Food Waste Recovery Group

VALORIZATION OF PLANT-BASED AGRI-FOOD REST RAW MATERIALS

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Ås, 14th November 2016

Agri-food processing by-products

- ✓ Agri-food by-products & waste considered as a matter of ***treatment***, ***minimization*** & ***prevention*** for more than 40 years

- ✓ Defined as "***wastes***" in most European Legislations (442/1975/EEC, 689/1991/EEC, 98/2008/EEC) due to the fact that they removed from the production line as undesirable materials

- ✓ The current challenge commands their valorization as ***a source of high-added value components***

Food By-products & Wastes

Why?

- ✓ Existing technologies promise the ***recovery*** & ***sustainability*** of high added-value ingredients inside food chain

But

- ✓ Despite the omnipresence of high quality studies & patented methodologies, ***market products are still rather limited***

Foods related to Agro-Industry

Plant Origin

- Cereals
- Roots & Tubers
- Oilseeds & Pulses
- Fruits & Vegetables

Animal Origin

- Meat
- Fish & Seafood
- Dairy products

Food Wastes & By-products

Production Stage

Agricultural Production	→	Abundant & less susceptible substrates
Post-harvest handling	→	Less abundant & not susceptible substrates
Consumption	→	Large distribution in many points & very susceptible substrates

Cereals

- ✓ Wheat is the dominant crop in medium- & high-income countries
- ✓ Rice is the dominant crop in South & Southeast Asia

Wheat milling & rice peeling → Bran & Straw → High nutritional value proteins & dietary fibers

Oat mill waste → Recovery of β-glucan with gelling properties

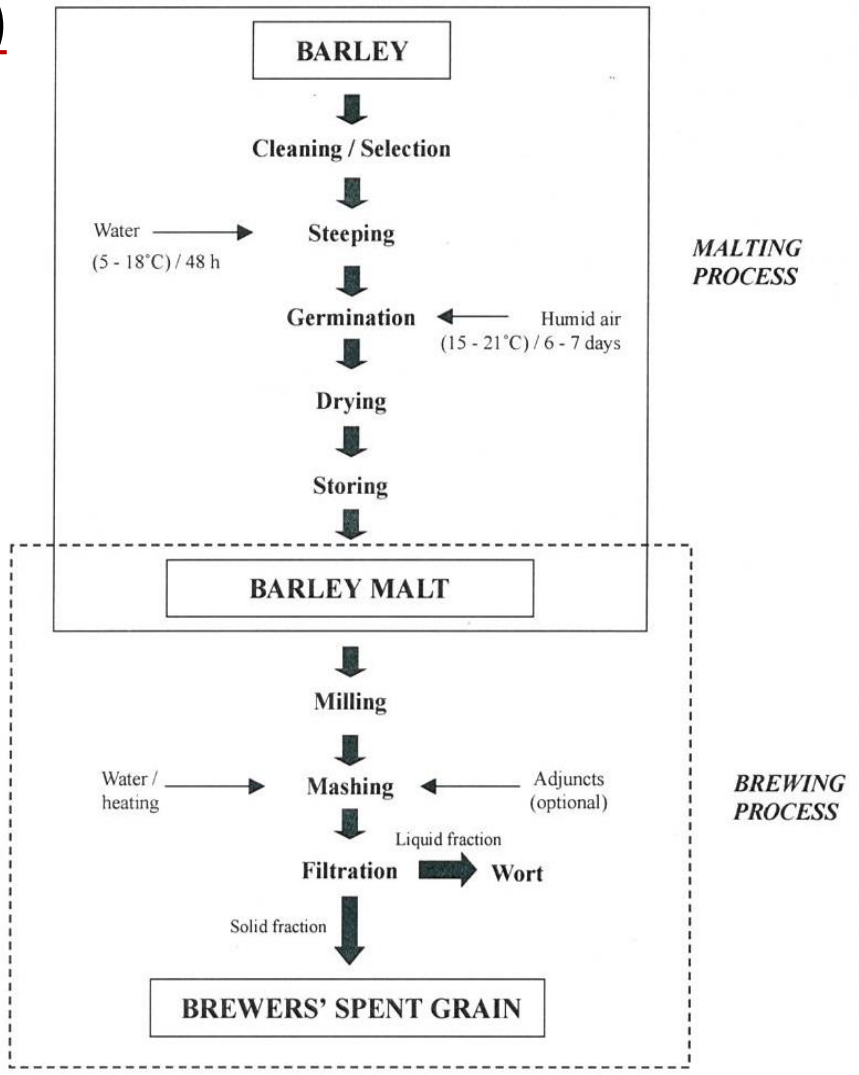
Patsioura, A., Galanakis, C. M., & Gekas, V. (2011). Ultrafiltration optimization for the recovery of β-glucan from oat mill waste. Journal of Membrane Science, 373(1-2), 53-63.

Barley mill fractions & malt

- ***Barley*** is a good source of ***tocols***, which have well known ***antioxidant properties*** & are important quenchers of reactive oxygen species & lipid radicals
- During milling, the tocols content of whole grain are concentrated in certain milling fractions such as ***bran, germ*** etc
- The ***pearling by-products*** of commercial hulled barley stock have higher concentrations of ***tocopherols*** & ***tocotrienols***
- Barley ***β-glucan*** is known to have a range of ***beneficial physiological effects***

Brewers' spent grain (BSGs)

- ✓ Consists of the husk, pericarp, seed & coat
- ✓ Chemical Composition:
  - Cellulose 21%%
  - Arabinoxylan 26%
  - Lignin 20%
  - Protein 20%
  - Lipid 5%
  - Ash 4%
- ✓ Most of the barley's ***starch is removed*** during mashing



Applications of BSGs

Animal Nutrition

As a wet residue shortly after separation from the wort at lautering or as a dried material for cattles

Human Nutrition

Applied as a high protein flour in the manufacture of flakes, whole wheat bread, biscuits & Aperitif snacks

Energy Production

Through direct combustion or by fermentation to produce biogas or by anaerobic fermentation

Charcoal Production

Through drying, pressing & carbonization in a low oxygen atmosphere

Added-value Products

Through hydrothermal or enzymatic hydrolysis to generate arabino-oligoxylosides

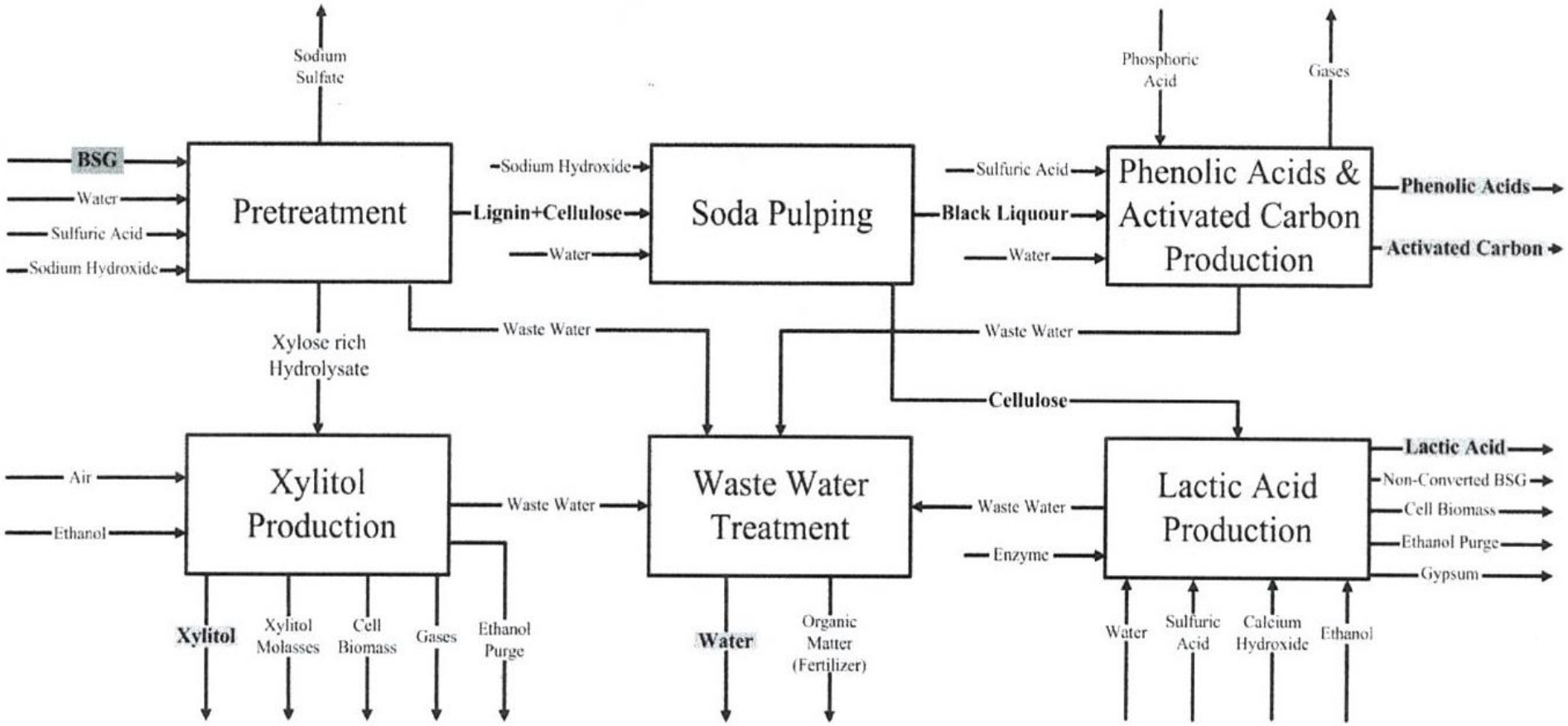
Other

Production of brick components & adsorbents, as well as paper manufacture

Biotechnological Applications of BSGs

- ✓ Rich in ***polysaccharides***, ***proteins*** & minerals
- ✓ ***Cultivation of microorganisms*** & mushrooms (*Pleurotus, Agrocybe & Lentinus*)
- ✓ ***Enzyme production*** through solid state fermentation
  - Xylanase by *Aspergillus awamori*
  - α-Amylase by *Bacillus subtilis*
  - Cellulases by *Trichoderma reesi*
- ✓ Additive or carrier in brewing (e.g. as ***antifoaming agent*** in the fermentor)

Biorefinery Concept for BSGs



Roots & Tubers

Potato processing for ***chips*** production → Peels  → Phenols Recovery

- ✓ Potato peel is a good source of ***carbohydrates (64%)***, moisture (11%), ash (8%), ***protein (14%)***, sugars (3%)
- ✓ Cassave peels contain 75-85% water, low protein content (1-4%), ***15-30% starch*** , >35% high crude, ***non-soluble dietary fibers*** (up to ***30%*** dmb)
- ✓ Can be used as a substrate for the production of commercially important enzymes, such as ***cellulase***, ***α-amylase***, ***glucoamylase*** & ***xylanase***

Sweet Potato Waste

- ✓ Sweet potatoes are typically processed in the cannery, distillery & ***starch industries***
- ✓ A variety of by-products (i.e. peels, vines & leaves, cannery wastes, distillery by-products & starch waste) is produced
- ✓ ***Waste powder*** from orange flesh sweet potato roots contains ***phenolic compounds***, ***β-carotene*** & α-***tocopherol***
- ✓ ***Dietary fibers*** have been extracted from sweet potato residues after starch isolation
- ✓ ***Sweet potato*** forage is a source of ***protein*** (15-30% dry matter basis, depending on the proportion of leaves & stems)

Oilseeds & Pulses

- ***Sunflower seeds*** & soybeans are considered as a substrate for the recovery of ***phytosterols***
- ***Pulses*** are ***rich source of proteins*** , carbohydrates, dietary fiber, vitamins, minerals, ***polyphenols***, ***flavonoids***, & ***phytosterols***
- ***Pulses' processing waste*** find applications in meat & pasta production, ready-to-eat breakfast cereals, baby & snack food, pet foods, dried soups & dry beverages, ***due to their protein content***

Oilseeds Processing Waste

- ***Peels***, ***seeds***, defatted oilseed meals & oil sludge
- Rich in ***proteins***, ***dietary fibers***, ***colorants***, ***antioxidants*** & other substances with positive health benefits effects
- Application of hemp seed oil press-cake in order to ***increase nutritional profile of gluten-free products***
- Protein isolates are of good functional properties, such as ***emulsifying capacity***, ***filmogenic properties*** & ***water solubility***

Food Wastes & By-products

Fruits & Vegetables

- ✓ The consequence of ***processing industry***, mechanical damage during harvest operation or crops sorted out to meet quality standards
- ✓ Drying & dehydration, juicing, canning, marmelade & paste production produce solid (i.e. pomace, pulp, peels, cores, seeds & stems) & liquid (i.e. juices) waste streams
- ✓ Composed of water (80-90%), hydrocarbons, polyphenols, dietary fibers, organic acids, enzymes, proteins & fat

Applications

Mango dietary fibers (DF)

Increase antioxidant capacity

Flavonols & anthocyanins of winery sludge

Increased antiradical & reducing power, food supplements

Apple, white grape, blueberry, raspberry pomace

Cookies & cakes enrichment with DF

Polyphenols & pectin from olive by-products

Antioxidants & fat substitutes in foodstuff

Citrus by-products (lemon & orange albedo)

cooked & dry-cured sausages to increase DF content

Table 1: Fruit & vegetable by-products & corresponded functional ingredients for recovery

Fruits & vegetables	By-product	Target ingredient
Mandarin, Orange	Peel	Flavanone glycoside - hesperidin, limonene
Lemon	By-product	Pectin
Apple	Pomace, Skin	Pectin, catechins, hydroxycinnamic acids
Peach	Pomace	Pectin
Apricot	Kernel	Protein
Grape	Pomace, Skin	Dietary fibers, anthocyanins, epicatechin
Black currant	Seed residue	Phenols
Banana	Bracts	Anthocyanin pigments
Kiwi, Pear	Pomace	Soluble & insoluble dietary fibre
Pineapple	Core & Stem	Proteolytic enzyme -bromelain
Mango	Peel	Gallic acid, carotenoids, dietary fibers
Carrot	Peel	β-carotene , phenols
Tomato	Pomace, peel	Carotenoids (lycopene, lutein, β-carotene)
Cauliflower	Floret & curd	Pectin
Broccoli	Leaves or stalks	Glucosinolates, phenolic acids, flavonoids

Table 2: Fruit & vegetable by-products & corresponded functional ingredients for recovery

Source	By-product	Target Compounds
Black currant	Residues	Anthocyanins
Blueberry	Processing wastes	Anthocyanins, hydroxycinnamates, flavonol glycosides
Cranberry	Pomace	Caffeic acid, ellagic acid
Star fruit	Residues	Procyanidins
Kiwifruit	Pomace, pulp	Phenolic acids, flavonol monomers, dimers & oligomers, flavonol glycosides
Banana	Bracts, peels	Anthocyanins (delphinidin, cyanidin, cyanidin-3-rutinoside, pelargonidin, peonidin, petunidin & malvidin), carotenoids (esterified xanthophylls)

Table 3: Flavonoids, phenolics & potential sources

Group	Target Compounds	Potential Sources
Flavonols	Kaempferol, quercetin	Onions, curly, kale, leeks, broccoli, blueberries, grape, tea, oil palm fruit
Flavones	Luteolin, apigenin, tangeretin, nobiletin, sinensetin	Parsley, celery, citrus fruits
Flavanones	Hesperidin, narirutin, naringenin, eriodictyol	Tomato, aromatic plants, mint, citrus, fruits
Isoflavones		Soybean-derived products, leguminous plants
Flavanols	Catechin, epicatechin, gallocatechin, epigallocatechin, epigallocatechin gallate	Apricot, grape, green tea, apples, chocolate, seeds of leguminous plants
Proanthocyanidins		Grape skin & seeds, peaches, pears
Phenolic acids	Coumaric, caffeic, ferulic, simapic acid	Blueberries, kiwis, plums, cherries, apples
Lignans		Oleaginous seeds, algae, remuninous plants, cereals, garlic, asparagus, carrots, pears, prunes
Stillbenes	Resvaratrol	Grape, wines

Commercialized Applications

Citrus Peel

- ✓ One of the firsts wastes that has been utilized for recovery purposes
- ✓ Essential oils, flavonoids, sugar & pectin via sequential solvent extraction
- ✓ Industrial exploitation of citrus peel accounts for 30 years
- ✓ The derived product ***"sugar syrup"*** used as natural sweetener in foods instead of artificial aspartame or saccharine
- ✓ Enhances ***sweetness*** & ***flavor*** of juices

Commercialized Applications

Tomato waste

- ✓ Industrial recovery of ***lycopene*** using sequential extraction with a polar & non-polar solvent
- ✓ Lycopene is one of the most popular ***natural pigments*** (red) & antioxidant agent accepted by food industry
- ✓ *In vitro*, *in vivo* & *ex vivo* studies have demonstrated that its addition to food is ***inversely associated to cancers*** & cardiovascular diseases

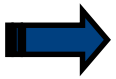
Table 4: Commercialized methodologies

Project Characteristics	Source	
	Citrus peel	Tomato waste
Patent application number	AU1983/0011308D	PCT/EP2007/061923
Applicant/ Company	Tropicana Products Inc. (Florida, USA)	Biolyco SRL (Lecce, Italy)
Title	Treatment of citrus fruit peel	Process for the extraction of lycopene
Product/Brand names	**Sugar Syrup**	**Lycopene**
Commercialized applications	Food natural sweetener	Food Antioxidant & supplement
Inventors/ Reference	Bonnell (1983)	Lavecchia & Zuorro (2008)

Commercialized Applications

Olive Mill Waste (OMW)

- ✓ The valorization of OMW as a source of phenols is the new trend
- ✓ Commercial ***hydroxytyrosol*** isolation (Crea, 2002):
  - OMW acid treatment
  - incubation
  - Supercritical fluid extraction
  - Freeze or spray drying



- ✓ A countercurrent mode-column
- ✓ A barrier (***membrane***) interface between hydroxytyrosol containing fluid & dense gas

- ✓ The obtained material is a ***GRAS-certified product*** used as functional supplement or food preservative

Commercialized Applications

Olive Mill Waste (OMW)

- ***Hydroxytyrosol*** has been recovered from OMW in pure form using chromatographic columns filled non-activated ionic & XAD-type non-ionic resins (Fernandez-Bolaños et al., 2002)
- The final product is available on the market & used as ***preservative in bakery products***
- Hydroxytyrosol possess advanced ***antiradical properties*** in comparison to Vitamins E & C
- Prevents ***oxidative deterioration*** of fish oils & lipids

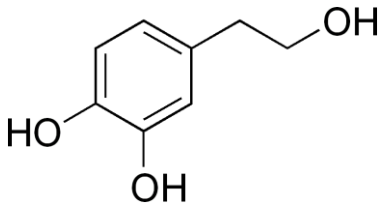


Table 5: Commercialized methodologies

Project Characteristics	Olive mill waste		
Patent application number	PCT/US2001/027132	PCT/ES2002/000058	PCT/SE/2007/001177
Applicant/ Company	CreAgri, Inc (Hayard, USA)	Genosa I+D S.A. (Malaga)	Charis M. Galanakis
Title	Obtaining a hydroxytyrosol-rich composition from vegetable water	Obtaining a purified hydroxytyrosol from products & by-products derived from olive tree	Olive Waste Recovery
Product/Brand names	**Hydroxytyrosol/ Hidrox®**	**Hydroxytyrosol (99.5%)/Hytolive®**	**Olive phenols & dietary fibers containing powders**
Commercialized applications	Food supplements & cosmetics	Conserving foods, functional ingredient in bread	Natural antioxidants in foodstuff & fat replacement in meatballs, respectively
Inventors/ Reference	Crea (2002)	Fernández-Bolaños et al. (2002)	Tornberg & Galanakis (2008)

Commercialized Applications

Apple Pomace

- ***Soluble dietary fibers*** (DF) granules are produced from depectinated apple pomace & disposed to the market as dietary supplements
- Recovery stages comprise of an alkaline & solubilization process, concentration, sediment, cleaning & drying
- DF are incorporated into food products as inexpensive, ***non-caloric bulking agents*** for partial replacement of flour, fat or sugar

Table 6: Commercialized methodologies

Project Characteristics	Source		
	De-pectinated apple pomace	Soy protein waste	Grape & cranberry seed
Patent application number	CN2008/1139768	CN/2008/10238791	JP1998/0075070
Applicant/ Company	Yantai Andre Pectin Co. Ltd. (Yantai, China)	ShanDong Wonderful Industry Group Co. Ltd (Shandong, China)	Kikkoman Corp. (Chiba. Japan)
Title	Process for extracting non-pectin soluble pomace dietary fibers	Process for extracting & recycling albumin from whey wastewater from production of soy protein isolate	Protein food
Product/Brand names	Apple dietary fiber granules	Soybean albumin	Proanthocyanidin
Commercialized applications	Dietary supplement	Food additive & supplement	Coloring additive in soy sauce
Inventors/ Reference	Anming et al. (2010)	Shenghui (1995)	Ariga et al. (1999)

Commercialized Applications

Coffee Silverskin

Pomegranate Seeds

Palm Agro-waste

Table 7: Commercialized methodologies

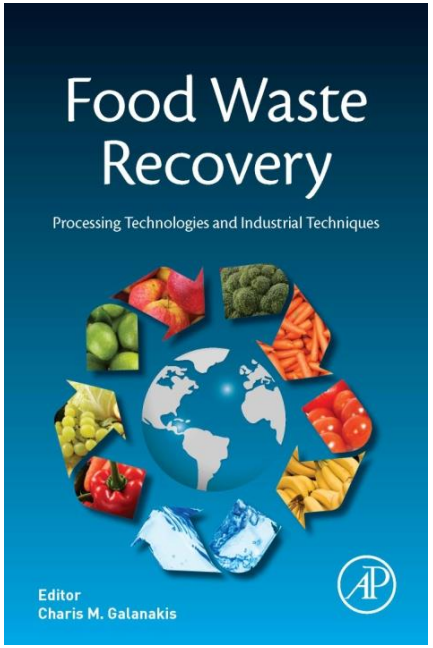
Project Characteristics	Source		
	Coffee silverskin	Pomegranate seeds	Palm Agro-waste
Patent application number	WO/2013/004873	US7943185B1	WO/2014/042509 A1
Applicant/ Company	Consejo Superior de Investigaciones Cientificas/CIAL (Madrid, Spain)	Pom Wonderful Llc (Los Angeles, CA, USA	Sime Darby Malaysia Berhad (Malaysia)
Title	Application of products of coffee silverskin antiaging cosmetics and functional food	Process for the extraction of pomegranate seed oil	Process for the extraction of lecithin
Product/Brand names	**Bioactive silverskin extract**	**Pomegranate seed oil**	**Lecithin**
Commercialized applications	Cosmetics, nutrition, health	Food supplement for medical uses	Food supplement for medical uses
Inventors/ Reference	Del Castro et al. (2013)	Anderson et al. (2001)	Mee et al. (2014)

Food Waste Recovery: Processing Technologies & Industrial Techniques (Academic Press, 2015)

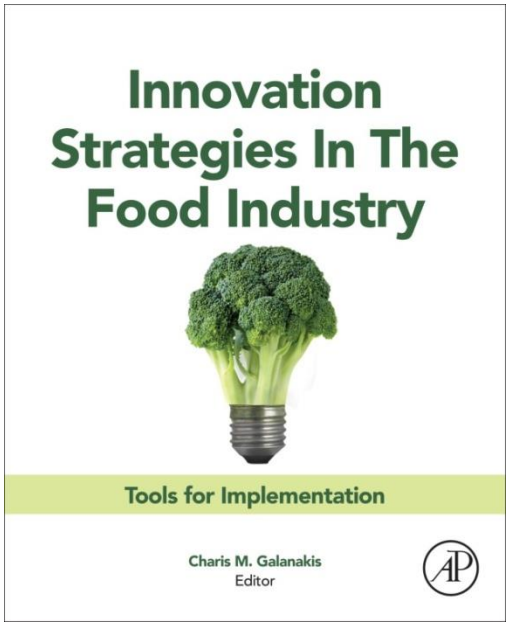
- ✓ Acts as a ***guide to recover valuable components*** of food by-products & recycle them inside the food chain, in an economic & sustainable way

- ✓ Investigates all the relevant recovery issues & ***compares different techniques*** to help you advance your research & ***develop applications***

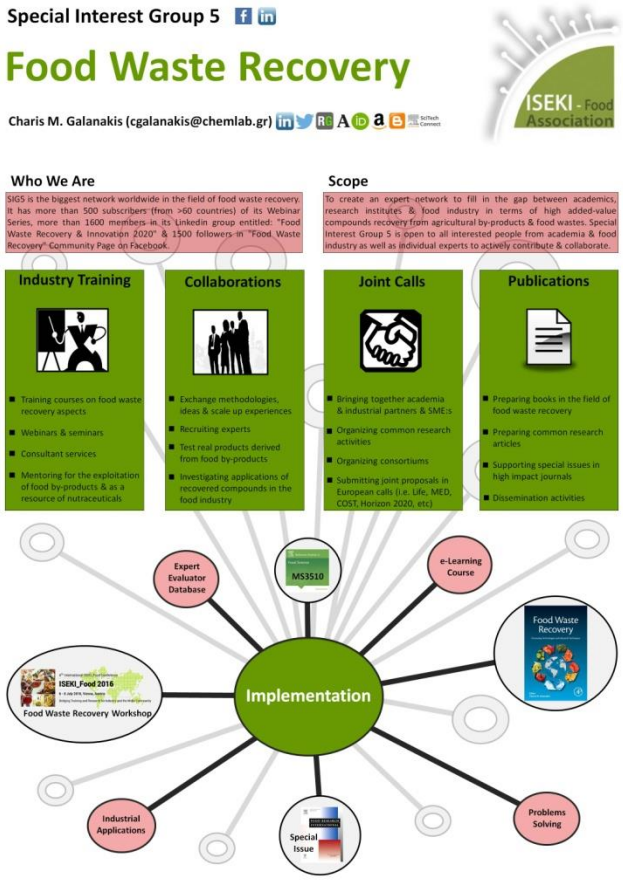
- ✓ Covers several ***conventional & emerging technologies***, keeping a balance between their characteristics



Innovation Strategies In the Food Industry: Tools for Implementation (Academic Press, 2016)



- ✓ Multi-author book
- ✓ It reports the ongoing innovations of food science
- ✓ It provides tools, ideas & strategies to overcome bottlenecks for their actual implementation in the industry



Food Waste Recovery Group

Open Innovation Network

- ✓ Training for the industry (seminars, webinars, e-learning course, workshops)
- ✓ Consulting services, collaborations, joint proposals, common publications

Information

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