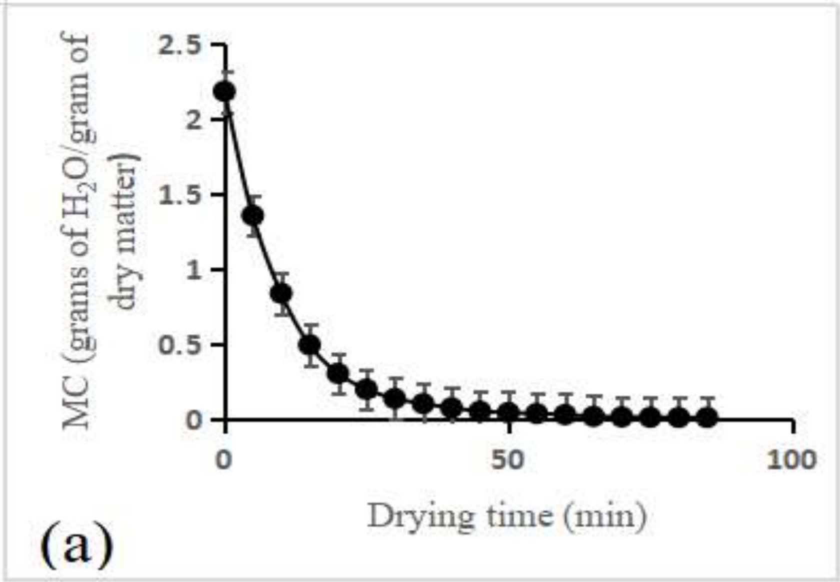
- Protocols for drying jackfruit using RWD developed
- Powder evaluated as an ingredient for processed foods

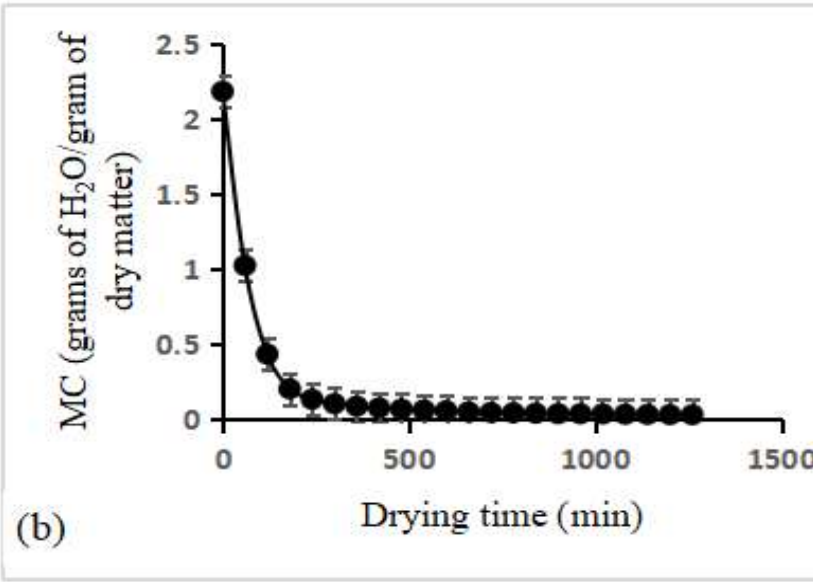
Responses
Drying time (T)
Ascorbic acid (A)
Antioxidant activity (AA)
Total carotenoids (C)

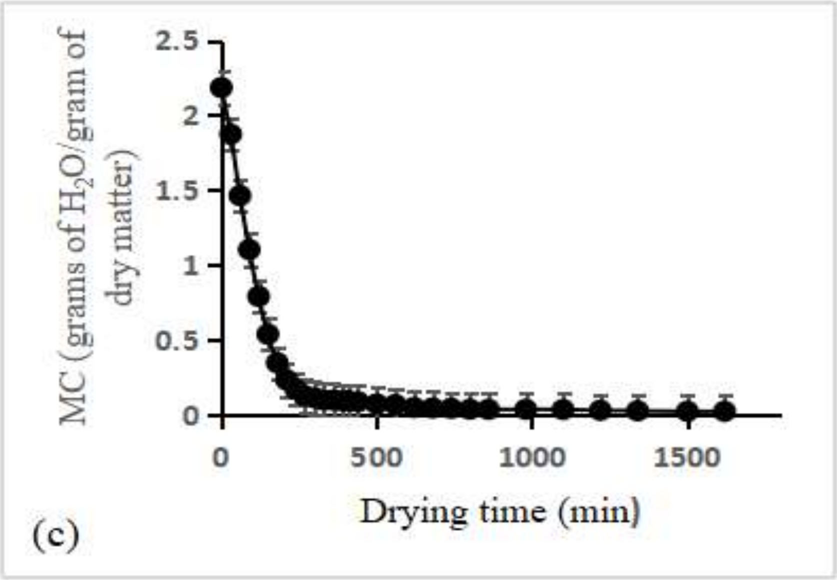


RSM used to optimize RW drying temperature and time

Functional properties
Bulk & tapped density
Carr Index
Hausner ratio
Flowability
Water Holding Capacity
Oil Holding Capacity
Solubility Index
Performance as flour aditive

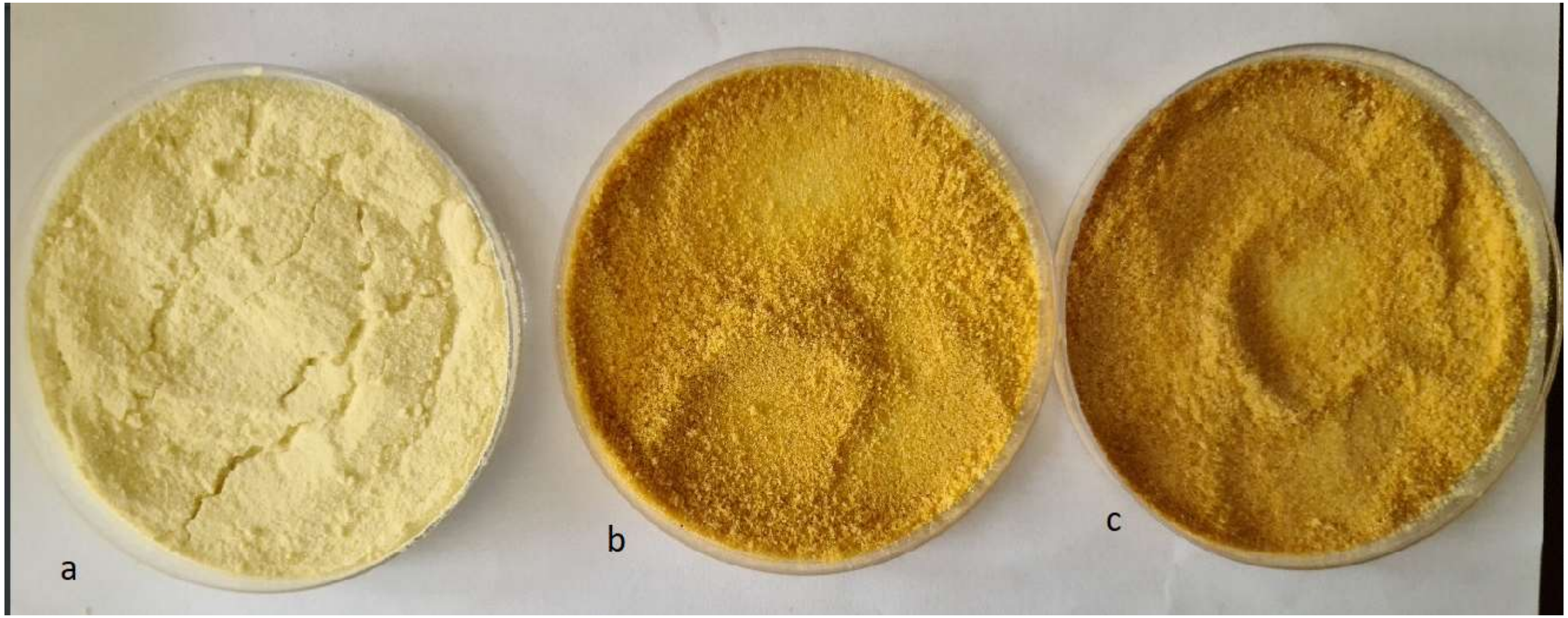






RWD achieved drying of jackfruit pulp in shorted time (60 min) compared to solar (3 days) and oven drying (18 hours)

Variation of moisture content with drying time for refractance window drying (a), oven drying (b) and solar drying (c



Dried jackfruit powders: (a) Freeze dried, (b) Refractance Window dried, and (c) Oven dried

Bioactive compounds and bioactivity for jackfruit dried using different methods

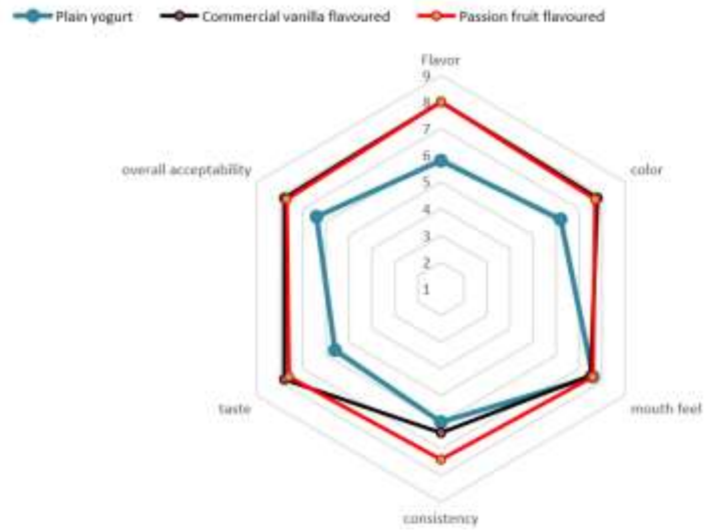
Parameter	Fresh	Oven drying	Freeze drying	RWD	Solar drying
Ascorbic acid	23.97± 0.20^{d}	13.12±0.35^{a}	17.81±0.49^{b}	19.96±0.10^{c}	14.04 ±0.03^{a}
β-Carotene (ug RAE)	1.83± 0.29^{e}	0.60± 0.02^{b}	1.26±0.07^{d}	1.15 ±0.03^{c}	0.21±0.09^{a}
Total phenolic content (GAE/100g)	73.32± 0.18^{b}	91.60± 1.00^{a}	71.41±0.28^{c}	92.08±1.00^{a}	65.96± 0.48^{d}
TFC (QE mg/100g)	57.42±0.18^{a}	39.21±0.16^{b}	56.45± 0.35^{a}	56.84± 0.67^{a}	37.74± 0.18^{c}
AA (mg/100g AscAE)	66.58± 0.77^{e}	80.32± 0.33^{c}	76.28± 0.23^{d}	82.26± 0.19^{b}	84.98± 0.14^{a}
TTC (TA mg/100g)	2.19± 0.01^{a}	1.75± 0.05b^{c}	1.50± 0.03^{c}	1.88± 0.01^{b}	1.99± 0.03^{ab}

Sensory acceptability and ascorbic acid content of cookies enriched with jackfruit flour

Attribute	0% JFP	25% JFP	50% JFP
Colour	6.460± 1.91[a]	7.860± 1.05[b]	6.140± 2.17[a]
Aroma	6.960± 1.28 [ab]	7.060± 1.50 [b]	6.300± 2.39 [a]
Taste	6.720± 1.63[a]	7.500± 1.16[b]	6.560±1.92[a]
Mouth feel	6.560± 1.58[a]	7.320 ±1.25[b]	6.200± 2.05[a]
After-taste	6.420± 1.91[ab]	7.020 ± 1.71[b]	6.080± 2.25[a]
Overall acceptability	6.820± 1.35[a]	7.540± 1.15[b]	6.380± 1.98[a]
Maximum force N	26.067 ±3.37[a]	30.723 ±6.84[a]	24.196±4.32[a]
Ascorbic acid (mg/100g)	4.970± 0.00[a]	11.73±0.65[b]	19.57 ± 0.28[c]

Values of different letters within the same column are statically different from each other ($P < 0.05$); presented data are mean value ± standard deviation (n=50)

Production and utilisation of passion fruit powder



J Food Sci Technol
https://doi.org/10.1007/s13197-021-05302-2

ORIGINAL ARTICLE

Drying behaviour and optimization of drying conditions of pineapple puree and slices using refractance window drying technology

John H. Muyonga[1] · Janet Natocho[1] · Julia Kigozi[2] · Emmanuel Baidhe[2] · Sophie Nansereko[1]

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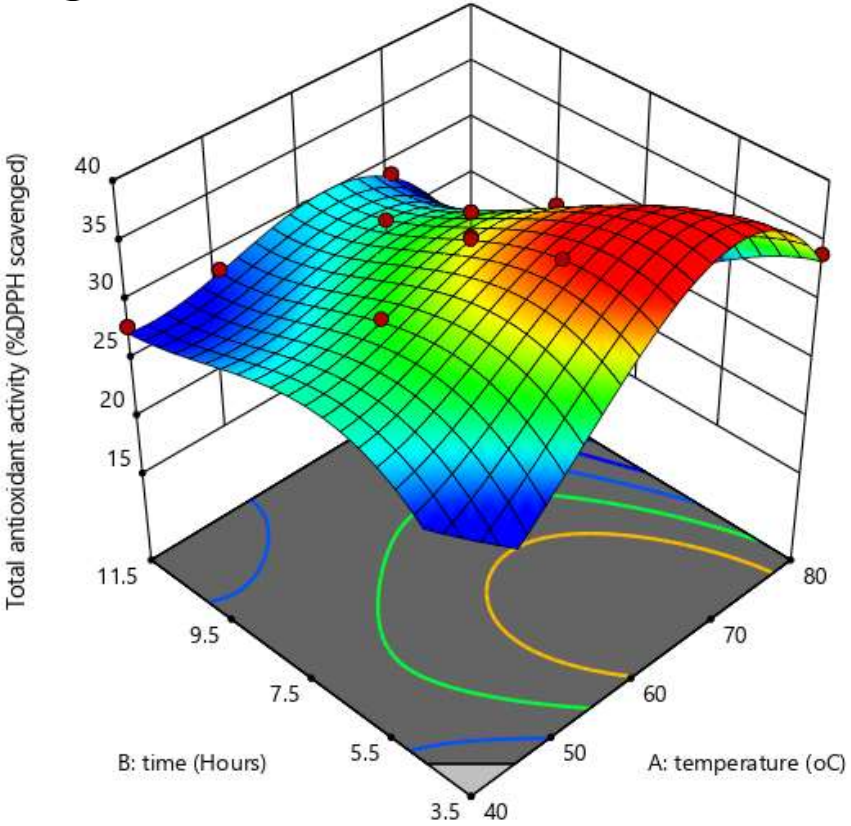
Optimization of refractance window drying conditions for passion fruit puree

A. Asiimwe, J.B. Kigozi, E. Baidhe, J.H. Muyonga*

School of Food Technology, Nutrition & Bioengineering, Makerere University, Kampala, Uganda

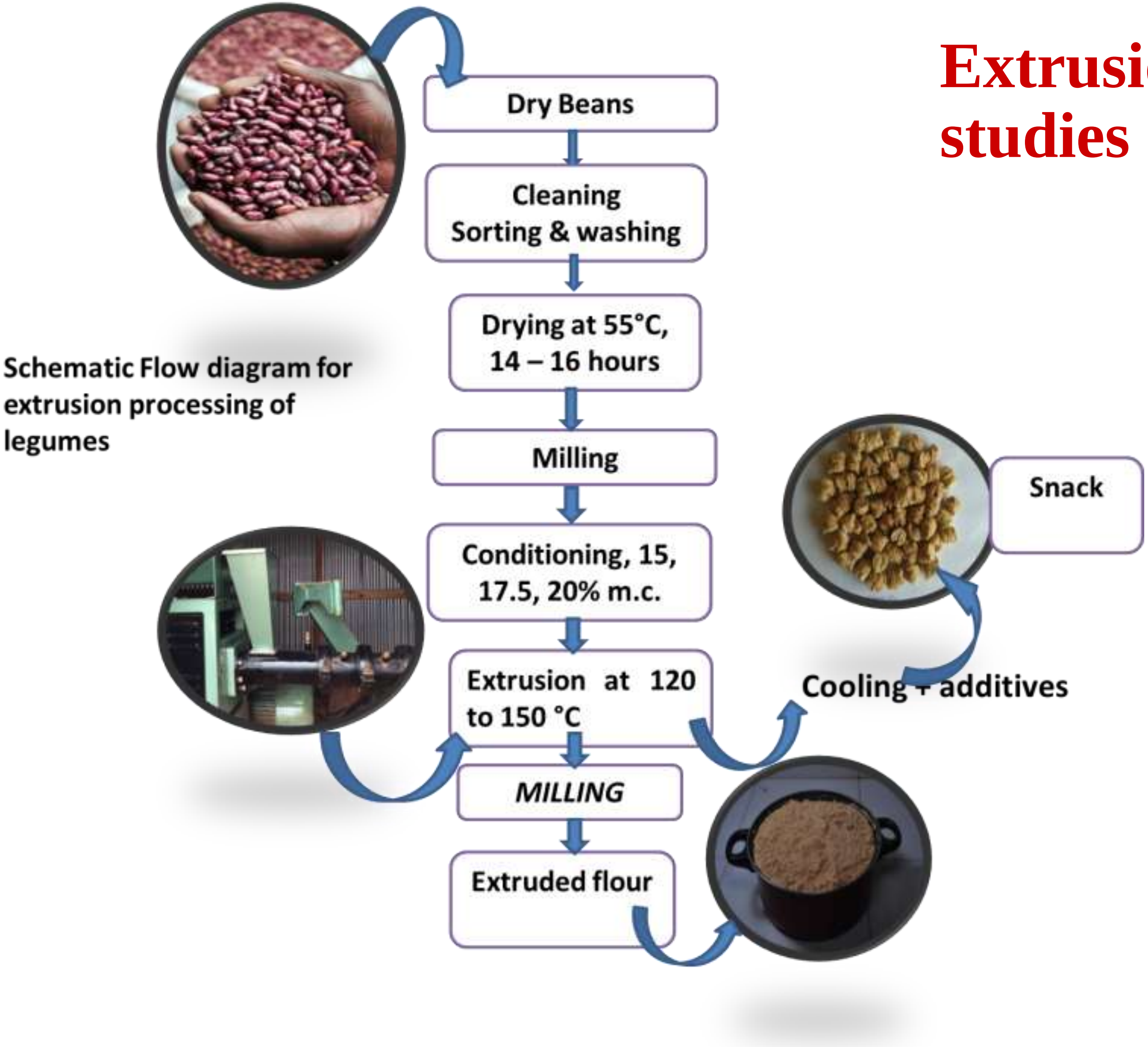
Pumpkin drying studies



- Produced shelf stable flours from seed and pulp of pumpkins
- Optimum drying conditions were 57℃; 6.9 h for flesh and 60℃; 3.15 h for seeds
- Flour from seeds high in phytochemicals and low bulk density
- Recommended for weight control

Processing of sweetpotato products into shelf-stable value added products

Extrusion processing studies



Schematic Flow diagram for extrusion processing of legumes

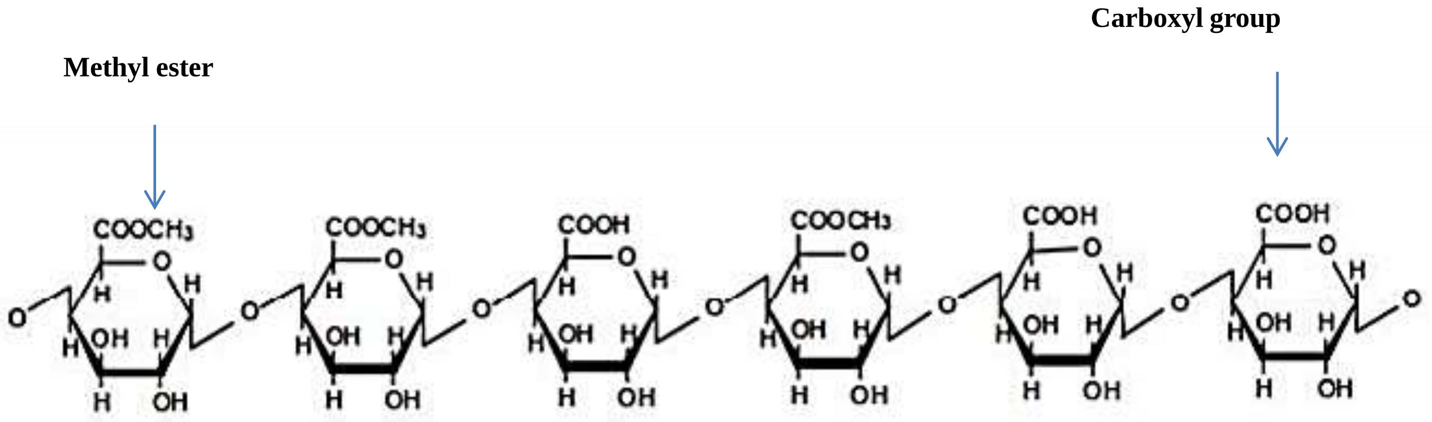
Foods utilised include

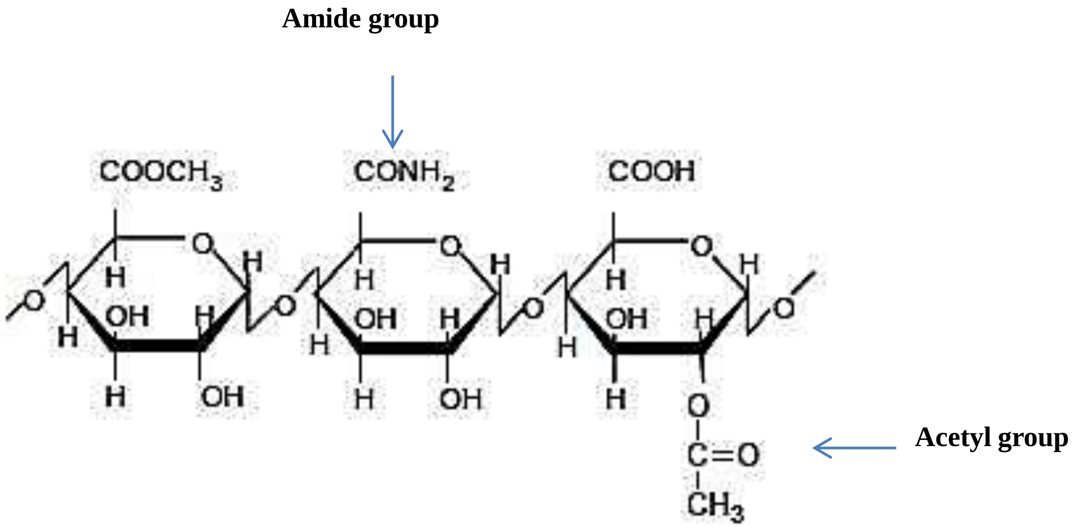
- Cereals
- Sweetpotatoes
- Carrots

Agri-food waste valorisation research

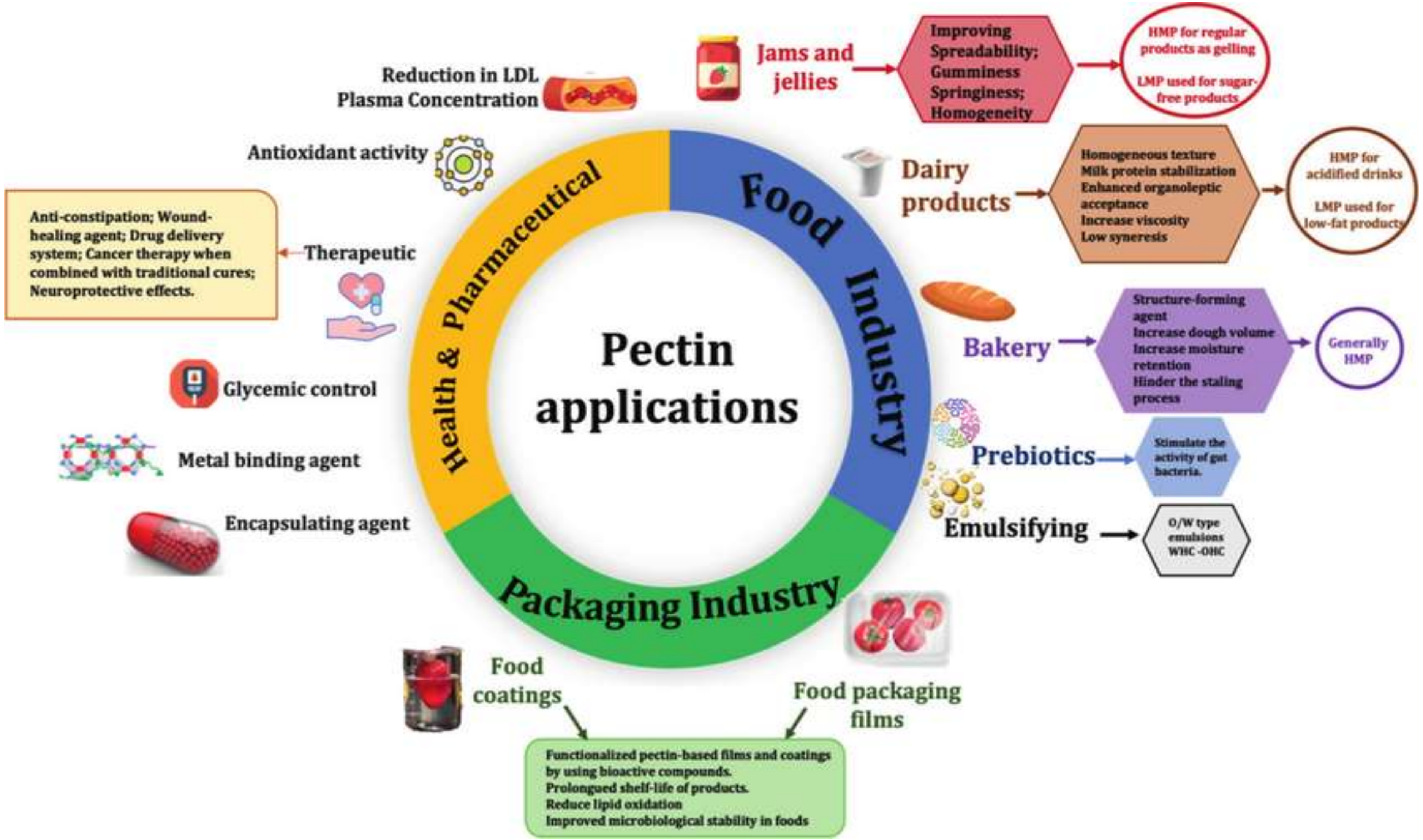
Jack fruit pectin research

- Pectin main sources include citrus peels and apple pomace.
- Our work entailed extracting pectin from jackfruit and assessing it's properties





Pectin applications

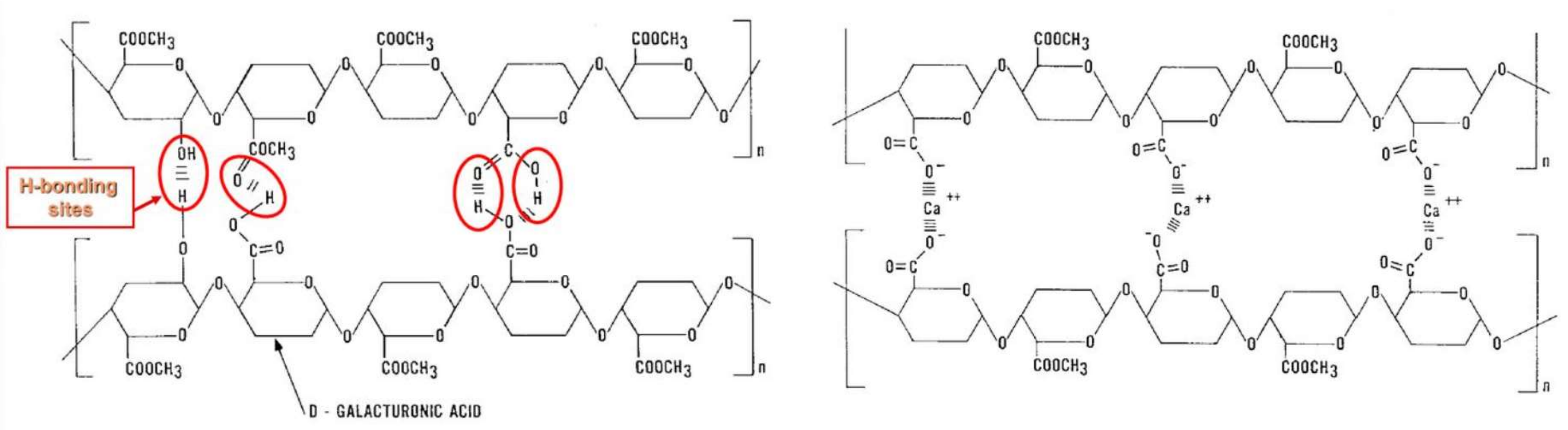


Source: Cortés-Camargo et al. (2023); http://dx.doi.org/10.5772/intechopen.109579

Jackfruit pectin extraction and characterisation

- Approx > 60% of jackfruit is considered inedible in Uganda.
- Inedible fraction of jackfruit used for production of pectin
- Pectin yield of 15-30% recorded for the different inedible parts of the fruit
- Pectin from different types of jackfruit, varied in gelling properties -gelling time and gel strength.

Explanation of variation in gelation of pectins



Source: https://slideplayer.com/slide/14223831/

- Pectins form gels, through junctions between chains, involving hydrogen bonding (for high methyl pectin) or Ca^{2+} mediated cross-links, for low methyl pectin (Lara- Espinoza et al., 2018)
- Strength of gels and the rate of gelation of the pectins extracted from different hackfruit parts varied and this was attributable to chemical differences (calcium content and the degree of methoxylation and esterification)

Tamarind seed analysis and utilisation

- Chemical analysis of tamarind seeds revealed high total phenolics and flavonoids content (Andabati and Muyonga, 2014)
- Tamarind seed powder found to be suitable for use as ingredient to enhance nutraceutical properties of juices and cookies (Andabati and Muyonga, 2014; Natukunda et al., 2015).

Effect of tamarind seed powder on phytochemical composition of tamarind juice

Tamarind seed powder concentration (%)	Total polyphenols (mg GAE 100 ml^{-1})	Total flavanoids (mg CE 100 ml^{-1})	Antioxidant activity (mg VCE 100 ml^{-1})
0	24.68 ± 1.3[c]	0.92 ± 0.0[d]	8.50 ± 0.2[d]
0.5	33.78 ± 2.2[b]	9.62 ± 0.1[c]	12.05 ± 0.3[c]
1.0	39.14 ± 2.0[b]	11.46 ± 0.3[b]	15.33 ± 0.7[b]
3.0	53.34 ± 0.6[a]	17.50 ± 0.1[a]	17.22 ± 0.7[a]

Effect of tamarind seed powder on phytochemical composition of mango juice

TSP concentration %	TPC (mg GAE 100 mL^{-1})	TFC (Mg CE 100 mL^{-1})	TAA (Mg VCE 100 mL $^{-1}$)	TCT (Mg CE 100 mL^{-1})
Control	6.54 ± 0.2^{a}	1.04 ± 0.0^{a}	4.64± 0.6^{a}	0.24± 0.0^{a}
0.5	19.50 ± 0.3^{b}	8.36 ± 0.1^{b}	8.84 ± 0.2^{b}	3.59 ± 0.2^{b}
1.0	29.60 ± 0.4^{c}	11.87 ± 0.1^{c}	13.96 ± 0.3^{c}	8.62 ±0.8^{c}
1.5	43.90 ± 0.1^{d}	13.06± 0.2^{d}	17.91 ± 1.0^{d}	11.33 ± 0.3^{d}
2.0	56.06 ± 0.7^{e}	17.75 ± 0.3^{e}	20.33 ± 0.1^{e}	15.99 ± 0.4^{e}
2.5	88.44 ± 0.8^{f}	22.48 ± 0.4^{f}	21.70 ± 0.0^{f}	21.81 ± 0.1^{f}

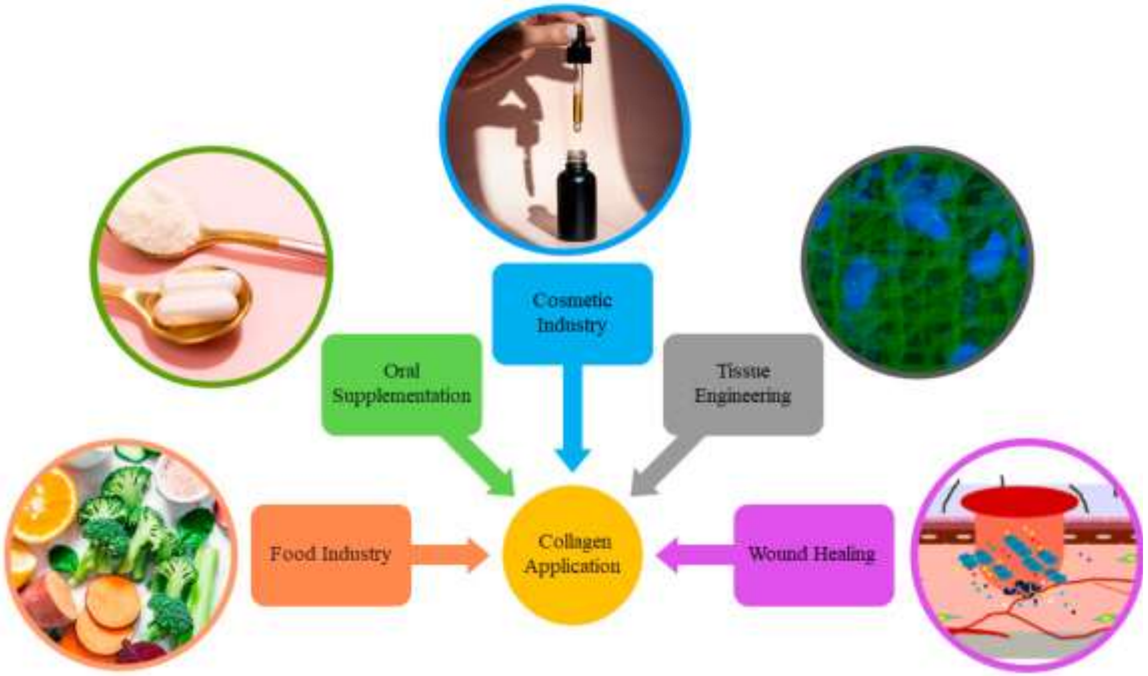
Data are means ± standard deviation from three independent experiments (n=3). Mean values in the same column with different superscript letters are significantly different ($p < 0.05$). TPC; total phenolic content; TFC: Total flavonoid content; TAA; Total antioxidant activity; TCT: Total condensed tannins

Cassava leaf characterisation, processing and utilisation

- Cassava leaves found to be high in **proteins, carbohydrates, beta-carotene, polyphenols and ascorbic acid**
- Blanching, pounding and solar/oven drying gives a safe and acceptable product

Nile perch collagen and gelatin studies

Uses of collagen and gelatin

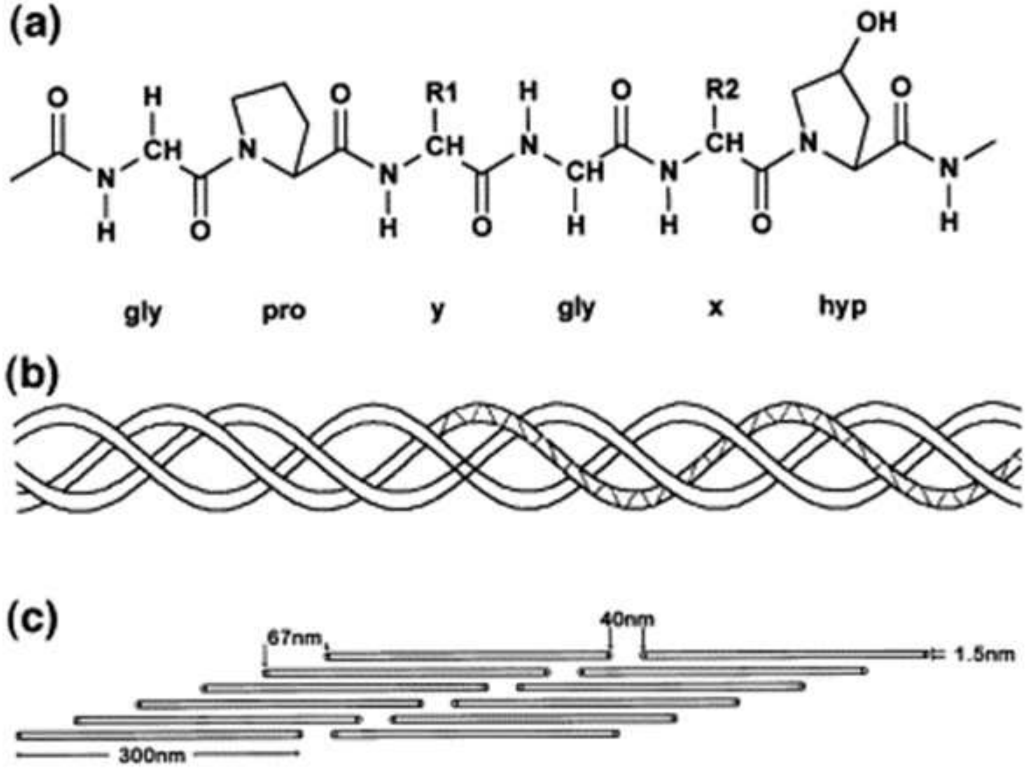


Source: Lionetto et al. (2023);
https://www.mdpi.com/2073-4360/15/3/544

Source: Abdullah et al. (2020);
DOI: 10.1016/j.matpr.2020.12.922

Collagen

- Most abundant protein in animal skins, hides and bones
- Has a unique amino acid profile that gives it peculiar properties, including the ability to form gels when dissolved in water
- Fish collagens lower in imino acids

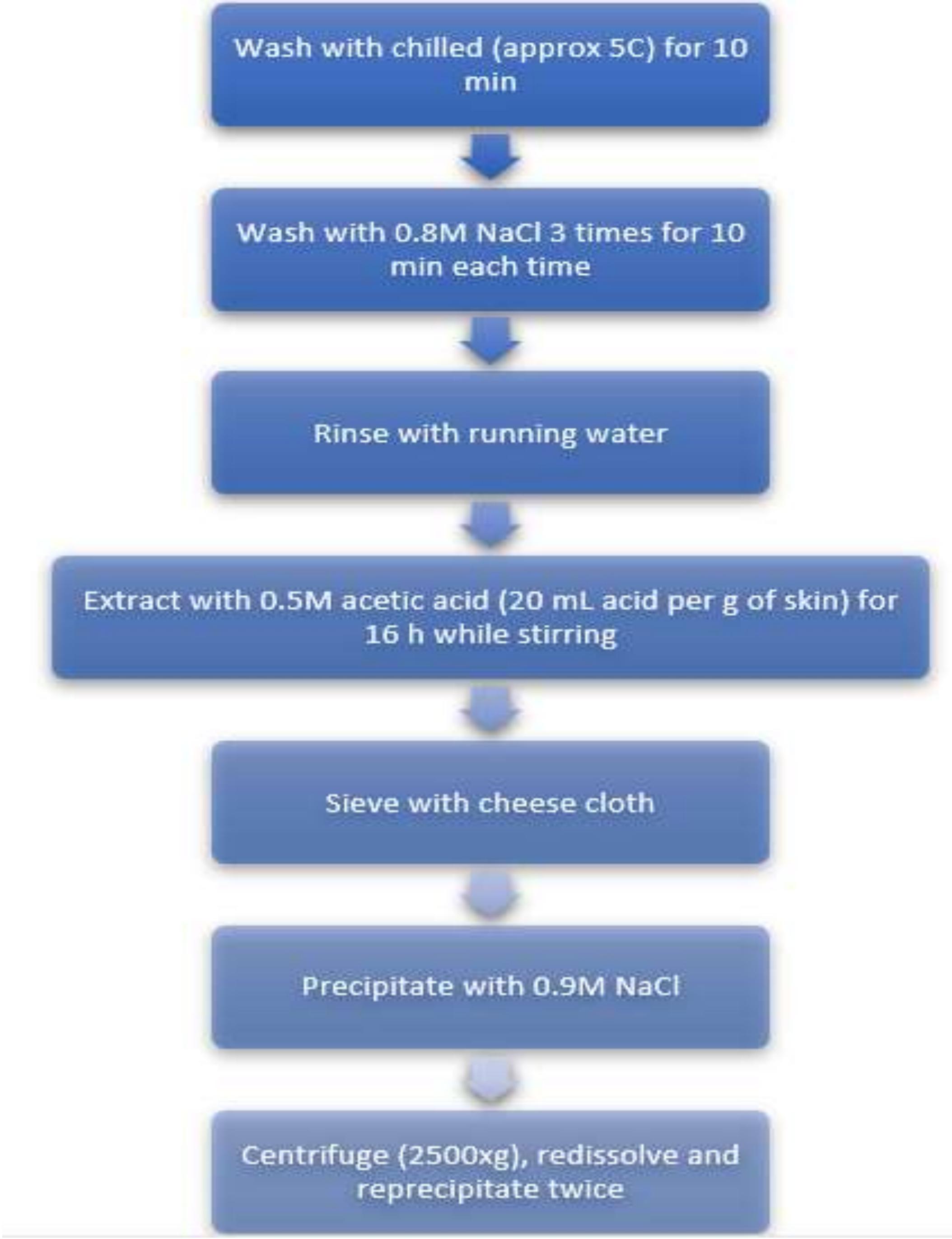


Structure of collagen. (a) Sequence of amino acids -primary structure, (b) left-handed helix -secondary structure; right-handed triple-helix -tertiary structure and (c) staggered -quaternary structure (Kulkarni and Maniyar, 2020)

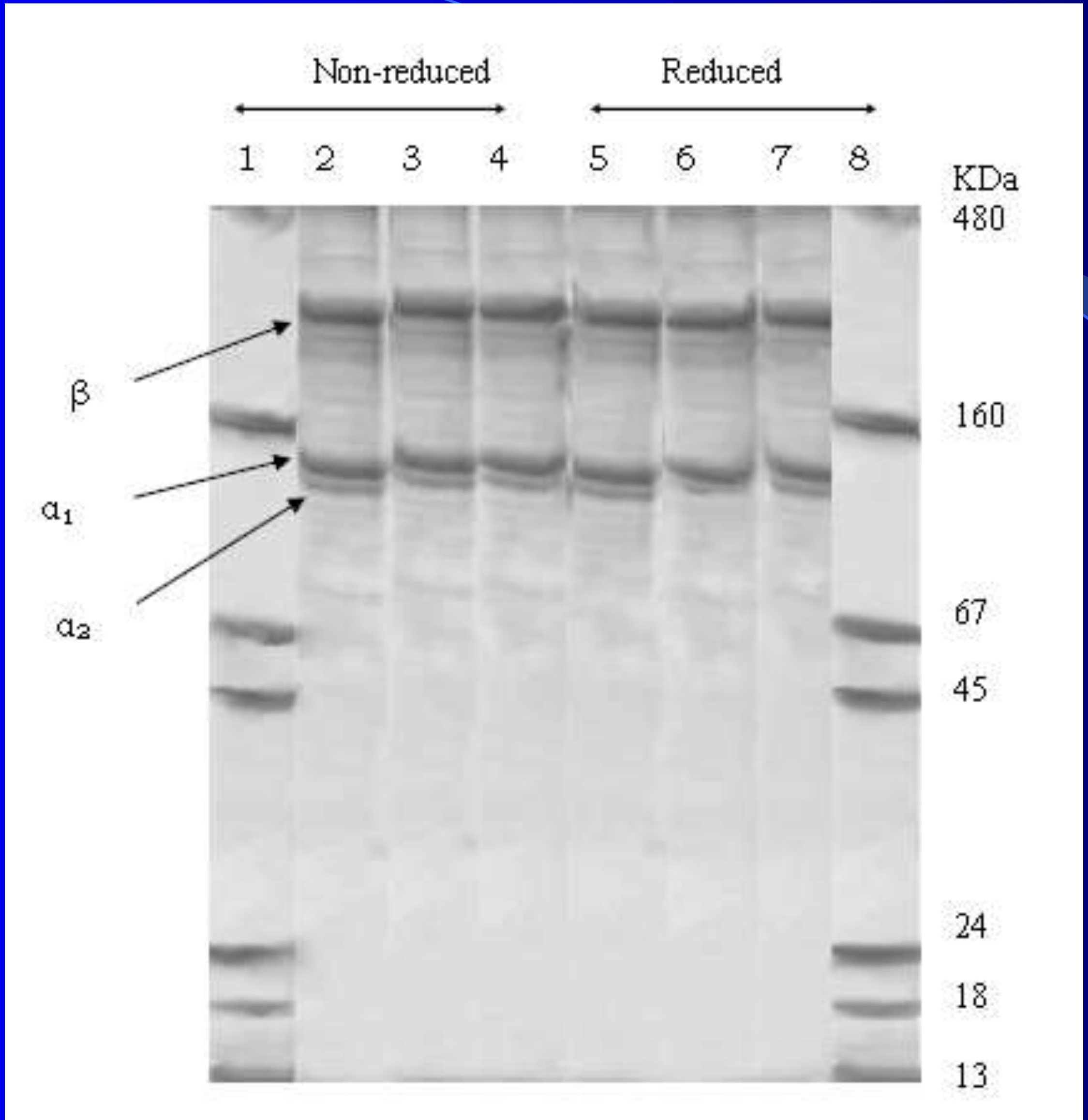
Nile perch skin collagen extraction

Yield

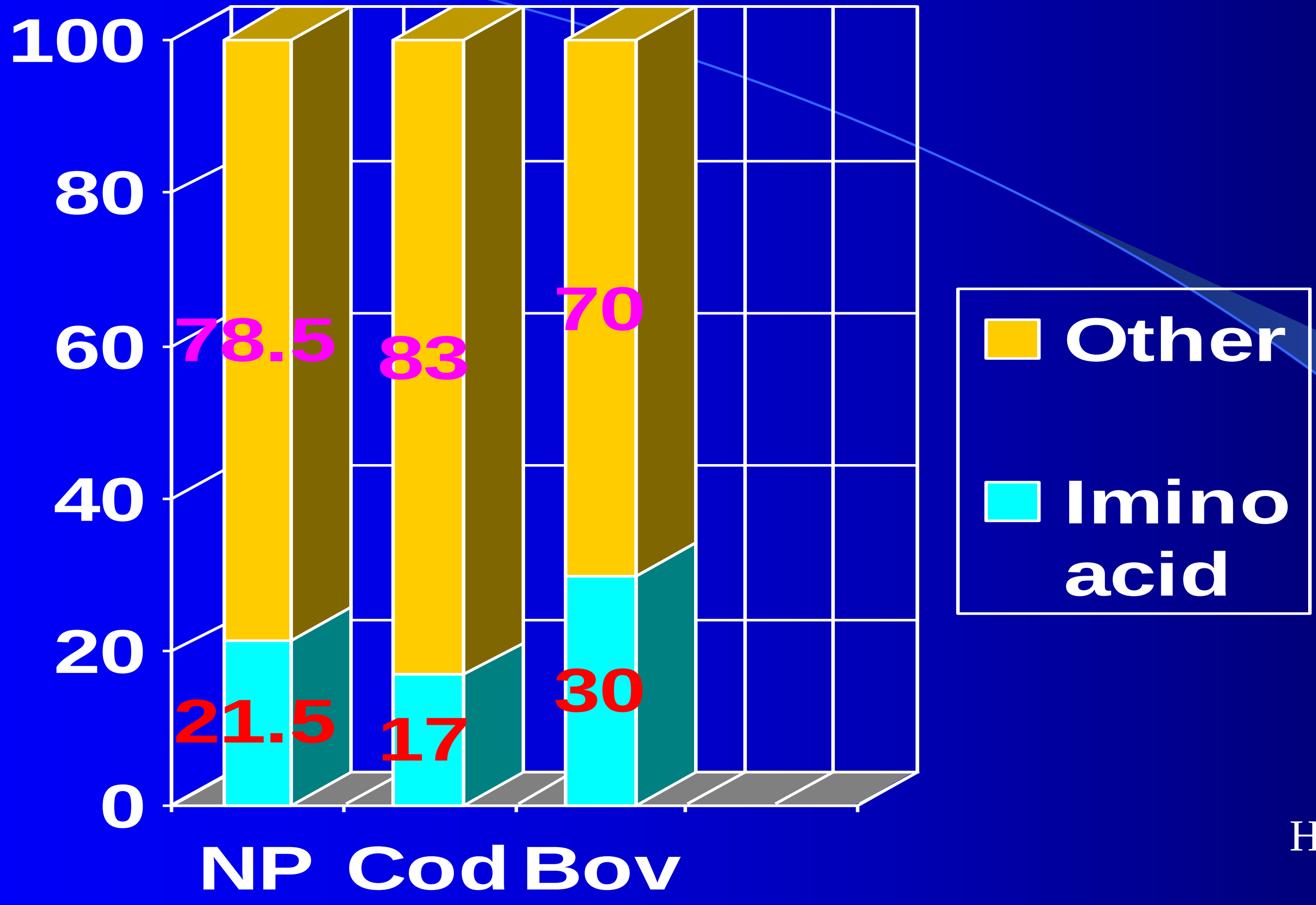
Young (<30 cm)	Old (>80 cm)
63.1%	58.7%

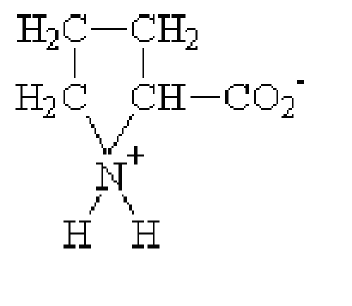


Molecular weight distribution of acid soluble collagen from Nile perch skin

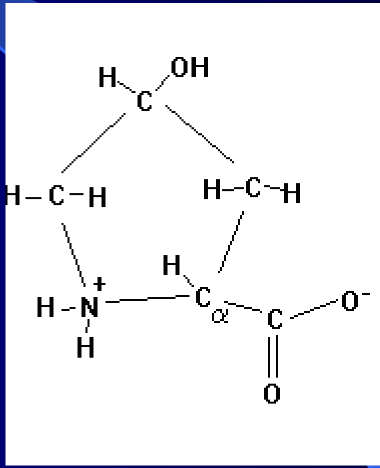


1 & 8 – Molecular weight markers, 2 & 5 – calfskin collagen, 3 & 6 – collagen from skin of adult Nile perch, 4 & 7 – collagen from skin of young Nile perch





Proline

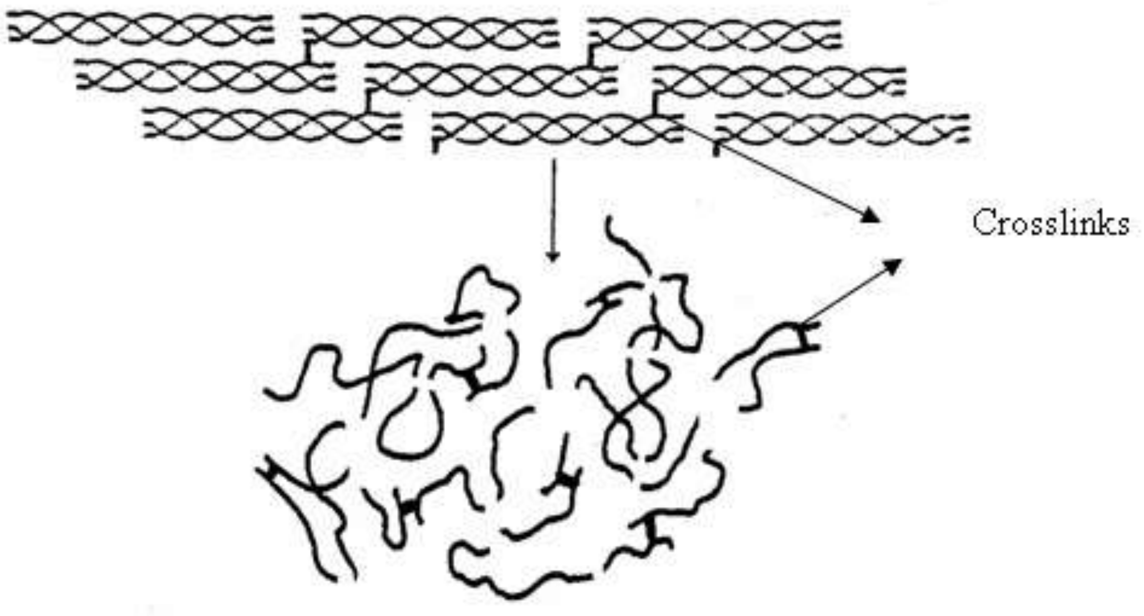


Hydrohyroxyproline

Proportion of imino acids in different collagens

Gelatin

- Poly-disperse polypeptide derived from collagen by severing of inter and intra-molecular bonds



Conversion of collagen to gelatin (Muyonga, 2003)

Gelatin manufacture process

De-scale, de-grease, de-mineralise

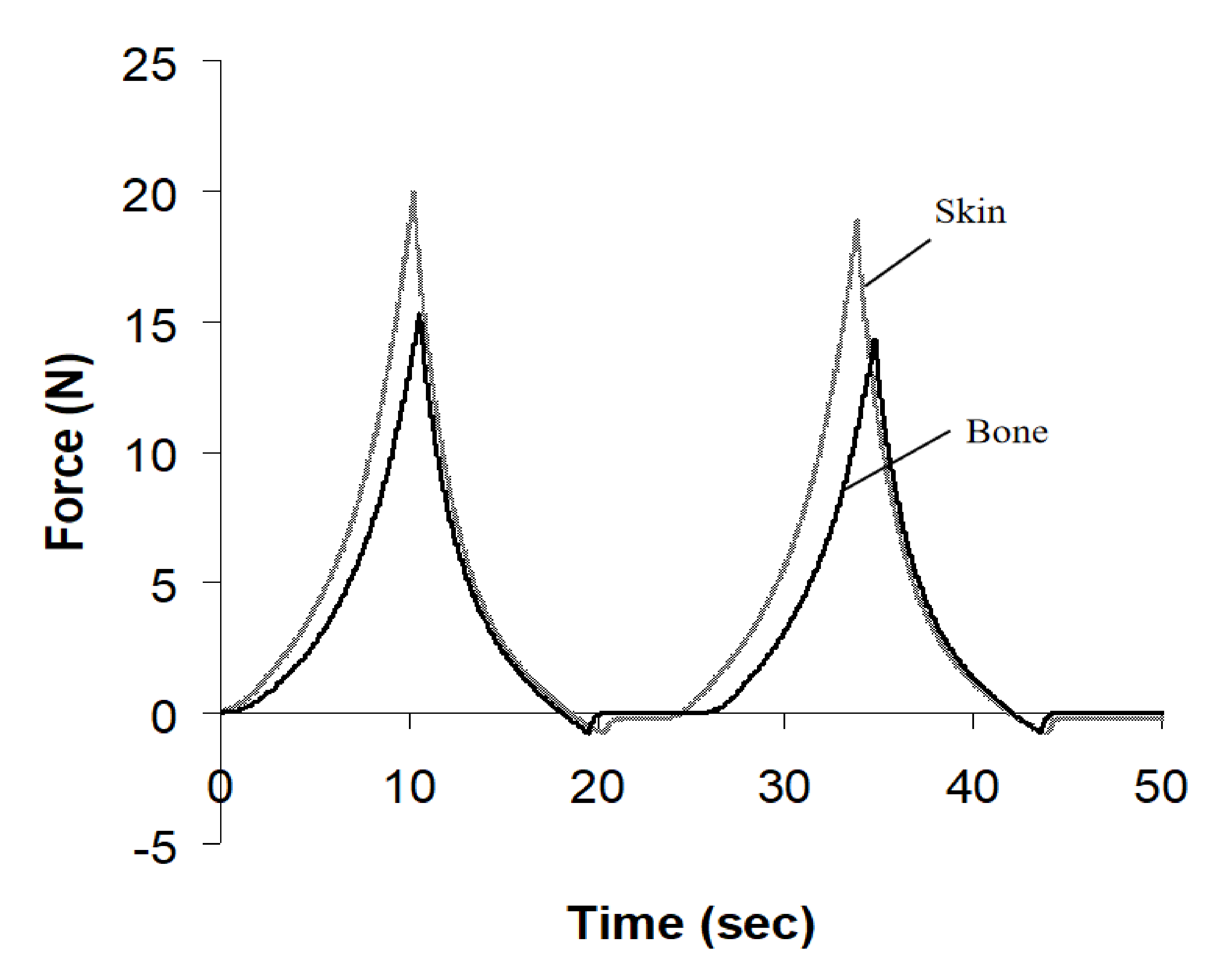
Acidulate

Hot water extraction - 50, 60 & 70C

Filtration and de-odourisation

Cool, dry and mill

Material yield of 64% and 12% registered for skin and bone respectively



Typical texture profile of Nile perch skin and bone gelatin

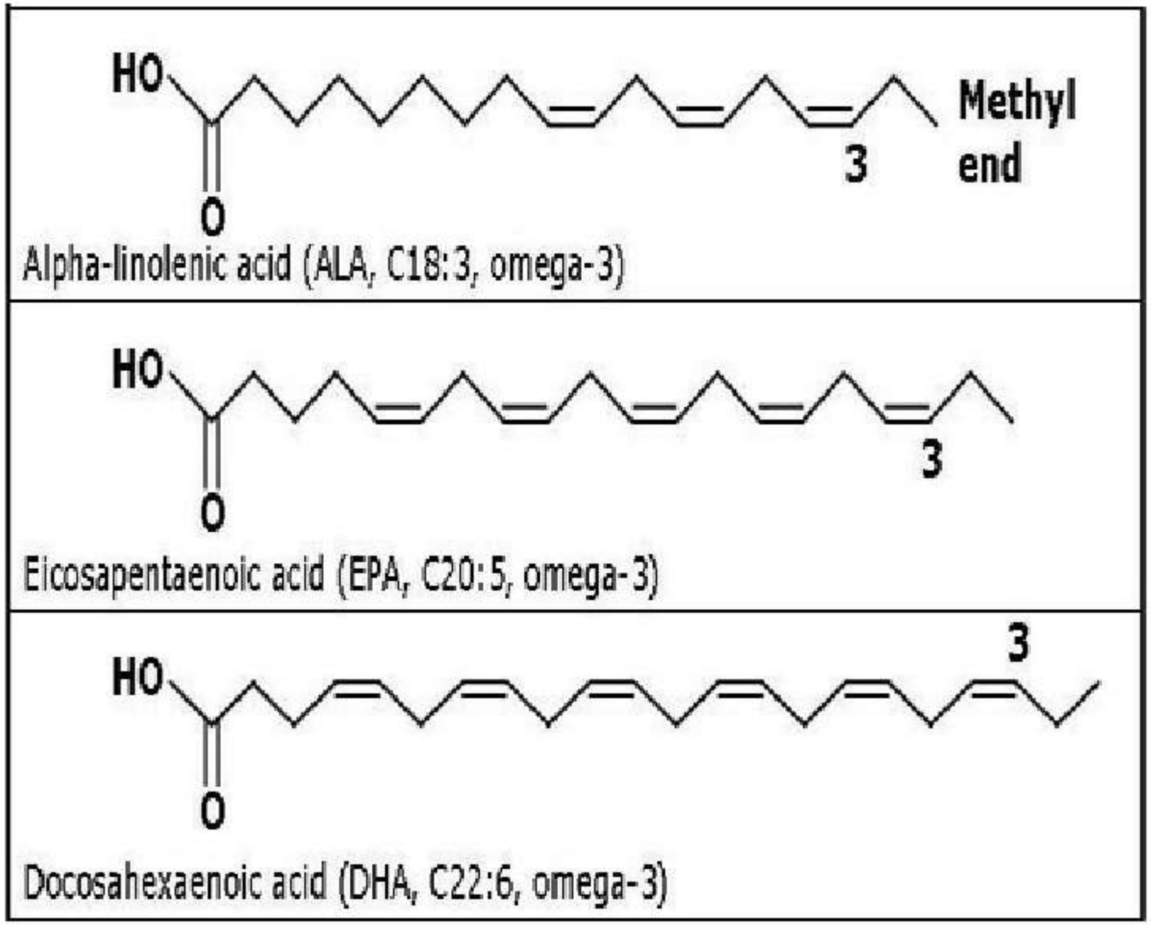
Bone gelatin and gelatin extracted at high temperature contained more of the smaller fragments while skin gelatins extracted at lower temperatures had more of the larger fragments

Gelatins with higher proportion of larger fragments exhibited higher gel strength and viscosity

NILE PERCH OIL EXTRACTION AND CHARACTERISATION

Fish oil

- Rich in omega 3 fatty acids
- Omega 3FAs contribute to brain development and protection against the following:
  - Cardiovascular diseases
  - Breast, colon and prostate cancer
  - Inflammation
  - Depression, pain and psychosis



Structure of omega 3 fatty acids (Olgunoğlu, 2017)


200
100

Nile perch belly flaps oil content and oil yield

Fish size	Oil content	Oil yield (%)
Small (1-2 kg)	62.85 ± 6.89^{c}	39.90 ± 2.77^{c}
Medium (10-20 kg)	75.36 ± 5.94^{b}	69.08 ± 8.69^{b}
Large (40-80) kg	78.98 ± 1.23^{a}	74.06 ± 7.51^{a}

Values in columns followed by a different superscript differed significantly ($p < 0.05$).

Source: Ogwok et al. (2008)

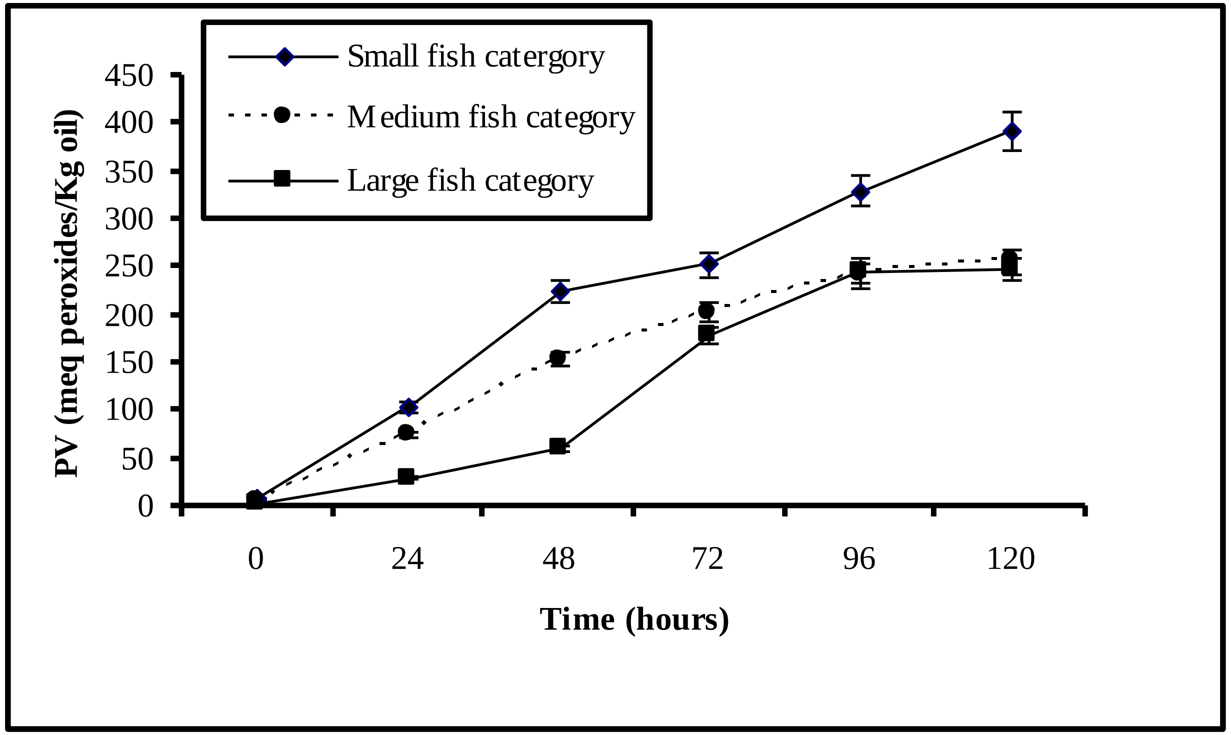
Content of selected bioactive components of oil from belly flaps from Nile perch of different sizes

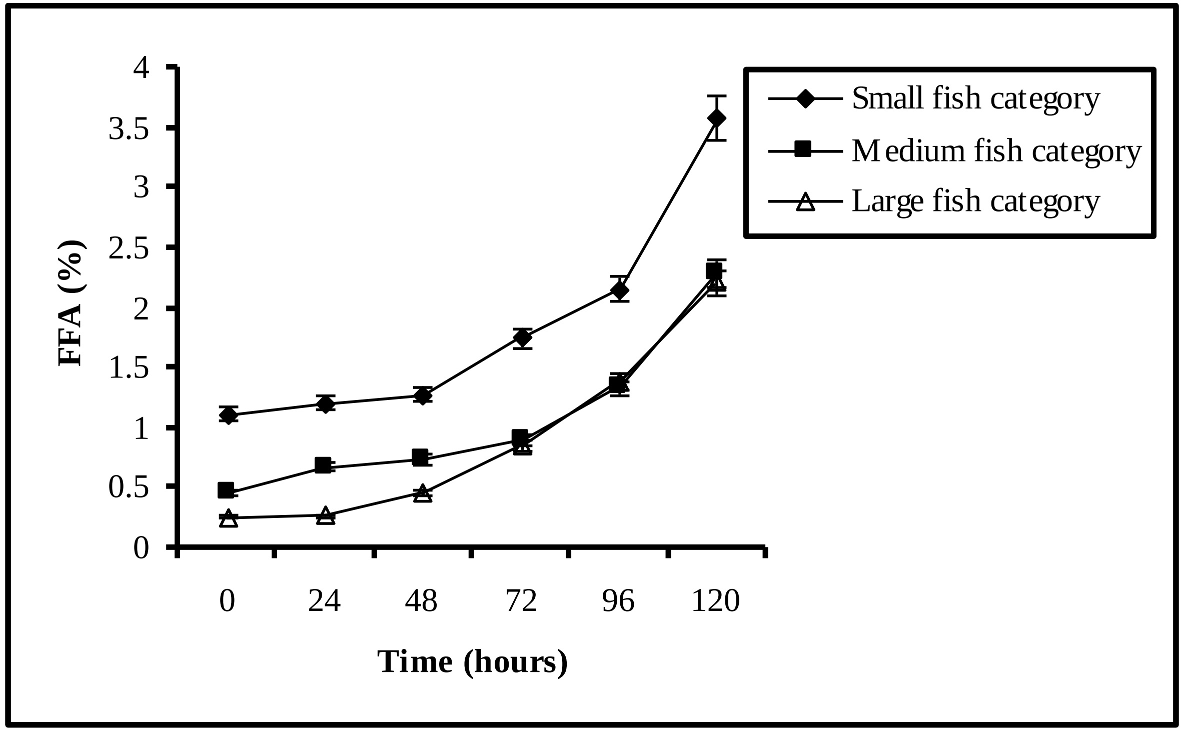
	Fish size		
Attribute	1-2 kg	10-20 kg	40-80 kg
Vitamin A content (mg/100 g)	3.94±0.02[c]	4.04±0.01 [b]	5.90±0.02[a]
β-carotene (mg/ 100g)	2.93±0.03[c]	3.35±0.01[b]	4.69±0.01[a]
α-tocopherol (mg/ 100g)	11.36±0.92[a]	6.57±0.63[b]	2.11±0.03[c]
Total polyunsaturated fatty acids (%)	**24.20±0.36[a]**	**21.70±0.21[c]**	**22.35±0.15[b]**
Total omega-3 fatty acids (%)	**11.15±0.10[a]**	**10.55±0.08[c]**	**10.90±0.06[b]**
Linolenic (18:3, n-3) (%)	2.45±0.10[a]	1.70±0.02[c]	1.80±0.00[b]
Eicosapentaenoic (20:5, n-3) (%)	3.40±0.15[bc]	3.50±0.00[ac]	4.00±0.00[a]
Docosapentaenoic (22:5, n-3) (%)	5.30±0.60[ab]	5.35±0.06[a]	5.10±0.07[b]
Docosahexaenoic (22:6, n-6) (%)	10.45±0.38[a]	9.15±0.08[c]	9.50±0.05[b]

Total PUFAs and omega 3 FAs higher for fish captured during wet season than dry season

Source: Ogwok et al. (2008)

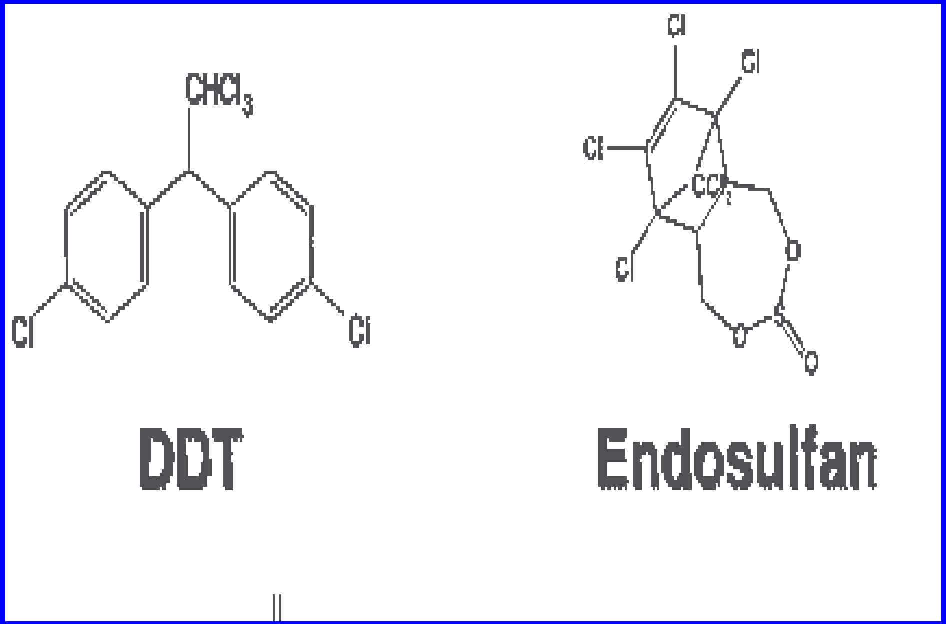
Oxidative stability of oil from Nile perch belly flaps





Source: Ogwok et al. (2008)

Contaminants



- The level of most common organochlorides and heavy metals contaminants of fish oil increased with age but were far below maximum recommended levels, regardless of the source of the fish and the size

Flour from Nile perch trimmings

Wash skeletons and off cuts to remove slime, soil and reduce bacterial

Precook, de-fat (at 95- 100 C for 18 minutes), debone

Drain and treat with BHT

Oven **dried at 55-60C for 16 hours**

Cool and mill

Proximate composition of flour from fish trimmings

Component	Percentage
Protein	77 (digestibility >90%)
Lipid	9.5
Ash	3.29
Water	9.0

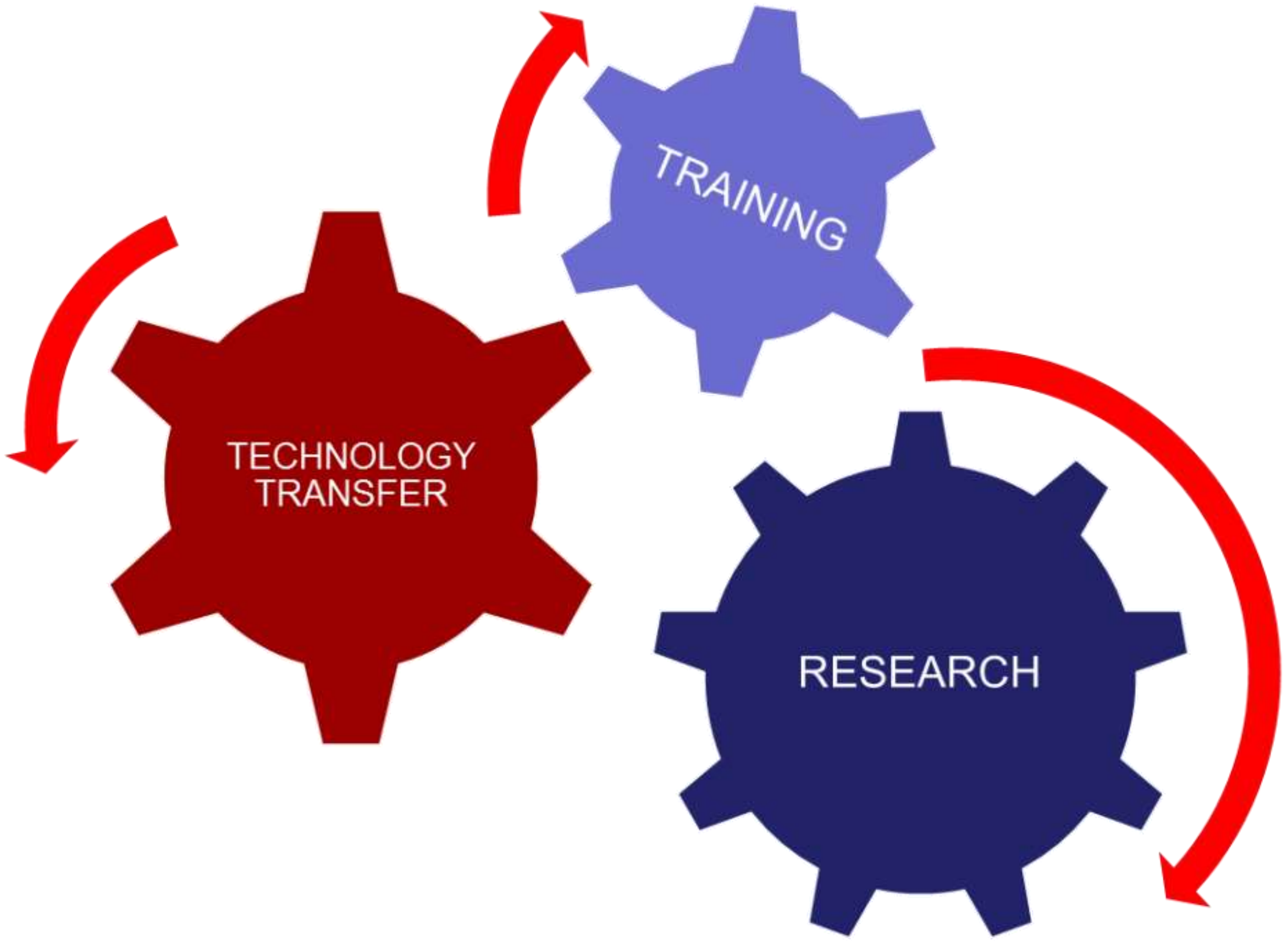
Source: Ocagiwu (2011)

- Adding flour from Nile perch trimmings to boiled beans significantly improved sensory acceptability
- Fish flour was prone to oxidation but addition of antioxidant significantly improved shelf stability

Future research

What we know is a drop. What we don’t know is an ocean - **Isaac Newton**

- Characterization of by-products from more agri-food materials produced in Uganda
- Application of novel and sustainable technologies in agri-food waste valorisation to improve extraction efficiency, efficacy and limit environmental impact
- Evaluating new applications of components of agri-food waste - e.g. in biobased packaging and biopreservation
- Policy and techno-economic analysis of valorisation options


TRAINING
TECHNOLOGY TRANSFER
RESEARCH

Appreciation

- Family
- Makerere University
- Students
- Research collaborators
- Funders
- Mentors
- Professorial Inaugural Lectures Organizing Committee
- Audience
- ALMIGHTY GOD